GEOLOGY OF THE NEWHALL AREA
OF THE
EASTERN VENTURA AND WESTERN SOLEDAD BASINS
LOS ANGELES COUNTY, CALIFORNIA

A Thesis Presented to
The Faculty of the Graduate College
Ohio University

In Partial Fulfillment
of the Requirements for the Degree
Master of Science

117 pp.

by

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November, 1978

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ABSTRACT

Surface and subsurface data are combined to determine the structure of the Newhall area from the Santa Susana reverse fault north to the San Gabriel fault. In the Ventura basin, basement rocks similar to those of the western San Gabriel Mountains are apparently overlain by Paleocene-Eocene strata which appear equivalent to the Paleogene south of the Santa Susana fault. An unnamed nonmarine sequence overlies the Eocene Llajas; it appears lithologically similar to the Mint Canyon Formation (Soledad basin) but is in the same stratigraphic position as the Sespe Formation (Ventura basin). The Modelo (lower and upper Mohnian), Towsley (Delmontian), and Pico (Pliocene) Formations overlie unconformably a major erosion surface in the Ventura basin. Nonmarine Mint Canyon strata of middle to late Miocene age are overlain unconformably by marine Pliocene strata in the Soledad basin. The Saugus Formation occurs on both sides of the fault. The San Gabriel fault accumulated right-slip between middle Miocene and late Pliocene time and has been mainly dip-slip in the late Quaternary. The Whitney Canyon fault represents two periods of displacement: pre-Pliocene juxtaposition of Paleogene strata against basement rocks along a normal fault of large separation and minor post-Saugus reverse displacement. The south-dipping Holser reverse fault intersects the San Gabriel fault in an unknown

manner. The San Gabriel, Holser, and Santa Susana faults may be potentially active. The Legion, Beacon, and Weldon south-dipping reverse faults may have been formed in response to folding of the Pico anticline and Oat Mountain syncline which were controlled by the north-dipping Santa Susana fault as it increased in dip and cut across bedding; therefore, these faults may be potentially active.

INTRODUCTION

Regional Setting

The Newhall area is located about 30 miles (50 km) northwest of downtown Los Angeles and lies within the Newhall, Mint Canyon, San Fernando, and Oat Mountain 7 1/2 minute quadrangels which cover parts of the Ventura and Soledad basins. The Ventura basin is an east-west depositional trough within the Transverse Ranges Province (Fig. 1). The basin extends east only to the San Gabriel fault which separates it from the Soledad basin. The depositional environments in the two basins are quite different. The formations in the eastern Ventura basin are principally marine in origin, whereas to the east across the fault the early Tertiary units of the Soledad basin are chiefly nonmarine. The area includes those parts of the two basins which are close to the western end of the San Gabriel Mountains.

On the southwest side of the San Gabriel fault, basement is encountered in several wells. The basement rocks cored are similar to the granodiorite, diorite gneiss, and metasedimentary rocks exposed to the east in the western San Gabriel Mountains. Neither basement rocks nor sedimentary rocks were drilled in the study area below the Mint Canyon Formation northeast of the San Gabriel fault.

Eocene rocks are exposed only in Elsmere Canyon and are equivalent in age to the Llajas Formation (cf. Howell, 1974). These

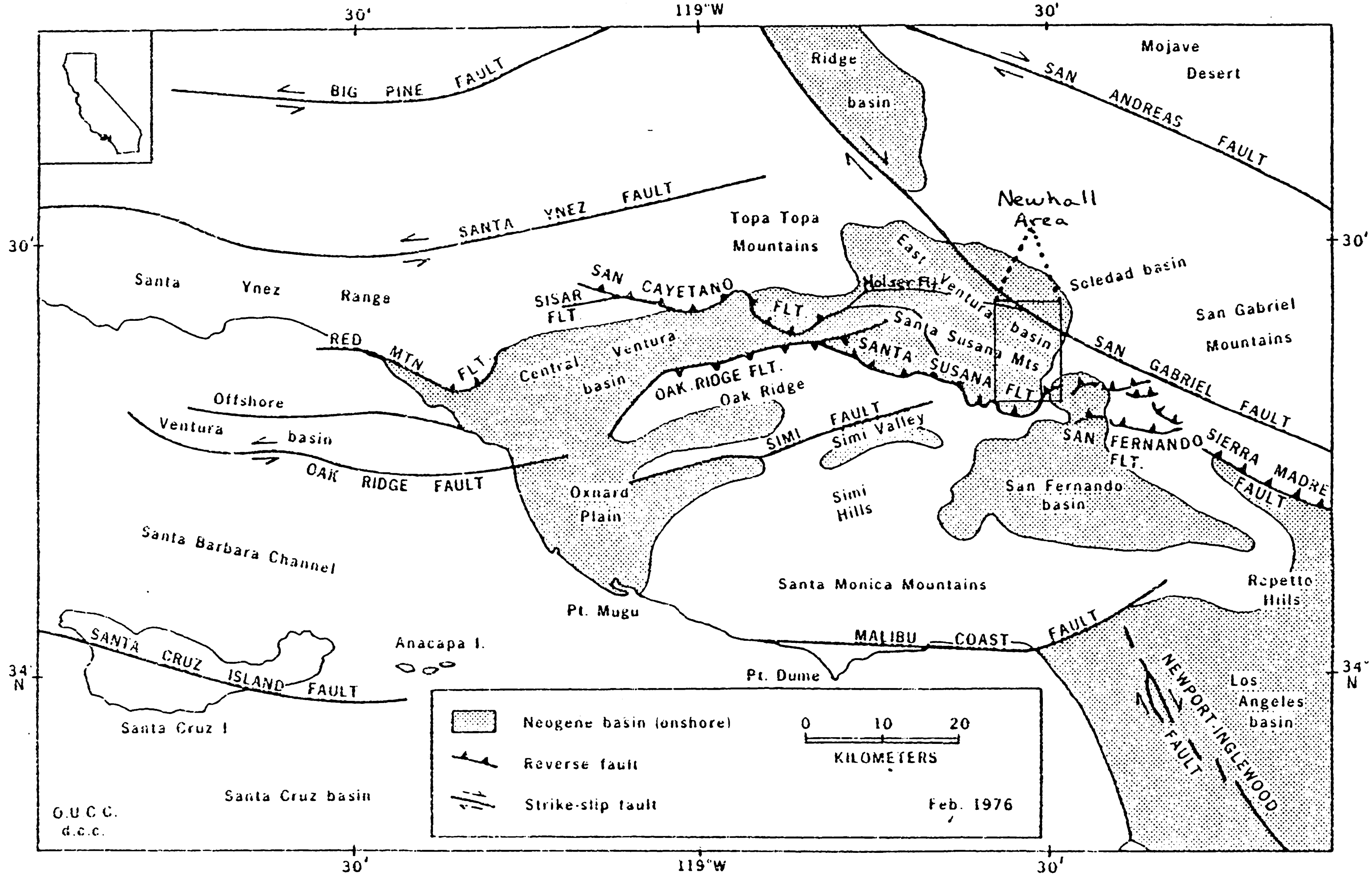

Figure 1. Location of the Newhall area with respect to the major Neogene basins and faults northwest of Los Angeles, California (after Yeats, 1976).

strata overlie a thick section of Paleocene-Eocene rocks which were penetrated in the Continental-Phillips 1 (17) well south of Placerita oil field; this well also reached crystalline basement. An unnamed nonmarine sequence of rocks overlies the marine Eocene and is itself overlain by late Miocene strata; this sequence has been compared with the Sespe Formation of the Ventura basin and the Mint Canyon Formation of the Soledad basin.

The lowermost sedimentary formation overlying basement in the Soledad basin is the nonmarine Vasquez Formation which consists of coarse-grained sandstone and conglomerate interbedded with volcanic rocks. The nearest exposure of Vasquez is several miles northeast of Newhall. The Vasquez is lithologically similar to the Sespe Formation found within the Ventura basin (Bohannon, 1975) but differs from it in that it contains interbedded volcanic rocks. The early Miocene Tick Canyon Formation rests on the Vasquez and is composed of nonmarine, fluviatile reddish brown claystone, siltstone, and sandstone. Neither the Vasquez nor the Tick Canyon is found in the subsurface or is exposed in the study area. The early to middle Miocene in the east Ventura basin is represented by the marine Topanga Formation which grades eastward to nonmarine strata in the northern San Fernando Valley (Oakeshott, 1958) south of the Santa Susana fault.

Two important and in part coeval units are the middle to late

Miocene nonmarine Mint Canyon Formation of the Soledad basin and the middle and late Miocene marine Modelo Formation of the Ventura basin. The Mint Canyon throughout the basin consists of deposits of fluviatile sandstone and conglomerate, lacustrine siltstone, and volcanic tuff. Clasts within the lower Mint Canyon include igneous and metamorphic rocks that are in part similar to the basement in the nearby western San Gabriel Mountains northeast of the San Gabriel fault. Volcanic clasts in the formation are similar to the volcanic flows in the Vasquez Formation to the northeast. The northwest-trending San Gabriel fault is believed to have undergone between 30 and 40 miles (48-64 km) of right-lateral movement (cf. Crowell, 1952; Ehlig, 1975); this may explain why the Mint Canyon crops out only northeast of the fault and its equivalent, the Caliente Formation exposed 30 miles (48 km) or more to the northwest, crops out only west of the fault. Overlying the Mint Canyon is the shallow water Castaic Formation which is in part coeval with the upper Modelo across the fault. The Modelo Formation consists of marine siltstone, mudstone, and shale rich in organic material.

The late Miocene to early Pliocene Towsley Formation consists of interfingering siltstone, sandstone, and conglomerate which successively overlie basement, Eocene, nonmarine, and Modelo rocks from east to west, respectively, into the Ventura basin. The overlying

Pliocene Pico Formation is coarse-grained and is found primarily in the Ventura basin, but it has been reported east of the San Gabriel fault in the subsurface of the Honor Rancho area (Schlaefer, 1978). Large scale horizontal displacement along the San Gabriel fault apparently ended prior to the late Pliocene when the Saugus Formation was deposited. The Saugus is found extensively on both sides of the fault; however, the formation in the Ventura basin of the Newhall area is much thicker than it is directly east of the fault. The Saugus grades upward from shallow marine and brackish water to nonmarine sandstone, conglomerate, and interbedded siltstone.

In addition to the San Gabriel fault, the Whitney Canyon fault is a major north-trending structural feature through the area. The fault was most active between the deposition of the Eocene and Pliocene strata; a section of Eocene rocks was downdropped over 6000 feet (1830 m) along an ancestral Whitney Canyon normal fault against basement rocks of the western San Gabriel Mountains. The Towsley Formation masks the early pre-Pliocene movement on the fault. Regional compression during the late Pleistocene formed a series of south-dipping reverse faults through the Newhall area (Fig. 2). The Whitney Canyon fault was reactivated so that Pliocene units were slightly offset in a reverse sense of separation.

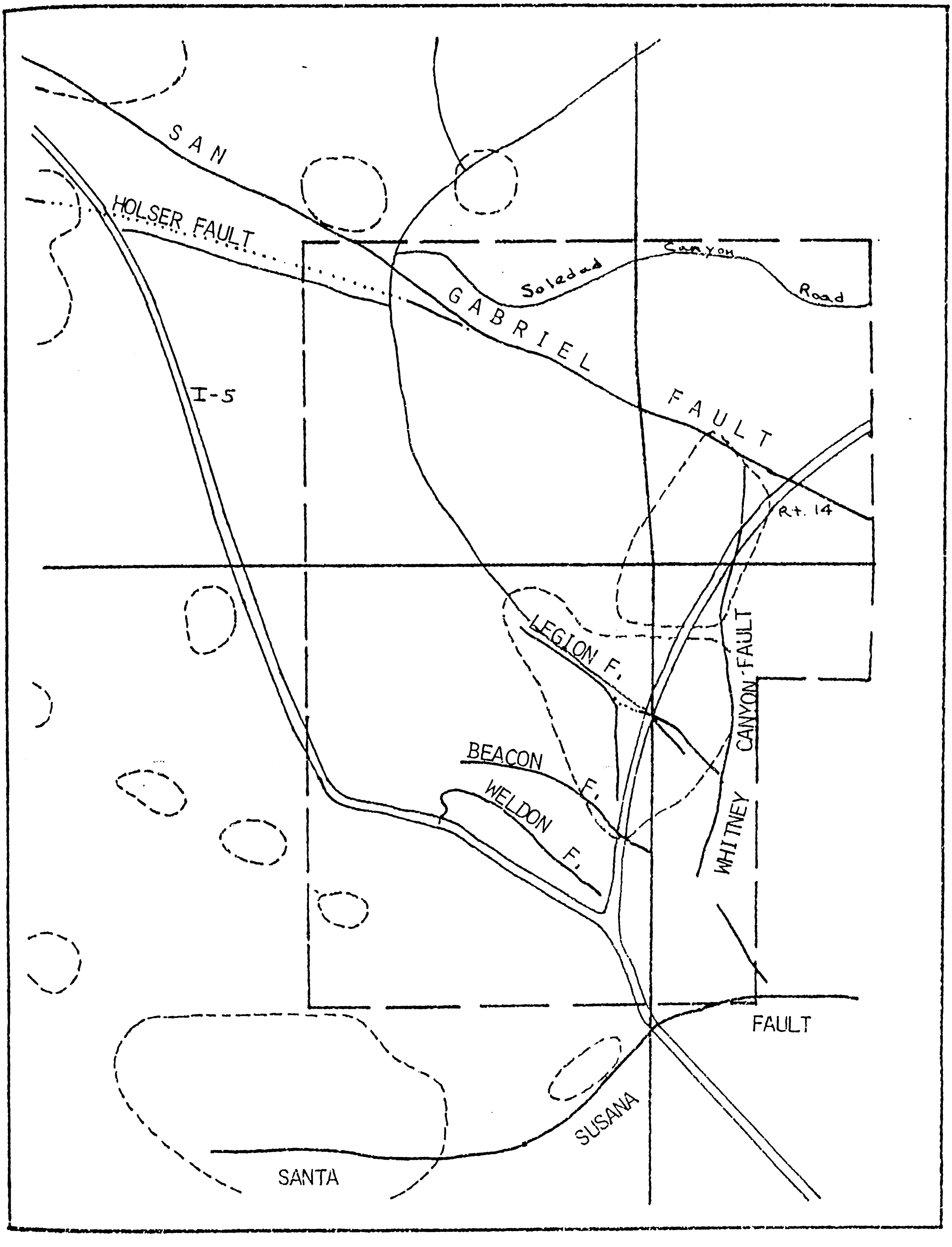

Figure 2. Location of faults in the Newhall area. Thesis area enclosed by dashed lines.

Purpose and Scope

In recent years, the urban sprawl of the San Fernando Valley has moved northwestward into the Newhall area. In zoning this area for urbanization, it is important that the nature and age of faulting in the area be understood; this is the main purpose of this thesis. The work has involved combining surface and subsurface data in order to construct accurate geologic maps and cross sections for an understanding of the area in three dimensions. This thesis has integrated late Quaternary surface data reported by others (cf. Weber, 1977; 1978) with subsurface oil well information to further define the fault zone.

The subsurface study of the Newhall area also serves to connect the subsurface studies of the Santa Susana thrust fault zone (cf. Lant, 1977; Shields, 1977; Yeats and others, 1977) with additional studies of the San Gabriel fault by Schlaefer (1978) and L. Stitt (in progress).

Methods of Study

Field work was completed in five weeks in March and June of 1977. Published surface maps of the Newhall area were field-checked to familiarize myself with formations found mainly in the subsurface and to verify field relations critical to the fault study. Most units prominent in the subsurface of the area were examined where they occur at the surface for a better understanding of the regional stratigraphy. The geologic map (Plate I) was revised from Winterer and Durham (1962), Kern (1973), Saul (1975), Shields (1977), and Weber (1977) based on field work and subsurface oil well data. Landsat imagery was used to map the location of the eastern end of the Holser fault where it intersects the San Gabriel fault. The Holser fault location is based on data from R. J. Proctor (personal comm., 1978) and Weber (1977, 1978).

Data were gathered for 214 wells (listed in Appendix A by section-township-range and by well index numbers which are in parentheses throughout the text) in the Newhall area. The principal source for this information was the California Division of Oil and Gas (DOG) from which electric logs, well histories, well surveys, directional surveys, drilling logs, and core descriptions were provided. Paleontology reports, dipmeter data, and core samples were furnished voluntarily by well operators.

Twenty-seven cross sections (Plate VI) were constructed, using electric logs and other oil well data, utilizing wells which were drilled in and around the Placerita, Newhall (Whitney Canyon, Elsmere Canyon, and Tunnel fields, and Rice Canyon oil fields (Fig. 3). Sixteen of these cross sections are presented in this report; they represent the more critical subsurface relations necessary to understand the stratigraphy and structure in the area. The

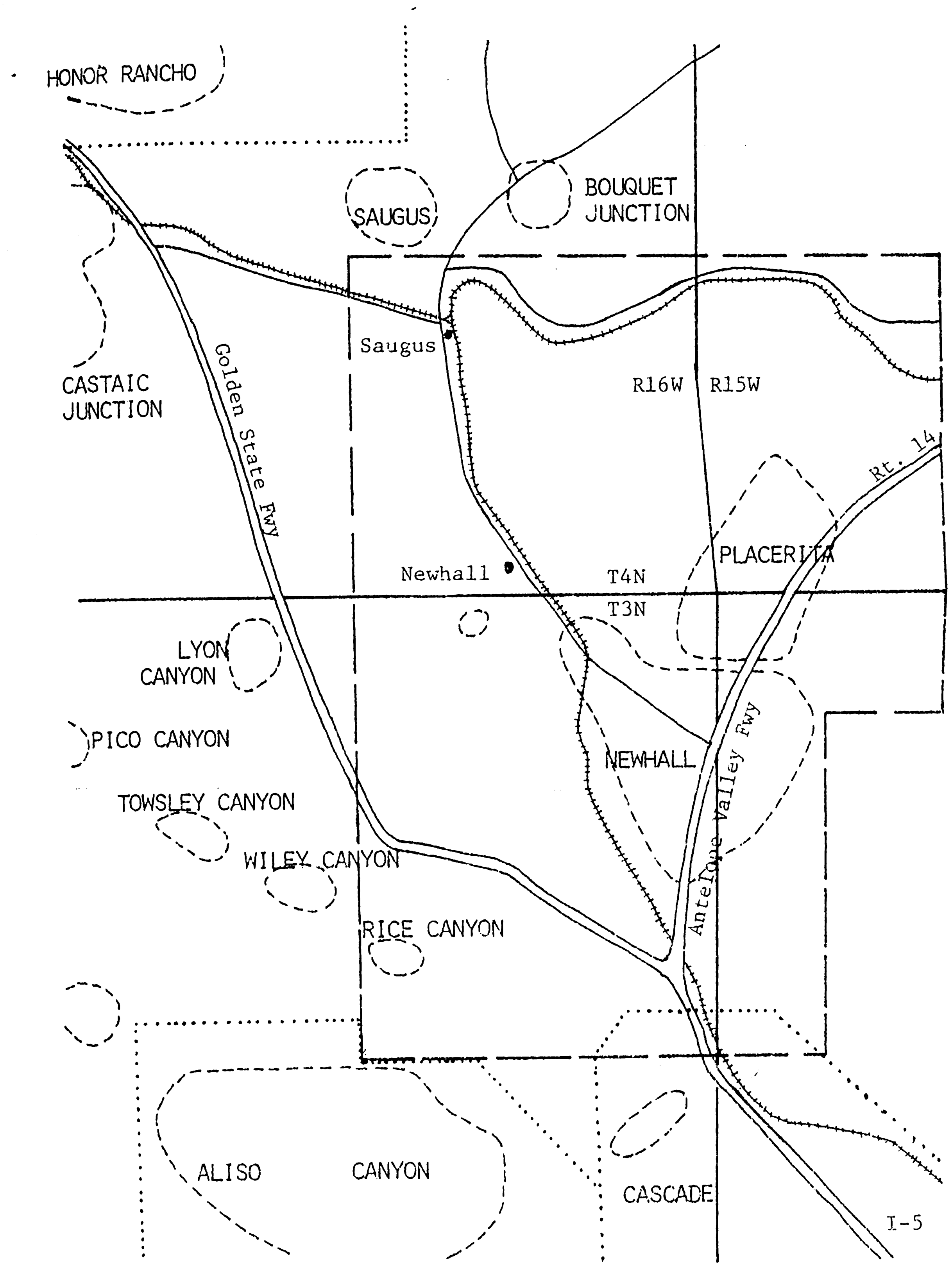

Figure 3. Oil fields in the Newhall, California area. Dashed lines enclose the thesis area. Other subsurface studies, dotted lines, are in the Aliso Canyon (Lant, 1977), Cascade (Shields, 1977), and Honor Rancho (Schlaefer, 1978) oil fields.

structure contour map of the faults in the area (Plate II) represents all the control available to me from oil well data. The structure contours on the pre-Modelo erosion surface and on the top of the Topanga Formation (Plate III), on the top of the Modelo and Mint Canyon Formations (Plate IV), and on the top of the Pico Formation (Plate V) give a better understanding of the subsurface geology. Canter (1974) and Ricketts and Whaley (1975) have discussed in greater detail the use of subsurface correlation techniques.

Previous Work

The first report on the geology of the Newhall area (Whitney, 1865) discussed the relationships between the sedimentary series of the eastern Ventura basin with the crystalline basement rocks of the San Gabriel Mountains. Hershey (1902) suggested several names for rock sequences in the Ventura and Soledad basins, including the Saugus Formation and the Mellenia Series (now the Mint Canyon Formation). A detailed geologic map of the region was made by Eldridge and Arnold (1907), and parts of the region were later remapped by Kew (1924). The Soledad basin was mapped by Jahns (1939, 1940) and Jahns and Muehlberger (1954). The Newhall area was mapped more recently by Oakeshott (1950, 1954, 1958), by Winterer and Durham (1951, 1954, 1962) who named and described the Towsley Formation, and by Kern (1973) in the Elsmere Canyon area only. Holloway (1940), Ford (1941), Daviess (1942), Morrison (1958), and Merifield (1958) have mapped parts of the eastern Ventura and Soledad basins as Master's theses.

Subsurface studies in the area have concentrated on the Placerita oil field (cf. Kew, 1924, 1943; Walling, 1934; Ford, 1941; Barton and Sampson, 1950; and Oakeshott, 1950). Willis (1952) correlated rock units in the Newhall area with the oil-producing zones in the Placerita oil field. The most recent subsurface study on the field was made by Tudor (1962), whose report contained the first published cross section through the area. Other oil fields in the area have been discussed briefly within the reports on the Placerita oil field.

The San Gabriel fault was identified in the San Gabriel Mountains by Kew (1924), who believed that the fault extended to the west as the fault now mapped as the Holser fault. The fault was eventually linked with the northwest-trending Palomas fault of Clements (1937) in the Castaic Junction area by Eaton (1939). Eaton was the first to speculate that the San Gabriel fault had a strike-slip component of movement, whereas it previously had been thought to be dip-slip (cf. Hill, 1930; Miller, 1934). The first substantial evidence for right-lateral movement on the fault was reported by Crowell (1952, 1954, 1962, 1975). Recent lines of evidence by Ehlig (1968), Ehlig and Ehlert (1972), Ehlig and others (1975), and Woodburne (1975) further substantiate major right-lateral movement on the fault. One study objecting to the idea of strike-slip movement was made by Paschall and Off (1961);

they concluded that the San Gabriel fault was principally dip-slip. Schlaefer (1978) restudied the subsurface in the Honor Rancho oil field, and found that pre-Towsley strata indicate strike-slip movement, whereas post-Towsley strata were displaced chiefly by dip-slip movement.

Acknowledgements

I would like to thank all of the people in California, Ohio, and Oregon who have helped to make my thesis work both enjoyable and educational. Special thanks goes to Jane Robles of the California Division of Oil and Gas, who made the acquisition of data very easy. Harold Weber, California Division of Mines and Geology, and R. J. Proctor, Metropolitan Water District of Southern California, provided valuable information on several faults in the area.

I especially thank Robert Yeats for introducing me to the thesis area, and for his help from start to finish. Also, thanks go to Kevin Lant and Kermit Shields for introducing me to subsurface work and for their encouragement in my undertaking this project. Leonard Stitt helped with petrographic descriptions of the basement rocks. I will always be indebted to my friends at Ohio University and especially to Jeff Smith who helped to make my transition from Ohio to Oregon as easy as possible. I appreciate the critical review of the thesis by Keith Oles and Robert Lawrence of Oregon State University. To all my friends at Oregon State, "Thanks." The support, understanding, and friendship of Jill, Len, Mary Clare, Tom, Tom, Linda, Joan, Jim, and Sherri helped to make my stay here in Oregon very enjoyable. Much gratitude goes to Paula Pitts and Linda Donaldson, who put in many long hours drafting the plates for this thesis.

This project was funded under USGS grants #14-08-0001-15371 and #14-0001-16747 of the Earthquake Hazards Reduction Program.

Lastly, I would like to thank all of the members of my family for their constant support, never ending encouragement, and for the use of their "ears."

STRATIGRAPHY

The Newhall area contains rock units which range in age from pre-Cretaceous to Holocene. South of the San Gabriel fault, several wells cored basement rocks consisting of granodiorite, granite, and schist. Crystalline basement has been found only south of the San Gabriel fault and is correlated to basement rocks exposed in the western San Gabriel Mountains south of the San Gabriel fault. The oldest sedimentary strata penetrated by drilling in the area was found west of the Whitney Canyon fault; almost 6000 feet (1830 m) of Paleocene-Eocene rocks were penetrated. This sequence is presumed to lie unconformably on basement, but the unconformable contact with basement was not drilled in the area. The lower section of the sequence is conglomerate that may be correlative with the Simi Conglomerate of the Simi Hills, whereas the middle and upper sections may correspond with siltstone and sandstone of the Santa Susana Formation and interbedded siltstone and sandstone of the Eocene Llajas Formation, respectively. In the west and southwest parts of the mapped area, the Eocene is overlain by a sequence of unnamed nonmarine rocks. In the past, this sequence was correlated with the Miocene Mint Canyon Formation of the Soledad basin, but the two units have only a couple of lithologic similarities, and the Mint Canyon more closely resembles a sequence in Lockwood Valley, west of the

San Gabriel fault 35 miles (55 km) to the northwest. The unnamed nonmarine sequence has also been tentatively correlated with the Sespe Formation exposed only south of the Santa Susana fault; however, the two units are not lithologically similar. Marine sandstone and shale of the middle Miocene Topanga Formation are found in the subsurface beneath the Pico anticline. Shale and siltstone of the Modelo Formation of middle to late Miocene age conformably overlie the Topanga in the Pico anticline area and unconformably rest on a major pre-Miocene erosional surface in the western third of the Newhall area, including the unnamed nonmarine sequence. Continuing the overlap of the Topanga and Modelo Formations over older units, the Towsley Formation (Delmontian Stage of Kleinpell, 1938) conformably overlies the Modelo and unconformably overlies the remainder of the erosion surface to the east. The Towsley is a time-transgressive unit that is in part Miocene age in the deeper part of the Ventura basin, but is almost entirely Pliocene in the shallower, eastern edge of the basin. West of Newhall, the Towsley is characterized by siltstone interbedded with lenticular sandstone and conglomerate largely deposited by turbidity currents. The formation changes from mainly finer grained clastics to interbedded sandstone and conglomerate with some siltstone stratigraphically upsection and to the east. The Pliocene seas began to regress during the deposition of the Towsley and Pico strata. The Pico conformably overlies and interfingers with the Towsley and is progressively higher stratigraphically and coarser grained to the east. With continued regression, the Pliocene grades vertically and laterally into brackish water and nonmarine siltstone and sandstone of the Saugus Formation.

East of the San Gabriel fault, the fluviatile and lacustrine siltstone and sandstone of the middle to late Miocene Mint Canyon Formation form a very thick sequence. In two small outcrops in the mapped area, Pliocene rocks of either the Towsley or Pico Formations overlie the Mint Canyon Formation unconformably. Over the remainder of the area, the Saugus Formation rests unconformably on the Mint Canyon or on Pliocene strata. The section of Saugus in the Soledad basin is about one-fifth as thick as it is south of the San Gabriel fault in the Ventura basin.

General Discussion of Micropaleontology of the Eastern Ventura Basin

For over 40 years benthic foraminifera have been the most widely used means in biostratigraphic correlation and age dating of marine Cenozoic rocks in California. Kleinpell (1938), the first to use benthic foraminiferal index species and assemblages, divided the Miocene into six stages (the Zemorrian, Saucesian, Relizian, Luisian, Mohnian, and Delmontian). Natland (1952) divided the Pliocene and early Pleistocene of southern California into four stages (the

Repettian, Venturian, Wheelerian, and Hallian), and Mallory (1959) separated the Paleogene of the California Coast Ranges into five stages (the Ynezian, Bulitian, Penutian, Ulatisian, and Narizian).

During the past ten years or so, criticism has increased over the use of benthic forams in biostratigraphic correlations. However, the first to recognize that benthic forams may be time transgressive was Natland (1933, p. 230), who stated that "the correlation of two widely separated outcrops based on the similarity of their foraminiferal assemblages alone is apt to be erroneous." Two approaches have been used to test the accuracy of the benthic foraminiferal chronology. In the first, Winterer and Durham (1962) traced lithologic units in the Newhall area from Pico Canyon to the Weldon-Gavin Divide (Plate I) to set up time lines within the Pico Formation. When these time lines are compared to benthic foraminiferal correlations along the same line of section, the benthic forams show a major time-transgressive character. They also noted that miscorrelations of up to 3200 feet (1000 m) could occur if benthic foram correlations were used exclusively (Winterer and Durham, 1962, Plate 47). The second approach involves the comparison of benthic foram chronology with recently developed planktic chronologies.

Planktic biostratigraphy is now regularly used for correlating and age dating marine rocks because it has a number of advantages over benthic foraminifera: 1) coccolith species are extremely abundant; and 2) they have evolved rapidly which means narrow stratigraphic ranges for many species (Crouch, Bukry, and Arnal, in press).

In light of the new planktic chronologies, it is evident that benthic foraminiferal biostratigraphy must be used with discretion when correlating between outcrops or oil wells where lithology is not diagnostic. The degree of error that might result in using benthics to age date marine sequences is shown in Figure 4. For example, the Narizian and Ulatisian Stages of Mallory (1959) are now considered to be time equivalent on the basis of planktic foraminifera and coccoliths identified by Steineck and Gibson (1971). Crouch, Bukry, and Arnal (in press) have determined that the Kleinpell (1938) stages, when compared with coccolith zones from the California Continental Borderland, show considerable overlap between stages. They believe that the overlapping stages may be caused by environmental factors, physical and biological, resulting from silled and unsilled Miocene basins. Also Kleinpell's type Delmontian Stage and type lower Mohnian Stage are essentially coeval according to the work of Pierce (1972), Ruth (1972), and Barron (1975, 1976a, b). It is very important that benthic foraminiferal correlations be queried and then used with discretion.

In the eastern Ventura basin, benthic forams have been used to identify and correlate rock units with varying success. It has been

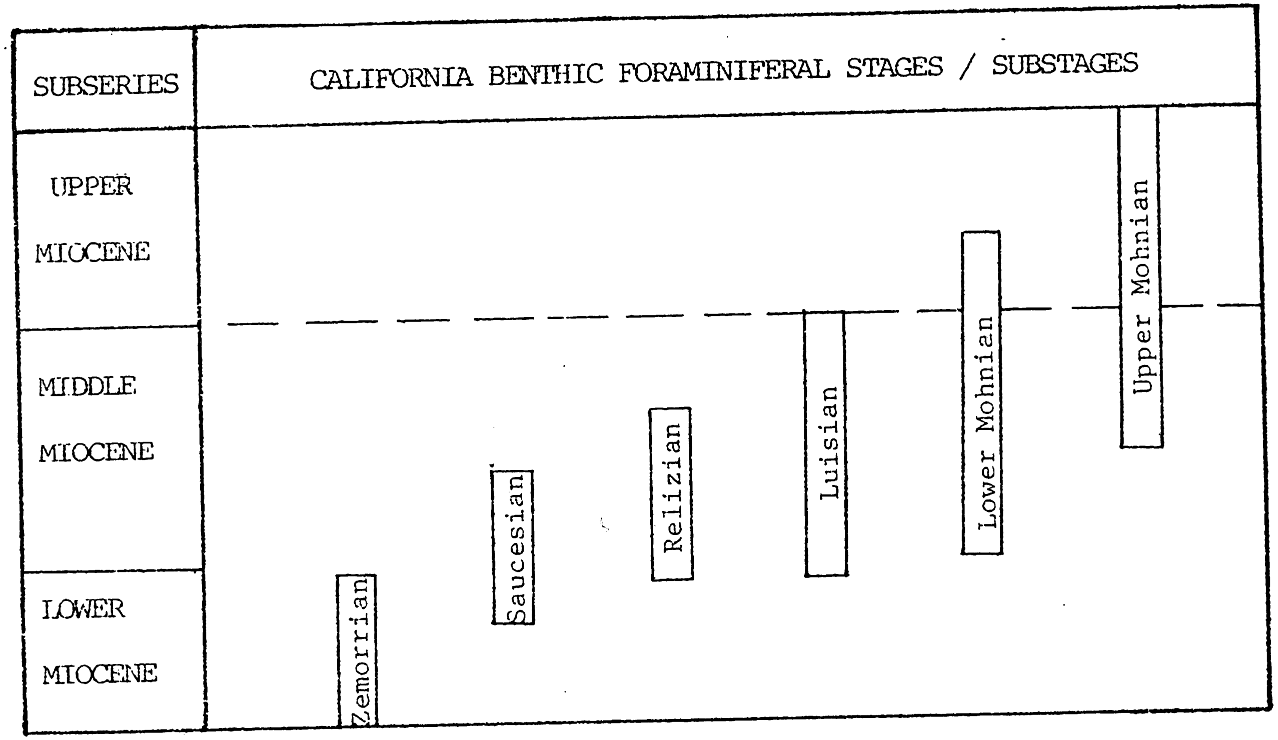

Figure 4. Comparison of provincial Miocene benthic foraminiferal stages of Kleinpell (1938) with coccolith zones from the California Continental Borderland (from Crouch, Bukry, and Arnal, in press).

found that the accuracy of benthic foraminiferal correlations is highest in a deep water basin-plain environment where a single environment persists for great distances. However, toward the edge of a basin it becomes increasingly difficult to recover, identify, and age date benthic forams. In sections where benthic forams are found and can be dated "accurately," one must consider 1) the apparent overlap of benthic stages, 2) the time-transgressive nature of benthic stages, and 3) the rapid facies changes that can occur over a short lateral distance at the edge of a basin. These are important factors to bear in mind when working with microfauna in the Ventura basin.

The formations within the Newhall area have been identified both with respect to lithology and to microfaunal assemblages. In this paper, the Modelo Formation is defined on the basis of lithology, and the top is picked on the basis of lithologic differences between it and the overlying Towsley Formation. The Towsley is identified tentatively west of Newhall in the deeper water depositional environment on the basis of Delmontian fauna, here probably of early Pliocene age in contrast to the type locality of the Delmontian in central California. In the subsurface, the Towsley and Pico Formations appear lithologically similar, unlike their surface outcrops. The formations are separated, where possible, on the basis of Delmontian or "Miocene" fossils in the Towsley and "Pliocene" fossils in the Pico. In the remainder of the Newhall area, shallow marine deposition has caused the time-transgressive character of the benthic forams and also of the stratigraphic units to be most pronounced. For these reasons the Towsley and Pico Formations are referred to as Towsley-Pico undifferentiated (Tt-p) where these conditions arise.

Basement Complex

The San Gabriel Mountains form part of the edge of the eastern Ventura basin; the San Gabriel basement rocks crop out in the eastern part of the mapped area (Plate I). Miller (1930, 1934) divided the basement into several units but applied the name "San Gabriel formation" to the entire assemblage because of the complexity involved in mapping individual units. He defined four rock units on the basis of small, scattered outcrops: 1) the Placerita Formation, 2) the Rubio diorite and metadiorite, 3) the Wilson diorite, and 4) the Lowe granodiorite. Oakeshott (1954, 1958) subdivided the basement of this same area into Placerita Formation, diorite gneiss, and granodiorite.

The Placerita Formation, of pre-Cretaceous age, is the oldest rock unit exposed in the area. Its outcrops are "fragments of a once widely distributed thick series" (Oakeshott, 1958). It is a metasedimentary rock assemblage composed of white crystalline limestone, dolomite, quartzite, and schist containing biotite, graphite, sillimanite, and in some cases tremolite. The formation is highly foliated and cataclastically deformed (Merifield, 1958). The difficulty in mapping is caused in part by the complex intrusive contact of diorite gneiss into the Placerita Formation. The gneissic rocks are so closely associated with the Placerita metasedimentary rocks in distribution (Oakeshott, 1958) that the two units are difficult to map separately. The diorite gneiss in the western San Gabriel Mountains consists of metadiorite, hornblende diorite, and amphibole and biotite schists. The Placerita Formation and diorite gneiss are further disrupted by the emplacement of late Jurassic to Cretaceous igneous plutonic rocks which vary in composition from quartz diorite to granite.

The basement rocks of the San Gabriel Mountains extend to the west beneath the eastern Ventura basin. This is clearly defined north and northwest of Newhall in the vicinity of the San Gabriel fault where Miocene and Pliocene strata overlie the basement directly. Southeast of Mobil - H&M 1 (187) (Cross section F; Plate XII), basement is not encountered. Instead, the Miocene and Pliocene sedimentary sequence is underlain by either Eocene or post-Eocene nonmarine strata. In addition to the Whitney Canyon fault juxtaposing basement rocks against marine Eocene, a pre-Miocene east-west trending fault is interpreted as separating Eocene and nonmarine strata from basement rocks just south of Mobil - H&M 1 (187) (Cross sections F, J, L, O; Plates XII, XVI, XVIII, XXI). The fault was active apparently prior to the erosional period; this is suggested by structure contours on the pre-Modelo erosional surface map (Plate III). The Eocene fossils in Mobil - Circle J 1 (185) are of the Ulatisian Stage of Mallory (1959) and comparable to those in Continental - Phillips 1 (17). Therefore, a thick section of Eocene south and west of Newhall is likely to be found in the subsurface down-dropped along a pre-Miocene fault. The Eocene section is most probably underlain by basement rocks similar to those in the western San Gabriel Mountains and in cores north of Mobil - H&M 1 (187), but an indisputable depositional contact between Eocene and basement has not been observed in wells or in outcrop. Oakeshott (1958) suggested that the Paleocene section in Continental - Phillips 1 (17) directly overlies the basement.

The following list of wells comprises those which have penetrated the basement complex in the eastern Ventura basin; see Figure 5 for locations. The wells are listed by section, township, and range; the number in parentheses following the well name and number is the well index number, as shown on Plate VI and in Appendix A. Several wells have had thin sections made and are described petrographically (denoted by *), whereas the remainder of the descriptions are from drilling and core logs recorded for each well.

Lee - Government 1 (2) 5-3N-15W

Basement hit at ± 404 feet.

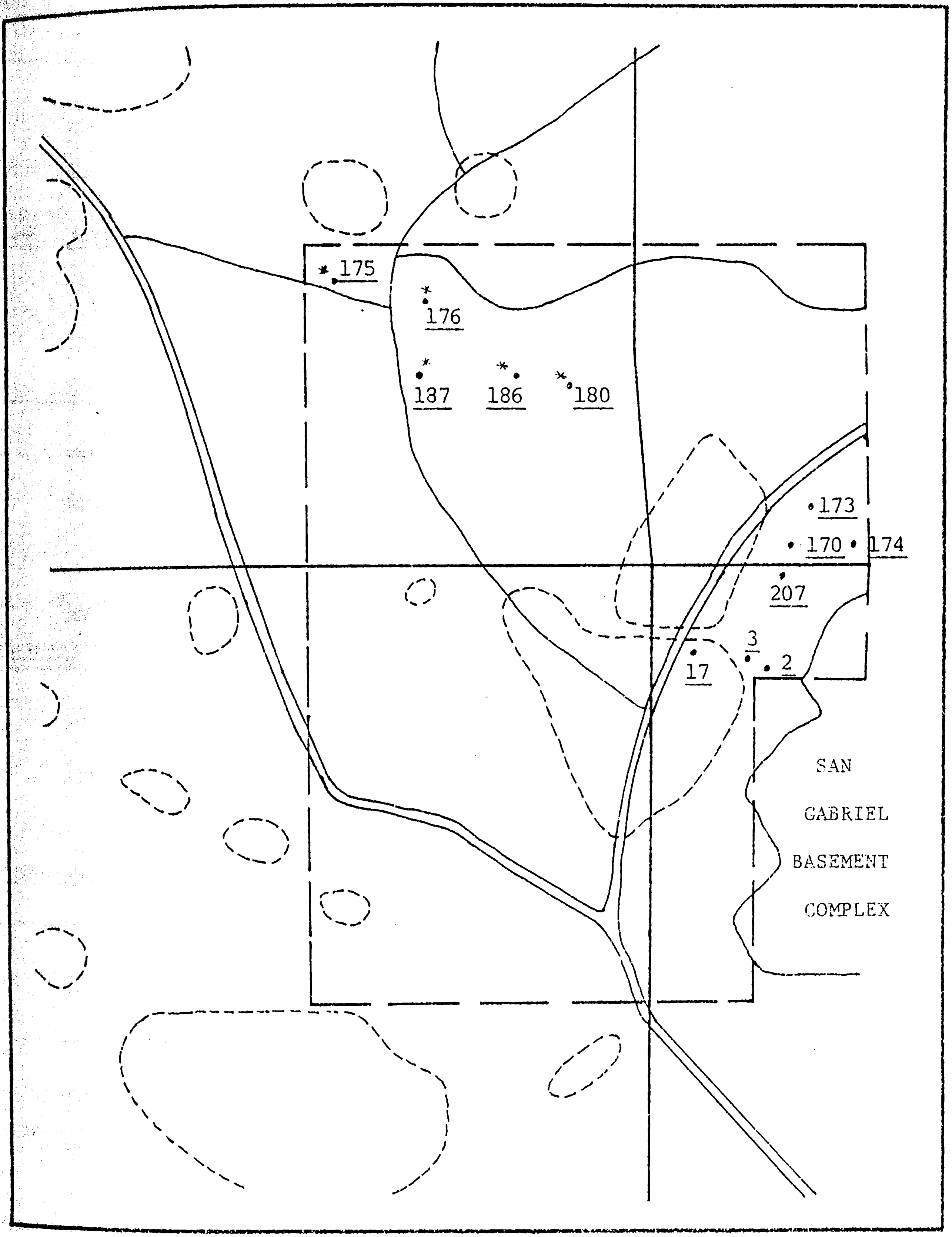

Figure 5. Oil wells drilled into basement rocks and the edge of the basement complex in the San Gabriel Mountains. (* = petrographic decription made in wells; wells identified by index number listed in Appendix A.)

Carter - Carter Earl 3 (207) 5-3N-15W

Basement at 990 feet.

Atlantic - Albert 1 (3) 6-3N-15W

Igneous basement at 925 feet.

Continental - Phillips 1 (17) 6-3N-15W

Cored at 7365-7376 (#27). Schist. Dark green to black with thin beds of recrystallized limestone. Core badly fractured and slickensided throughout. Probably the Placerita Formation.

Sidewall cored at 7410. Gneiss. Weathered, green to greenish gray and fractured.

Cored at 8268-8283 (#30). Gneiss. Fractured with local foliation similar to nearby outcrops in western San Gabriel Mountains.

Lee - Heil 1 (170) 32-4N-15W

Cored at 1431-1435. Basement complex.

San Gabriel Oil - San Gabriel 1 (173) 32-4N-15W

Sidewall cored at 1875, 1979, and 2123. Decomposed granite. Light gray with quartz, feldspar, mica and "iron" minerals.

Rothschild - Wickham Ferrier 1 (174) 32-4N-15W

Cored at 1635-1648. Serpentine schist, olive-green.

Union - NL& F 2 (175) 22-4N-16W

* O.H. (original hole): Cored at 10,102-10,115 (#2). Muscovite granite to granodiorite. The rock contains large amounts of strained anhedral quartz crystals, 0.2 to 2 mm across, with mortar and

sutured grain boundaries. Muscovite is sheared and kink banded and occurs as subhedral to anhedral grains 0.5 to 2.5 mm across. Subhedral plagioclase (An_{35}) and potassium feldspar occur throughout in addition to the quartz. There are a few subhedral hornblende grains, 1 mm in length. The slide shows unsheared areas alternating with highly sheared zones. The thin section consists of approximately 45% quartz, 30% plagioclase, 20% potassium feldspar, 5% muscovite, and a trace of hornblende.

RD (redrill): Cored at 10,680-10,682. Granitic gneiss. The rock varies from light to medium gray, and is medium- to coarse-crystalline with some biotite streaks. There are clusters of medium-grained pyrite cubes in the core.

<u>Superior - Bonelli 14-23 (176) 23-4N-16W</u>

* O.H.: Cored at 8494-8515 (#11). Schist. Quartz grains are cataclastically deformed; the majority are anhedral and less than 0.2 mm across. The biotite is 0.1 to 0.8 mm long, greenish brown, moderately pleochroic, and of metamorphic origin. Clusters of subhedral muscovite are bent and strongly deformed. Over 30% of the thin section is made up of secondary calcite which is extensively sheared and obscures much of the slide.

Cored at 8499-8532. Mica schist and white granitic fragments. Low to medium grade metamorphic rock with biotite predominating and thin quartz veins common.

Cored at 8532-8542. White granitic fragments.

Cored at 8753-8781. Granite. Varies in color from white to pink, medium-crystalline slightly decomposed, accompanied by thin parallel and converging layers of dark gray slate(?) or hard compressed gouge(?).

Cored at 8781-8796. Mica schist. Predominantly a dark gray, firm, low grade schist which has been fractured throughout. Has irregular bands of decomposed granite characterized by "talc" and badly weathered feldspar. One 8 inch piece of hard, medium-crystalline granite was recovered. Several fragments of breccia(?) were found with a light gray, firm, clayey matrix and angular inclusions of gray silt and clay(?); this may be gouge.

* Cored at 8781-8796 (#9). Andalusite-sillimanite schist (Fig. 6). The thin section is dominated by a mosaic texture of quartz, plagioclase (oligoclase), and biotite grains. The greenish brown biotite also occurs in aggregates that are from 2 to 10 mm across. Porphyroblasts of andalusite, 1 to 5 mm across, are euhedral, "freckled" with possible garnet, poikiloblastic with inclusions of biotite, and rimmed with muscovite. Sillimanite consists of long needle-like crystals, 0.5 to 1.5 mm long together with very fine-crystalline aggregates of fibrolite. The biotite and andalusite lack preferred orientation, suggesting that they are post-kinematic. The thin section consists of approximately 40% quartz, 25% plagioclase, 25% biotite,

and 10% andalusite. This rock is correlated with the Placerita Formation.

RD: Cored at 8030-8045. Schist. Dark gray, fractured, with slickensided biotite. The rock has light gray quartz inclusions throughout.

Mobil - Bermite 1 (180) 25-4N-16W

Cored at 4951-4964 and 4976-4984. Granite. Gray green with large amount of pink feldspar, coarse-crystalline moderately hard to friable, and highly weathered. Throughout the core are fractures which have been stained yellow, apparently by high gravity oil.

Cored at 5001-5006. Granite. Gray green, highly weathered, firm to friable. The yellow color of the core may be due to weathering of minerals. No definite oil stain in core.

Cored at 5018-5029. Granite. Gray green with the top 2 feet (0.6 m) highly weathered and friable, and the bottom 9 feet (3 m) less weathered and firm to friable. No stain or oil is found in the granite or in the fractures.

* Cored at 5018-5043 (#5). Altered granodiorite (Fig. 7). The original texture was coarse-crystalline granodiorite, later altered and moderately sheared. Anhedral quartz is strained and sheared, and has undulatory extinction and sutured boundaries; it ranges in size from 0.5 to 2 mm. The plagioclase (An_{35}) has been extensively deformed; it is now subhedral to anhedral and 1 to 4.5 mm long.

Potassium feldspar, 1 to 4 mm across, and greenish brown, euhedral to subhedral biotite, 0.5 to 2 mm across with bent cleavages are also found in the thin section. Secondary minerals include epidote which forms within plagioclase and around biotite grains, carbonate which fills fractures, chlorite, and apatite, 1 to 4 mm across. The igneous and broken texture of the rock is interrupted in a few places where shearing has formed interstices that were later filled with unsheared carbonate. The thin section is composed of approximately 50% plagioclase, 30% quartz, 10% potassium feldspar, and 10% biotite. This description fits well with Oakeshott's (1958) biotite granodiorite which is one of the most extensive units cropping out in the western San Gabriel Mountains south of the San Gabriel fault.

Mobil - Circle J 2 (186) 26-4N-16W

* Cored at 6070-6082. Sheared granite (Fig. 8). Plagioclase (An_{35}), potassium feldspar, and biotite occur as subhedral to anhedral grains ranging in size from 1 to 5 mm. The potassium feldspar is microcline-perthite. The feldspar cleavage is altered and fractured, while the crystals themselves are commonly altered to clays. The rock is sheared with grains from 0.1 to 1 mm across; this is also visible in the hand specimen. Minor amounts of chlorite and epidote occur in the rock. The thin section consists of approximately 50% plagioclase, 25% quartz, 15% potassium feldspar, and 10% biotite.

Mobil - H&M 1 (187) 27-4N-16W

Cored at 7453-7461 and 7465-7476. Schist, Dark green, coarse-grained, micaceous, chloritic, hard, with high-angle fractures.

* Cored at 7453-7465 (#1). Biotite-actinolite schist (Fig. 9). Consists of aggregates ranging from 1.5 to 5.5 mm across of biotite and actinolite. Biotite is euhedral to anhedral, 0.5 to 2 mm across, and has some bent cleavages. Actinolite is primarily anhedral, 1 to 3.5 mm in length, high relief, has inclusions of biotite, and is highly fractured. Accessory minerals include apatite and magnetite. The thin section consists of approximately 55% actinolite, 40% biotite, and 5% plagioclase.

* Cored at 7465-7485 (#2 and #4). Biotite-actinolite schist. Amphibole grains are deformed cataclastically, whereas the relatively uncommon twinned plagioclase grains have been extensively saussuritized. Aggregates of biotite and actinolite, 0.5 to 2.5 mm across, appear schistose in places. The anhedral actinolite is smaller, 0.5 to 2 mm, and the brown biotite ranges from 0.3 to 1.5 mm long as euhedral to subhedral crystals. The thin section is composed of approximately 55% actinolite, 40% biotite, and 5% plagioclase. These two cores are similar to Oakeshott's (1958) description of biotite schist and amphibolite which he has included in his diorite gneiss unit. These rocks were first considered to be

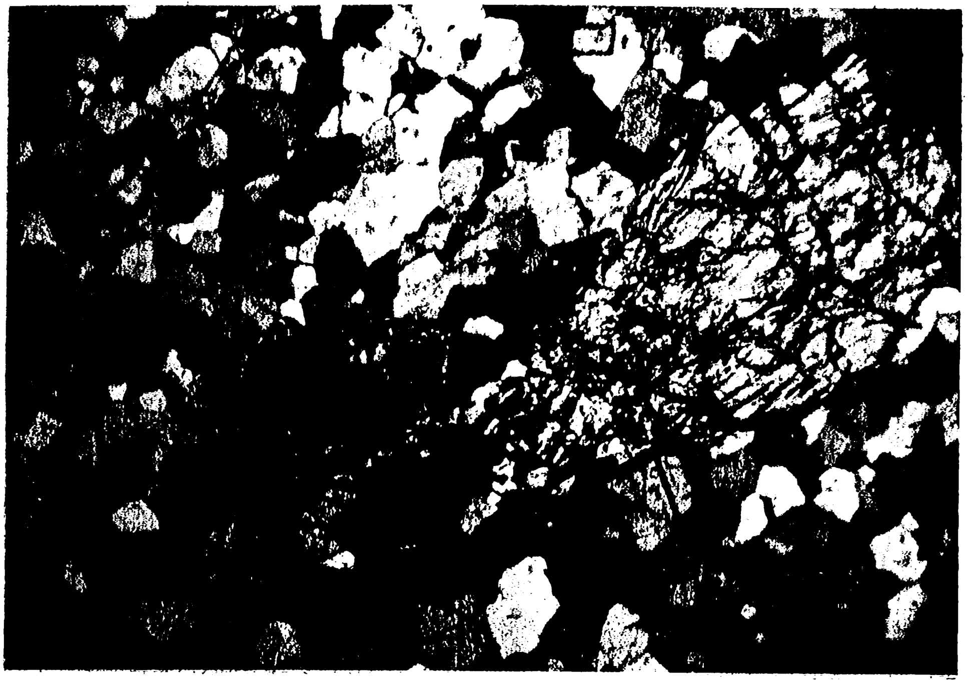

Figure 6. Superior - Bonelli 14-23 (176) 23-4N-16W. Cored at 8781-8796 (#9). Photomicrograph of an andalusite-sillimanite schist. Mosaic texture includes quartz, oligoclase and biotite. Three porphyroblasts of andalusite rimmed with muscovite appear in the center and lower right of the picture. Biotite occurs between the two large porphyroblasts. Field of view is 5 mm across. Crossed nicols.

Figure 7. Mobil - Bermite 1 (180) 25-4N-16W. Cored at 5018-5043 (#5). Photomicrograph of an altered, coarse-crystalline granodiorite. Anhedral to subhedral biotite appears in center surrounded by plagioclase. Minor amounts of potassium feldspar occur around the biotite in the lower central part of the picture. Carbonate fills some fractures in the plagioclase. Field of view is 5 mm across. Crossed nicols.

Figure 8. Mobil - Circle J 2 (186) 25-4N-16W. Cored at 6070-6082. Photomicrograph of a sheared granite. Potassium feldspar is microcline-perthite with cleavages fractured in places, lower right of picture. A zone of rounded cataclastic fragments in a matrix of gouge appears in upper part of field extending from left to right. Feldspar and plagioclase crystals are cataclastically deformed. Field of view is 5 mm across. Crossed nicols.

Figure 9. Mobil - H&M 1 (187) 27-4N-16W. Cored at 7453-7465 (#1). Photomicrograph of biotite-actinolite schist. Aggregates of biotite and actinolite are common. Amphibole grains appear to be cataclastically deformed. Field shows two generations of growth. Field of view is 5 mm across. Plane light.

similar in hand specimen to Pelona Schist as exposed in the Sierra Pelona north of the San Gabriel fault. The core sample appears to have a fairly high degree of schistosity; however, the mineralogy and textural relations as seen in thin section, particularly the association of coarse-grained biotite and actinolite, suggest that the basement rocks in the Mobil - H&M 1 (187) well are more likely correlative to outcrops of biotite schist and amphibolite found in the western San Gabriel Mountains.

Paleocene-Eocene

The oldest exposed sedimentary rocks in the Newhall area are Eocene sandstones and siltstones which crop out in Elsmere Canyon (Plate I). The outcrop extends south for about 3/4 mile (1.2 km) and is bounded on the east by the post-Eocene and pre-Pliocene Whitney Canyon dip-slip fault. The fault juxtaposes a large section, greater than 6000 feet (1830 m), of Paleocene-Eocene strata to the west against the basement complex of the western San Gabriel Mountains to the east. No Eocene rocks have been found east of the fault.

The lowest exposed unit of the Eocene in Elsmere Canyon is a thin conglomerate containing well-rounded granitic and gneissic boulders derived from the nearby basement complex. The overlying units consist of sandstone that is light to medium gray weathering grayish orange, fine- to medium-grained, thick bedded, well indurated with graded bedding; and siltstone that is medium to dark gray with limy concretions, and weathers light to medium brown (Holloway, 1940; Oakeshott, 1958; Winterer and Durham, 1962). The Eocene-Pliocene contact in Elsmere Canyon is a prominent angular unconformity as it is throughout the subsurface of the Newhall area.

The first to recognize the resemblance of the Elsmere Canyon strata to the Eocene Domengine Stage was Watts (1901). McMasters (1933) formally introduced the name Llajas Formation for a middle Eocene unit containing Domengine megafauna exposed in the Simi Valley. Kew (1943) noted that the Eocene in Elsmere Canyon contained numerous oil and tar seeps from fractured, less indurated rocks. The correlation of part of the Elsmere Canyon sequence to the type Llajas in the Simi Valley was made by Oakeshott (1958). Based on megafauna, Winterer and Durham (1962) reported that the Elsmere Canyon Eocene is probably middle to early late Eocene in age with a megafauna similar to that of the Santiago Formation of the Santa Ana Mountains (Woodring and Popenoe, 1945). This age is comparable with Laiming's Foraminiferal B-1 zone which is correlated with the Ulatisian Stage of Mallory (1959).

The thick Paleocene-Eocene sequence in the Newhall area is based on the Continental - Phillips 1 (17) well (Cross sections F, O; Plates XII, XXI) drilled in Whitney Canyon, approximately 1.5 miles

(2.5 km) north of the Eocene outcrop. This well penetrated a thick series (5875 feet, 1790 m) of siltstone, claystone, sandstone and conglomerate, and a small fault, before passing through the Whitney Canyon fault into gneissic basement. Oakeshott (1958) interpreted this section as directly overlying basement rocks (see the section on the Whitney Canyon fault). Oil industry foraminiferal data indicate the following biostratigraphic correlations:

1) 1325-3520 feet (405-1075 m) - Laiming B-zone, Ulatisian-Penutian
2) 3520-5280 feet (1075-1610 m) - Laiming C-zone, Bulitian
3) 5280-5940 feet (1610-1810 m) - Laiming D-zone, upper Ynezian (Schmidt, 1970)
4) 5940-7200 feet (1810-2195 m) - Indeterminate, barren section.

The barren section below the upper Ynezian is primarily conglomerate that is dark green to greenish gray, thick bedded, and hard, with pebbles of igneous and metamorphic rock set in a matrix of medium- to coarse-grained sandstone. This section may be correlative with the Simi Conglomerate Member of the Calabasas Formation exposed in the Simi Hills. The conglomerate in the Phillips 1 (17) well and the Simi Conglomerate are both unfossiliferous. In the area adjacent to the Santa Susana fault, the nonmarine Paleocene is found only south of the fault and is overlain disconformably by the Santa Susana Formation. If the conglomerate in Continental - Phillips 1 (17) is correlative with the Simi Conglomerate, it would be the first described occurrence of this member north of the Santa Susana fault. Alternatively, the barren conglomerate section may be equivalent to a possible basal conglomerate section of the Santa Susana Formation (Yeats and others, 1977; Lant, 1977) south of the Santa Susana fault.

Overlying the Paleocene conglomerate section is a sequence of siltstone, sandstone, and conglomerate. The lowermost 1000 feet (305 m) of dark gray to steel-gray siltstone is thick bedded, hard, brittle, and has traces of sandstone and conglomerate. The middle sandstone unit is light gray, hard, and is interbedded with conglomerate consisting of boulders and pebbles of granite and syenite. Overlying the sandstone is a section of limy siltstone that is interbedded locally with steel blue-gray claystone. This section is apparently equivalent in part to the Santa Susana Formation based on lithology and paleontology; this formation also was previously undescribed north of the Santa Susana fault. The sequence in the Continental - Phillips 1 (17) well and the Santa Susana Formation are both thick bedded gray siltstone interbedded with sandstone; however, one of the more distinguishing similarities of the two is the steel gray to steel blue-gray color of the siltstone and interbedded claystone. In addition to the lithologic similarity, microfauna of the Bulitian and lower Penutian Stages were reported by Mallory (1959) in the Santa Susana Formation in the Simi Valley and are also found in the

Phillips 1 (17) well.

The uppermost sequence of siltstone, sandstone, and conglomerate in Continental - Phillips 1 (17) appears to be lithologically similar to the type Llajas Formation of the Simi Valley. This Eocene sequence consists predominantly of siltstone that is dark gray, massive to poorly bedded, and silty to clayey. In the middle of the siltstone, there is a 600 foot (185 m) thick section of interbedded dark gray, hard, limy siltstone and light gray thick bedded, fine- to coarse-grained, hard sandstone with some lenses of conglomerate. The Llajas south of the Santa Susana fault is generally poorly sorted siltstone, sandstone, and conglomerate. The difference between the two sequences is that the Llajas contains megafossils and worm impressions, features not found in the Phillips 1 (17) well. Howell (1974) concluded that the Eocene in this well is in part equivalent to the shallow marine rocks found several miles south in the Simi Valley. Furthermore, Ulatisian Stage microfauna are reported by Mallory (1959) to be indicative of the Llajas Formation.

Most of the wells in the area that reach the Eocene extend no more than a few hundred feet into it. However, there are two exceptions where over 1000 feet (305 m) of Eocene have been drilled, but in these wells, little paleontology has been done. The Mobil - Circle J 1 (185) (Cross sections F, J; Plates XII, XVI), contained foraminifera identified as upper Llajas (Laiming's B-1A zone or Ulatisian

Stage of Mallory, 1959). Cross Section F (Plate XII) illustrates the relationship between the thick Paleocene-Eocene sequence in Continental - Phillips 1 (17) and the Eocene in Mobil - Circle J 1 (185). Between Mobil - Circle J 1 (185) and Mobil - H& M 1 (187), a fault juxtaposes Eocene Ulatisian Stage strata against basement rocks, based on the assumption that the Paleocene-Eocene sequence is relatively the same thickness as in the Continental - Phillips 1 (17) well to the southeast, An unconformity between these two wells would be possible only if the Ulatisian strata overlapped the Bulitian and Ynezian beds between the Phillips 1 (17) and the Circle J 1 (185) wells to rest directly on the basement. The subcrop map also indicates a possible contact between Eocene and nonmarine strata if this latter relationship exists; this is shown by short dashed lines curving towards the west. In this report, the Eocene in the Newhall area is interpreted to be down-dropped on the west by the Whitney Canyon fault and on the south by the unnamed fault south of the San Gabriel fault between the Circle J 1 (185) and H& M 1 (187) wells, resulting in the local preservation of the thick Paleocene-Eocene section.

Unnamed Nonmarine Sequence

Several wells southwest of Newhall penetrated a sequence of gray, red, green, and bluish shale, claystone, siltstone, sandstone, and conglomerate which is nowhere exposed at the surface. This nonmarine sequence directly overlies Eocene rocks and is itself overlain unconformably by Miocene and Pliocene strata. Various names have been applied to these rocks, including the Mint Canyon Formation (Daviess, 1942) and the "Sespe(?)" Formation (Winterer and Durham, 1962) based on lithology and stratigraphic position.

The thickest described section of the unnamed nonmarine sequence is south of Newhall in the British American - Edwina 1 (73) well (Cross sections A, J; Plates VII, XVI) where over 2000 feet (610 m) were drilled. The sequence in that well consists of siltstone that varies from brown to red to green and is soft, angular, and floury; sandstone that is red, green, and blue, fine- to coarse-grained, silty, poorly sorted, with some bentonite; and interbeds of pebble conglomerate that vary from green gray to mottled red brown and blue gray with a silty sand matrix. One other well penetrates a large section of these nonmarine rocks--Basenberg - Hamilton 1 (92) (Cross section A; Plate VII); however, only the upper few hundred feet of the 3600 foot (2000 m) section were described and recorded in the drillers log. Also the nonmarine sequence in that well may be repeated by the Beacon fault. Geologists have applied the name "Mint Canyon" informally to these rocks based on a few lithologic similarities. The Mint Canyon Formation directly across the San Gabriel fault consists primarily of light gray, thin-bedded lacustrine siltstone and volcanic tuff interbedded with light gray fluviatile sandstone and conglomerate. Also, the microfauna (ostracods and rare forams) and megafauna (gastropods and fish remains) found in the outcrop and in well samples are not present in the unnamed nonmarine sequence. The lower half of the Mint Canyon, exposed northeast of the area, consists of poorly sorted, reddish brown sandstone, conglomerate, and siltstone units. However, the nonmarine strata south of the fault are not as extensively conglomeratic as the lower half of the Mint Canyon. The most striking similarity between the two rock units is the presence of local beds of blue to blue gray bentonite. Crowell's (1952) hypothesis involving large right-lateral displacement on the San Gabriel fault makes the use of the term "Mint Canyon" inappropriate for this sequence southwest of the fault.

Winterer and Durham (1962) tentatively assigned the nonmarine sequence to the "Sespe(?)" Formation based on its stratigraphic position. The nearest exposure of the Sespe to the Newhall area is several miles to the west in the central Santa Susana Mountains south of the Santa Susana fault (Ricketts and Whaley, 1975; Yeats and others, 1977). Typical Sespe in that area consists of light gray to maroon siltstone, sandstone, and conglomerate with rare interbeds of gray green siltstone. Both the Sespe and the nonmarine sequence are unfossiliferous and were deposited between the Eocene and late Miocene. However, the unnamed nonmarine sequence commonly contains thin beds of bentonite, which are unknown in the Sespe.

On the north flank of the Pico anticline, rocks of the Topanga Formation occur in the same area as the unnamed nonmarine sequence (Cross section E; Plate XI) but are not in contact with it. The Topanga in the area consists of marine sedimentary rocks; however, 7 miles (11 km) southeast of the mapped area in Pacoima Hills, Oakeshott (1958) described a section of unfossiliferous nonmarine Topanga rocks. The section consists of coarse-grained, reddish arkosic sandstone and conglomerate interbedded with basalt flows. The nonmarine Topanga differs from the nonmarine sequence in the Newhall area lithologically; the nonmarine sequence is composed of variegated sandstone and siltstone units which are brown, red, green, and blue in color, whereas the nonmarine Topanga is composed of reddish brown, pale red, light red arkosic sandstone and pebble conglomerate in an arkosic matrix which is interbedded with basalt flows.

The unnamed nonmarine sequence does not appear to be similar in lithology to either the Sespe or the nonmarine Topanga Formations. The fact that both the Mint Canyon Formation and the nonmarine sequence southwest of the San Gabriel fault contain local beds of bentonite makes this correlation the most likely based on lithology. However, because the two units do not have any other definitive lithologic similarities and because the Mint Canyon is in part fossiliferous, I have not correlated the sequence to the Mint Canyon but have referred to it as the "unnamed nonmarine sequence."

Mint Canyon Formation

The Mint Canyon Formation was named by Kew (1923, 1924) for a series of nonmarine strata which had previously been described by Hershey (1902) as the "Mellenia series" east of the San Gabriel fault in the Soledad basin. Jahns (1940) reassigned the lower part of Kew's "Mint Canyon" to the Tick Canyon Formation based upon the presence of an angular unconformity separating different lithologies and different vertebrate faunas. The Mint Canyon was subdivided by Durham, Jahns and Savage (1954) into a "Lower variegated member" and an "Upper gray member," each containing vertebrate faunas of different ages. The formation was subdivided by Morrison (1958) into a lower member, sandy member, landslide member, tuff-bearing member, and lacustrine member. The Mint Canyon is most extensive in the central Soledad basin where it is over 9000 feet (2745 m) thick (Morrison, 1958).

Mint Canyon strata crop out east of the San Gabriel fault in the thesis area (Plate I). The exposures correspond to Morrison's (1958) tuff-bearing and lacustrine members which are found at the top of the formation. The tuff-bearing unit is composed of generally arkosic sandstone, siltstone, sandy conglomerate, and conglomerate that are light brown to white, sub-angular to angular, with several vitreous tuffs and locally thin beds of tuffaceous sandstone. These rocks were deposited in both lacustrine and fluviatile environments in which the continuous and well bedded tuffs were water-laid, and the sandier tuffs and tuffaceous sandstones were reworked by streams (Daviess, 1942). The uppermost lacustrine member consists of sandstone that is generally thick bedded, buff, sub-angular and coarse-grained, and has local well-rounded pebbles and streaks of pebble conglomerate. The fluviatile sandstone exhibits cross-bedding and channel-fill structures. Alternating with the sandstone unit is dark gray to dark brown, shaly siltstone which occurs as thin laminations with gastropods and ostracods commonly found. The uppermost Mint Canyon records a time of lacustrine deposition in which streams introduced sand and gravel into the silty, lacustrine sediments.

The largest section of Mint Canyon strata drilled in the area was in Lago Vista - Roland 1 (105) (Cross section I; Plate XV) in which over 5000 feet (1525 m) of the "Upper gray member" of Durham and others (1954) was penetrated. The lowest unit in the well consists of light to medium gray, fine-grained sandstone that is clayey, angular, and friable with streaks of well-sorted, dark gray siltstone and silty shale. Fluviatile characteristics in the unit include cross-bedding and ripple marks. The presence of streaks of variegated sand suggests that these lower rocks are in the transition zone between the upper and lower members of Durham and others (1954). The overlying section of 3500 feet (1070 m) of sandstone, claystone, and shale, corresponds best with the lacustrine and tuff-bearing members of Morrison (1958), though no tuffs or tuffaceous sandstones have been cored in the area. The sandstone is light gray, fine- to coarse-grained, friable, thick bedded, fair to poorly sorted, angular to subrounded, and locally arkosic. The uppermost strata in several wells, e. g. Terminal Drilling - Independent Ghiggia 1 (178) (Cross sections H, L; Plates XIV, XVIII), are lacustrine and consist of interbedded shale and claystone with interlaminations of light gray, silty sand. The shale is dark brown to light blue, silty, bentonitic, fractured and slickensided, and it also contains ribbons of gray to white chert and fresh to brackish water ostracods. Claystone is greenish gray to dark gray, massive to laminated, micromicaceous, bentonitic, fractured, and contains gastropods, ostracods, fish remains, and carbonaceous material.

The lower Mint Canyon Formation has not been drilled in the mapped area. In outcrops northeast of the area, this section consists of brightly colored, poorly sorted, fine- to coarse-grained, red-brown conglomerate and breccia (Oakeshott, 1958).

There has been a general lack of consistency in dating the Mint Canyon Formation using invertebrate and vertebrate faunas. Durham and others (1954) point out that megafaunas in the formation range in age from late Miocene to early Pliocene. Rare forams in Lago

Vista - Roland 1 (105) have been reported by the operator as Mohnian (late Miocene). The age of the Mint Canyon is middle to late Miocene, Barstovian to Clarendonian mammalian age (Woodburne, 1975), which is consistent with the stratigraphic relations to underlying and overlying formations in the Soledad basin.

Topanga Formation

The middle Miocene Topanga Formation is found in the subsurface only beneath the Pico anticline in the southwestern part of the area (Plate I); the nearest exposure crops out about one mile south at Aliso Canyon in the core of the Oat Mountain anticline. Within the Santa Susana Mountains, the Topanga has been found only in the hanging-wall block of the Santa Susana fault, as based on subsurface work in the Aliso Canyon area (Lant, 1977) and the Mormon Canyon area (Yeats and others, 1977). The Topanga and the overlying Modelo Formation appear to be conformable in both the Pico anticline and in the Santa Susana fault area (Saul, 1975; Lant, 1977).

In the subsurface of the mapped area, the lower Modelo and upper Topanga are characterized by interbedded sandstone and shale. The contact between the two occurs approximately at the contact between shale, siltstone, and chert of the Modelo and sandstone and conglomerate of the Topanga in the hanging wall block of the Santa Susana fault. The upper Topanga sandstone contains local basalt flow in the hanging wall block; it may be in part equivalent to the basal Modelo sandstone that rests unconformably on pre-Topanga rocks in the footwall block of the fault.

The Topanga is characterized by interbedded sandstone and silty to sandy shale and an amygdaloidal basalt flow in the subsurface. In Chevron - Orcutt Trustee 2-1 (213) an unknown thickness of hard basalt, at least 50 feet (15 m) or more, was cored (Cross section E; Plate XI). An exposure of basalt near Mormon Canyon, just west of Aliso Canyon, was potassium-argon dated by Turner (1970) as 14 ± 1 million years; this may be the same flow as that found in the Chevron - Orcutt Trustee 2-1 (213) well.

Modelo Formation

The Modelo Formation is widespread in the eastern Ventura basin but is not present in the Soledad basin. The Modelo crops out in the southwest part of the Newhall area (Plate I) along the axis of the Pico anticline and along the crest of the Santa Susana Mountains. It is found in the subsurface west of a line that runs through the towns of Saugus and Newhall (Plate IV) where the Modelo wedges out against an erosion surface cut on the unnamed nonmarine sequence. The Modelo has a distinctive electric log character of short wavelength, high amplitude peaks of resistivity and spontaneous potential. The Towsley overlies the Modelo conformably. Many wells penetrate the base of the Modelo (Cross sections B, C, E, F, J, N; Plates VIII, IX, XI, XII, XVI, XX). The Modelo overlies the Topanga conformably to the southwest and the basement unconformably to the northwest. The Modelo is not found to be in contact with the Eocene in the Newhall area although there may be a contact west of Mobil - Circle J 1 (185). The Modelo apparently overlies unconformably the fault contact between basement and Eocene-nonmarine in the northern part of the area. The Modelo is not found at all northeast of the San Gabriel fault, although Mohnian forams (?) are reported from the Mint Canyon in the Lago Vista - Roland 1 (105) well by the operator.

The Miocene Modelo Formation was divided in its type area into four members by Eldridge and Arnold (1907): a lower sandstone, lower shale, upper sandstone, and upper shale. In 1924 Kew redefined the Modelo to include the units correlated by Eldridge and Arnold as Vaqueros and part of the later defined Towsley Formation of Winterer and Durham (1954). Subsequent paleontological work by Hudson and Craig (1929) caused another redefinition of the Modelo, and Kew's lower three members were reassigned to the Topanga.

A complete section of Modelo occurs between Aliso Canyon (Saul, 1975; Lant, 1977) and the Pico anticline (Winterer and Durham, 1962). The siltstone, claystone, and mudstone are light brownish gray to grayish orange, weather medium brown, and are diatomaceous. Layers of silty to coarse-grained sandstone are interbedded locally in the shale and generally have graded beds similar to the sandstone in the overlying Towsley Formation. The upper exposed unit also locally has gray limestone concretions or thin phosphatic nodules which commonly contain fish remains.

A few wells in the southwest part of the area penetrated a full section of Modelo; however, it is nearly impossible to determine the true thickness because of strong folding, 40-85° dips, and the general ductile character of the shalier units. Mobil - Mendota 1 (212) (Cross section E; Plate X) penetrated over 5000 feet (1525 m) of Modelo overlying interbedded sandstone and shale of the Topanga Formation. The basal Modelo sandstone is medium brown, fine- to coarse-grained, silty, fairly to well graded, oil stained, and probably a few hundred feet thick. An extensive shale unit overlies the basal sandstone; this may be correlative with the middle shale member of Eldridge and Arnold (1907). The shale is dark gray brown, hard, fissile, fractured, has arenaceous forams and fish remains; it is streaked with thinly laminated chert and is interbedded with local hard, fine- to medium-grained, gray sandstone. This unit is intensely folded, and bedding plane slips are common. Overlying the shale is sandstone that is brown to gray, medium- to coarse-grained, well sorted to fairly sorted, oil stained, friable, angular to subrounded, arkosic and conglomeratic. The sandstones are interbedded with siltstones that contain abundant forams, and with subordinate amounts of cherty shale and limestone. The sandstone interbeds common to the upper part of the Modelo are characteristic of proximal turbidites.

Between the Pico anticline and Weldon Canyon (Plate I) there is an abrupt change in the thickness of the Modelo Formation. Cross Section N (Plate XX) illustrates the relationship of a section of lower and upper Mohnian strata greater than 6000 feet (1830 m) thick in Texaco - Eadie 1 (97) to a thinner section of lower and upper Mohnian, less than 1000 feet (305 m) thick, in Texaco - Eadie 2 (98) about 1/3 mile (0. 5 km) to the northeast. Whether this area was controlled by a strike-slip fault or was a marginal area that was tightly folded is unclear.

The upper Modelo west of Newhall contains a late Mohnian fauna. Winterer and Durham (1962) suggested that the presence of a west-facing submarine slope against which the late Miocene strata were deposited would explain the subsurface distribution and thickness of the Modelo. In Von Glahn - Lassalle 1 (210) (Cross section A, E; Plates VII, XI), only the upper shale and sandstone members of the Modelo are found overlying the nonmarine sequence. Farther to the north, the formation consists solely of interbedded sandy shale and sandstone, North of the Holser fault, the Modelo contains a basal conglomerate above the basement (Union - NL& F 2 (175), Cross section F; Plate XII) which is partially similar to that found in the Honor

Rancho area to the northwest (Schlaefer, 1978), but differs in that it does not contain angular breccia. Specht (1969) concluded in a study of the Castaic Junction oil field northeast of Saugus that channel trends within the Modelo indicate an easterly source.

Towsley Formation

The Towsley Formation was originally named by Winterer and Durham (1951) for a sequence of brown-weathering siltstone, sandstone, and mudstone which crops out north of the Santa Susana Mountains and lies between the Modelo and Pico Formations (Plate I). Kew (1924) had previously mapped the strata as a member of the Modelo Formation in the Santa Susana Mountains and as a member of the Pico Formation in Elsmere Canyon. Oakeshott (1950) mapped the upper half of the Towsley as Pico in Elsmere Canyon and named the lower half the Elsmere member of the Repetto Formation. Kern (1973) later subdivided the Towsley in Elsmere Canyon into an upper and a lower unit.

In the Santa Susana Mountains, the Towsley Formation consists of siltstone, mudstone, and shale interbedded with lenticular sandstone and conglomerate. The sandy mudstone weathers chocolate brown, is poorly sorted, and contains ellipsoidal limy concretions. The sandstone and conglomerate are lenticular and variable in thickness and are generally difficult to trace as individual beds for more than a few hundred yards. The poorly sorted sandstone and conglomerate beds have graded bedding, and the contacts with overlying beds are abrupt. Other sedimentary structures found in the area are load casts, current ripples, convolute bedding, slump structures, and small cut-and-fill structures. To the east, in Elsmere Canyon, Kern (1973) has mapped the Towsley as a lower unit and an upper unit separated by a local disconformity. Exposed in Whitney Canyon, the lowermost beds contain angular blocks of crystalline basement east of the Whitney Canyon fault, and blocks of Eocene rocks west of the fault. The remainder of the lower unit is composed of siltstone, sandstone, and conglomerate. East of the Whitney Canyon fault, the lower unit rests directly on crystalline basement rocks, whereas to the west it unconformably overlies Eocene sedimentary rocks. The upper unit in the area consists of siltstone and mudstone that are well indurated, poorly bedded, fossiliferous, and tar- and oil-stained. This unit corresponds to the lower Kraft shale zone of the Placerita oil field about two miles (3.2 km) to the north (Willis, 1952). The upper unit also contains a sandstone and conglomerate tongue that interfingers with the overlying Pico. This tongue grades laterally to the west into siltstone, sandstone, and conglomerate and also grades upward into the basal Pico.

Most of the Towsley Formation in the subsurface of the Newhall area is gray to gray green sandstone and siltstone. The siltstone and shale are sandy, micaceous, thick bedded, friable, with thin streaks of fine-grained gray sandstone. The sandstone units are fine- to medium-grained, fairly to poorly sorted, friable, and micaceous, with carbonaceous and bituminous material. Several wells, cf. Cross Sections C, F (Plates IX, XII), drill through a basal Towsley sandstone and conglomerate unit consisting of igneous pebbles to cobbles, a sandy matrix, and some oil-stained interbedded sandstone. This conglomerate unit is correlated with the Hasley conglomerate which is well exposed at the base of the Towsley in the Santa Susana Mountains. The Hasley conglomerate is an informal name for a basal member of the Towsley exposed several miles to the west in Hasley Canyon. Toward the east, the Towsley siltstone and shale grade laterally and upsection into more dominantly sandy siltstone and sandstone.

The age of the Towsley is based on relatively scarce Delmontian foraminifera collected at the base of the formation in Towsley Canyon immediately above lower Mohnian forams assigned to the Modelo (Winterer and Durham, 1962). In Elsmere Canyon, megafauna identified as early Pliocene are found throughout the Towsley (cf. Winterer and Durham, 1962; Addicott, 1970; and Kern, 1973). Kern has summarized the megafossil chronology that has developed over many years for the Elsmere fauna. The Elsmere fauna is represented by mollusks and echinoids, most of which are found in rocks of Pliocene and younger age in the California Coast Ranges. However, Kern (1973) noted that there are scattered species of definite Miocene age in the Elsmere Canyon fauna. The Miocene-Pliocene boundary occurs within the Towsley Formation but it is identified only at a few localities. Winterer and Durham (1962) placed the Miocene-Pliocene boundary in Towsley Canyon about 500 to 1000 feet (150-305 m) above the base of the formation. Furthermore, it is estimated that the basal Towsley in Elsmere Canyon, 4.3 miles (7 km) to the east, is 1500 feet (460 m) stratigraphically higher than the base in Towsley Canyon; therefore, the basal rocks in Elsmere Canyon are probably of Pliocene age. Throughout the subsurface of the area, there are many problems involved in accurately determining the Miocene-Pliocene boundary. Paleontological determinations in the oil industry are based on many species defining the same stages and epochs; one company uses one index fossil to determine a boundary while another company uses a different species. The microfaunal determination of "Miocene" in much of the subsurface Towsley is provincial terminology used by industry and does not necessarily refer to beds equivalent in age to the type Miocene. Therefore, trying to draw a boundary using different industry sources results in a Miocene-Pliocene boundary that varies up to a thousand feet (305 m) stratigraphically. See Cross Section C (Plate IX) wells (208), (209), and (211).

The Towsley in the Newhall area was deposited in water that varied from deep to shallow. For many years Pliocene basins in California were believed to have been developed under shallow water environments based on the volume of coarse clastic deposits and shallow water megafossils found in the centers of the basins (<u>cf.</u> Reed, 1933). However, benthic foraminiferal faunas in the Ventura basin indicate that depths ranged from 2000 to 5000 feet (610-1525 m) in the central, deeper parts of this basin (Natland, 1957). Woodring and Trumbell identified mollusks (in Winterer and Durham, 1962) from the Santa Susana Mountains that lived in 60 to 600 feet (20-180 m) of water. These megafossils were found in coarse-grained, graded sandstone and conglomerate units which indicate they were transported by turbidity currents downslope into deeper water after death. Also in the southern part of the thesis area, there are intraformational breccias in the Towsley which contain siltstone and sandstone fragments. Most of these breccias appear to have been transported from sources several miles upslope (Winterer and Durham, 1962). The Pliocene depositional environment was primarily shallow marine in Elsmere Canyon. The lower part of the Towsley there was deposited on a surface of low relief, and the upper siltstones were deposited on an irregular surface because of the turbulent, shallow water environment. Kern (1973) believes that the Towsley in Elsmere Canyon was deposited about a mile or so off an exposed shore, based on large scale cross beds and channels found in the area.

Towsley-Pico Undifferentiated

The Towsley and Pico Formations are two lithologically and faunally distinct units in much of the east Ventura basin. Diagnostic foraminifera for these two formations are relatively rare in the Newhall area, especially in the eastern half which is near the edge of the basin. The most apparent lithologic distinction between the two is their color: the Towsley characteristically weathers brown, and the Pico is primarily gray green and greenish gray in the outcrop. Winterer and Durham (1962, p. 308) place the Towsley-Pico contact "at the base of the first prominent sandstone or conglomerate unit below the lowest bed of olive-gray concretion-bearing soft siltstone." However, in the subsurface of the area this relationship does not apply; the Towsley and Pico siltstones cannot be differentiated on the basis of color. Drillers' logs and core descriptions of the upper Towsley and lower Pico commonly describe the section as being gray green to gray sand, siltstone, and shale (cf. Mobil - Circle J 2 (186), Cross sections G, J; Plates XII, XVI). Where there is no definitive microfauna or lithologic descriptions, the sequence of rocks is identified as Towsley-Pico undifferentiated (Tt-p).

The contact between the Towsley and Pico in the subsurface is believed to be conformable and gradational throughout most of the Newhall area. This is partially the reason why it is difficult to separate the formations in the subsurface where siltstone comprises the upper Towsley and lower Pico. Toward the east, where shallower water depositional conditions existed, there is exposed a local unconformity between the two formations which is not evident in the subsurface. The base of the Pico in San Fernando Pass is sandstone and conglomerate which interfinger with brown-weathering siltstone of the Towsley. North and east of the Beacon fault in Elsmere and Whitney Canyons, the units are separated by an unconformity. In Placerita Canyon, the Pico Formation overlaps the Towsley completely and lies directly on basement rocks (Plate I).

East of the San Gabriel fault in the Soledad basin, there is a railroad cut which has been mapped by Oakeshott (1958) as Repetto and by Winterer and Durham (1962) as Towsley. Winterer and Durham (1962) correlated this outcrop with the lower Towsley (Oakeshott's Elsmere Member of the Repetto Formation) exposed in Elsmere Canyon on the basis of lithology and stratigraphic position. However, in this paper the outcrop is identified as Towsley-Pico undifferentiated (Plate I) because there are neither conclusive lithologic similarities nor fossils identified which are unique to the Towsley Formation in Elsmere Canyon. The Towsley-Pico undifferentiated sequence in the railroad cut lies unconformably on the Mint Canyon Formation and is overlain unconformably by the Sunshine Ranch Member of the Saugus Formation. The outcrop is light olive gray silty sandstone, and sandy siltsone with some fossiliferous material. The fauna identified from the outcrop consists of moderate depth, shallow to moderate depth, and shallow water species. Furthermore, in Texaco - NL& F H-1 (179) (Cross sections H, I, J; Plates XIV, XV, XVI) a thin sequence overlying Mint Canyon strata has been identified as Pliocene or latest Miocene in age and is reported to contain faunules identified as Pico in Mobil - Circle J 1 (185) (Cross sections F, J; Plates XII, SVI) of the Ventura basin. This section appears to correlate with the railroad cut to the east (Cross section I; Plate XV). Therefore, without substantial proof, it is more appropriate to map the railroad cut and the section in Texaco - NL& F H-1 (179) as Towsley-Pico undifferentiated.

Pico Formation

The first published description of Pliocene strata was made by Eldridge and Arnold (1903) from outcrops in the Santa Clara Valley. They introduced the name "Fernando Formation" for these beds, Kew (1924) divided the Fernando into the Pico and Saugus Formations of the Fernando Group. The Pico was applied as a formation name on the basis of distinctive exposures of marine siltstone, sandstone, and conglomerate in Pico Canyon four miles (6.5 km) west of Newhall. Further work by Kew (1932) and Reed (1933) led to Kew redefining the Pico Formation as middle to late Pliocene age and applying the name "Repetto Formation" to the underlying early Pliocene strata.

Winterer and Durham (1962) have since renamed the "Repetto" in the Ventura basin as the Towsley Formation because the type Repetto in the Los Angeles basin could not be correlated with the "Repetto" of this area. Natland and Rothwell (1954) divided the Pico of the Los Angeles and Ventura basins into two benthic foraminiferal stages, the Venturian (lower Pico, middle Pliocene) and the Wheelerian (upper Pico, late Pliocene). However, these stages are not apparent either in in outcrop or well cores in the area. The term "Pico Formation" is used in this report to describe the marine sequence of rocks which overlie the Towsley Formation in the Newhall area.

The Pico Formation crops out in a large arc around the Newhall area; it extends southeast along the northern Santa Susana Mountains and east through Elsmere, Whitney, and Placerita Canyons (Plate I). The Pico becomes coarse-grained in the southwestern corner of the mapped area, the olive gray siltstone and sandy siltstone giving way to tongues of graded and cross-stratified sandstone and conglomerate. As San Fernando Pass is approached, the siltstone is progressively lower stratigraphically in the formation and occurs in lesser amounts. From San Fernando Pass towards Whitney Canyon the Pico is composed almost entirely of cross-stratified sandstone and conglomerate which interfinger with the underlying Towsley. In the Elsmere Canyon area, the coarse-grained, cream colored to yellow brown sandstone and light brown conglomerate beds are lenticular in shape.

Conglomerate beds in the lower part of the Pico are tar soaked and are probably correlative with the upper Kraft zone in the Placerita oil field to the north (Tudor, 1962). The Pico overlaps the Towsley and rests directly on crystalline rocks in the Placerita Canyon area. The lower Pico there consists of lenticular, brown gray conglomerate and cross-stratified, cream colored pebbly sandstone, and the upper Pico in this area is composed of brown gray siltstone and silty sandstone.

The general west to east coarsening of grain size in the Pico, exposed in the outcrop, is also evident in the subsurface. For example, in Cross Section F (Plate XII), the upper Pico becomes increasingly coarser grained towards the east as based on core descriptions and electric log character. In Mobil - H&M 1 (187), drilled about 2 miles (3.2 km) north of Newhall, the Pico is predominantly gray brown to gray siltstone and silty shale, both of which are biotitic and clayey, with abundant shell fragments. Within the siltstone units are local interbeds of sandstone and pebbly conglomerate which increase in number and thickness stratigraphically upsection and eastward.

Two miles (3.2 km) west of the thesis area, in Towsley Canyon, the Pico was deposited in deep water (2000-3000 feet, 610-915 m) which shoaled from 1600 to 600 feet (490-185 m) in depth at the time of upper Pico deposition (Winterer and Durham, 1962). Winterer and Durham also presented evidence that to the east, in Gavin Canyon (Plate I), the water was never much deeper than 1500 feet (460 m) and may have been shallower. Foraminifera collected in this area also show evidence of increased water temperature towards the top of the Pico. Graded bedding in the sandstone and conglomerate units of the Santa Susana Mountains and in well cores (cf. Mobil - H&M 1 (187)) are indicative of turbidity current deposition. Megafossils in the vicinity of Towsley and Pico Canyons are shallow, moderate, and deep water faunas brought together after death by turbidity currents. The source area of the shallow marine faunas apparently was to the east, directly adjacent to an exposed shore.

The relationship of the uppermarine Pico Formation with the overlying Saugus Formation is not clearly understood in the Newhall area. Hazzard (in Oakeshott, 1958) introduced the term "Sunshine Ranch formation" for interfingering marine, brackish water, and non-marine beds above the Pico in the San Fernando Valley. Winterer and Durham (1958) redefined the Sunshine Ranch as the lower member of the Saugus Formation. In the San Fernando Valley, the Pico and Sunshine Ranch are differentiated by a noticeable change in color: the Pico olive gray siltstone grades into greenish gray siltstone and sandstone of the Sunshine Ranch. However, in the Newhall area, the Sunshine Ranch consists of interbedded greenish gray and reddish brown siltstone and sandstone which cannot be separated accurately from the overlying continental Saugus rocks. Without the Pico siltstone present in the eastern part of the Ventura basin and without the definitive color change between the Pico and the Sunshine Ranch Member, it is very possible that beds mapped as marine Pico may actually be stratigraphically equivalent to the marine Sunshine Ranch of the San Fernando Valley. In other words, part of the upper Pico and lower Saugus may be coeval. Figure 10 shows the relationship between the depositional environments of the Pico and the Saugus Formations.

Saugus Formation

Hershey (1902) introduced the term Saugus Formation to identify a series of exposures in Soledad Canyon north of the town of Saugus. The Saugus was later defined by Kew (1924) as the upper part of the Fernando Group. Winterer and Durham (1958; 1962) divided the Saugus Formation into two members: a lower marine to brackish water Sunshine Ranch Member and an upper unnamed nonmarine member.

The relationship of the Sunshine Ranch Member with the underlying Pico Formation is not clearly delineated in the eastern Ventura basin, as already discussed, because of the variable lithology and the interfingering and gradational contact between the two units. Winterer and Durham (1962) place the contact rather arbitrarily at

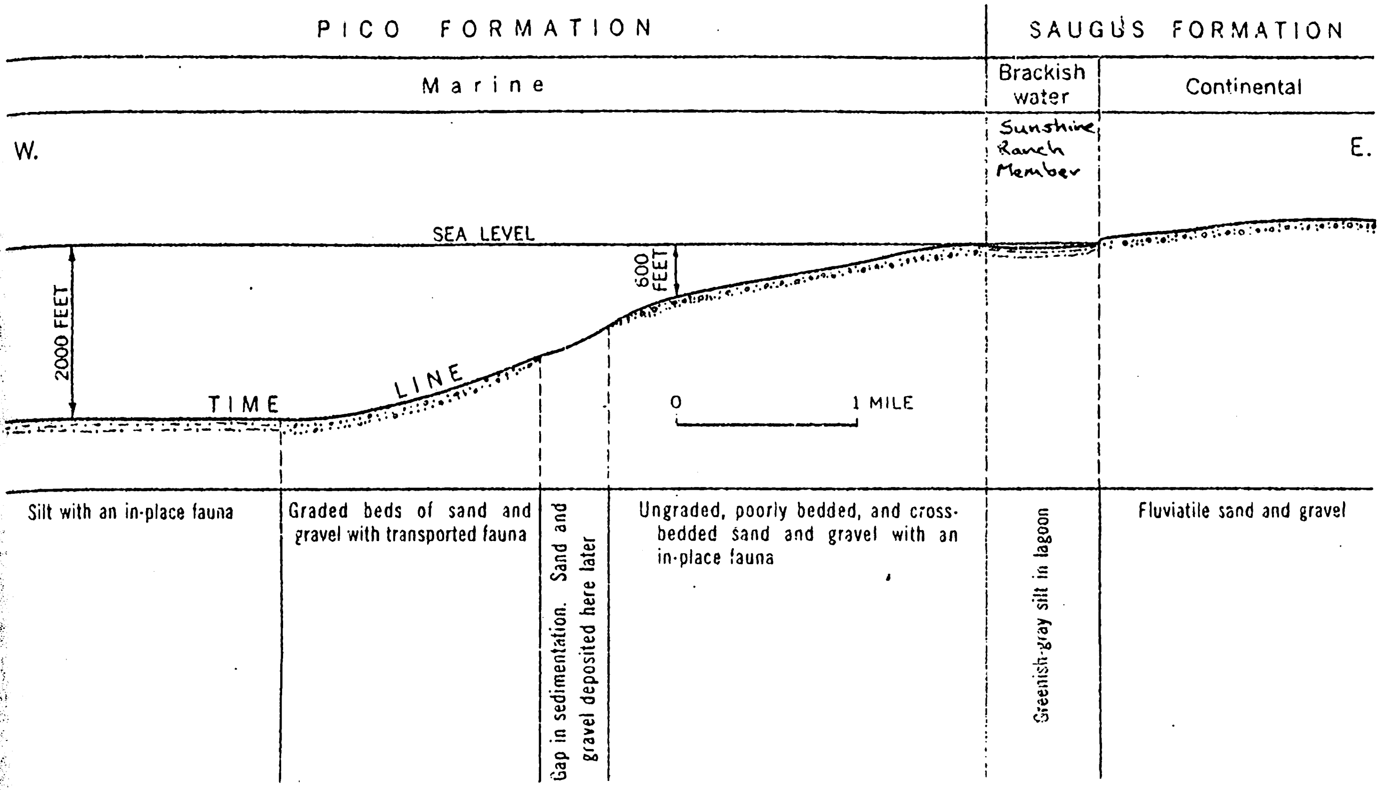

Figure 10. Relation between late Pliocene Pico and Saugus Formations (from Winterer and Durham, 1962, p. 309).

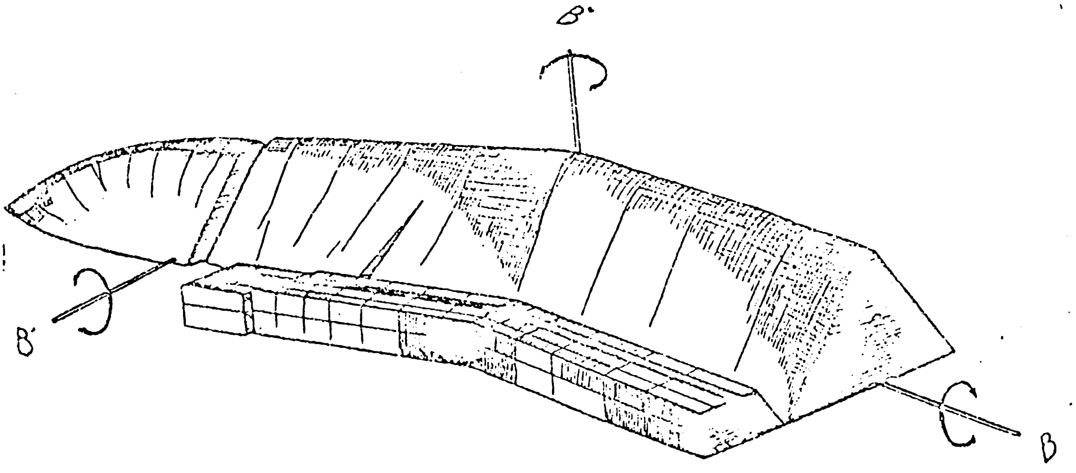

Figure 11. Idealized block diagram of the Pico anticline showing three axis of rotation (from Bonham, 1957, p. 253).

the upper limit of the abundantly fossiliferous beds of the Pico. In the Newhall area, the Saugus consists primarily of light colored, loosely consolidated, indistinctly bedded, poorly sorted conglomerate, conglomeratic sandstone, and sandstone. Interbeds of green gray siltstone, silty sandstone, and light brown to reddish brown sandy siltstone and claystone are common. The greenish gray interbeds, possibly representative of the Sunshine Ranch, are most often found in the lower Saugus, whereas the red brown beds are greatest in number in the nonmarine upper units. East of the San Gabriel fault, Oakeshott (1958) and Morrison (1958) mapped fine-grained, light gray and reddish siltstone and fresh-water limestone beds as part of the Sunshine Ranch Member. Morrison also reported that these strata contain some remains of small pelecypods in a transition zone from fine-grained sandstone and siltstone into thickly cross-bedded conglomeratic rocks.

The Saugus Formation varies from over 6000 feet (1830 m) thick in the western part of the Newhall area to less than 1000 feet (305 m) in Placerita oil field. In Union - NL& F 2 (175) (Cross section F; Plate XII), the lower units of the formation consist of reddish brown to green gray, clayey sandstone and siltstone which are fine- to coarse-grained, poorly sorted, and micaceous. Higher in the Saugus and to the east, sandy siltstone gives way to hard sandstone and conglomerate. Clasts within the conglomeratic beds are rounded to well rounded and generally increase in diameter from west to east (Winterer and Durham, 1962).

A few Pliocene vertebrate fossils have been collected from the lower Saugus west of Newhall. Oakeshott (1958) collected a horse tooth in the upper continental section in the San Fernando Valley; it was identified as Pleistocene in age. The majority of the upper units are unfossiliferous and represent continental deposits. The sandstone and conglomerate strata are most likely broad fan and stream deposits off the nearby San Gabriel Mountains.

Terrace Deposits

Extensive terrace deposits are found north of Newhall in the vicinity of the town of Saugus (Plate I). The deposits rest unconformably on the Saugus and in several places appear compositionally similar to the loosely consolidated gravels of the underlying formation. The terraces consist of reddish brown gravel, sand, and silt which are poorly consolidated to crudely stratified. The largest thickness of terrace gravels is southeast of Saugus where the gravels are 200 feet (60 m) thick. These deposits are adjacent to the present Santa Clara River, but they are actually remnants of an older and broader alluvial cover, at least several miles wide, that at one time was continuous. Terrace deposits in Placerita Canyon yielded the first placer deposits of gold discovered in California (Morrison, 1958).

The late Pleistocene age of the terrace deposits is based on the fact that the deposits overlie unconformably the early Pleistocene Saugus Formation. Winterer and Durham (1962) mentioned the discovery of a late Pleistocene bison tooth at the contact between the Saugus and the terrace deposits, but state that it is unknown whether the tooth was from the Saugus or washed out of the terrace gravels.

Landslides

South of Elsmere Canyon, in the steep foothills of the western San Gabriel Mountains, landslides are common within the Towsley and Pico Formations (Plate I). Siltstones of both formations are commonly exposed in dip slopes which are susceptible to creep and landsliding. Mapping is difficult in this area because of the landslides and the generally poor exposures of the siltstone beds in the Towsley and Pico Formations.

Alluvium

A large part of the Newhall area is covered with alluvium which is associated with the drainage of the Santa Clara River (Plate I). Most streams that drain into the Santa Clara Valley from the canyons off the San Gabriel and Santa Susana Mountains have alluvial covers ranging from a few feet to over 50 feet (15 m) in thickness. The deposits consist of unconsolidated gravel, sand, and silt. Pebbles in the alluvium are predominantly granitic together with some gneissic and sedimentary clasts.

STRUCTURE

The structural geology of the Newhall area is dominated by the San Gabriel fault, the Whitney Canyon fault, and the Pico anticline. Folds are discussed first followed by the faults in the area. The relationship between structure and stratigraphy is largely discussed in the geologic history.

Pico Anticline

The Pico anticline is one of the major structural features in the Newhall area (Plate I). Beginning at the southwestern corner of the area, the Pico anticline and Oat Mountain syncline (mapped as the Pico syncline by some geologists) extend westward for about 9 miles (14.5 km) (Winterer and Durham, 1962). The anticline is asymmetric with a steeper north flank which dips from 50° to overturned. Locally, the core of the anticline is almost a chevron fold. The trace of the Pico anticline axis is relatively easy to map, especially where shale of the Modelo Formation has been eroded away in the core to produce a very deep canyon, e.g. Towsley Canyon, 2 miles (3.2 km) west of the thesis area. The axial plane of the Pico anticline appears to dip steeply southward at the surface and also in the subsurface (Cross section E; Plate XI). Toward the east, the anticline and syncline fade out in the area through which Cross Section N (Plate XX) was constructed. Similarly, the Oat Mountain anticline, south of the mapped area, becomes unrecognizable east of Aliso Canyon. In the Aliso Canyon area, the Santa Susana fault dips moderately north-northeast and is in part a bedding thrust along a plane in the Topanga Formation (Lant, 1977). The fault may dip more steeply at depth, beneath the Oat Mountain syncline. The folds within the area may be contemporaneous with movement on the Santa Susana fault. Near the surface, where the fault dips moderately and essentially parallels bedding, the broad Oat Mountain anticline was developed. However, farther to the north where the fault dips steeply, cutting across bedding, the Topanga, Modelo, and Towsley Formations were arched up into tight folds (Cross section E; Plate XI). The Oat Mountain syncline may mark the surface expression of where the Santa Susana fault first cuts across bedding with increasing depth. The Pico anticline and the Oat Mountain anticline and syncline appear to have been developed similarly to folds (Cemen, 1977, his Cross section P; Plate XXIII). In the Fillmore area, broad folds were formed above the thrust fault, and as the fault began to dip more steeply and cut across bedding, the formations above the fault were more tightly folded. The folds in the Santa Susana Mountains south of Newhall may also be controlled by the structural downstep of the Santa Susana fault where it changes strike south of San Fernando Pass (Fig. 3). In the downstep, the fault changes strike to northeast and increases in dip (Cross section O; Plate XXI) and no major folds are present. Refer to Whitcomb and others (1973) and Shields (1977) for a discussion on the nature of the Santa Susana downstep zone. The Santa Susana fault may also control the Pico anticline several miles west of the Newhall area in Gillibrand Canyon where the fault once again downsteps. The Pico anticline is not found west of the Newhall-Portrero oil field and the Santa Susana fault dies out at the Oak Ridge oil field; it appears that the two structures are contemporaneous in this area. Therefore, the Pico anticline and Oat Mountain anticline and syncline are believed to have developed in response to late Pleistocene-Holocene thrusting along the Santa Susana fault (Lant, 1977). Present-day uplift on the Pico anticline could be indirect evidence of continued activity on the Santa Susana fault.

The sandstone and conglomerate units in the Pico anticline and Oat Mountain syncline, though generally poorly indurated, acted as competent layers during folding and were deformed by laminar slip on bedding planes, forming slickensides. Bonham (1957) reported that some thin sandstone beds were drag-folded and sheared in the vicinity of the Pico anticline axis. Shale and siltstone units of the Modelo and Towsley Formations were incompetent and deformed plastically. Cross Section E (Plate XI) shows the greater thickness of Modelo shale in the axial region of the anticline in comparison to the section on the north flank. Some of the thinner shale beds were pinched out completely along the north flank while others were rotated and deformed.

A detailed petrofabric study of the Modelo and Towsley Formations was made along the Pico anticline by Bonham (1957), who determined that there were three axes of rotation responsible for the development of the Pico anticline structure (Fig. 11). One axis (B) coincided with the anticlinal axis and controlled the degree of folding or rotation of the rock units. The second axis (B') was horizontal and normal to the axial plane of the anticline; this axis caused the structure to plunge to the southeast and to the west. The final axis of rotation (B'') caused the bend in the surface trace of the axis from its strike of N. 65°W, on the east limb to around N. 75°W. at the western end. Folded rocks in this area have a slight preferred orientation, exhibited by fossils, ooids, concretions, pebbles, and mineral grains. Bonham (1957) further pointed out that joints in the axial region of the Pico anticline and Oat Mountain syncline are attributed to extension normal to the north-south direction of regional compression.

Placerita Oil Field Area

The Placerita oil field is a large homoclinal structure. The Pliocene and Pleistocene units in the Placerita area dip to the northwest around 15° to 20° (see Top Pico structure contour map; Plate V). The homoclinal nature of the Towsley, Pico, and Saugus Formations is one of the important reasons for oil accumulation in this area, in addition to the San Gabriel and Whitney Canyon faults which form barriers to oil migration. Also, minor faults through the area and the lenticularity of Pliocene strata south of Placerita Canyon aid in the entrapment of oil updip.

Folding Northeast of the San Gabriel Fault

In the Mint Canyon outcrop, adjacent to the railroad track 1 1/3 miles (2 km) southeast of Honby (Plate I), there are two anticlines which have steep dips on both flanks. The northernmost anticline, the Highway North anticline of Oakeshott (1958), plunges about 25° to the west. This anticline curves to the southeast beneath alluvium out of the mapped area, and is exposed again farther to the southeast in Mint Canyon strata. Each formation which lies above the Mint Canyon in the railroad outcrop decreases in dip upward and is separated by an angular unconformity. This is indicative of several periods of folding, the result of which is that the Mint Canyon strata are folded most steeply. Structure contours on the unconformity at the top of the Mint Canyon Formation reflect a very broad and generalized anticlinal structure because of the sparse well control; however, other minor folds within the formation may be present that are not shown. Cross Sections H, I, J, and L (Plates XIV, XV, XVI, XVII) show the relationships of the units in this area with one another, but the degree of angular discordance between each formation in the cross sections is not known.

San Gabriel Fault

The San Gabriel fault is a major right-lateral strike-slip fault that extends across the area north of Newhall and dips 75° northeast at the surface. Terrace deposits and the Saugus Formation are cut throughout the fault zone (Weber, 1977). The San Gabriel fault commonly consists of two to four surface traces which vary in length; the width of the zone ranges from 150 to 900 feet (45-275 m). The San Gabriel fault was mapped by Weber (1977, 1978) over a 44 mile (70 km) length from Frazier Mountain southeast to Little Tujunga Canyon to determine the extent of late Quaternary activity. Near Bouquet Junction (Plate I), geomorphic evidence indicates late Quaternary vertical offset throughout the fault zone. At several localities, terrace deposits are offset vertically up to 40 feet (14 m), with the southwest side up. One outcrop at the head of Oakdale Canyon exposes Saugus rocks faulted against terrace deposits (Weber, 1977). There is no conclusive evidence which indicates late Quaternary lateral movement along any part of the San Gabriel fault (Weber, 1978).

The pre-Pliocene sequence of rocks on either side of the fault appears to be dissimilar. Cross Sections J, L, and O (Plates XVI, XVIII, XXI) illustrate to contrasting rock types across the San Gabriel fault. In the area immediately south of Bouquet Junction and the San Gabriel fault, a sequence consisting of crystalline basement and marine Modelo, Towsley, and Pico Formations is juxtaposed against a very thick sequence of lacustrine and fluviatile Mint Canyon Formation directly across the fault. In the Superior - Bonelli 14-23 (176) well (Cross section G; Plate XIII), the basement consists of granodiorite that is dissimilar to outcrops of anorthosite several miles to the east across the fault (Fig. 12). Overlying the basement in this well is an 830 foot (250 m) sequence of Modelo (upper Mohnian) shale, sandstone, and conglomerate. A 150 foot (45 m) thick section of sandstone and shale is interbedded with rounded to subangular chert and granitic pebbles and cobbles which range in diameter from 0.5 to 3 inches (1.3-7.5 cm). Some of the sandstones and gravels were transported south a short distance by turbidity currents and deposited in fans; for example, Mobil - H& M 1 (187) (Cross section F; Plate XII) contains igneous pebbles and cobbles with rare granitic boulders larger than 8 inches (20 cm) in diameter. This coarse-grained material is similar to that in the proximal turbidites noted a few miles to the northwest (Schlaefer, 1978), but differs in that rocks similar to the angular brecciated beds in the Modelo of the Honor Rancho area are not present in the Newhall area. The Mint Canyon Formation east of the fault consists of fine-grained lacustrine and fluviatile siltstone

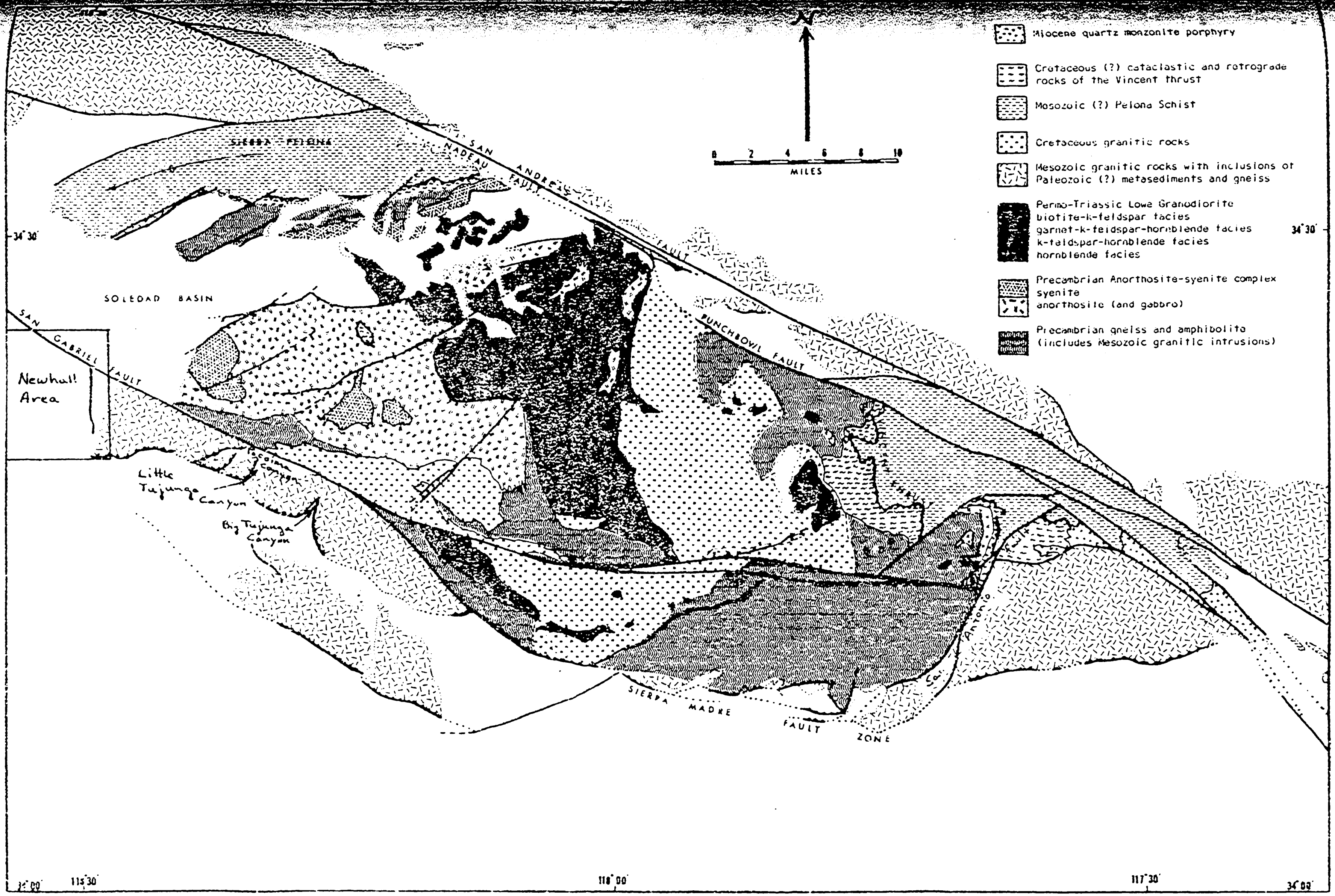

Figure 12. Map showing the distribution of basement rocks and regional fault relationships in the San Gabriel Mountains (after Ehlig, 1975).

and sandstone that are lithologically unlike the coarse-grained deposits in the Modelo Formation. Therefore, the Mint Canyon Formation in the immediate area could not have been the source for these clasts and coarse detritus, the source area apparently having been removed by right-lateral movement on the fault. The lower Mint Canyon could possibly have been the source of the clasts if it were undergoing a period of erosion at the time of Modelo deposition; however, the upper and lower Mint Canyon appear to be conformable. Therefore, the basement rocks of the San Gabriel Mountains, exposed over 6 miles (10 km) to the east, may have been the source area of the Modelo clasts.

Throughout the Newhall area, the Towsley, Pico and Saugus Formations contain sandstone and conglomerate with a wide range of clast types and sizes, all generally well rounded. The Towsley contains predominantly gneissic and plutonic clasts and additionally contains minor amounts of anorthosite and norite clasts whose source outcrops lie several miles east and northeast of the area (Fig. 12). Flows and sills of andesite found in the nonmarine Vasquez Formation about 12 miles (19 km) northeast of Newhall in the Soledad basin (Kew, 1924) appear lithologically similar to some of the clasts in the Towsley conglomerate beds. Many of the clasts within the Towsley and Pico Formations may have been derived from older conglomeratic formations in adjoining areas (Winterer and Durham, 1962). Ehlig

(1975) pointed out that the Pico conglomerate units in Placerita Canyon contain small subangular clasts of Mendenhall gneiss, anorthosite, and gabbro apparently derived from sources north of the San Gabriel fault and four to 12 miles (7-19 km) to the southeast. Clasts within the Saugus Formation are all rounded to well rounded and are representative of sources on both sides of the San Gabriel fault. In the Newhall area, the clasts decrease gradually in size from east to west away from the western San Gabriel Mountains.

The Saugus Formation crops out on both sides of the San Gabriel fault; however, the thickness of the formation is very different on opposite sides of the fault. In the eastern Ventura basin, a thick section of Saugus (about 3500 feet, 1065 m thick) conformably overlies the Pico in Mobil - Bermite 1 (180) (Cross sections G, K, L; Plates XIII, XVII, XVIII), whereas in the Soledad basin, about 3/4 of a mile to the north, a thinner section of Saugus (less than 1500 feet, 455 m) unconformably overlies Mint Canyon strata in Terminal Drilling - Independent Ghiggia 1 (178) (Cross section L; Plate XVIII). No intraformational markers could be correlated across the fault between the two wells.

The Mint Canyon Formation is interpreted as being truncated by the San Gabriel fault in this area. The Caliente Formation in the Lockwood Valley and the Mint Canyon in the Soledad basin, separated by 30 to 40 miles (48-64 km), are believed to have been deposited in the same east-west-trending basin (Carman, 1964; Ehlig et al., 1975). This correlation is based on an assemblage of rapakivi-textured quartz latite porphyry, anorthosite, and Lowe Granodiorite clasts which are found in both the Mint Canyon and Caliente Formations (Ehlig and Ehlert, 1972). If, however, the unnamed nonmarine sequence in the eastern Ventura basin corresponds to the Mint Canyon Formation whose base was not penetrated in the mapped area, the argument for right-lateral displacement of the Mint Canyon would not apply.

The San Gabriel fault has undergone approximately 30 miles (48 km) of right-lateral slip since the middle Miocene (Woodburne, 1975). The metasedimentary rocks of the Placerita Formation, the oldest rock unit in the western San Gabriel Mountains, would ideally have a corresponding unit across the fault and 30 miles (48 km) or so to the southeast. The San Gabriel fault splits into two major branches and smaller subsidiary branches east of Big Tujunga Canyon (Fig. 12), obscuring the offset relationships along the fault. In the eastern San Gabriel Mountains, the San Antonio fault cuts across the San Gabriel fault zone making point-to-point offsets very difficult to reconstruct. East of the San Antonio fault is a Paleozoic(?) metasedimentary unit (Woodford, 1960) which might correspond with the Placerita Formation last exposed in Little Tujunga Canyon over 40 miles (65 km) to the west. Morton (1975) reported that these rocks in San Antonio Canyon are amphibole biotite schist, graphitic schist, marble, and quartzite and are cataclastically deformed, foliated, and complexly intruded by quartz diorite of the Placerita Formation. The easternmost exposure of the Placerita Formation and the westernmost exposure of the San Antonio metasedimentary rocks are separated by over 40 miles (65 km), much farther than the previously demonstrated maximum offset of 30 miles (48 km) on the San Gabriel fault.

East of the mapped area in Pacoima Canyon, several slivers of Paleocene rocks are exposed within the San Gabriel fault zone for about 8 miles (13 km) (Fig. 13). Mollusks of the Martinez Stage were described by Oakeshott (1958) in these slivers, which correspond with the lower Ynezian Stage (Schmidt, 1970). These rocks crop out between the main fault strand and the De Mille fault, a smaller branch. The outcrop consists of dark green black, coarse-grained marine sandstone, thin interbeds of black shale, and thick lenticular beds of pebble conglomerate (Oakeshott, 1958). The Paleocene strata exposed in the fault zone may be correlative with the barren section of Paleocene conglomerate in the Continental - Phillips 1 (17) well. Because the Paleocene-Eocene sequence in the eastern Ventura basin south of the San Gabriel fault zone is not found east of the Whitney Canyon fault, the slices of Paleocene strata east of Pacoima Canyon may have been displaced by about 14 miles (22 km) of right-lateral offset. The Whitney Canyon fault, apparently truncated by the

San Gabriel fault, may have a corresponding segment which was displaced right-laterally and is now found in the western San Gabriel Mountains north of the fault.

The subsurface configuration of the San Gabriel fault is difficult to determine in the Newhall area because of the lack of well control. The structure contours on the principal strand of the San Gabriel fault (Plate II) are based on fault cuts in three wells, on the approximate surface trace of the main strand, and on a measured dip of 75° on the fault plane at the surface. The San Gabriel fault dips in this area at a lower angle than along the remainder of the fault trace. For instance, in Little Tujunga Canyon to the southeast, the dip on the fault is 83° northeast (Oakeshott, 1958) and in the Honor Rancho area to the northwest it dips 85° to the east (Schlaefer, 1978).

Whitney Canyon Fault

The Whitney Canyon fault crops out along the eastern part of the area from Elsmere Canyon to the San Gabriel fault (Plate I). The fault is named for its exposure in Whitney Canyon; however, it is best exposed in Elsmere Canyon where it juxtaposes rocks of Eocene age on the west against Pliocene to the east. Immediately north of Placerita Canyon, where the fault cuts through the Saugus, it is difficult to trace the fault at the surface. In the eastern Placerita oil field, where well control is extensive, one can map the fault tentatively on the basis of wells on either side of the fault.

The fault represents two periods of activity: a pre-Pliocene dip-slip and possibly strike-slip movement, and a post-Pliocene dip-slip episode. In the Continental - Phillips 1 (17) well (Cross sections F, O; Plates XII, XXI), the deepest test drilled east of Newhall, a thick section of Paleogene strata was penetrated to a depth of over 6000 feet (1830 m) below sea level before passing through two faults into basement. The question as to whether this sequence of rock represents a partial section of Paleogene rocks in fault contact with basement (Winterer and Durham, 1962, Plate 45), or whether it represents a complete Paleogene sequence resting on basement (Oakeshott, 1958) is open for speculation. In this report the former interpretation is accepted on the basis of structure contours drawn on the Whitney Canyon fault (Plate II). The contours are based on the surface location of the fault, the 75° fault plane dip in Whitney Canyon measured by Hazzard, and the depths below sea level where Continental - Phillips 1 (17) is cut by two faults. The fault zone in the well is marked by brown green gouge which is very fractured and slickensided with shear planes dipping 75-85°. Gneiss, limestone, sandstone, and conglomerate are found within the section between the two faults (Cross section F; Plate XII). The contours on the fault reflect a fault plane dipping 75° to the west. The minimum vertical separation on this pre-Pliocene dip-slip fault is over 6000 feet (1830 m).

The pre-Plicoene period of movement of the Whitney Canyon fault is suggested (Oakeshott, 1958) as having a major left-lateral component along the edge of the eastern Ventura basin. Oakeshott believes this fault may be similar to left-lateral faults which separate sedimentary strata of the Soledad basin from basement rocks of the San Gabriel Mountains northeast of the San Gabriel fault, Oakeshott reported that Pliocene beds are offset left-laterally 150 feet (45 m) along the Whitney Canyon fault. The only other evidence cited was the similarity of minor folds found in the Placerita oil field to folds mapped adjacent to left-lateral faults northeast of the San Gabriel fault. However, no evidence for lateral displacement along the Whitney Canyon fault has been found in the subsurface of the area; all Pliocene strata correlated directly across the fault with no lateral juxtaposition of dissimilar rock types. The Whitney Canyon fault definitely had a period of dip-slip movement prior to the deposition of Pliocene strata; however, it would be speculative to suggest a corresponding fault similar to the Whitney Canyon northeast of the San Gabriel fault. The Towsley, Pico, and Saugus Formations cover the fault, making it difficult to find a pre-Pliocene trace north of the San Gabriel fault.

The presently exposed trace of the Whitney Canyon fault was formed by dip-slip movement, but in a reverse sense of direction to the pre-Pliocene displacement. The Pleistocene episode of reverse faulting in the mapped area caused the displacement of Pliocene and Pleistocene units along the pre-existing, pre-Pliocene fault. Vertical displacement of the Pico Formation of the Whitney Canyon fault is at the most 100 to 200 feet (30-60 m) (Cross sections C, D; Plates IX, X) with the west side up. Contours on the top of the pre-Modelo erosion surface (Plate III) adjacent to the fault indicate that the basement and Eocene are separated about 300 to 400 feet (90-120 m). The Whitney Canyon fault may have had two periods of reverse displacement, one period occurring prior to Pico deposition and the second after Pico deposition. However, because there is no control on the basement adjacent to the Whitney Canyon fault, it is not possible to evaluate whether the two periods of reverse faulting have occurred or not.

Holser Fault

The surface trace of the Holser fault intersects the San Gabriel fault in an unknown manner immediately southeast of Bouquet Junction (Plate I). The Holser can be traced northeast and east from Piru Creek (Figure 1) to Castaic Creek where it is concealed by alluvium. The fault extends to the east beneath the alluvial cover of the Santa Clara River for about 5.5 miles (9 km) and forms a lineament on aerial photographs (Weber, 1977) and on Landsat imagery (NASA ERTS E-1144-1815, bands 4, 5, & 7). Terrace deposits are cut by the Holser fault in the northwest corner of the Newhall area. In the area where the Holser fault cuts terrace deposits south of Bouquet Junction, a tunnel was constructed by the Metropolitan Water District across the fault. Figure 13 locates the trace of the tunnel with respect to the Holser and San Gabriel faults, and shows the tunnel cross section through the fault zone (R. J. Proctor, personal communication, 1978). The main fault plane dips 72° to the south, and five smaller faults dip at steeper angles in the 150 foot (45 m) wide fault zone. The minimum reverse displacement of the base of the terrace along the fault is 14 feet (4.5 m). The surface expression of the San Gabriel fault and Holser fault junction is extremely complex (Plate I). In the few outcrops of Saugus between the faults, the dips are very steep to the north and to the south. Because of the many small faults which cut through the area, it is only possible to infer the area where the two faults intersect at the surface, as has been done on the fault contour map (Plate II).

In the Del Valle and Ramona oil fields 9 miles (14 km) to the west, the Holser fault is interpreted as a south-dipping reverse fault which has been folded (Nelson, 1952; Cemen, 1977). Winterer and Durham (1962, Plate 45) interpret the fault north of Saugus as south-dipping at about 70°. However, there are no wells in the Newhall area or immediately to the west of the area which cut the Holser fault. Union - NL& F 2 (175) (Cross section F; Plate XII) may cut the fault,

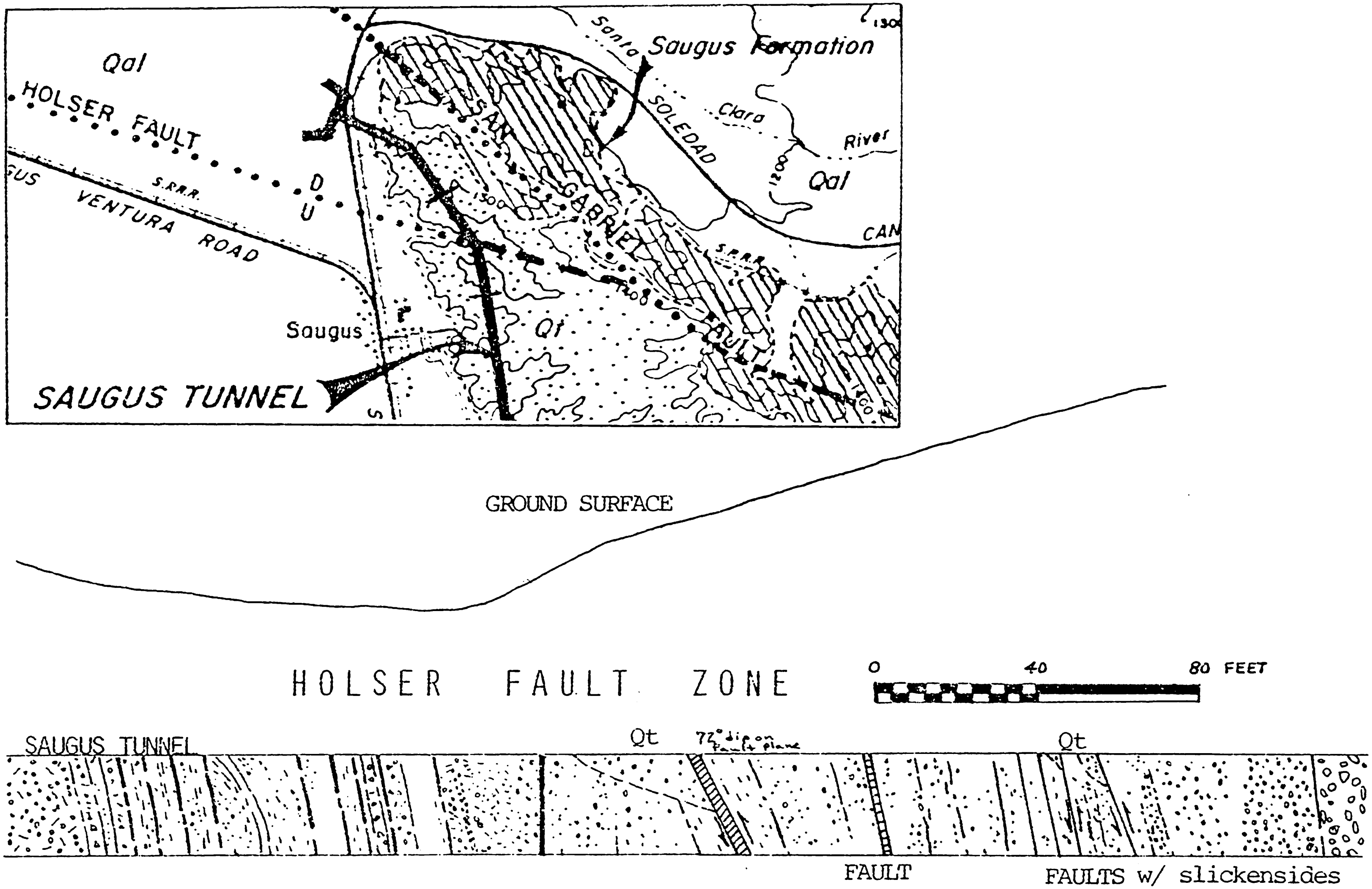

Figure 13. Holser fault zone. Cross section of the Saugus Tunnel in the vicinity of the San Gabriel fault and Holser fault intersection (from R.J. Proctor, personal communitcation, 1978, Metropolitan Water District of Southern California).

but if so, it was cut at a very shallow depth in the well where no core or ditch sample data were collected. The structure contour maps for the pre-Modelo erosion surface (Plate III), the top of the Modelo (Plate IV), and the top of the Pico (Plate V) indicate fault separation. The vertical separation of the Pico Formation is about 500 feet (150 m) between wells (187) and (176). The contours on the Holser fault plane are dashed and queried because of lack of subsurface control in this area. Isopachs of the Modelo show no lateral offset north and south of the Holser fault; so essentially it is a dip-slip fault.

Weber (1978) reported that a strand of the Holser fault may intersect the San Gabriel fault near the mouth of San Francisquito Canyon, three miles (5 km) northwest of its generally accepted junction. The basis for this reasoning is that clasts in the Saugus Formation in the Valencia area (Castaic Junction) are solely Pelona Schist, whereas to the southeast the Saugus contains Pelona Schist and abundant anorthosite clasts. He concludes that this abrupt change across the alluvium of the Santa Clara River is the result of a principal trace of the Holser fault. In light of the data from the Saugus tunnel, the Holser fault clearly occurs in the mapped area; however, this does not mean that another strand of the Holser fault might not exist elsewhere.

Legion Fault

The Legion fault is the northernmost of the south-dipping reverse faults in the Newhall area. It is named for its exposure behind the American Legion Hall about 1 mile (1.6 km) east of Newhall. Most of the fault trace is covered by alluvium along Newhall Creek. The fault is inferred to connect with a series of reverse faults exposed on the ridges through Elsmere Canyon. Vertical separation is probably no more than a hundred feet along the entire length of the fault which is less than the Beacon and the Weldon faults (Cross section M; Plate XIX).

The main trace of the Legion fault cuts two wells in the area; Grayson - Hilty 1 (78) and Morton and Dolley - Needham 4 (81) (Plate II). Contours on the top of the Pico and on the pre-Modelo erosion surface indicate that the fault dies out to the west. The Legion fault cuts Saugus, Pico, Towsley, and Eocene strata.

Beacon Fault

The Beacon fault is a south-dipping reverse fault which was named for its exposure near an airway beacon at the head of San Fernando Pass (Plate I). The fault plane at the surface dips between 70° and 75° at the western end and decreases in dip towards the east. Immediately east of San Fernando Pass, the fault plane is parallel to bedding and cannot be traced further. The Beacon fault has a prominent effect on the surface geology in the area. Along a half mile section of the fault, gently dipping Pico sandstone and conglomerate strata are thrust over Saugus Formation. In Railroad Canyon, south of Newhall, the fault dips 40° south and has two smaller north-dipping faults in the hanging wall block which have juxtaposed Pico and Saugus strata as well (R. J. Proctor, personal communication, 1978). The fault zone in this area is around 650 feet (200 m) wide.

Along the eastern half of the Beacon fault, where it is a thrust, the fault plane steepens at depth (Cross sections M, N; Plates XIX, XX; Plate II). The fault has been cut by two wells in the area; British American - Edwina 1 (73) and Union - Needham 1 (88). In Union - Needham 1 (88), the Pico is thrust over Saugus, and the Towsley and nonmarine sequence are displaced about 200 feet (60 m). Cross Section N (Plate XX) also illustrates how the fault developed in an area where the nonmarine and Pliocene strata dip steeply to the south. One well that may have cut the Beacon fault is Basenberg - Hamilton 1 (92) (Cross section A; Plate VII); however, no lithology descriptions were made for this section of the well.

Weldon Fault

The Weldon fault is similar to the Beacon fault in that they are both south-dipping reverse faults which steepen with depth. However, the Weldon fault is a thrust fault along its entire surface trace, dipping between 15° and 16°. The western section of the thrust flattens out and almost parallels the bedding planes, making mapping difficult. A klippe is isolated at the top of a small hill northwest of the head of Gavin Canyon (Winterer and Durham, 1962). Along the thrust zone, Pico conglomerate has been thrust over less resistant sandstone and siltstone of the Pico and Saugus Formations. The result is a topographic ridge with a steep cliff about 100 feet (30 m) above the Weldon fault at the base. In the area around San Fernando Pass, the footwall block is sliced up by a number of minor faults adjacent to the main fault plane (Ford, 1941). Slickensides are common along bedding planes in this area.

In the subsurface below Weldon Canyon, the fault apparently separates a very thick sequence of Modelo strata (over 5000 feet, 1525 m) to the south from a thinner section of Modelo (less than 1000 feet, 305 m) to the north which overlies nonmarine strata (Plate IV). The difference in thicknesses of the Modelo cannot be explained solely on the basis of reverse displacement on the Weldon fault; vertical separation is at most a few hundred feet (Cross section N; Plate XX). Winterer and Durham (1962) allued to the possibility that a left-lateral strike-slip fault juxtaposed the two anomalous sections of Modelo against each other. However, 1.5 miles (2.5 km) west of this area, Cross Section E (Plate XI) does not require a strike-slip fault to interpret the geology; also the Weldon fault apparently dies out to the west.

The Legion, Beacon, and Weldon faults form a series of south-dipping reverse faults which die out to the west (Plate II). Saugus strata are the youngest rocks cut by these faults which are, therefore, younger than early Pleistocene. The possibility exists that this group of faults developed in response to the folding of the Santa Susana Mountains, i. e., the development of the Pico anticline and Oat Mountain syncline. The faults, like the folds, appear to die out to the southeast in the general area of the Santa Susana fault downstep (Plate I).

GEOLOGIC HISTORY

The basement rocks of the western San Gabriel Mountains extend into the subsurface south of the San Gabriel fault. The basement includes the Placerita Formation (Miller, 1934), the oldest rock unit in the area, which is found in scattered outcrops. The Placerita metasedimentary rocks were intruded by diorite gneiss (Oakeshott, 1958), and, prior to the end of the Cretaceous, granodiorite was emplaced. These rocks underwent strong cataclastic deformation prior to deposition of the Paleocene-Eocene sequence.

The Paleocene-Eocene sequence of strata in the Continental - Phillips 1 (17) well represents the oldest sedimentary rocks in the subsurface of the area and are presumed to lie unconformably on basement. The relationship of this Paleocene-Eocene sequence to rocks of the same age several miles to the south in the Simi Valley is not clearly understood. South of the Santa Susana fault, the Simi Conglomerate pinches-out to the north as it is overlapped by the Santa Susana Formation (Shields, 1977; Yeats and others, 1977). Howell (1974) speculated that the basal section of barren conglomerate in Phillips 1 (17) may correlate with the Simi Conglomerate; if so, this would be the first described Paleocene north of the Santa Susana fault. However, the possibility exists that this barren section might be correlative to a suggested basal conglomerate of the Santa Susana Formation south of the fault (Shields, 1977). The Paleocene-Eocene strata were deposited as a transgressive-regressive sequence in which the Paleocene conglomerate was overlain by a sequence of siltstone and sandstone which may correlate to the lower to middle Santa Susana Formation. The upper siltstone units of the formation have been suggested (Howell, 1974) as representing a regressive sequence which exhibits graded bedding, suggestive of turbidity current deposition. These beds in the subsurface, together with outcrops in Elsmere Canyon, are correlated tentatively with the Eocene Llajas Formation of the Simi Valley. The unnamed nonmarine sequence mapped in the subsurface of the southwestern part of the Newhall area overlies the Eocene and marks the end of a major regression in the area. These nonmarine rocks were deposited above marine Eocene and below late Miocene strata, and thus may have been deposited during the same period of continental deposition as the Sespe Formation which spanned the Oligocene Epoch. But whether these two nonmarine units are coeval is unknown; they are not lithologically similar. The occurrence of bentonite in the Mint Canyon Formation and in the nonmarine sequence, however, is significant evidence which might suggest that these two sequences are correlative. It is reasonably possible that the volcanic ash in these two nonmarine sequences, though, was deposited in two separate basins many miles apart and not in one continuous basin. Again, as in the comparison with the Sespe, it is not possible to determine whether these units were deposited in the same depositional basin.

The major pre-middle Miocene erosional surface throughout the subsurface in the area is interpreted by Winterer and Durham (1962) as the result of regional uplift. The marine Topanga Formation of middle Miocene age represents the initial deposits of a new transgression in the Newhall area. As the seas transgressed farther, the Modelo was conformably deposited over the Topanga and extended farther northeast. These deep water deposits are characteristic of turbidity current deposits transported down-slope. In the eastern Ventura basin, the Modelo grades laterally and upsection into coarser grained strata of the Towsley Formation. It is unknown whether the thick section of Modelo in the southern part of the area (Cross sections E, N; Plates XI, XX) represents a marginal area thinning out to the north and northeast, or whether the area has a Miocene fault which juxtaposed sections of Modelo of contrasting thicknesses.

The Whitney Canyon fault can be dated as pre-Pliocene because of the Pliocene Towsley Formation which overlaps Eocene on one side of the fault and basement on the other. The dip-slip movement of over 6000 feet (1830 m) on the fault down-dropped and tilted the thick sequence of Paleocene-Eocene rocks on which the late Miocene and younger sediments were deposited.

Northeast of the San Gabriel fault, prior to its development, the Mint Canyon Formation was deposited in an east-trending basin, from middle to late Miocene time, in a fluviatile and lacustrine environment (Ehlig and others, 1975). The Modelo (lower Mohnian) and Mint Canyon strata are interpreted as having been separated by a ridge of basement (the Piru Mountains southwest of the fault) during their deposition (Winterer and Durham, 1962). The San Gabriel fault displaced these different terranes, right-laterally beginning in the late Miocene between the Barstovian and Clarendonian mammalian stages (Woodburne, 1975). During this time, the Modelo northwest of Newhall received coarse-grained clastics which were interbedded with siltstone and shale (Cross sections F, G; Plates XII, XIII). The source of this coarse detritus could not have been the finer grained upper half of the Mint Canyon Formation which occurs in the subsurface across the San Gabriel fault. A possible source area is the western San Gabriel Mountains north of the fault which are exposed several miles to the east.

The Ventura and Soledad basins were juxtaposed by late Miocene time which allowed intercommunication between the two basins. The Castaic Formation northeast and east of the Newhall area is found only in a few scattered outcrops in the Soledad basin; no outcrops occur in the mapped area. Sometime between the late Miocene and late Pliocene, the area was uplifted and the Castaic eroded; the more extensive outcrops of the formation are north and northwest of the area.

The Miocene and Pliocene seas, in which the Towsley Formation was deposited, covered the area south of the San Gabriel fault, including the area of the present western San Gabriel Mountains. Oakeshott (1958) mapped a small outcrop of Towsley immediately east of Big Tujunga Canyon that is over 1000 feet (305 m) higher stratigraphically than the Towsley in the area around Elsmere Canyon. The Pico probably did not cover as wide an area as the Towsley; clasts in the Pico are typical of an eroding San Gabriel basement complex. Also, the Pico in Elsmere Canyon is indicative of a nearshore environment (Kern, 1973). The outcrop of Towsley-Pico undifferentiated north of the San Gabriel fault indicates that the Pliocene sea extended across the fault at least a short distance. Most of these marine Pliocene deposits in the Soledad basin were subsequently eroded away, leaving only a few outcrops. The result is that very prominent angular unconformities separate the Mint Canyon Formation, the Towsley-Pico undifferentiated, and the Saugus Formation north of the fault.

The Pliocene marks the time in the depositional history of the Ventura basin in which the rate of deposition became greater than the rate of subsidence; thus, as the basin filled, the seas regressed. In the eastern Ventura basin, the Pico grades laterally and upward into the shallow marine Sunshine Ranch Member of the Saugus Formation which extended over much of the area occupied by the present

San Gabriel Mountains. This regression extended through the Pleistocene; the Saugus Formation graded from brackish water deposits into nonmarine rocks of the upper unnamed member (Fig. 10).

The San Gabriel Mountains east of the Soledad basin are known to have been a positive element since the Oligocene, supplying clastics to the Vasquez, Tick Canyon, and lower Mint Canyon Formation of the Soledad basin (cf. Jahns and Muehlberger, 1954; Bohannon, 1975). However, the San Gabriel Mountains proper were uplifted in the early Pleistocene and Holocene at which time their present day heights were attained. Remnants of a subdued erosion surface and of terrace deposits in the San Gabriel Mountains indicate that they had a very low relief in the middle Pleistocene (Ehlig, 1975). Early Pleistocene deposits in the Newhall area contain clasts which are also found in Pleistocene strata in the Soledad basin. Ehlig (1975) interpreted the Newhall area during this time as an alluvial slope that drained southward across the Soledad basin, through San Fernando Pass, and into the San Fernando Valley. The uplift of the Santa Susana Mountains, therefore, began in late Saugus (Saul, 1975; Lant, 1977) and continued through the late Pleistocene and Holocene. The Pico anticline and Oat Mountain anticline and syncline developed as a result of displacement on the Santa Susana fault. The Legion, Beacon, and Weldon reverse faults are probably associated with the folding of the Santa Susana Mountains. During this period of compression and uplift, the Whitney Canyon fault was reactivated and caused reverse displacement of the Towsley, Pico, and Saugus Formations. The Holser fault in the Newhall area cuts terrace deposits (Weber, 1977), whereas to the west, the fault is folded and is believed to have developed between the late Miocene and early Pliocene (Cemen, 1977). The most recent fault activity in the Newhall area is represented to the north by the minor dip-slip movement on the San Gabriel and Holser faults and to the south by the north-dipping Santa Susana thrust fault.

SEISMIC HAZARDS

The San Gabriel fault appears to be still active at depth based on seismicity near the fault in the Honor Rancho area (Murdock, 1977). Late Quaternary movement on the San Gabriel fault suggests principally dip-slip displacement with terrace deposits offset (Weber, 1977, 1978); therefore, the San Gabriel fault appears to be capable of minor displacement.

The north-dipping Santa Susana fault is apparently associated with the active San Fernando fault along which the 1971 San Fernando earthquake occurred; therefore, the fault should be considered potentially active. The Newhall earthquake of 1893 was centered only slightly west of the 1971 epicenter and apparently slightly less in magnitude. The series of south-dipping reverse faults and the Whitney Canyon fault cut all formations except Recent alluvium; terrace deposits do not cover any of these faults. It is not known whether they have been active in recent time, but they could act as zones of weakness and move slightly if a major earthquake occurred in the area. The Holser fault is considered to be potentially active because it cuts terrace deposits east of Saugus where it intersects the San Gabriel fault (Weber, 1977); however, the fault is folded in the subsurface west of the Newhall area (Nelson, 1952; Cemen, 1977).

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APPENDIX A

Wells Utilized in Study

Key to Abbreviations used in Appendix A

Index No.	Corresponds to well number on Plate VI
Elevation	Elevation of kelley bushing in feet above sea level, except where GL indicates ground level
T. D.	Total measured depth of well
OH	Original hole
RD	Redrill hole
Faults	Measured depth to fault point in well from sea level
SGF	San Gabriel fault
WC	Whitney Canyon fault
LE	Legion fault
BE	Beacon fault
WE	Weldon fault
Crown	Crown Central Petroleum
Riley	James Riley, Jr.

Location	Index no.	Well Operator and Well Name		Elevation	Measured T. D.	Faults
Section 5, T3N, R15W	1	Bevco Drilling Co.	Carter-Earl 4	1506	1247	
	2	W. Y. Lee	Government 1	1504	2625	
	207	W. J. Carter	Carter-Earl 3	1462	1038	
Section 6, T3N, 15W	3	Atlantic Oil	Albert 1	1662	1018	
	4	Jacob Albert	Albert 2	1531	1087	
	5	Jacob Albert	Albert 4	1639	2000	
	6	Jacob Albert	Albert 5	1571	1025	
	7	Jacob Albert	Albert 19	1716	830	
	8	Jacob Albert	Albert 21	1666	1061	
	9	Jacob Albert	Albert 23	1612	890	
	10	Jacob Albert	Albert 27	1742	1145	
	11	Jacob Albert	Albert 101	1548	974	
	12	Jacob Albert	Albert 102	1599	939	
	13	J. L. Gruber	Banner 5	1550	1482	
	14	J. L. Gruber	Banner 7	1721	760	
	15	Crestmont Oil	Dudley 1	1431	1389	
	16	Crestmont Oil	Dudley 3	1398	1409	
	17	Continental Oil	Phillips 1	1657	8252	WC = -6253
	18	Continental Oil	Phillips 2	1562	1813	
	19	Chevron U. S. A.	Placerita 1	1403	821	
	20	Chevron U. S. A.	Placerita 2	1389	1400	
	21	Chevron U. S. A.	Placerita 3	1407	1061	
	22	Chevron U. S. A.	Placerita 4	1391	1055	
	23	Chevron U. S. A.	Placerita 6	1458	650	
	24	Chevron U. S. A.	Placerita 7	1367	1460	
	25	Chevron U. S. A.	Placerita 10	1372	1488	
	26	Chevron U. S. A.	Placerita 12	1406	1220	
	27	Chevron U. S. A.	Placerita 13	1384	1325	
	28	Chevron U. S. A.	Placerita 15	1423	1020	
	29	Chevron U. S. A.	Placerita 17	1383	1515	

Location	Index no.	Well Operator and Well Name		Elevation	Measured T. D.	Faults
Section 6, T3N, 15W	30	Chevron U. S. A.	Placerita 18	1389	1420	
	31	Chevron U. S. A.	Placerita 25	1428	1030	
	32	Republic Petroleum	Price 5	1475	1812	
	33	Camtex Industries	Vagabond-Poco 1	1620	1336	
	34	Camtex Industries	Vagabond-Poco 2	1430	1084	
	35	Camtex Industries	Vagabond-Poco 3	1580	1225	
	36	Camtex Industries	Vagabond-Poco 9	1490	1310	
	37	Riley	York 11	1426	1400	
	38	Riley	York 13	1440	1336	
	204	J. Albert	Albert 9	1707	1204	
Section 7, T3N, R15W	39	J. Albert	Albert 3	1748	671	
	40	J. Albert	Albert 20	1483	1245	
	41	J. Albert	Albert 103	1504	672	
	42	Chevron U. S. A.	Elsmere 23	1459	2807	
	43	Rothschild Oil	Phillips 2	1445	3000	
	44	Chevron U. S. A.	Elsmere 24	2058	1567	
	45	M. R. Peck & Sons	Brown 1	GL 2100	796	
Section 19, T3N, R15W	46	Atlantic Richfield (ARCO)	T. I. & T. 1	1321	8207	
	47	Tesoro Petroleum	T. I. & T. 1	1343	3180	
Section 1, T3N, R16W	48	D. C. R. Bailey	Bailey 1	1664	2469	
	49	D. C. R. Bailey	Bailey 2	1403	816	
	50	Calrary Petroleum	Betsy Linda 1	1381	2819	
	51	E. M. Breen	Betsy Linda 2	1406	1262	
	52	Southwest Oil	Braille 1	1325	3196	
	53	Bettymac Oil	Braille 2	GL 1325	3586	
	54	Talisman Oil	Braille 2	1315	3648	
	55	Continental Oil	Braille 3	1319	3835	

Location	Index no.	Well Operator and Well Name		Elevation	Measured T. D.	Faults
Section 1, T3N, R16W	56	Petroleum Corp. America	Myron Buttram 6	1554	1385	
	57	Crestmont Oil	Schisler 1	1432	1601	
	58	Crestmont Oil	Schisler 4	1587	1700	
	59	Petroleum Corp. America	Shephard 1	1563	1827	
	60	Petroleum Corp. America	Shephard 5-A	1415	1700	
	61	G. E. Kadane & Sons	Warren 1	1486	2722	
	62	Riley	York 5	1367	1620	
	63	Riley	York 9	1428	1650	
	64	Riley	York 15	1451	1693	
	65	Riley	York 25	1432	1627	
	66	Riley	York 26	1449	1595	
Section 2, T3N, R16W	67	Frazier	Eagle Oil-Bishop 2	1278	6014	
	68	Lockhart	Miller 1	1331	5423	
	69	Sherman	Newhall-Community 1-1	1345	5891	
	70	Sherman	Newhall-Community 3-1	1280	5843	
	71	Gulf	Phillips 1	1270	5264	
Section 3, T3N, R16N	208	Rheem	Happy Valley Unit E-1	1297	7042	
	209	Rheem	Miller Ranch 1	1288	7638	
	211	SCOPE Industries	Lassalle 44-1	1350	6073	
Section 10, T3N, R16W	210	Von Glahn Oil	Lassalle 1	1403	8065	
	214	Aidlin & Bering	Atwood 1	1438	6134	
Section 11, T3N, R16 W	72	Anderson & Palmet	A-P Tomato Can 1	1611	4726	
	73	British American Oil	Edwina 1	1656	6196	BE = -2284
	74	Bering & Ass.	Perkins 1	1659	4200	
	75	Brazell, Trustee	Perkins 1	GL 1600	4473	
	76	Bush	Perkins 1	1559	5123	

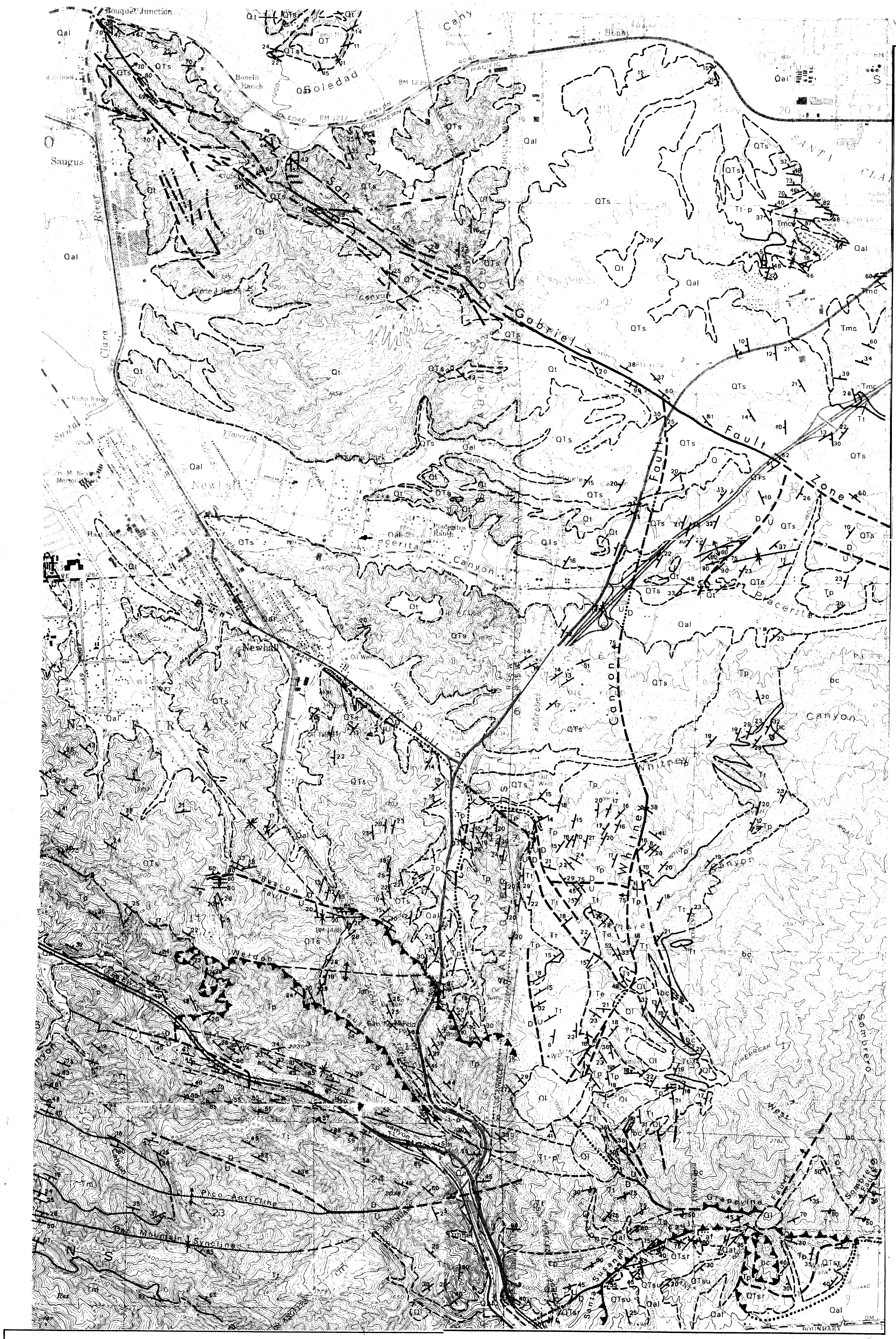
Location	Index no.	Well Operator and Well Name		Elevation	Measured T. D.	Faults
Section 12, T3N, R16W	77	C. M. S. Oil	Cook 1	1405	1538	
	78	Grayson	Hilty 1	1409	2785	LE = -896
	79	Morton & Dolley	Needham B-1	1669	3069	
	80	Airline	Needham 2-2	1667	1848	
	81	Morton & Dolley	Needham 4	1555	1801	LE = -244
	82	Morton & Dolley	Needham 5	1539	4031	
	83	Terminal Drilling	Phillips 1	1397	1350	
	84	Watkins	Thompson 1	1557	2163	
Section 13, T3N, R16W	85	Morton & Dolley	Clampitt 1	1728	1061	
	86	Morton & Dolley	Clampitt Community 1	1385	1959	
	87	Tunnel Oil	Needham 1	GL 1681	1760	
	88	Union	Needham 1	1775	4007	BE = -925
	89	Burmah Oil & Gas	Signal-Needham 1	1604	4997	
	90	Atlantic Richfield	Watson 1	1718	4000	
	91	Atlantic Oil	Weldon Canyon 1	1562	2215	
Section 14, T3N, R16W	92	Basenberg	Hamilton 1	1697	6626	
	93	Terminal Drilling	Hamilton 1	1785	3505	
	94	Crown	McCloskey-Bering 1	2255	3752	
	95	Russell	Needham 1	1886	4340	
	96	Texaco	Whitnah 1	1936	4999	
Section 22, T3N, R16W	212	Mobil	Mendota 1	1834	6834	
	213	Chevron U. S. A.	Orcutt Trustee 2-1	2393	5805	
Section 23, T3N, R16W	97	Texaco	Eadie 1	2149	8011	WE = Below -6000
	98	Texaco	Eadie 2	2069	4297	WE = -1231
	99	Texaco	Evans 1	GL 1783	992	
	100	Century Service	Evans 1	2335	3137	
	101	Texaco	Evans 1-A	GL 1783	8209	

Location	Index no.	Well Operator and Well Name		Elevation	Measured T. D.	Faults
Section 24, T3N, R16W	102	Kahler	Eadie 1	1679	2994	
	103	Apex Petroleum	Weldon 1	2035	4517	
Section 19, T4N, R15W	104	Coast Exploration	Golden Triangle 2	GL 1335	1000	
	105	Lago Vista Oil	Roland 1	1448	5096	
Section 29, T4N, R15W	106	Contrato Oil	Jill 1	1556	1680	
Section 30, T4N, R15W	107	Crown	Frew 1	1836	1970	
	108	Crown	Frew 2	GL 1855	2311	
	109	Crown	Newhall Royal Community 1	1882	2311	
	110	Crown	Newhall Royal Community 2	1852	2374	
	111	Crown	Newhall Royal Community 4	1886	2286	
	112	Crown	Newhall Royal Community 5	1882	2117	
	113	Crown	Newhall Royal Community 6	1858	2239	
	114	Crown	Newhall Royal Community 14	1777	2740	SGF = +677?
	115	Crown	Placerita 1	1818	2262	
	116	Crown	Placerita 2	1772	2325	
	117	Crown	Placerita 5	1725	2585	
	118	Crown	Placerita 6	1696	2573	
	119	Crown	Morrow-Independent 1	1682	2619	
	120	Serago Oil	Yeager-Community 1	1782	3338	SGF = +82

Location	Index no.	Well Operator and Well Name		Elevation	Measured T. D.	Faults
Section 31, T4N, R15W	121	Riley	Castrucio 4	1373	1515	
	122	Riley	Castrucio 5	1376	1470	
	123	Riley	Castrucio 6	1380	1480	
	124	Riley	Castrucio 13	1491	1900	
	125	Riley	Castrucio 18	1505	1680	
	126	McCue	Clarella 1	GL 1590	1680	
	127	Crown	Doc 1	1605	1983	
	128	Crown	Doc 2	1689	1150	
	129	Crown	GPM 4	1772	2022	
	130	Crown	GPM 6	1705	1765	
	131	Crown	GPM 9	1733	1500	
	132	Crown	GPM 10	1689	1560	
	133	Crown	GPM 24	1520	1501	
	134	Crown	GPM 26	1466	4115	
	135	Crown	GPM 33	1448	1707	
	136	Crown	GPM 34	1436	1842	
	137	Crown	GPM 36	1604	1900	
	138	Crown	KPM 5	1487	1310	
	139	Crown	KPM 6	1508	1367	
	140	Crown	KPM 7	1518	1948	
	141	Crown	KPM 8	1556	1134	
	142	Crown	KPM 18	1561	1204	
	143	Crown	Kraft 2	1433	782	
	144	Crown	Kraft 5	1447	600	
	145	Crown	Kraft 6	1546	864	
	146	Crown	Kraft 7	1511	1038	
	147	Crown	Kraft 11	1419	1170	
	148	Crown	Kraft 15	1439	1050	
	149	Crown	Kraft 19	1589	1175	
	150	Crown	Kraft 21	1480	1000	
	151	Crown	Kraft 23	1579	1279	
	152	Crown	Kraft 25	1537	1350	
	153	Crown	Kraft 28	1504	1458	

Location	Index no.	Well Operator and Well Name		Elevation	Measured T. D.	Faults
Section 31, T4N, R15W	154	Crown	Kraft 31	1488	1582	
	155	Crown	McCue 1	1022	851	
	156	Breckenridge	Morrow 1	1798	999	
	157	Myers & Wilhite	Myers & Wilhite 1	1576	650	
	158	Section 31 Petroleum	One	1500	2008	
	159	Riley	Orwig 15	1746	1887	
	160	Riley	Orwig 18	1642	1950	
	161	J. M. T. Oil	Parton 1	1382	1401	
	162	J. M. T. Oil	Philbert 1	1380	1375	
	163	Crown	Rae 3	1386	1208	
	164	Parbe Oil	Swall-Ferrier 1	1739	1066	
	165	Nelson-Phillips Oil	Swall-Ferrier 3	1494	842	
	166	Crown	WF 35	1389	2394	
	199	Riley	Aqueduct 2	1497	1590	
	200	Riley	Castruccio 7	1379	1450	
	201	Riley	Castruccio 7-A	1381	1430	
	202	Riley	Castruccio 15	1490	1680	
	203	Riley	Castruccio 19	1484	1625	
Section 32, T4N, R15W	167	Range Oil & Ault	Dorothy 1	1581	1648	
	168	Breckenridge	GP 1	1859	1211	
	169	Twentieth Century	GP 1	1907	1088	
	170	Lee	Heil 1	1680	1430	
	171	Lee	Lee 1	1655	1815	
	172	Crawford & Hiles	Placerita 1	GL 1625	3302	
	173	San Gabriel Oil	San Gabriel 1	1832	2185	
	174	Rothschild Oil	Wickham-Ferrier 1	1810	1648	
Section 22, T4N, R16W	175	Union	N. L & F. 2	1156	11, 014 OH 10, 682 RD	

Location	Index no.	Well Operator and Well Name		Elevation	Measured T. D.	Faults
Section 23, T4N, R16W	176	Superior	Bonelli 14-23	1267	8969 OH 8070 RD	
Section 24, T4N, R16W	177	Coast Exploration	Golden Triangle 1	1335	4488	
	178	Terminal Drilling	Independent-Ghiggia 1	1387	1933	
	179	Texaco	N. L. & F. H-1	1247	1700	
Section 25, T4N, R16W	180	Mobil	Bermite 1	1494	5046	
	181	Rothschild Oil	Bermite 1	1524	4719	
	182	Union	Bermite 1	1417	3863 OH 7270 RD	SGF = -650? & -3316?
	183	Provost Associates	Protrana 1	1546	1120	
	184	Provost Associates	Protrana 2	1579	3653	
Section 26, T4N, R16W	185	Mobil	Circle-J 1	1349	6560	
	186	Mobil	Circle 2	1336	6112	
Section 27, R4N, R16W	187	Mobil	H. & M. 1	1199	7485	
Section 36, T4N, R16W	188	Riley	Breckenridge 3	----	1640	
	189	Roco	D. & C. 1	1379	4012	
	190	Barmore	Hays 1	1404	2384	
	191	Corinth Petroleum	Karen 1	1386	2700	
	192	Superior	L. A. H. 1	1362	5400	
	193	Ellis	Lowe 1	1334	3445	
	194	Riley	Sir Kegian 4	1379	1565	
	195	Riley	Sir Kegian 5	1372	1592	
	196	Riley	Sir Kegian 11	1380	2195	
	197	Murray-Teague Ass.	Thompson 1	1664	3967	
	198	York	Wegner 2	1219	1687	



LEGEND

QUATERNARY	HOLOCENE	af	Artificial fill
		Ql	Landslide
		Qal	Alluvium
	PLEISTOCENE	Qt	Terrace deposits
		QTs	Saugus Formation: undifferentiated
		QTsu	Saugus Formation, upper member: nonmarine sandstone and conglomerate (Winterer & Durham, 1962)
		QTsr	Saugus Formation, Sunshine Ranch Member: brackish water siltstone and sandstone (Winterer & Durham, 1962)
TERTIARY	PLIOCENE	Tp	Pico Formation: marine, blue-gray fossiliferous sandstone, with conglomerate and siltstone (Kew, 1924)
		Tt-p	Pico-Towsley: undifferentiated
		Tt	Towsley Formation: marine gray sandstone and conglomerate with chocolate-brown siltstone (Kern, 1973)
	MIOCENE	Tm	Modelo Formation: marine, cherty, diatomaceous shale and sandstone (Winterer & Durham, 1962)
		Tmc	Mint Canyon Formation: nonmarine sandstone and conglomerate, with some siltstone and mudstone (Winterer & Durham, 1962)
	EOCENE	Te	Eocene undifferentiated: siltstone, sandstone, and conglomerate (Howell, 1974)
PRE-TERTIARY		bc	Basement complex: granodiorite and diorite gneiss (Oakeshott, 1958)

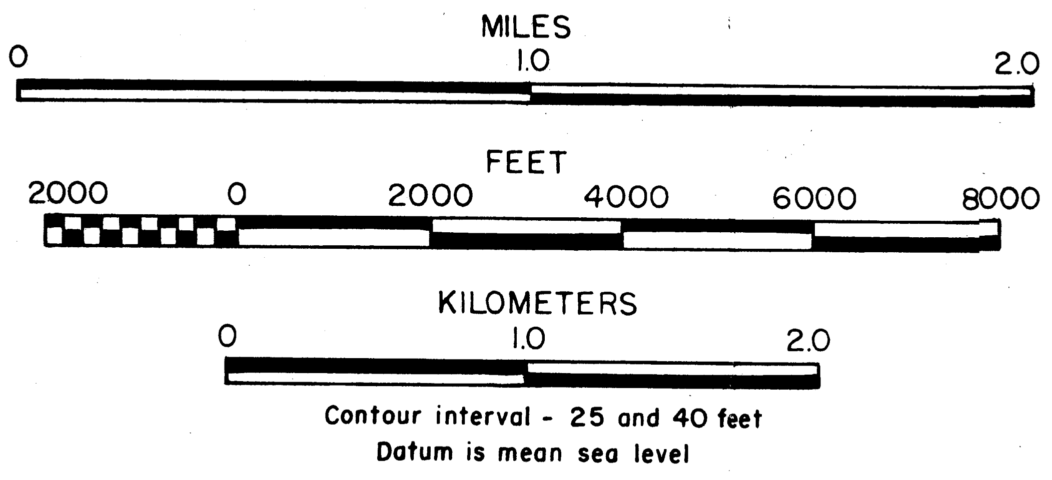
SYMBOLS

———— - - - -	Formation contact: dashed where inferred
———— —?—···	Fault: dashed where inferred, queried where doubtful; dotted where covered
60 U D ⇄	Fault: arrow showing dip; U = upthrown, D = downthrown; arrows show lateral offset
▲▲▲▲···	Thrust fault: dashed where inferred; dotted where covered, barbs on upper plate
··—— — —··	Topographic or vegetative lineaments suggestive of faults: dashed where doubtful (Weber, 1977)
10	Strike and dip of inclined beds
40	Strike and dip of overturned beds
	Vertical beds

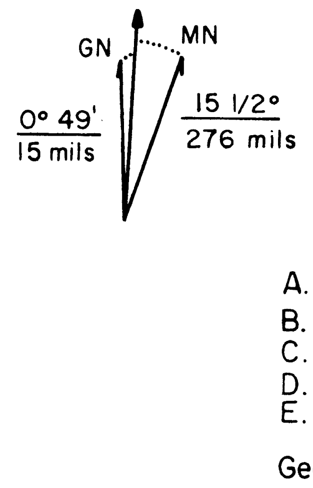
PLATE I

GEOLOGIC MAP OF THE NEWHALL AREA, CALIFORNIA

Thesis
M [illegible]



Contour interval - 25 and 40 feet
Datum is mean sea level



A. Kern, 1973
B. Saul, 1975
C. Shields, 1977
D. Weber, 1977
E. Winterer and Durham, 1962

Geologic compilation and
revision by Fred M. Nelligan,
Ohio University, 1978

Map Data Sources