AN ABSTRACT OF THE THESIS OF

LEONARD TIMOTHY STITT for the degree of MASTER OF SCIENCE

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Abstract approved: Signature redacted for privacy.

Dr. Robert S. Yeats

Surface and subsurface mapping are combined to determine the geologic history along the San Gabriel fault near the town of Castaic. Palomas Gneiss, Whitaker Granodiorite, and Pelona Schist are basement terranes encountered in the subsurface. West of the San Gabriel fault, basement is unconformably overlain by marine middle to late Miocene Modelo Formation. The late Miocene to early Pliocene Towsley Formation overlies the Modelo and was deposited in a submarine fan environment. East of the San Gabriel fault, marine Paleocene San Francisquito Formation accumulated while Pelona Schist was undergoing regional metamorphism at depths of 20 to 27 kilometers. Nonmarine Oligocene (?) Vasquez Formation is faulted against both the Pelona Schist and San Francisquito Formation. Charlie Canyon Megabreccia accumulated in late Oligocene (?) time as a large landslide deposit. The source is controversial, but may

have been from the La Panza Range. Pelona Schist-bearing San Francisquito Canyon Breccia accumulated in late Miocene (?) (Barstovian) time as the Pelona Schist first became subject to erosion in northern Soledad basin. Nonmarine alluvial fan and lacustrine deposits of the middle to late Miocene Mint Canyon Formation unconformably overlie older units east of the San Gabriel fault and apparently intertongue with San Francisquito Canyon Breccia. A late Miocene (Mohnian) marine transgression resulted in deposition of the Castaic Formation in Soledad basin while the Modelo and possibly Towsley Formations accumulated in Ventura basin. Violin Breccia intertongues with Castaic Formation and accumulated at the base of a Miocene San Gabriel fault scarp. Marine Pliocene Pico Formation unconformably overlies the Castaic Formation east of the San Gabriel fault and conformably overlies the Towsley Formation west of the San Gabriel fault; it is overlain conformably by marine to nonmarine Plio-Pleistocene Saugus Formation. Quaternary landslides, and older, intermediate, and younger alluvium overlie older rocks throughout the study area.

The St. Francis fault may have been active in late Oligocene and early Miocene time, removing Charlie Canyon Megabreccia by right-slip from a possible source in the La Panza Range. The low-angle San Francisquito fault and associated Bee Canyon fault and San Francisquito syncline were active after deposition of the Charlie

Canyon Megabreccia but prior to deposition of the Mint Canyon Formation. The San Gabriel fault became active after deposition of the Mint Canyon Formation in late Miocene time. The San Gabriel fault exhibits right-lateral separation of approximately 60 kilometers on the Mint Canyon and older formations, approximately 30 kilometers on Violin Breccia and Modelo Formation, and about two kilometers on the Pico Formation. San Gabriel fault "C" (?) and Castaic Hills reverse fault moved in late Miocene time and became inactive prior to deposition of the Pico Formation. The Charlie Canyon anticline, Charlie Canyon syncline, Castaic anticline, and Ridge Basin syncline were formed in the Castaic Formation prior to deposition of the Saugus Formation. The Saugus is deformed by: (1) folding which produced the Dry Canyon syncline, Dry Canyon anticline, Townsend syncline, Loma Verde anticline, North and South Hasley Canyon synclines, and Oak Canyon anticline; (2) reverse faulting on the south-dipping Hasley fault; (3) normal faulting in eastern Castaic Hills oil field; (4) normal faulting on the San Gabriel fault. The San Gabriel fault may also offset Quaternary alluvium by normal separation in Castaic Creek. Geomorphic evidence suggests continuing movement on the San Gabriel fault, but the nature of seismic activity on the fault is still unresolved.

Geology of the Ventura and Soledad Basins in the Vicinity of Castaic, Los Angeles County, California

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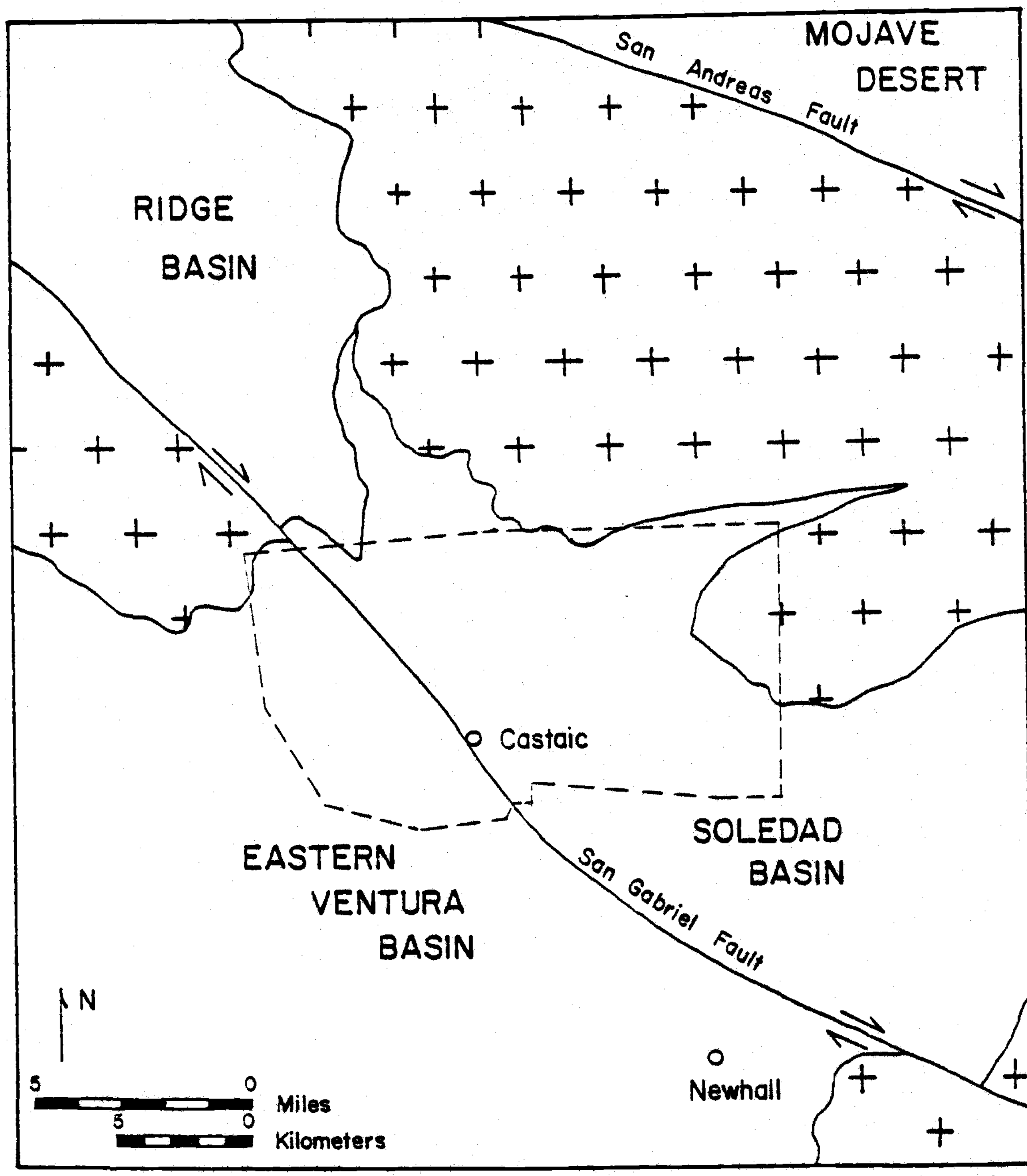
INTRODUCTION

Regional Setting

The Castaic study area is located approximately 40 miles (65 km) northwest of downtown Los Angeles, and covers approximately 70 square miles (190 km^2) within the Newhall, Val Verde, Whitaker Peak, and Warm Springs Mountain 7.5 minute topographic quadrangles of the U.S. Geological Survey.

The area is located in that part of the central Transverse Ranges of California where the Ridge, Soledad, and Ventura basins adjoin one another (Figure 1). The San Gabriel fault transects the area from northwest to southeast and marks the boundary between the Ventura basin to the west and the Ridge and Soledad basins to the east. Neogene sedimentary rocks of the Ventura basin are primarily of marine origin, whereas those of the Ridge and Soledad basins are primarily nonmarine.

In the Castaic area, the San Gabriel fault separates two distinct stratigraphic sections of Miocene and older rocks (Plate I; Figure 2). Marine rocks of the Pliocene Pico Formation of the Ventura basin correlate across the San Gabriel fault with minor strike-slip offset,



L.T. Stitt, 1980

Figure 1 : Regional geologic setting of the Castaic area. Areas marked with crosses represent pre-Oligocene "basement" rocks. Castaic study area within dashed line boundary (after Jennings and Strand, 1969).

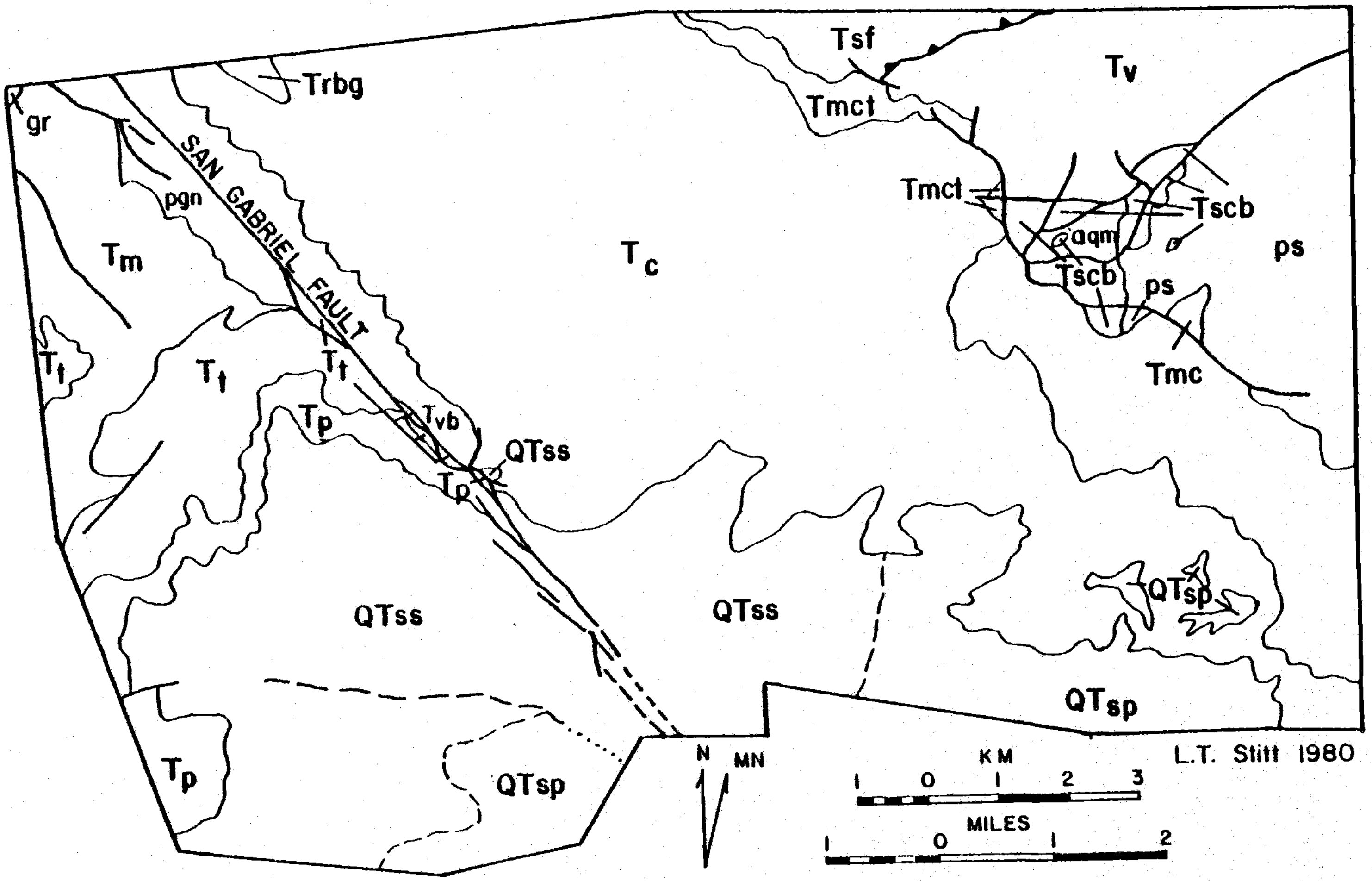


FIGURE 2: Generalized geologic map of the Castaic area; see Plate I for details. gr: granite; pgn: Palomas Gneiss; aqm: aplitic quartz monzonite; ps: Pelona Schist; Tsf: San Francisquito Fm; Tv: Vasquez Fm; Tscb: San Francisquito Canyon Breccia; Tmc: Mint Canyon Fm; Tmct: Taylor Fanglomerate Member; Tc: Castaic Fm; Tvb: Violin Breccia; Tm: Modelo Fm; Tt: Towsley Fm; Trbg: Ridge Basin Group; Tp: Pico Fm; QTss: Saugus Fm (San Francisquito ss clasts); QTsp: Saugus Fm (Pelona Schist clasts).

indicating that the Ventura basin extended across the fault in late Pliocene time. Nonmarine rocks of the Plio-Pleistocene Saugus Formation overlap the fault from Castaic to the vicinity of Newhall, obscuring stratigraphic relationships in older rocks in this region. Here the San Gabriel fault is marked by a zone of disturbed and faulted Saugus Formation (Weber, 1979).

Purpose and Scope of Study

The major purpose of this study is to determine the movement history of the San Gabriel fault in the Castaic area. In this area, pre-Pleistocene units, including the major crystalline basement terranes, crop out (Plate I; Figure 2). Here also the Plio-Pleistocene Saugus Formation overlaps the fault, obscuring surface relationships between older units where they cross the fault. More than 700 exploratory and developmental wells for oil and gas have been drilled in the eastern Ventura and western Soledad basins along the overlapped segment of the San Gabriel fault. These wells provide a data base to analyze the stratigraphic and structural relationships of rock units older than the Saugus Formation in the vicinity of the fault. It was, therefore, proposed that a detailed analysis of the subsurface geology be carried out between Castaic and Newhall in order to interpret the geologic history of this segment of the San Gabriel fault. Subsurface studies of the Newhall and Honor Rancho segments of the fault have been completed (Nelligan, 1978 and Schlaefer, 1978, respectively). The Castaic study presents an analysis of the surface and subsurface geology of the Castaic segment of the San Gabriel fault, extending from Honor Rancho northwest to the pre-Pleistocene strata which crop out near the town of Castaic (Plate I).

Methods of Study

No detailed geologic map of the Castaic area has been published. Therefore, it was necessary to prepare a surface geologic map which would be correlated with the subsurface geology. Masters and Ph.D. theses, which cover parts of the area were obtained during the 1977-1978 academic year, and a preliminary geologic map was compiled. At the beginning of the 1978 summer field season, aerial photos of the Castaic area were obtained on loan from the Fairchild Collection at Whittier College. These photos were used during field mapping in July and September, 1978, and June, 1979. The final geologic map (Plate I; Figure 2) was compiled largely from unpublished sources, then later revised on the basis of field work and air photo interpretation. The surface geologic map includes all sedimentary formations and basement lithologies encountered in the subsurface, thus permitting correlation between surface and subsurface geology.

A list of wells drilled in the study area was compiled during the 1977-1978 academic year (Plate II; Appendix I), and data for these wells were obtained during the summer of 1978. The California Division of Oil and Gas (DOG) provided most of the data, including well histories, electric logs, and core and sidewall sample descriptions. Oil companies voluntarily provided the remaining data, including directional surveys, dipmeter results, and paleontological reports. Core samples from some of the wells were examined at the California Core Sample Repository in Bakersfield during the summer of 1978.

Cores of basement rocks were obtained for three wells in the study area (Figure 3). Thin sections of these cores were prepared and examined during the 1978-1979 academic year. Forty-three cross sections (located on Plate II), 16 of which are included in this report (Plates IX-XXIV), and six contour and isopach maps (Plates III-VIII) were constructed from September, 1978 through November, 1979.

Geographic Sketch

The area is accessible by car via public, private, and oil field roads, and by foot along creeks and ridges. Many slopes, especially in the vicinity of Loma Verde and at the heads of most of the creeks in the area, are too steep for easy access.

Altitudes in the area range from approximately 1,070 feet (325 m) in Castaic Creek to about 3,100 feet (945 m) along the south flank of Townsend Peak in the northwest corner of the area.

The climate is semi-arid, and most rainfall occurs from

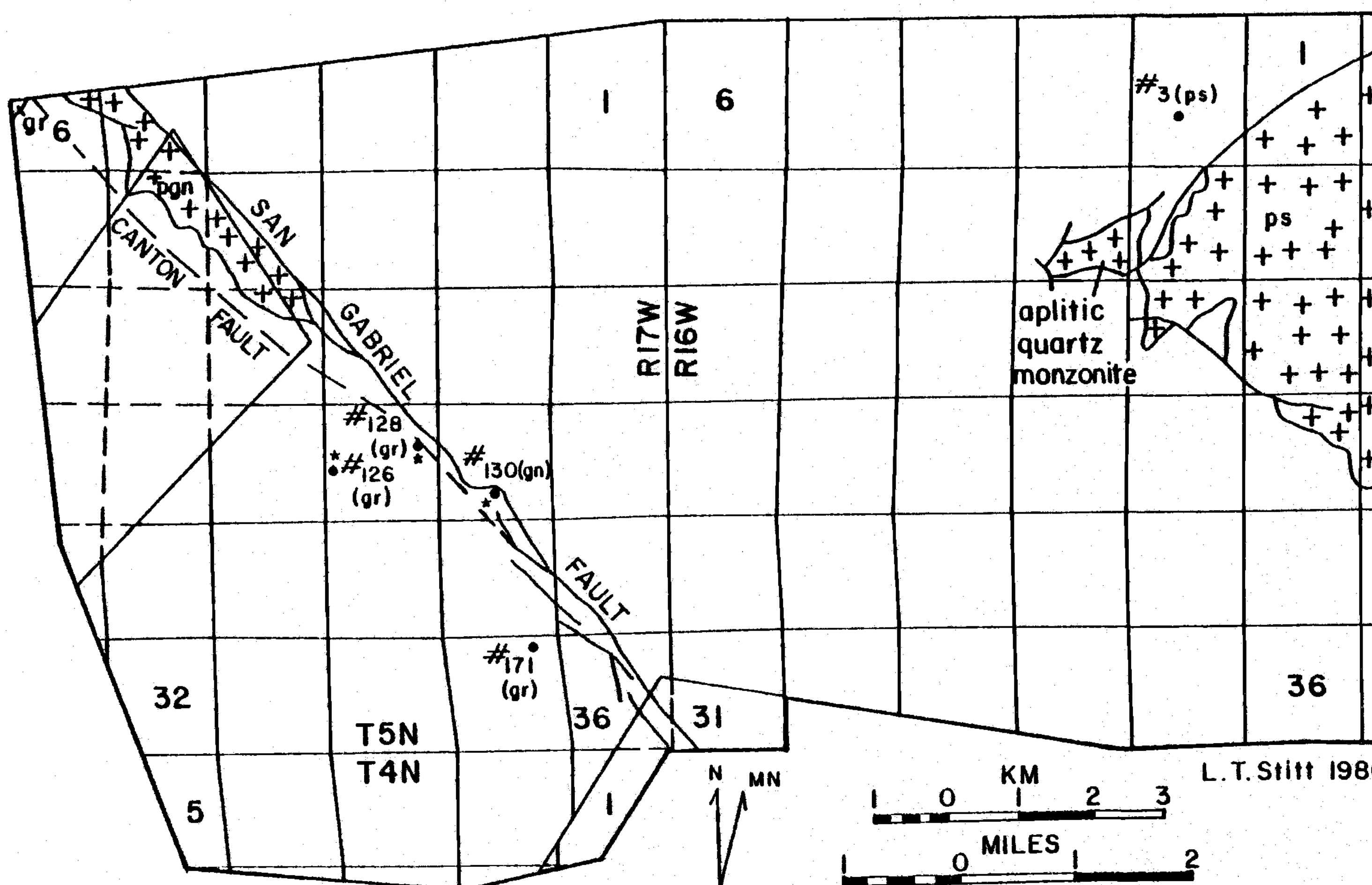


FIGURE 3: Location of wells drilled to basement in Castaic area. Crossed pattern indicates outcrops of basement: gr = granite; pgn = gneiss; ps = Pelona Schist. Well numbers as in Appendix I, Plate II; * = thin sections of cores examined from these wells (see text). Possible pre-Modelo trace of Canton fault of Crowell (1954b) assumes that fault marks the boundary between pgn and gr in the subsurface as it does at the surface.

December to April. The summer is dry, and the temperature occasionally exceeds 120 °F during the afternoon. Fire hazard is extreme in the summer months.

Previous Work

Early regional reports which covered all or part of the area include Hershey (1902a, b), Kew (1924), Clements (1929, 1932, 1937), Simpson (1934), and Eaton (1939). These early workers named and mapped most of the stratigraphic units and structures in the study area, including the San Gabriel fault.

Later mapping on a regional scale by Bailey (1954), Crowell (1954b), Jahns and Muehlberger (1954), Muehlberger (1958), and Dibblee (1967) provided better geologic maps of the area.

More detailed information concerning the geology of the study area is found in masters and Ph.D. theses by Wallace (1940), Daviess (1942), Wright (1943), Buffington (1947), Chambers (1947), Kriz (1947), Martin (1947), White (1947), Dehlinger (1950), Harris (1950), Smith (1951), Johnson (1952), Miller (1952), Elizondo (1953), Muehlberger (1954), Pollard (1958), Scanlin (1958), Shepherd (1960), Stanton (1960), Szatai (1961), Sams (1964), Konigsberg (1967), Harvill (1969), Howell (1974), Sage (1973a), and Bohannon (1976). All these theses were consulted during compilation of the geologic map.

Topical studies concerning the Castaic area and surrounding region include: Crowell (1952, 1954a, 1962, 1968, 1973a, b, 1974, 1975a, b, 1979), Paschall and Off (1959, 1961), Ehlig (1973), and Weber (1979) on the movement history of the San Gabriel fault; Smith (1977) on the San Juan-St. Francis and San Francisquito faults; Ehlig (1968, 1975a, b), and Haxel and Dillon (1978) on basement rocks of the region; Woodburne (1975) on the Cenozoic stratigraphy of the Transverse Ranges; Sage (1973b, 1975) on the Paleocene, and Howell (1975) on the Eocene stratigraphy of southern California; Bohannon (1975) on the mid-Tertiary nonmarine rocks of southern California; Jahns (1940), Ehlig and Ehlert (1972), and Ehlig et al. (1975) on the Mint Canyon Formation; Skolnick and Arnal (1959), and Stanton (1966) on the paleoecology of the Castaic Formation; Crouch and Bukry (1979, 1980), and Arnal (1980) on the use of benthic foraminifera as chronostratigraphic markers for Tertiary rocks; Link and Osborne (1978) on the depositional environment of the Pliocene Ridge Basin Group; Ensley and Verosub (1979) on the magnetic reversal stratigraphy of the Castaic Formation and Ridge Basin Group; Silver et al. (1962), Hsü et al. (1963), Silver (1968, 1971), Turner (1970), and Kistler et al. (1973) on radiometric age determinations for crystalline and volcanic rocks of the central Transverse Ranges; Kamerling and Luyendyk (1977, 1979a, b), Kamerling et al. (1978), Luyendyk et al. (1980), and Greenhaus and Cox (1978, 1979) on the clockwise rotation of paleomagnetic vectors for middle Cenozoic igneous rocks of southern

California; Robson (1972) on the water resources of the Saugus-Newhall area; and Murdock (1979) on the seismicity of the Castaic area. Results of these studies are considered in subsequent chapters of this report.

Previous general reports on the geology of oil fields in the study area were done for Castaic Hills (Matthews, 1953), Honor Rancho (Matthews, 1953; Herring, 1954), Tapia (Miller and Turner, 1959; Dosch and Beecroft, 1959), and Wayside Canyon (Mefferd and Johnson, 1967) (Figure 4). Schlaefer (1978) and Nelligan (1978) completed subsurface studies of the San Gabriel fault near Honor Rancho and Newhall, respectively, as part of the present San Gabriel fault project.

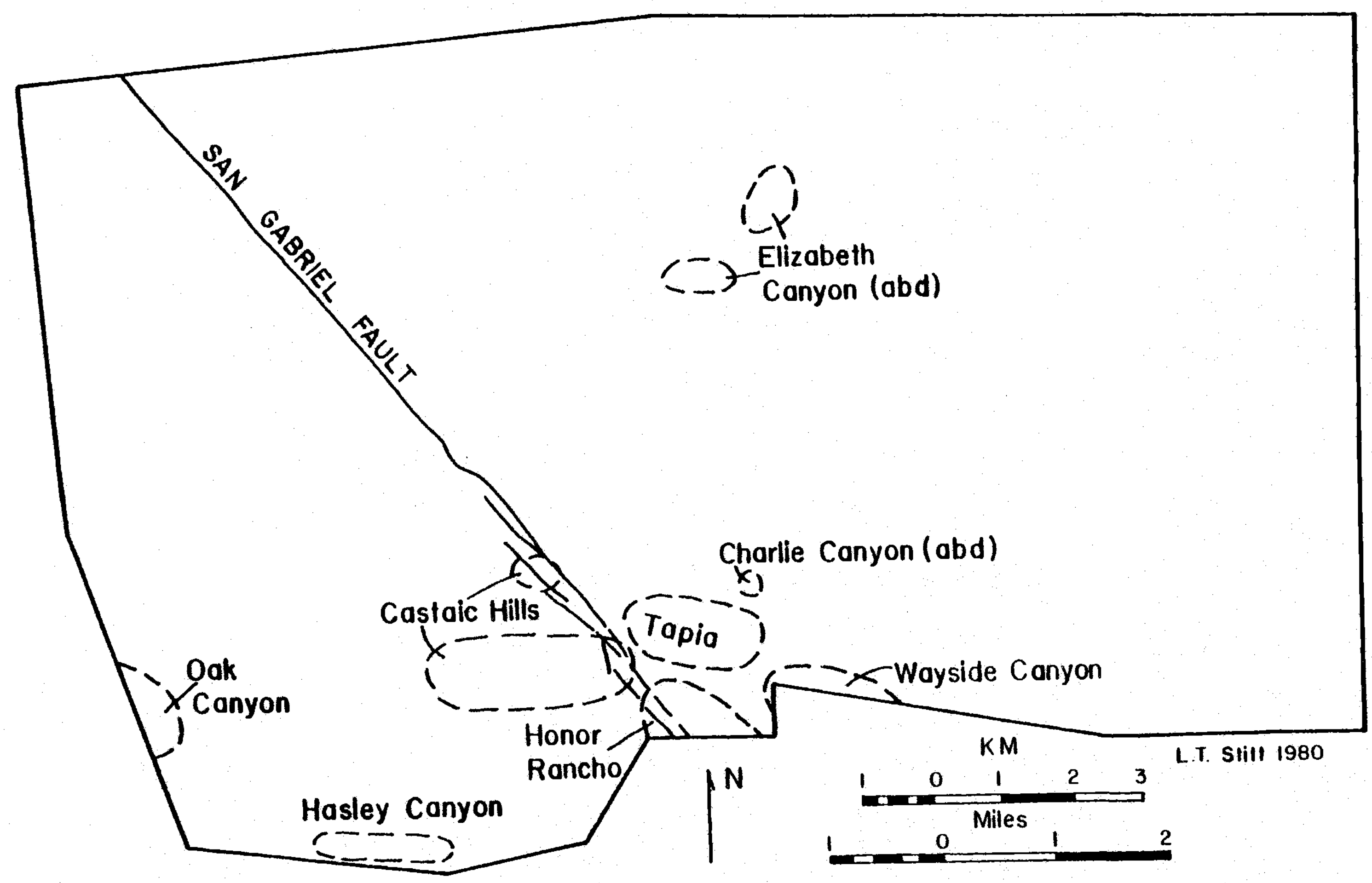


Figure 4 : Oil fields in the Castaic area (outlined by dashed lines)
abd = abandoned

STRATIGRAPHY

General Statement

Rock units ranging in age from Precambrian to Holocene occur in the study area (Plate I). The stratigraphic column west of the San Gabriel fault (Figure 5) shows a basement terrane of Precambrian Palomas Gneiss which is faulted against Mesozoic (?) plutonic rocks of Whitaker Peak. In the study area, basement is unconformably overlain by the marine middle to late Miocene Modelo Formation. One well (#117b,[1] Plate II) penetrates approximately 11, 000 feet (3, 350 m) of Modelo Formation. In this well, the Modelo unconformably overlies the early Miocene Rincon Formation. It is not known what the Rincon rests upon, as the base of this formation was not penetrated in the well. However, in Canton Creek, located approximately two miles (three km) west of the study area, the Rincon Formation overlies marine Oligocene (?) to early Miocene Vaqueros Formation, which is underlain in succession by nonmarine Oligocene Sespe Formation, and marine Eocene strata (Shepherd, 1960). The Eocene rocks are in fault contact with Whitaker Granodiorite. Pre-Miocene sedimentary rocks similar to those which crop out in the Canton Canyon area have not been penetrated in wells in the Castaic study area. The Modelo is

[1] NOTE: Wells are listed in Appendix I by township-range-section, and by well index numbers on Plate II, and are in parentheses throughout the text.

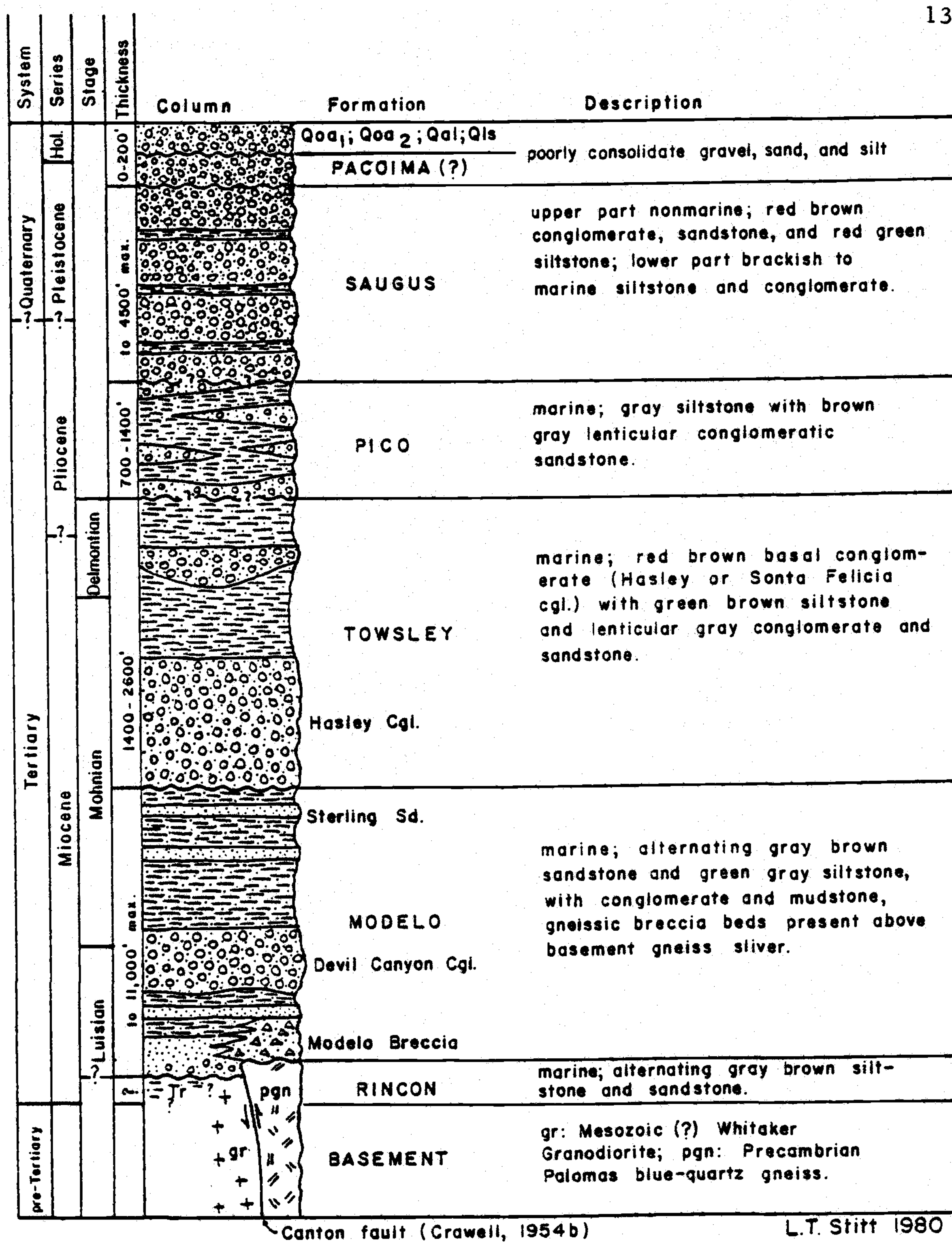


FIGURE 5: Generalized columnar section west of San Gabriel fault (see Plate I; not to scale).

unconformably overlain by the marine late Miocene to early Pliocene Towsley Formation. The Towsley was deposited in a submarine fan environment in bathyal to outer neritic water depths (see note beneath well #152, Plate IX). Overlying the Towsley Formation is the shallow marine Pliocene Pico Formation, which is overlain by brackish water to nonmarine strata of the Plio-Pleistocene Saugus Formation. The Quaternary nonmarine Pacoima Formation (?) of Weber (1979) (after Oakeshott, 1958) unconformably overlies the Saugus Formation in the southern part of the study area (Plate I).

The stratigraphic column east of the San Gabriel fault (Figure 6) begins with Pelona Schist basement. The schist has yielded radiometric ages which range from approximately 47 to 59 My (Haxel and Dillon, 1978). The next youngest unit, the Paleocene San Francisquito Formation, is not in contact with the Pelona Schist in the Castaic study area (Plate I), but east of the area the two units are juxtaposed along the San Francisquito fault (Dibblee, 1967). The San Francisquito Formation was deposited as part of an extensive submarine fan system which characterizes much of the early Tertiary deposits of southern California (Sage, 1973a, b). The next unit is the nonmarine Oligocene to early Miocene (?) Vasquez Formation which is in fault contact with both the Pelona Schist on the south and the San Francisquito Formation on the north (Plate I). It is unconformably overlain by the Charlie Canyon Megabreccia (Smith, 1977 after Sams, 1964).

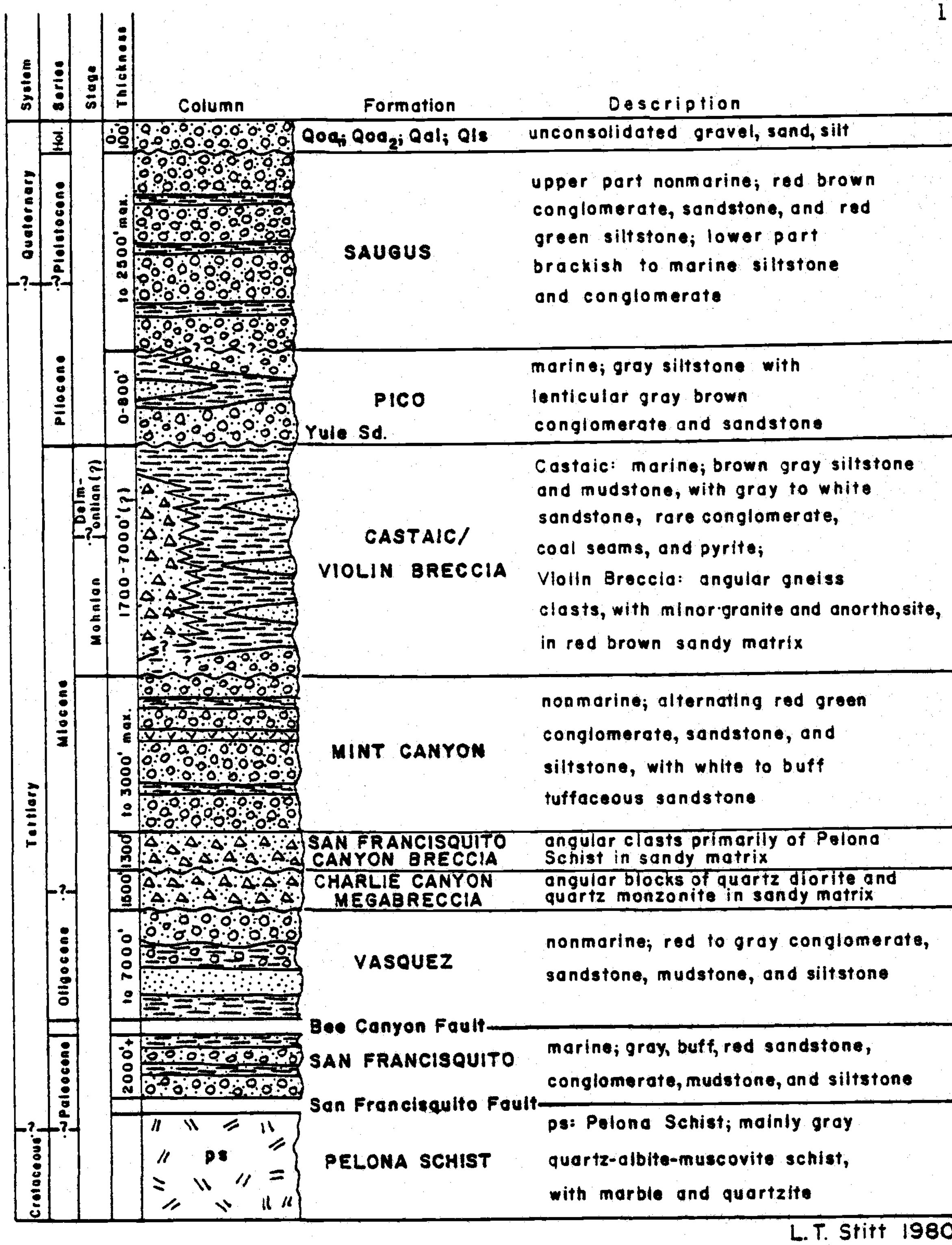


FIGURE 6: Generalized columnar section east of San Gabriel fault (see Plate I; not to scale).

The megabreccia is composed almost entirely of exotic, angular blocks of quartz monzonite. The Miocene (?) San Francisquito Canyon Breccia (Sams, 1964) is in fault contact with the Vasquez Formation, Charlie Canyon Megabreccia, and Pelona Schist, and also overlies unconformably the latter two units. The most common lithology in the San Francisquito Canyon Breccia comprises angular blocks of Pelona Schist with subordinate quartzite, gneiss, and granite clasts. This is the oldest unit in the area which contains Pelona Schist detritus. Overlying the San Francisquito Canyon Breccia is the Mint Canyon Formation of late Miocene age. Szatai (1961) described the Mint Canyon-San Francisquito Canyon Breccia contact as an angular unconformity, whereas Sams (1964) concluded that the two units intertongue. The Mint Canyon unconformably overlies the Pelona Schist, San Francisquito Formation, and Vasquez Formation (Plate I). The Mint Canyon Formation of the Castaic area was deposited in an alluvial fan and lacustrine environment. The Castaic Formation onlapped the Mint Canyon Formation from the west during a late Miocene marine transgression into the Soledad basin. Although the Castaic Formation is coeval with parts of the Modelo and possibly the Towsley Formations which occur west of the San Gabriel fault, it has a microfaunal assemblage (Charlie Canyon fauna) which is distinct from the assemblages found in the Modelo and Towsley. Schlaefer (1978) concluded, however, that similarities between the two microfaunal assemblages indicate that the Castaic Formation of Soledad basin was connected in some way with the Modelo and Towsley of the Ventura basin. Stanton (1966) reached the same conclusion on the basis of his study of megafauna from the Castaic Formation. The shallow-marine Pliocene Pico Formation unconformably overlies the Castaic Formation, and is itself unconformably overlain by brackish to nonmarine Saugus Formation. The Pico does not crop out east of the San Gabriel fault, but is present in the subsurface (Plates XIII, XIV, XVI, XIX-XXII). The Saugus Formation overlaps the Pico such that the Castaic Formation is everywhere overlain by Saugus at the surface. The subcrop of the Castaic-Pico contact at the base of the Saugus is shown on Plate III. Quaternary alluvium and landslides are present in many parts of the study area.

Fossil localities compiled from theses are located on the geologic map (Plate I). The key for these locations is listed in Appendix II.

Basement Complex

Four distinct basement terranes crop out in and adjacent to the study area, and three are penetrated by wells (Figure 3). The terranes are: Precambrian Palomas Gneiss; Mesozoic (?) plutonic rock rocks of Whitaker Peak, which are predominantly granodiorite; aplitic quartz monzonite; and Pelona Schist.

Near Palomas Canyon, the Palomas Gneiss (pgn; Precambrian) crops out as a sliver bounded on the east by the San Gabriel fault and on the west by the Canton fault of Crowell (1954b) which separates it from the Whitaker Granodiorite. The gneiss is overlain by the Modelo Formation (Plates I, IX, XXIV) with angular unconformity. The Palomas Gneiss is correlated with Precambrian gneiss in the Alamo Mountain region and with the Mendenhall Gneiss in the western San Gabriel Mountains (Crowell, 1962). The Mendenhall Gneiss yields ages of 1,650 to 1,680 and 1,425 to 1,450 My based on U/Pb isotope relations in zircons (Silver, 1971). The most common variety of gneiss is medium-crystalline and crudely banded as a result of alternating layers of light colored quartz and feldspar with dark green hornblende and muscovite. Feldspar augen also are common.

Conoco Alexander #1 (well #130) penetrates approximately 2,800 feet (855 m) of metamorphic rock correlated with the Palomas Gneiss (Plate IX). Thin sections of 11 cores from this well were examined and compared to outcrop samples of the gneiss. Major minerals observed in thin section include pelochroic blue green hornblende grains with a local poikiloblastic texture which is largely obscured by intense shearing; pleochroic brown yellow biotite; plagioclase extensively altered to clay minerals; quartz; and potassium feldspar, locally as augen. Other abundant to rare minerals include epidote, apatite, magnetite, and sphene (which generally rims magnetite grains). Secondary muscovite, leucoxene, chlorite, and calcite also are present. All thin sections exhibit evidence of shearing; some have a schistose fabric. Textures, indicative of deformation observed in thin section, include suturing and granulation of crystal boundaries, fracturing of hornblende, plagioclase, and potassium feldspar grains, kinking of biotite cleavages, local preferred orientation of biotite grains, and undulatory extinction and mortar texture in quartz. The most common texture comprises relatively large crystals of potassium feldspar, plagioclase, and quartz in a granulated groundmass of quartz, biotite, hornblende, and feldspar. Varieties of gneiss observed in Conoco Alexander #1 include apatite-magnetite (?)-hornblende gneiss; apatite- and sphene-bearing hornblende-biotite gneiss; epidote-hornblende gneiss. Thin sections of surface samples of the Palomas Gneiss contain blue green hornblende, biotite, strained quartz, plagioclase, potassium feldspar (including augen), magnetite (?), and sphene rimming magnetite (?). Mineralogical and textural similarities permit correlation of the metamorphic rock in Conoco Alexander #1 with the Palomas Gneiss.

In the extreme northwest corner of the study area the Mesozoic (?) Whitaker Granodiorite crops out (Plate I). Different facies are present within the massif, and rock composition ranges from quartz diorite to granite, with granodiorite predominating (Shepherd, 1960).

Three wells cored granitic rocks tentatively correlated with the Whitaker Granodiorite (Figure 3). They are Continental Rynne-Fisher #2 (well #171), Union Alexander #1 (well #128), and Continental Vier Kenny #1 (well #126). Thin sections of cores from the latter two wells were examined.

Core descriptions for Continental Rynne-Fisher #2 for the interval 8,700 to 8,706 feet (drilled depth[2]), indicate fragments of weathered biotite granodiorite with pieces of dark gray brown, hard, brittle, clayey siltstone. These cores are assigned to the Modelo Formation because of the presence of siltstone and the weathered characteristics of the granitic debris (Plate XIII). Fragments of 13 cores were recovered from 8,827 feet to 8,973 feet in the well. A summary of these core descriptions is fresh to altered granodiorite, white to gray, medium- to coarse-crystalline, with biotite, kaolinite, secondary chlorite after biotite, secondary epidote after plagioclase, with a vein of black siliceous material cutting one of the core fragments. These cores are considered to be crystalline basement tentatively correlated with the Whitaker Granodiorite.

Union Alexander #1 penetrated approximately 900 feet (275 m) of granitic rock (Plate XXIV). Fourteen sidewall cores of "biotite granite" were taken from 3,275 to 4,043 feet in the well. Thin

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[2] NOTE: All measurements in wells are drilled depths, unless otherwise indicated.

sections of a core taken at 3, 252 to 3, 281 feet were examined. Major minerals are plagioclase (~25% of the rock) altered to kaolinite, calcite, and muscovite; potassium feldspar (~30%), partially altered to clay minerals, with common perthite and microcline twinning; quartz (~30%) myrmekite developed with plagioclase; biotite (~15%), primary, altered to chlorite and an opaque mineral (magnetite ?). According to the IUGS classification of igneous rocks (Streckeisen, 1976), the rock is a biotite granite. Accessory minerals include zircon, apatite, and an opaque mineral (magnetite ?). The primary texture of the rock is modified by shearing, as indicated by granulated and sheared crystal boundaries, undulatory extinction and mortar texture in quartz, and kinked basal cleavages in biotite and secondary muscovite. The kinking of secondary muscovite indicates that deformation of the rock is younger than the secondary alteration. The biotite granite in Union Alexander #1 is tentatively correlated with the Whitaker Granodiorite.

Thin sections of five cores from Conoco Vier Kenny #1 (Figure 3) were examined. Intervals cored were 4, 382 to 4, 390 feet, 4, 562 to 4, 568 feet, 4, 568 to 4, 577 feet, 4, 584 to 4, 589 feet, and 4, 605 to 4, 612 feet. According to the IUGS classification of igneous rocks (Streckeisen, 1976), one of the cores is biotite granodiorite, two are biotite granite, and two are biotite granite to granodiorite. Major minerals are plagioclase (from ~20 to 40% in the samples), altered to clay, sericite, and chlorite; potassium feldspar (from ~10 to 30%), perthitic, with inclusions of plagioclase and apatite; quartz (from ~30 to 40%) myrmekite with plagioclase and micropegmatite with potassium feldspar; biotite (~10% in all samples), primary, as individual crystals and aggregates, altered to chlorite, muscovite, and an opaque mineral which is embayed by quartz and potassium feldspar, with inclusions of apatite and zircon. Accessory minerals include apatite, zircon, and an opaque mineral (magnetite ?). Secondary chlorite, muscovite, an opaque mineral (magnetite ?), and clays are present in all samples. Evidence of deformation is observed in all thin sections, including granulated and sheared crystal boundaries, undulatory extinction and mortar texture in quartz, and local kinking of basal cleavages in biotite.

In all three wells which penetrate granitic basement, the granite is overlain by arkosic sandstone, conglomerate (Tmdc), and gneissic breccia (Tmcb) of the Modelo Formation (Plates XIII and XXIV).

The pre-Modelo Canton fault of Crowell (1954b) separates the Whitaker Granodiorite from the Palomas Gneiss at the surface. The Canton fault also apparently separates the two units in the subsurface (Plates IX and XXIV). If this fault forms the boundary between the Whitaker Granodiorite and the Palomas Gneiss in the subsurface, it must follow a permissive path as shown in Figure 3.

The third major basement terrane in the study area is the Pelona Schist, which crops out along the eastern margin of the area (Plate I). The most common rock type is gray schist composed of albite, muscovite, and quartz in varying proportions (Ehlig, 1968). Radiometric dates for the schist range from 47 to 59 My (Haxel and Dillon, 1978), which suggest an early Tertiary age of metamorphism of the schist. Mineral assemblages in the Pelona Schist exposed in Sierra Pelona, of which the outcrops in the study area area a part, indicate metamorphism occurred at depths of 20 to 27 km (Graham and England, 1976). The Pelona Schist protolith comprised turbidites with a high sand/shale ratio, submarine lava flows (relict pillow structures), and small amounts of chert (now quartzite), and limestone (now marble), possibly deposited on oceanic crust (Haxel and Dillon, 1978).

Petro-Tek #1 (well #3; Figure 3) penetrates approximately 1,700 feet (520 m) of "chlorite schist with quartz" which is correlated with the Pelona Schist (Plate XVII). The driller's log describes the rocks below 3, 078 feet as: chlorite schist; calcareous material (marble ?); and vitreous quartz (quartzite ?). The driller's log also describes brown, hard siltstone as occurring with the above lithologies. The origin and characteristics of any siltstone are unknown, because none has been reported in the Pelona Schist. The schist is separated from the Vasquez Formation by the Francisquito fault at the surface, and in Petro-Tek #1 (Plates I and XVII).

East of the San Gabriel fault in T. 5N., R. 16W., sections 10 and 11, there is a body of shattered aplitic quartz monzonite (Mesozoic ?) (Plate I). No basement rocks similar to this body occur near the San Gabriel fault. Smith (1977) suggested that this shattered body occurs within a major fault zone, and he named it the St. Francis fault zone. He correlated this fault zone with the San Juan-Chimeneas-Morales faults of the La Panza and Caliente Ranges, and the Clemens Well fault of the Mecca Hills and Orocopia Mountains. The aplitic quartz monzonite within the St. Francis fault zone is correlated with quartz monzonite in the La Panza Range. The once-continuous San Juan-St. Francis fault zone of Smith (1977) was dismembered during Miocene and later time by movements on the San Francisquito, San Gabriel, and San Andreas faults (Smith, 1977, Figure 5).

San Francisquito Formation

The name San Francisquito Formation was first applied by Dibblee (1967) to a sequence of Paleocene to early Eocene (?), buff, arkosic sandstone and conglomerate, dark gray mudstone, and siltstone which crops out in and adjacent to the Castaic study area (Plate I). Early workers referred to this sequence as the Martinez or "Martinez" Formation (Clements, 1932, 1937; Simpson, 1934; Muehlberger, 1954, 1958; Jahns and Muehlberger, 1954; Crowell, 1954b; Stanley, 1966; and Konigsberg, 1967), the Necktie Canyon

Formation (Harris, 1950), the Fish Creek beds (Smith, 1951), the Fish Canyon Formation (Johnson, 1952; Szatai, 1961), and the Elizabeth Canyon Formation (Miller, 1952; Szatai, 1961; and Sams, 1964). Sage (1973a) concluded that the San Francisquito Formation was deposited in a submarine fan to basin floor environment, with sediment transport primarily to the southwest. Sage (1973a) also presented a palinspastic restoration of late Paleocene deposits of southern California which placed the San Francisquito Formation of the Elizabeth Lake Canyon area opposite Paleocene rocks of the Caliente Range; this required approximately 30 miles (50 km) of post-Paleocene right slip on the San Gabriel fault. Resistant sandstone, volcanic, plutonic, and metamorphic clasts from the San Francisquito Formation are reworked in younger rocks throughout the Castaic study area. No wells in the study area encountered the San Francisquito Formation.

Vasquez Formation

Hershey (1902b) described a sequence of nonmarine rocks in Tick Canyon which he named the Escondido Series. Kew (1924) called this sequence the Sespe (?) Formation, based on similar lithology and stratigraphic position to the Sespe Formation of the Ventura basin. Clements (1929, 1932) first mapped these rocks in the Castaic study area as the Sespe Formation. Simpson (1934) considered the sequence to be of middle Miocene age; because this is younger than the Sespe Formation of the Ventura basin, he dropped the name Sespe and reverted to Hershey's (1902b) Escondido Formation. Sharp (1935) reasoned that the name Escondido was preempted, and that correlation of these rocks with the Sespe Formation was premature, therefore, he renamed them the Vasquez Series of Oligocene (?) age. Subsequent workers used the name Vasquez Formation for these nonmarine rocks of similar lithology and stratigraphic position which crop out in three sub-basins within the Soledad basin (Muehlberger, 1954; Bohannon, 1976).

In the Castaic study area, the Vasquez Formation occupies a wedge-shaped basin, and comprises approximately 7,200 feet (2,195 m) of nonmarine sandstone, mudstone, siltstone, and conglomerate. The formation is in fault contact with the San Francisquito Formation to the north, and with the San Francisquito Canyon Breccia and Pelona Schist to the south. It is overlain unconformably by the Mint Canyon Formation to the west and by the Charlie Canyon Megabreccia to the south (Plate I).

The Vasquez Formation is divided into four members on the basis of distinctive lithologies, following Sams (1964) and Bohannon (1976): a lower member (Tvl), which includes the "lowermost sandstone," "gray sandstone," and "shale and siltstone members" of Sams (1964); a lower middle member (Tvm_1), the "maroon sandstone member" of Sams (1964); an upper middle member (Tvm_2), the "conglomeratic red mudstone member" of Sams (1964); and an upper member (Tvu), the "granite conglomerate member" of Sams (1964), which overlies the upper middle member with slight angular unconformity. The lower three members are conformable with one another.

The depositional environments of the Vasquez Formation were a nonmarine saline lake for the lower member; an alluvial fan which encroached into the lake from the east for the middle members; and another alluvial fan, with a more southerly source, for the upper member (Bohannon, 1976). Paleocurrent data for the Vasquez Formation indicate transport of sediment from the east, southeast, and south (Bohannon, 1976).

No fossils have been found in the Vasquez Formation, and the Oligocene to early Miocene (?) age is based primarily on its stratigraphic position. Southeast of the Castaic study area, the Vasquez Formation includes volcanic flows interbedded with the sedimentary rocks. Radiometric dates for these flows range from 20.2±0.8 My (Woodburne, 1975) to 24.9±2.1 My (Crowell, 1973a), indicating a late Oligocene to early Miocene age for the formation.

Three wells in T. 5N., R. 16W., section 2 drilled rocks of the Vasquez Formation (Plates I and XVII). These wells have been correlated to the surface on the basis of the distinctive conglomerate of the upper middle member (Tvm_2) in the subsurface. The Vasquez is in contact with the Pelona Schist along the San Francisquito fault both at the surface and in the subsurface.

Charlie Canyon Megabreccia

The Charlie Canyon Megabreccia (Smith, 1977, after Sams, 1964) disconformably overlies the Vasquez Formation (Sams, 1964). Szatai (1961), however, described the Vasquez-Charlie Canyon Megabreccia contact as an angular unconformity. Sams (1964) mapped this unit as the quartz diorite megabreccia of the Vasquez Formation. Most workers have included the megabreccia in the Vasquez Formation (Clements, 1929, 1932, 1937; Muehlberger, 1954; Jahns and Muehlberger, 1954; Sams, 1964; Konigsberg, 1967; and Bohannon, 1976), but Miller (1952) mapped it separately as the West Fork Formation, and Szatai (1961) included it in his Charlie Canyon Formation, which also included the overlying San Francisquito Canyon Breccia. The Charlie Canyon Megabreccia was named by Smith (1977), and is discussed separately here because it represents a distinct change in sedimentation from the underlying Vasquez Formation (Sams, 1964; Bohannon, 1976), and because of its distinct lithology.

The Charlie Canyon Megabreccia is in fault contact with, and unconformably overlain by, the San Francisquito Canyon Breccia, and is in fault contact with the Mint Canyon and Castaic Formations (Plate I). It is approximately 1,600 feet (490 m) thick, massive to poorly bedded, and comprises primarily coarse-crystalline quartz diorite with rare gneiss clasts. A concentration of gneiss clasts within the megabreccia was mapped by Sams (1964) in the southwest corner of section 3, T. 5N., R. 16W. (gn. cl., Plate I). The absence of reworked San Francisquito sandstone, volcanic, and granitic clasts, which characterize the underlying Vasquez Formation is remarkable. There is essentially no matrix between the tightly packed clasts and, in some outcrops, veins can be matched in adjacent clasts, indicating little relative movement between clasts during transport (Bohannon, 1976).

Sams (1964) and Bohannon (1976) interpreted the megabreccia as a landslide mass derived from very close by. Overturned folds in beds directly below the megabreccia indicate movement from southeast to northwest (Bohannon, 1976).

There is no nearby source for the large blocks of quartz diorite in the megabreccia. Smith (1977) suggested that the source area is in the La Panza Range crystalline basement terrane, located approximately 110 miles (175 km) northwest of the study area. Major post-Oligocene movements on the San Juan-St. Francis and San Gabriel fault zones would have separated the Charlie Canyon Megabreccia from its source. Bohannon (1976), in contrast, suggested that the source area for the blocks may have been eroded off the Sierra Pelona antiform.

San Francisquito Canyon Breccia

Unconformably overlying the Charlie Canyon Megabreccia along San Francisquito Canyon is a reddish gray breccia containing clasts of Pelona Schist. Sams (1964) named this unit the San Francisquito Canyon Breccia (Plate I). Most earlier workers included the breccia in the Mint Canyon Formation (Clements, 1929, 1932, 1937; Wright, 1943; Muehlberger, 1954; and Jahns and Muehlberger, 1954), and Sams (1964) stated that the breccia appears to intertongue southward with the Mint Canyon Formation. Miller (1952) and Szatai (1961) included parts of the breccia in both the Mint Canyon and Charlie Canyon Formations, although they defined these two formations differently. The breccia is separated here from the Mint Canyon Formation because of its distinct lithology.

The San Francisquito Canyon Breccia unconformably overlies the Charlie Canyon Megabreccia, Pelona Schist, and aplitic quartz monzonite, and also is in fault contact with these units and the Vasquez, Mint Canyon, and Castaic Formations (Plate I). According to Sams (1964), the breccia apparently intertongues with the Mint Canyon Formation along the west side of San Francisquito Canyon. However, Szatai (1961) considered the contact to be an unconformity.

Schist breccia is the most common rock in the unit, and comprises crudely bedded, subangular to angular slabs of Pelona Schist with minor quartzite, gneiss, and granite clasts, all in a reddish gray, sandy matrix. The schist breccia exhibits a decrease in clast size and an increase in numbers of granitic clasts to the south, where it may intertongue with conglomerate of the Mint Canyon Formation. Other lithologies present in the unit include yellow red conglomerate, jasper-chert breccia, and a sandy, tuffaceous, fresh water limestone bed five feet (1.5 m) thick. Szatai (1961) collected vertebrate fossil fragments from the limestone which were dated as late Miocene (Barstovian) in age (Locality F-38, Plate I, Appendix II). Higher in the section, a yellow-red conglomerate yielded Ostrea sp. and an unidentified foraminifer (?) (Sams, 1964), indicating a possible marine depositional environment for the conglomerate (Locality F-39, Plate I, Appendix II). The total thickness of the San Francisquito Canyon Breccia is approximately 1,300 feet (395 m).

In the subsurface, Atlas Acosta #1 (well #26, Plate XVII) drilled approximately 1,800 feet (550 m) of schist boulders and "shale" which are correlated with San Francisquito Canyon Breccia. Cores recovered from this unit are described as schist boulders or schist boulders in chocolate brown shale. A core taken near the bottom of the well, at 3,900 to 3,910 feet, is described as "gray shale: firm, compact, not broken into plates; brown shale; and a schist pebble, two inches in diameter." On the basis of the sedimentary nature of this core, it was concluded that the basement of Pelona

Schist was not reached in this well.

International Powell #301 (well #101) penetrates approximately ten feet (three meters) of "detrital schist and conglomerate" at the bottom of the well which also are correlated with San Francisquito Canyon Breccia (Plate XIV).

Sams (1964) interpreted the San Francisquito Canyon Breccia to be talus derived from adjacent Pelona Schist.

Sams (1964) and Szatai (1961) suggested a late Miocene age for the San Francisquito Canyon Breccia on the basis of the vertebrate fossils of Barstovian age (late Miocene) in the fresh water limestone within the breccia (Szatai, 1961) and the intertongueing relationship of the breccia with the Mint Canyon Formation (Sams, 1964).

The San Francisquito Canyon Breccia is the oldest unit in the study area containing clasts of Pelona Schist, and thus it marks the beginning of unroofing of Pelona Schist in the rising Sierra Pelona antiform. Elsewhere in the Soledad basin, the Tick Canyon Formation (late early to earliest middle Miocene age, Jahns, 1940) is the oldest unit to contain Pelona Schist clasts (Remenyi, 1966). The Tick Canyon Formation occupies the same general stratigraphic position as the San Francisquito Canyon Breccia, but the two formations are not lithologically similar, and the Tick Canyon is older, based on non-marine vertebrate fossils.

Mint Canyon Formation

Hershey (1902b) described a sequence of nonmarine rocks, 1,700 feet (520 m) thick, in Tick Canyon which he named the Mellenia Series. Kew (1924) renamed the unit the Mint Canyon Formation, because "Mellenia" was not a proper stratigraphic term for the formation. Jahns (1940) distinguished the Tick Canyon Formation (late early to earliest middle Miocene age) from the basal part of Kew's (1924) Mint Canyon Formation. The Mint Canyon in the Castaic study area was first mapped by Clements (1929), and his mapping of this unit is essentially the same as that shown on Plate I of this report.

The Mint Canyon Formation rests with angular unconformity on the Pelona Schist, San Francisquito, and Vasquez Formations. It also is in fault contact with these units as well as the aplitic quartz monzonite, Charlie Canyon Megabreccia, and San Francisquito Canyon breccia. It apparently intertongues with the latter (Sams, 1964). The Mint Canyon Formation is overlain unconformably by the Castaic Formation in the study area (Plate II).

The Mint Canyon Formation crops out in two separate areas in the study area (Plate I). The southern area (Tmc) extends southeast from the vicinity of Charlie Canyon to the southeast corner of the map, and the northern area extends southeast from the north-central margin of the map to the southeast corner of section 4, T. 5N., R. 16W., and is named the Taylor Fanglomerate member (Tmct). Lithologies in the two outcrop areas are significantly different.

Outcrops in the southern area (Tmc) range in thickness from approximately 1,200 feet (365 m) near Charlie Canyon, to approximately 2,300 feet (700 m) in the Dry Canyon area, and comprise gray, buff, and yellow sandstone and conglomerate, red, silty mudstone, and three beds of gray white tuff (Wallace, 1940; Martin, 1947). Clast types in conglomerate include well-rounded sandstone, reworked from the San Francisquito Formation, rounded to angular cobbles of Pelona Schist, and granite and volcanic clasts.

The Taylor Fanglomerate member of the Mint Canyon (Tmct) comprises approximately 400 feet (120 m) of conglomerate and breccia in a red mudstone matrix. Clasts are almost exclusively reworked from the nearby San Francisquito Formation and include predominantly subrounded to angular sandstone with lesser amounts of well-rounded granite, volcanic, and ultramafic clasts. Pelona Schist clasts are absent in the Taylor Fanglomerate, in contrast to the southern area where clasts of Pelona Schist are abundant. The Taylor Fanglomerate is not recognized in the subsurface, therefore, the Mint Canyon is not differentiated into members in the subsurface.

In the subsurface, the Mint Canyon (undifferentiated) comprises alternating beds of red brown and gray sandstone and conglomerate, with mottled red, brown, and green siltstone (Plate XIX). These lithologies contrast with the overlying Castaic Formation, which comprises gray brown sandstone, conglomerate, and siltstone. In contrast to the Mint Canyon, the Castaic lacks red and green mottling; and has abundant megafossils, foraminifera, pyrite, and phosphatic and carbonaceous material. The Mint Canyon is normally barren of fossils in the subsurface, but where fossils are present, they are mainly brackish water foraminifera and fresh water ostracods (Plate XIV, well #101). The Mint Canyon also has a distinctive electric log character of abruptly alternating high and low peaks on the spontaneous potential and resistivity curves which further distinguish it from the Castaic Formation in the subsurface (e.g. Plates XIV and XIX).

The Mint Canyon is distinguished from the underlying San Francisquito Canyon Breccia in the subsurface on the basis of the relatively large amount of schist detritus in the latter unit (Plates XIV and XVII).

The Mint Canyon Formation of the Castaic study area represents alluvial fan deposits to the north and east and lacustrine deposits in the subsurface to the south and west (Ehlig et al., 1975). Brackish water foraminifera and freshwater ostracods in International Powell #301 (well #101, Plate XIV) indicate a brackish to nonmarine lacustrine environment in this area. The different lithologies observed for the Taylor Fanglomerate member, which has a notable lack of Pelona Schist clasts, and the southern area of Mint Canyon outcrops, with abundant clasts of Pelona Schist, may be explained if separate streams, with different provenances, emptied into the larger Mint Canyon depositional basin to the south, as suggested by Wright (1943).

The age of the Mint Canyon Formation is middle to late Miocene (Clarendonian to Barstovian Vertebrate Stages). This age assignment has been somewhat controversial (see Winterer and Durham, 1962, p. 284-285 for complete discussion) because the Mint Canyon contains early Pliocene vertebrates, especially Hipparion, whereas the invertebrate fauna indicates a late Miocene age. The Mint Canyon of the Castaic study area is overlain by the Castaic Formation, dated as late Miocene on the basis of an abundant marine fauna (Stanton, 1966). The age of the Castaic Formation and the overlying Ridge Basin Group, exposed in the northwest-plunging Ridge Basin syncline (Plate I), ranges from 8.45 My for outcrops of Castaic Formation along Interstate 5 just north of the town of Castaic to 6.0 My for the Piru Gorge sandstone exposed in Piru Gorge approximately six miles (ten kilometers) north of the Castaic study area, based on magnetic reversal stratigraphy (R. Ensley, personal commun., 1980). This section of Castaic Formation and the lower part of the Ridge Basin Group are late Miocene in age, and based on superposition, the Mint Canyon can be no younger than late Miocene also.

The middle to late Miocene dating of the Mint Canyon Formation indicates that this formation is coeval with much of the marine Modelo

Formation (Relizian, Luisian, and Mohnian foraminiferal stages of Kleinpell, 1938). The Modelo crops out in the study area west of the San Gabriel fault. Ehlig et al. (1975) measured predominantly east-west trending paleocurrents in the Mint Canyon. On the basis of a distinctive clast assemblage and the paleocurrent data, they correlated the Mint Canyon with the Miocene part of the Caliente Formation of the Lockwood Valley area. Since they were deposited, the Mint Canyon and Caliente Formations have been separated by approximately 35 miles (60 km) of right-slip on the San Gabriel fault (Ehlig et al., 1975). This fault movement explains the juxtaposition of nonmarine Mint Canyon with coeval marine strata of the Modelo Formation in the Castaic study area.

Castaic Formation

The Castaic Formation was named by Crowell (1954b) for a sequence of marine siltstone, mudstone, sandstone, and conglomerate of late Miocene age exposed in the vicinity of Castaic Creek. Earlier workers referred to these strata as "Modelo", Modelo, or Modelo (?) Formation because they occupy the same stratigraphic position, and are about the same age (late Miocene) as the Modelo Formation of the Ventura basin. Crowell (1954b) distinguished the Castaic Formation from the Modelo because of lithologic differences; primarily, the Castaic is deficient in sandstone and conglomerate when compared to the type Modelo.

At the surface, the Castaic rests upon the Mint Canyon Formation with a slight angular unconformity. It is in fault contact with the Vasquez Formation, Charlie Canyon Megabreccia, and San Francisquito Canyon Breccia, and it intertongues with the Violin Breccia along the San Gabriel fault (Plate I).

The Castaic is unconformably overlain by the Pico Formation in the subsurface, and, north of where the Pico wedges out, by the Saugus Formation (Plates XII, XIV, and XIX to XXII).

The angular unconformity between the Castaic and Mint Canyon Formations is best defined in the subsurface (Plate XIV). The lowest electric log correlation in the Castaic Formation is about 250 feet (75 m) above the top of the Mint Canyon in International Powell #301 (well #101), whereas in Sun Dodge #1 (well #92) approximately 1,370 feet (415 m) of Castaic Formation is found below the same electric log marker, and the top of the Mint Canyon is not reached. This apparently represents a west-to-east onlap of the Castaic Formation onto the Mint Canyon.

In the study area, the Castaic Formation comprises 1,700 to 7,000 feet (520 to 2,135 m) of marine, brown gray mudstone, siltstone, sandstone, and conglomerate. Carbonaceous matter is ubiquitous, and coal beds are commonly reported in drillers' logs (e.g. Plate XIV, wells #103 and 109; Plate XXI, well #132; <u>cf.</u> Skolnick and

Arnal, 1959). Bentonite, pyrite, and phosphatic material also are common in this unit. Sandstone and conglomerate, comprising a higher proportion of the section near the eastern and northern margins of the study area, become less common to the south and west, where the thickest section of Castaic is found (e.g. Plate X). However, a thick conglomerate in the Castaic is found locally in wells near the San Gabriel fault (Plate XII, well #56; Plate XIII, well #79). This conglomerate may be a proximal turbidite fan deposited against an east-facing scarp of the ancestral San Gabriel fault. The lack of subsurface control of the lower part of the Castaic Formation near the San Gabriel fault prevents a detailed facies analysis of the conglomerate.

West of the San Gabriel fault, the Pliocene Pico Formation is underlain by the Towsley Formation (Plate I). Though coeval, in part, with the Castaic Formation which underlies the Pico east of the San Gabriel fault, the Towsley contains abundant conglomerate. However, strata tentatively correlated with the Castaic Formation are present in three wells located west of the main branch of the San Gabriel fault (wells #140, 141, and 150; see Plates V and XI). In Macson Radovich #1 (well #141, Plate XI), the strata below the Pico lack thick beds of conglomerate, exhibit a mixture of Pliocene (Delmontian ?) and Miocene (Mohnian) microfossils, contain fault breccia, and have a relative abundance of carbonaceous and phosphatic material, and bentonite.

These features are more characteristic of the Castaic Formation than the Towsley. The paleontology report for Macson "Radovich" #1 also indicates the presence of the Charlie Canyon fauna (CCF) which characterizes the Castaic Formation, at 3,151-3,171 feet. On the basis of the distinctive lithology and paleontology, the strata beneath the Pico in Macson Radovich #1, Macson Lindsay #1 (well #141), and below 3,400 feet in Morton and Dolley and MJM&M Radovich #1 (well #150) are tentatively correlated with the Castaic Formation. As a result, a pre-Pico strand of the San Gabriel fault, San Gabriel fault "C", is inferred to be present in the subsurface, west of the main San Gabriel fault "B" of this report (Plates IV, V, and XI).

The Castaic-Mint Canyon contact is located in the subsurface by: (1) down-section changes from gray-brown mudstone, sandstone, and conglomerate to red, brown, and green sandstone, conglomerate, and mottled siltstone (Plate XIX); (2) changes from strata containing marine Miocene megafossils and foraminifera to barren rocks or to strata containing fresh and brackish water faunas (Plate XIV, well #101); (3) changes from strata with common phosphatic and carbonaceous material and pyrite, to rocks lacking these (Plate XIX) and; (4) abruptly alternating spontaneous potential and resistivity curves on electric logs which characterize the Mint Canyon Formation (Plates XIV, XVIII, qnd XIX).

The contact of the Castaic with the overlying Pico or Saugus is marked by the appearance of relatively thick basal conglomeratic sandstones which are either barren of fossils, or contain Pliocene faunas (Plate XII). Where the Pico or Saugus are less coarse, the top of the Castaic is located on the first appearance of the Miocene Charlie Canyon fauna (Mohnian, CCF; Plate XX, Texaco WCU #48, Plate XXI, well #44b).

According to Stanton (1966), the deposition of the Castaic Formation occurred in a transgressive marine environment. Facies recognized include: a basal, coarse-grained nearshore unit with a rich megafauna; a fine-grained mid-basin unit of alternating mudstone and sandstone which is poor in megafauna but rich in microfauna; a breccia (Violin Breccia) which accumulated along the base of the San Gabriel fault and intertongued with the fine-grained mid-basin facies (Plates I, IX, and X); and a conglomerate close to the San Gabriel fault and southeast of the Violin Breccia.

Skolnick and Arnal (1959) described the microfauna which characterizes the Castaic Formation. This microfauna is referred to informally as the Charlie Canyon fauna (CCF) by the petroleum industry, and is assigned to the Mohnian and Delmontian (?) Stages of Kleinpell (1938). The Delmontian faunas suggest that the Castaic Formation may extend into Pliocene time. Stanton (1966), however, concluded that the Castaic megafauna was exclusively late Miocene in age. The magnetic reversal stratigraphy of the Ridge basin indicates that the age of the Castaic Formation, and the overlying Ridge Basin Group exposed in the northwest-plunging Ridge Basin syncline (Plate I), ranges from 8.45 My for outcrops of Castaic Formation along Interstate 5 north of the town of Castaic to 6.0 My for the Piru Gorge sandstone exposed in Piru Gorge approximately six miles (ten kilometers) north of the Castaic study area (R. Ensley, personal commun., 1980). Because the base of the Delmontian stage of Kleinpell (1938) is approximately 6.0 My (Boellstorff and Steineck, 1975), Delmontian faunas should not occur below the Piru Gorge sandstone of the Ridge Basin Group, or in the underlying Castaic Formation.

Both the megafauna and the microfauna of the Castaic Formation are predominantly shallow-water, nearshore assemblages. However, deep water microfossils such as Globigerina, Gyroidina, coupled with radiolarians within the Charlie Canyon fauna suggest an open marine environment (Schlaefer, 1978; Stanton, 1966). Winterer and Durham (1962, cf. Figure 68) suggested that the Soledad basin may have connected with the Ventura basin in late Miocene time. Paschall and Off (1961) and Schlaefer (1978) noted the presence of Charlie Canyon fauna in wells in Honor Rancho oil field west of the San Gabriel fault within strata assigned to the Modelo Formation (Schlaefer, 1978; Plates VII and VIII), which indicates a possible link between the two basins during Mohnian time. The distribution of the Violin Breccia and the conglomerate facies within the Castaic suggest that the link was southeast of the Castaic study area.

Violin Breccia

Near the San Gabriel fault, fine-grained rocks of the Castaic Formation intertongue with and overlie the Violin Breccia (Plates I and IX). This breccia accumulated as talus at the base of the San Gabriel fault scarp (Crowell, 1952, 1954b). The oldest breccia beds intertongue with siltstone of the Castaic Formation that have early Mohnian faunas (Plate IX, well #130). Crowell (1952), using the age of the breccia, dated the onset of movement on the San Gabriel fault as Mohnian (late Miocene). The Violin Breccia can be traced in the subsurface at least as far as 4,400 feet (1,340 m) southeast of the nearest breccia outcrop. In Max Pray NL & F #1 (Plate X, well #132), two lenses containing green, angular gneiss clasts in a fine, silty sandstone matrix were drilled from 1,880 to 1,920 feet and 2,020 to 2,030 feet. These lenses are correlated with the Violin Breccia, and a larger body of Violin Breccia is inferred to be present along the San Gabriel fault in the subsurface near this well (Plate X).

At the surface, the Violin Breccia mainly consists of angular blocks of blue-quartz gneiss and augen gneiss, with minor granite and diorite-gabbro clasts in a reddish brown sandy matrix (Weber, 1979).

Rincon Formation

West of the San Gabriel fault, Gulf J. I. Hathaway #1 (well #117b) penetrates approximately 11,000 feet (3,355 m) of Modelo Formation and approximately 800 feet (245 m) of gray shale, siltstone, and sandstone correlated with the Rincon Formation. The Rincon Formation, named by Kerr (1931), does not crop out in the Castaic study area (Plate I). Shepherd (1960), near Canton Creek, described a sequence 400 foot (120 m) thick of grayish brown and brown siltstone and claystone, with minor hard, calcareous, fine-grained sandstone of the Rincon Formation. This locality is approximately two miles (three km) west of the study area. Cemen (1977) described a complete section of Rincon, 2,800 feet (855 m) thick, in the subsurface west of Piru Creek, approximately eight miles (13 km) southwest of the study area. It is not known what the Rincon Formation rests upon in J. I. Hathaway #1, but at Canton Creek, it is underlain by the late Oligocene Vaqueros Formation (Shepherd, 1960).

The age of the Rincon at Canton Creek and in Gulf J. I. Hathaway #1 is early Miocene (Zemorrian and Saucesian Stages of Kleinpell, 1938).

The Rincon Formation is overlain by the Modelo Formation with angular unconformity at the surface, but the type of contact in J. I. Hathaway #1 is not known.

Modelo Formation

Eldridge and Arnold (1907) first named the Modelo Formation for 10,000 feet (3,050 m) of sandstone and mudstone exposed near Modelo Canyon. Kew redefined the Modelo, and he recognized two mudstone ("shale") and three sandstone members in the formation. Kew mapped the Modelo as resting on the Vaqueros Formation, and included the Rincon Formation as the lower "shale" member of the Modelo. Crowell (1954b) mapped the Modelo Formation in the Castaic study area, and recognized lower, middle, and upper members, each separated by an angular unconformity. The upper member of Crowell (1954b) was referred to as the Towsley Formation by Paschall and Off (1959), and their usage is followed in this report.

The Modelo Formation of the Castaic study area comprises up to 11,000 feet (3,355 m) of alternating beds of gray brown siltstone, brown to black laminated mudstone, and gray, arkosic, fine-grained to conglomeratic sandstone. Locally, a basal breccia (Tmcb), which contains angular clasts of gneiss with less common clasts of anorthosite and granite in a red brown sandy matrix, is developed near the Palomas Gneiss sliver (Plates I and XXIV). In eastern outcrops and in the subsurface, the Modelo contains a prominent gray brown conglomerate, named the Devil Canyon conglomerate by Crowell (1953) (Tmdc; Plates I, IX, X, XIII, and XXIV). This conglomerate contains an early Mohnian fauna and is characterized by angular to subrounded clasts of anorthosite, granite, metamorphic, and volcanic rocks. Some anorthosite clasts reach several feet in diameter, with the largest adjacent to the San Gabriel fault (Crowell, 1952). Clast size distribution indicates a source to the northeast. Because no anorthosite is now present across the San Gabriel fault, Crowell (1952) suggested that in late Miocene (early Mohnian) time, the anorthosite complex in the western San Gabriel Mountains was adjacent to the accumulating Devil Canyon conglomerate. Right slip of approximately 30 kilometers on the San Gabriel fault later displaced the Devil Canyon conglomerate from its source terrane.

In three wells (#126, #128, and #171, Figure 3), the Devil Canyon conglomerate rests upon a granitic basement which is correlated to Whitaker Granodiorite (Plates XIII and XXIV), but in Gulf J. I. Hathaway #1 (well #117b) approximately 3, 000 feet (915 m) of early Mohnian sandstone, correlated with the Devil Canyon conglomerate, is underlain by another 4, 000 feet (1, 220 m) of Modelo. The Modelo sandstone, siltstone, and mudstone contain foraminifera of the early Mohnian, Luisian, and Relizian stages of Kleinpell (1938). In the Gulf well, approximately 11, 000 feet (3, 355 m) of Modelo rests upon the early Miocene Rincon Formation.

In the Castaic study area, the Modelo Formation is overlain with angular unconformity by the Towsley Formation. The Modelo-Towsley contact is generally the base of a thick, red brown conglomerate (Hasley or Santa Felicia conglomerate; Ttcb; Plates I, IX-XVI, XXIII, XXIV). However, in two areas in the subsurface, the Hasley conglomerate is not present (Plate V), and the base of the Towsley is located on the basis of either paleontology or electric log correlations with nearby wells containing Hasley conglomerate. In six wells in sections 21, 22, 27, 28, and 29, T. 5N., R. 17W., a conglomerate-filled channel lies immediately below the base of the Hasley conglomerate. This channel appears to merge with the Hasley conglomerate to the south, so it is included in the Towsley Formation (Plate V).

The environment of deposition of the Modelo Formation has been interpreted by Berger (1977). West of the Ramona and Del Valle oil fields, southwest of the Castaic study area, the sandy, conglomerate-free rocks of the Modelo were deposited as a series of coalescing deep water fans. East of Ramona and Del Valle, including the Castaic study area, Modelo sandstones are conglomeratic and were deposited as a more shallow, marginal marine facies. Paleobathymetry studies, based on benthic foraminifera in two wells, indicate outer neritic to upper bathyal water depths for deposition of the Modelo Formation (well #159, and well #152, Plate IX).

The age of the Modelo is middle and late Miocene (Relizian, Luisian, and early to late Mohnian Stages of Kleinpell, 1938). Where the Devil Canyon conglomerate overlies the basement near the

San Gabriel fault, the basal Modelo Formation is early Mohnian (late Miocene) in age, and suggests that the Modelo Formation onlapped the basement from west to east along the eastern margin of the Ventura basin during late Miocene time.

Towsley Formation

The Towsley Formation was named by Winterer and Durham (1954). Previously, Eldridge and Arnold (1907) included these rocks in the Modelo and Fernando Formations, Kew (1924) included them in the Modelo and Pico Formations, Oakeshott (1958) referred to them as the Elsmere member of the Repetto Formation, and, in the Castaic study area, Crowell (1954b) included them as the upper member of the Modelo Formation. In the study area, the Towsley Formation is found only west of the San Gabriel fault (e.g. Plates I, V, IX, and X). Crowell (1953) mapped four members of his upper Modelo (Towsley of this report); a lower, red-brown conglomerate (Ttcb, Plate I; Santa Felicia or Hasley conglomerate); a lower, green-brown silt-stone (Tts, Plate I); an upper red-gray conglomerate (Ttc, Plate I); and an upper, green-brown siltstone (Tts, Plate I). Cemen (1977) recognized these four members in the Towsley Formation near Piru Creek, approximately two miles (three kilometers) southwest of the Castaic study area. In the subsurface, a four-fold subdivision of the Towsley Formation was found to be impractical. The upper conglomerate is not everywhere separated from the lower conglomerate (Plates I, IX, XIV, and XV), and there commonly are more than two distinct conglomerates within the Towsley Formation (Plates XIV-XVI). In contrast to the Hasley conglomerate, which is comparatively sheet-like and of relatively uniform thickness, overlying conglomerate beds in the Towsley Formation are lenticular in cross section, and have many of the characteristics of channelized suprafan deposits (*cf.* Walker, 1978, Figure 18). The Hasley conglomerate contains anorthosite clasts which generally are subrounded to well-rounded. These clasts may be reworked from the underlying Devil Canyon conglomerate, which subcrops against the base of the Hasley conglomerate near the San Gabriel fault (Plate VIII; also Paschall and Off, 1959, 1961, and Weber, 1979). However, some of the anorthosite clasts may have been derived from the anorthosite complex in the western San Gabriel Mountains. Weber (1979) reported no clasts of anorthosite in Towsley or Pico conglomerates above the Hasley. However, core descriptions in one well (well #170, Plate XXIV) suggest that there are anorthosite clasts in conglomerate of the Pico Formation.

In the subsurface, the Towsley overlies the Modelo Formation with angular unconformity (Plate XXIV). This contact appears to become conformable in the subsurface in the southwestern part of the study area (Plates XII and XXIII). The subcrop of the Modelo siltstone-Devil Canyon conglomerate contact against the base of the

Towsley indicates a northwest paleostrike of the Modelo Formation near the San Gabriel fault during deposition of the Hasley conglomerate (Plate VIII). As mentioned in the discussion of the Modelo Formation, the contact between the Towsley and Modelo is usually the base of the Hasley conglomerate, except as noted on Plate V, where a conglomerate-filled channel lies immediately below the Hasley, or where the Hasley is not present.

The contact between the Towsley and the overlying Pico Formation is a slight angular unconformity. The Towsley thins gradually from south to north and from east to west (Plates IX, X, XXIII, and XXIV).

In the eastern part of Castaic Hills oil field, in section 36, T. 5N, R. 17W., the Towsley Formation changes abruptly in thickness and lithology (Plates XIII-XVI). In this area, the Castaic Hills fault cuts the Modelo and Towsley Formations, but not the Pico Formation. The Towsley is thicker by up to 900 feet (275 m) east of the fault than it is to the west. Electric log correlations also become difficult in the Towsley across this fault. It is possible that the thickening and poor correlation observed in the Towsley Formation may be explained if the Castaic Hills fault was active during deposition of the Towsley, acting as a growth fault. This would permit a thicker accumulation of Towsley on the downthrown side of the fault, and lithologies would not correlate well across the fault.

In the northern area of production in the Castaic Hills oil field (Figure 4), in section 26, T. 5N., R. 17W., the Towsley is juxtaposed against rocks tentatively correlated with the Castaic Formation across San Gabriel fault "C" (Plates V and XI).

Deposition of the Towsley Formation occurred in bathyal to outer neritic water depths (Plate IX, well #152; Plate XII, well #250), in a proximal, submarine fan environment. The facies seen in the Towsley Formation in the Castaic Hills oil field, where there is a close well control, are similar to those suggested by Walker (1978) for a prograding submarine fan system (Plates XIII-XVI). The vertical sequence of such a system comprises a basal, blanket-like sandstone of the lower fan association (Hasley conglomerate, Ttcb) and a mudstone or siltstone blanket (Tts) deposited between lenticular, channelized, thick, pebbly sandstones of a suprafan lobe facies (Ttc) (cf. Walker, 1978, figure 18). The Towsley Formation, in its type area south of Castaic, comprises typical turbidites which exhibit displaced foraminiferal faunas, broken megafossils, graded bedding, and abrupt facies changes (Winterer and Durham, 1962).

Microfauna in the Towsley Formation indicate a late Miocene to early Pliocene age (late Mohnian and Delmontian stages of Kleinpell, 1938). Thus, the Towsley may be coeval, in part, with the Castaic Formation east of the San Gabriel fault. Where these formations are juxtaposed along the San Gabriel fault in the Castaic area, they have dissimilar lithologies and faunas (Plates X-XVI). Conglomeratic sandstone of the Towsley submarine fan system thickens and coalesces sourceward to the San Gabriel fault, but similar conglomerate is absent in coeval strata east of the fault. Instead, relatively fine-grained siltstone and mudstone of the Mohnian Castaic Formation are encountered. These fine-grained clastics cannot be the source for the conglomeratic Towsley turbidites. As suggested by Crowell (1952), the Towsley fan system probably was derived from the San Gabriel Mountains, which were later displaced southeastward by strike-slip on the San Gabriel fault, thus beheading the fan system.

Pico Formation

Rocks of the Pico Formation were originally assigned to the Fernando Formation by Eldridge and Arnold (1907). Their Fernando rests unconformably upon the Modelo, and is overlain by Pleistocene nonmarine strata. Kew (1924) elevated the Fernando to group status and subdivided it into the early Pliocene Pico Formation and the late Pliocene and early Pleistocene Saugus Formation. The Pico of Kew (1924) rests unconformably upon the Modelo Formation, and is separated from the overlying Saugus by an angular unconformity. Oakeshott (1958) separated the Pico Formation of Kew (1924) into the early Pliocene Repetto Formation, and the middle to upper Pliocene Pico Formation. Oakeshott (1958) subdivided the Pico into three members; a lower Pico member (middle Pliocene) a middle

Pico member (late Pliocene); and the upper brackish to nonmarine Sunshine Ranch member (late Pliocene). The lower and middle members of the Pico Formation of Oakeshott (1958) are characterized by microfaunas of the Venturian and Wheelerian foraminiferal stages, respectively, of Natland and Rothwell (1954). Winterer and Durham (1962) renamed Oakeshott's Repetto Formation as the Towsley Formation, because the type Repetto, in the Los Angeles basin, is lithologically different. Winterer and Durham (1962) also placed the Sunshine Ranch member of the Pico Formation of Oakeshott (1958) in the overlying Saugus Formation. The stratigraphic nomenclature of Winterer and Durham (1962), for Pliocene strata of the eastern Ventura basin, is used in this report.

West of the San Gabriel fault, the Pico rests unconformably on the Towsley Formation (e.g. Plates I, XXIII, and XXIV). In the subsurface, the base of the Pico is normally a conglomeratic sandstone resting on Delmontian siltstone (e.g. Plate XXIII, well #242).

East of the San Gabriel fault, the Pico Formation is present only in the subsurface where it overlies the Castaic Formation with angular unconformity (Plates XII, XIV, XVI, XIX-XXII). The Pico is overlapped by the Saugus Formation such that Saugus rests directly on the Castaic Formation northeast of the point of overlap. The subcrop of the Castaic-Pico contact against the base of the Saugus is shown on Plate III.

In the subsurface on both sides of the San Gabriel fault, the Pico Formation comprises up to 1,400 feet (425 m) of gray, green gray, and white gray, lenticular, fine-grained to pebbly sandstone, and gray to gray green, clayey to sandy, bioturbated siltstone (e.g. Plate XII, well #250). Clasts recognized in cores of Pico conglomerate include anorthosite (?), schist, and other metamorphic and granitic rocks.

The Pico of the Castaic study area is mainly of shallow-marine origin, and represents the last marine deposits in the eastern Ventura basin as the Pliocene sea regressed westward.

The age of the Pico Formation in the study area is early to late Pliocene. Most paleontology reports for wells in the Castaic area describe Pico faunas as undifferentiated Pliocene or "Pico." There are no references to the Venturian or Wheelerian Stages, and few of the Repettian of Natland and Rothwell (1954) (Plates XII, well #250, XVI, well #164, and XXIII, well #242). The Pico faunas are so provincial that it is not possible to correlate local faunal boundaries to an absolute time scale (cf. Ingle, 1967).

Saugus Formation

Hershey (1902b) recognized nonmarine rocks near the town of Saugus which he referred to as the "Saugus division" of the late Pliocene series. Eldridge and Arnold (1907) included these rocks in their Fernando Formation. Kew (1924) divided the Fernando of Eldridge and Arnold (1907) into the early Pliocene Pico Formation and the late Pliocene Saugus Formation. Winterer and Durham (1962) characterized the Saugus of the eastern Ventura basin as including a lower shallow-marine to brackish water member (Sunshine Ranch), and an upper unnamed nonmarine member. Oakeshott (1958) had earlier included the Sunshine Ranch as the upper member of his Pico Formation. The nomenclature of Winterer and Durham (1962) is followed in this report. Outcrops of Saugus Formation in the Castaic study area are all part of the nonmarine Saugus. The Sunshine Ranch lithology is recognized in the subsurface (e.g. Plate XIII, well #73 and #76), but is not differentiated because the Sunshine Ranch member cannot be correlated consistently between wells in the study area.

West of the San Gabriel fault, the Saugus disconformably overlies the Pico Formation. East of the San Gabriel fault, the Saugus unconformably overlies both the Pico and Castaic Formations. The Charlie Canyon anticline, Charlie Canyon syncline, Castaic anticline, and Ridge Basin syncline deformed the Castaic Formation prior to deposition of the Saugus Formation. The subcrop of the Castaic-Pico contact against the base of the Saugus is shown on Plate III.

Near its base, the Saugus Formation consists of green gray and gray pebbly sandstone and green gray siltstone which may contain marine to brackish water faunas of the Sunshine Ranch member

(Plate XXI, well #73, Plate XXII, well #74 and #76). The green gray color of the siltstone and sandstone of the Saugus contrasts with the gray and gray brown color so dominant in Pico siltstone and sandstone. Few core descriptions are available for the nonmarine member of the Saugus Formation, but at the surface, gray green lenses of siltstone are present and alternate with beds of red brown and gray pebbly sandstone. Pebbles and cobbles in Saugus conglomerate are well-rounded and include clasts of granite, anorthosite, Pelona Schist, volcanic and metamorphic rocks, and San Francisquito sandstone. The well-rounded clasts suggest that most of them are reworked from older formations. Weber (1979) subdivided the Saugus Formation of the Castaic area on the basis of clasts contained in conglomerates: Saugus with clasts of gray brown, resistant sandstone of the San Francisquito Formation, but none of Pelona Schist (QTss); and Saugus which contains clasts of Pelona Schist, but not of anorthosite (QTsp) (Plate I). These members could not be recognized in the subsurface because, being part of the nonmarine Saugus, they rarely are cored in the subsurface. However, west of the San Gabriel fault, projection of the surface contact between QTss and QTsp, parallel to the base of the Saugus Formation as mapped in the subsurface, suggests that QTsp conformably overlies QTss (Plates XII and XXIII). East of the San Gabriel fault, the surface trace of the QTss-QTsp contact does not conform to bedding attitudes, suggesting that here the contact may cut across bedding and be a facies boundary.

In the subsurface, the base of the Saugus Formation was placed at the top of the marine Pliocene, where paleontology reports were available (e.g. Plate XIII). This paleontological pick was found to correspond with a reasonably good electric log signature. The spontaneous-potential and resistivity curves for rocks of the basal Saugus commonly exhibit a gradual upward increase in amplitude, indicating a coarsening-upward vertical sequence from siltstone to sandstone (e.g. Plate XVI). Electric log correlation of the Pico-Saugus contact is locally difficult where the upper Pico is conglomeratic (e.g. Plate XIV). East of the San Gabriel fault, where Saugus rests upon the Castaic Formation, the contact usually was picked based on the first appearance of Mohnian Charlie Canyon fauna (CCF), or of gray brown, hard mudstone and siltstone of Castaic lithology (e.g. Plates XIV and XX).

At the surface, the Saugus Formation is unconformably overlain by the Quaternary Pacoima Formation (?) of Weber (1979) and alluvial deposits (Plate I).

Deposition of the Saugus Formation represents the final regression of the marine Ventura basin westward out of the Castaic study area. The Sunshine Ranch member was deposited in a brackish water lagoonal environment, followed in vertical succession by prograding alluvial fan gravels and silts of the nonmarine member of the

Saugus (Winterer and Durham, 1962, figure 54).

The age of the Saugus Formation in the Castaic study area is late Pliocene to Pleistocene. Pliohippus teeth have been reported from four localities by Pollard (1958) (F-32 through F-35, Plate I, Appendix II). Remains of a Pleistocene bison were found near the San Gabriel fault zone in what is shown as Pico Formation on Plate I (Locality F-37, Appendix II). As suggested by Pollard (1958), these remains may have been deposited in the Saugus Formation or in terrace material which has since been disrupted by movement on the San Gabriel fault. Paleontology reports from wells in the study area indicate a Pliocene to Pleistocene (?) age for the sparsely fossiliferous lower part of the Saugus (e.g. Plate XXII).

Pacoima Formation (?) of Weber (1979)

Oakeshott (1958) named the Pacoima Formation for fanglomerate found around the western margin of the San Gabriel Mountains. These lie unconformably upon the Saugus Formation and are unconformably overlain by Quaternary terrace deposits. Eldridge and Arnold (1907) designated these deposits as "Pleistocene Formations" which unconformably overlie their Fernando Formation. Kew (1924) and Winterer and Durham (1962) mapped these rocks as Quaternary terraces. Weber (1979), after Oakeshott (1958), mapped a small outcrop of Quaternary Pacoima Formation (?) along Castaic Creek in the southern part of the study area (Plate I).

The Pacoima fanglomerate is poorly to well-consolidated and contains angular pebbles and boulders in a reddish brown sandy matrix; the San Gabriel Mountains were the source.

Older Alluvium

In the study area, older alluvium (Qoa_1) is present mainly along Haskell, Dry, San Francisquito, Charlie, and Elizabeth Lake Canyons, and Castaic Creek (Plate I). Older alluvium includes terraces and older fan deposits and comprises poorly to unconsolidated sand and gravel. A bison of possible Holocene age was found in strata mapped as older alluvium (Pollard, 1958; Locality F-36, Plate I, Appendix II).

Intermediate-Age Alluvium

Unconsolidated sand and gravel which have been somewhat dissected (Qoa_2) are mapped along Castaic Creek in the southern part of the study area, and at the mouth of Grasshopper Canyon where it joins Castaic Creek (sections 13 and 14, T. 5N., R. 17W., Plate I).

Younger Alluvium

Younger alluvial deposits (Qal) of unconsolidated silt, sand, and gravel are found throughout the Castaic study area (Plate I). They represent colluvium, slope wash, stream channel, and floodplain deposits.

Landslides

Landslides (Qls) are mapped throughout the Castaic area, especially along the upper reaches of San Francisquito, Marple, Santa Felicia, and Hasley Canyons (Plate I). Landslides are distinguished on the geologic map (after Weber, 1979) as being either surficial or bedrock slides. Siltstone of the Towsley, Modelo, and Castaic Formations are especially susceptible to sliding.

STRUCTURE

General Statement

Major structures in the Castaic study area (Figure 7, Plate I) may be subdivided according to age into three stages. Stage I structures (Figure 8) pre-date deposition of the Mint Canyon Formation. They include the eastern part of the San Francisquito syncline, the Bee Canyon fault, the San Francisquito fault, the Dry Gulch fault, the Community fault, the St. Francis fault zone of Smith (1977) and the Canton fault. Stage II structures (Figure 9) post-date deposition of the Mint Canyon Formation and pre-date deposition of the Saugus Formation. They include the western part of the San Francisquito syncline, the Charlie Canyon anticline, the Charlie Canyon syncline, the Castaic anticline, the Ridge Basin syncline, an unnamed syncline west of the San Gabriel fault, normal faults east of the San Gabriel fault, the Castaic Hills fault, the San Gabriel fault "B", and the San Gabriel fault "C" (?). Stage III structures (Figure 10) post-date deposition of the Saugus Formation. They include the Dry Canyon syncline, the Dry Canyon anticline, the Townsend syncline, the Loma Verde anticline, the North and South Hasley Canyon synclines, the Oak Canyon anticline, the normal fault in Castaic Hills, the San Gabriel fault "B", and the Hasley fault, including the Villa

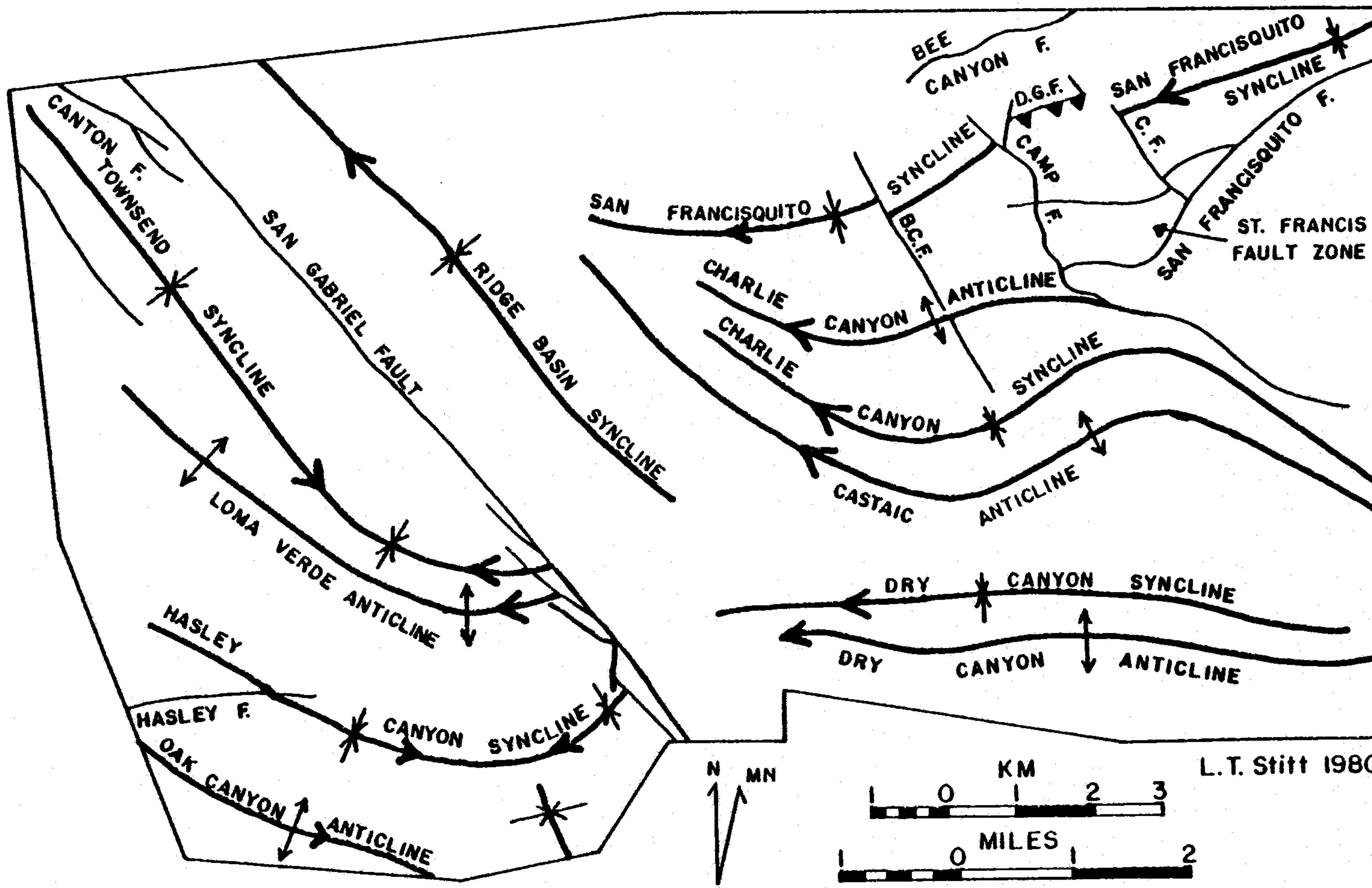


FIGURE 7: Major Structures in the Castaic Study Area. D.G.F. = Dry Gulch fault, C.F. = Community fault, B.C.F. = Bitter Canyon fault.

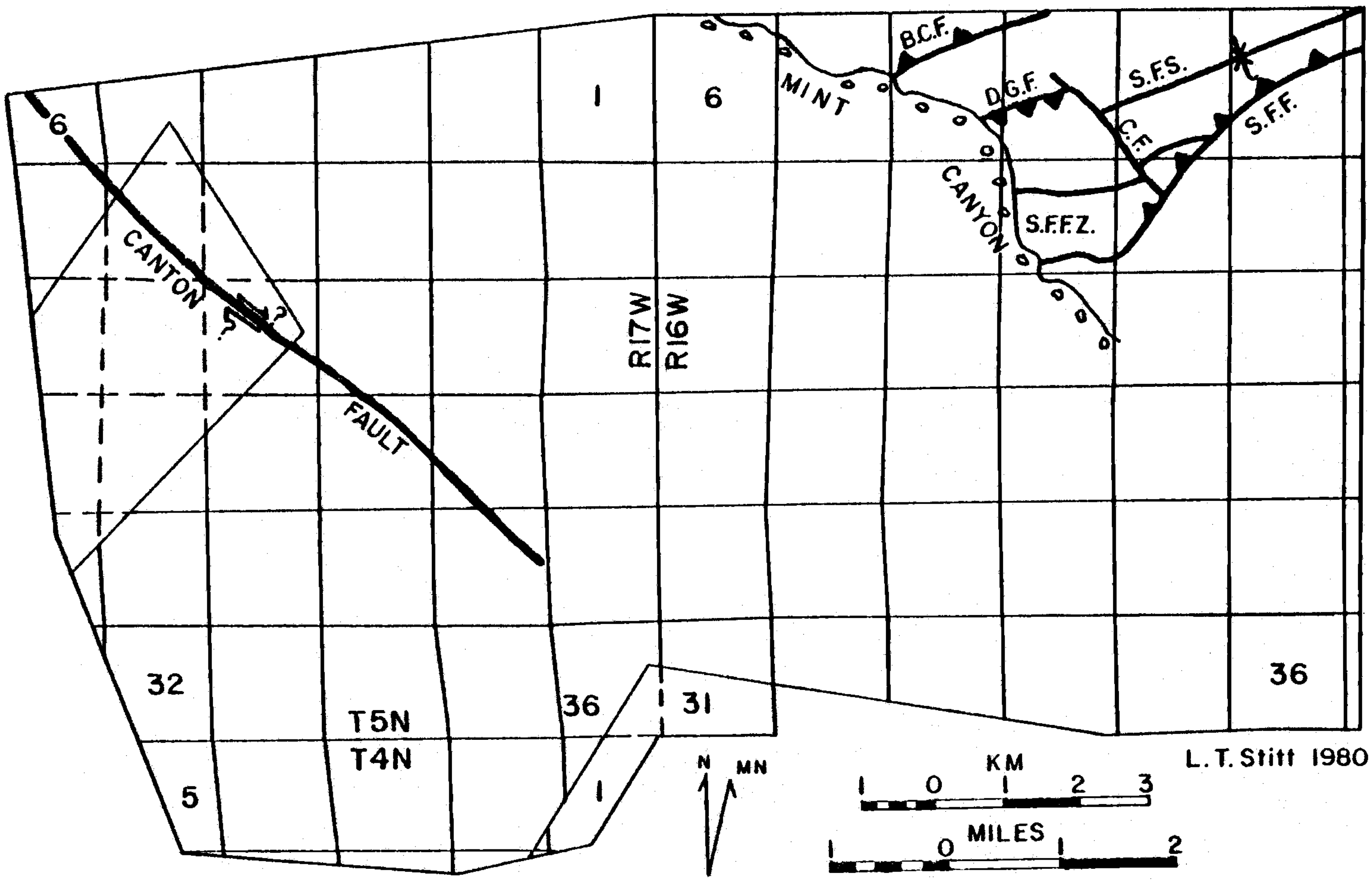


FIGURE 8: Post-Vasquez, Pre-Mint Canyon Structures (Late Oligocene - Early Miocene ?). See Figure 7 for names of structures.

STAGE I

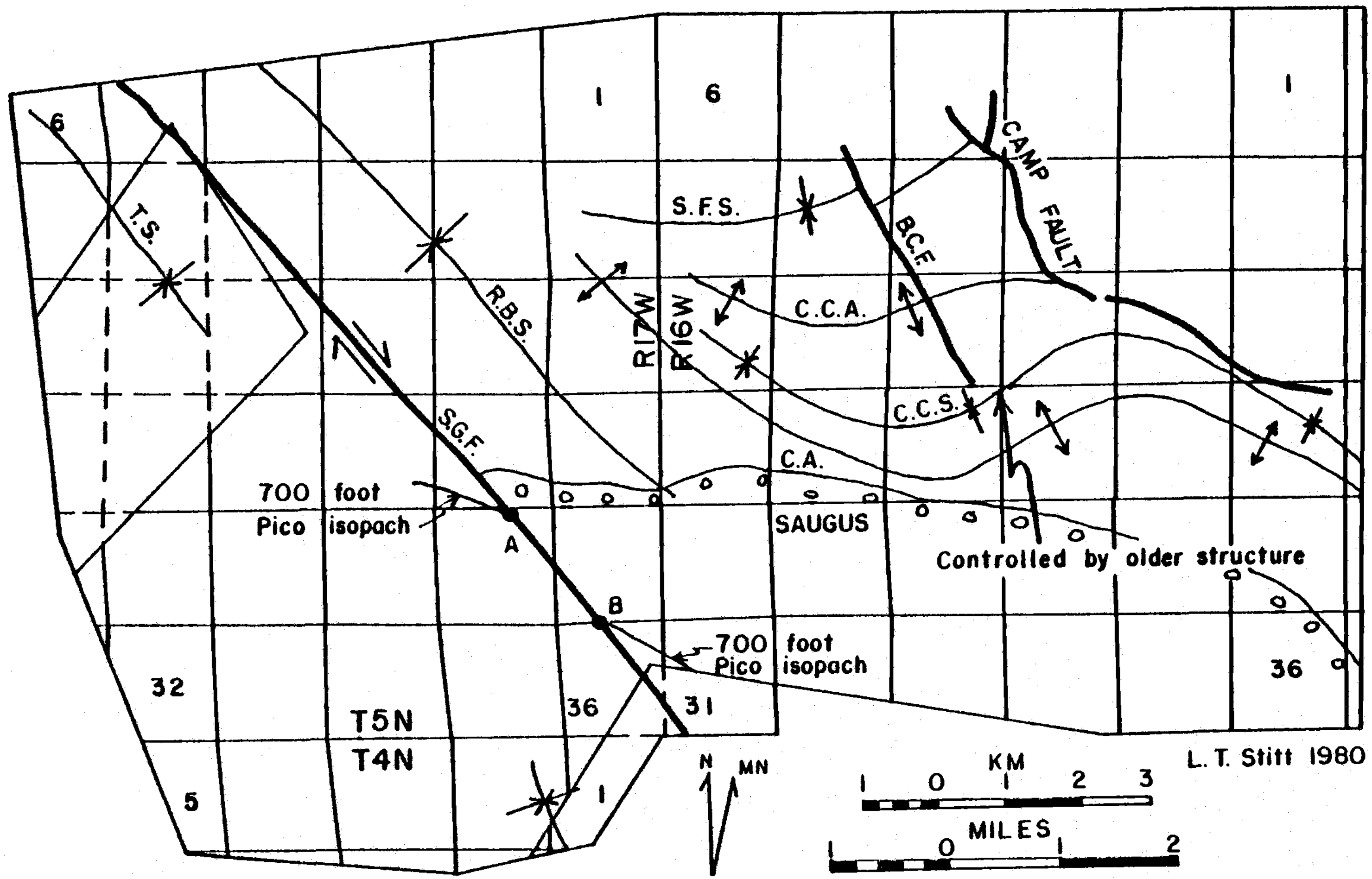


FIGURE 9: Post-Mint Canyon, Pre-Saugus Structures (Late Miocene – Late Pliocene). See Figure 7 for names of structures.

STAGE II

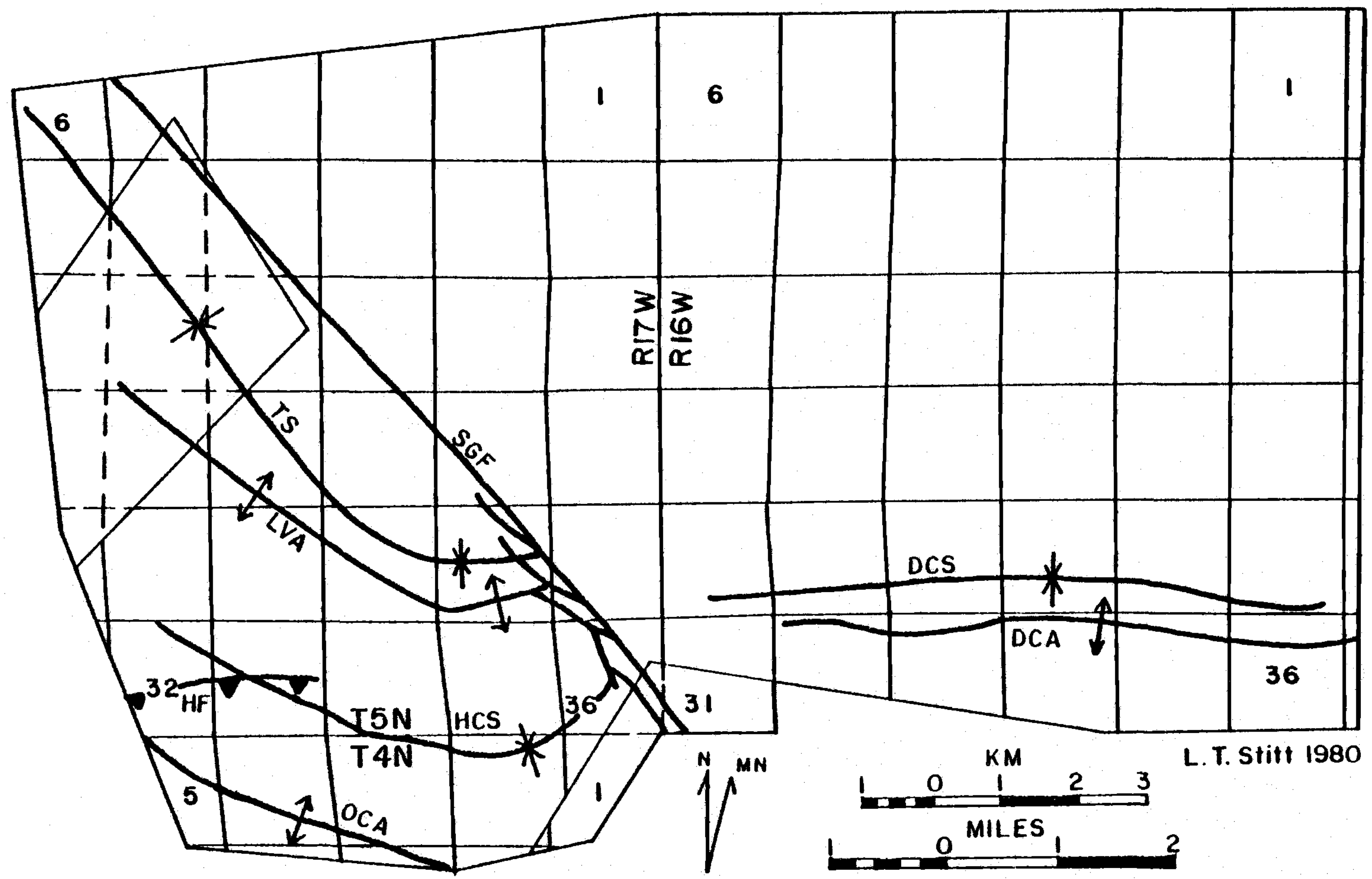


FIGURE 10: Post-Saugus Structures. See Figure 7 for names of structures.

STAGE III

Canyon structure of Weber (1979).

Stage I Structures

Eastern Part of the San Francisquito Syncline

The eastern part of the San Francisquito syncline trends approximately east-west and plunges approximately 20° west-southwest. To the west, it terminates against the Community fault (Plate I). The eastern part of the San Francisquito syncline appears to have formed as the Vasquez Formation was thrust over the Pelona Schist along the San Francisquito fault (Plate XVII).

Bee Canyon Fault

The Bee Canyon fault is a thrust fault which dips approximately 30 to 40° to the north and juxtaposes the Paleocene San Francisquito Formation against the Vasquez Formation. To the west, the fault is overlain by the Taylor Fanglomerate member of the Mint Canyon Formation (Plate I).

Dry Gulch Fault

The Dry Gulch fault (Sams, 1964) is a bedding plane thrust within the Vasquez Formation (Plate I). The fault is detected by the sudden change in attitude from near vertical beds north of the fault to shallow south-dipping beds south of the fault. The fault trends east-west and dips 30 to 40° to the south. It is truncated to the east by the Community fault, and to the west by the Camp fault (Plate I).

Community Fault

The Community fault (Sams, 1964) is a normal fault which strikes northwest. It is split into two parts by an unnamed normal fault (Plate I). The southeast part of the Community fault dips 25 to 50° to the southwest and the northwest part dips 55° to the northeast. The fault appears to die out to the north within relative steeply dipping beds of the upper middle member of the Vasquez Formation. To the south, it appears to die out within the San Francisquito Canyon Breccia.

San Francisquito Fault

The San Francisquito fault is a major structure which can be traced eastward approximately 19 miles (31 km) from the northeast corner of the Castaic study area to the San Andreas fault (Konigsberg, 1967). In the study area, it is a reverse fault which dips approximately 45° northwest, separating Pelona Schist from the Vasquez Formation (Plate I). The dip is controlled by a point on Petro Tek #1 (well #3), as shown on Plate XVII. The western end of the fault is truncated by the Camp fault (Plate I). In this area, the fault dips to the southwest. Smith (1977) suggested that the San Francisquito fault cuts the Mint Canyon Formation, and that the fault exhibits about 20 kilometers of left-slip. Approximately three miles (five kilometers) east of the study area, the San Francisquito fault juxtaposes the San Francisquito Formation and the Pelona Schist. The schist was metamorphosed in Paleocene to Eocene time (47 to 59 Ma, Haxel and Dillon, 1978) at a depth of approximately 20 to 27 km (Graham and England, 1976). At the same time, the San Francisquito Formation was deposited during Paleocene time in a submarine fan-basin floor environment (Sage, 1975). This contrast between coeval units suggests a large displacement on the San Francisquito fault.

In section 1, T. 5N., R. 16 W., the St. Francis dam was built across San Francisquito Canyon. The dam was completed on May 4, 1926 and it failed on March 12, 1928, killing 450 people. The cause of failure is attributed to undermining of the dam foundation by percolation of water and subsequent erosion along the crush-zone of the San Francisquito fault (Assoc. Engineering Geologists, Southern Calif. Sect., 1978). Failure was not due to movement on this fault.

St. Francis Fault Zone of Smith (1977)

The St. Francis fault zone of Smith (1977) strikes east-west. It is truncated on the west by the Camp fault, and on the east by the San Francisquito fault (Plate I).

Smith (1977) correlated the aplitic quartz monzonite, exposed within the St. Francis fault zone, and the Charlie Canyon Megabreccia with a basement terrane in the La Panza Range, presently located approximately 110 miles (175 km) northwest of the study area. Subsequent to deposition of the Charlie Canyon Megabreccia in late Oligocene (?) time, the postulated Red Hills-San Juan-St. Francis-Russell-Chimeneas-Clemens Well fault (Smith, 1977; Crowell, 1979) accumulated up to 175 kilometers of right-lateral displacement. This occurred prior to movement on the San Francisquito fault, as the latter truncates the St. Francis fault zone (Plate I). The movement of both faults pre-dates deposition of the Mint Canyon Formation in middle to late Miocene time, and also pre-dates the movement of the San Gabriel fault.

Canton Fault

The Canton fault separates the Palomas Gneiss and Whitaker Granodiorite at the surface north of the study area (Crowell, 1954b). Crowell (1954b) showed the fault with a steep northeast dip, and suggested that it cuts the lower part of the Modelo Formation (Figure 5). In the subsurface, the fault separates the Palomas Gneiss and Whitaker Granodiorite. It is apparently overlain by rocks of the Modelo Formation (Plates IX and XXIV). A permissive subsurface trend of the Canton fault is shown on Figure 3.

The Canton fault may have been an early branch of the San Gabriel fault, separating the Palomas Gneiss from gneiss presently located in the Alamo Mountain region.

Stage II Structures

Western Part of the San Francisquito Syncline

The western part of the San Francisquito syncline exhibits a general east-west trend and plunges approximately 10° west-southwest (Sams, 1964). The fold is offset by the Bitter Canyon fault; is truncated on the east by the Camp fault; and dies out to the west within the Castaic Formation (Plate I).

Charlie Canyon Anticline, Charlie Canyon Syncline, and Castaic Anticline

The Charlie Canyon anticline, Charlie Canyon syncline, and Castaic anticline are sinuous folds; the eastern segments of the folds follow a general east-west trend, the central segments trend northeast-southwest, and the western segments trend southeast-northwest. The folds plunge gently to the west and die out to the west as they approach the Ridge Basin and San Francisquito synclines (Plate I). Where the folds change trend from southwest to northwest, the limbs steepen and four sharp, minor folds are developed. Isopachs of the Pico Formation (Plate VI) east of the San Gabriel fault are parallel to the trend of the Castaic anticline and show thinning of the Pico toward this structure, suggesting that the Castaic anticline formed a topographic high against which the Pico was deposited.

Ridge Basin Syncline

The Ridge Basin syncline is a major regional structure which follows a northwest trend parallel to the San Gabriel fault for approximately 25 miles (40 km) from the vicinity of Castaic to the Frazier Mountain region. The fold is asymmetric, having a gentle eastern limb which dips approximately 20° and a steeper western limb which dips generally 40 to 60°. The fold plunges 10° to 15° to the northwest. In the study area, the southeast end of the syncline affects the Saugus Formation (Plate III), and Weber (1979) mapped it as folding Quaternary older alluvium (Qoa_1, Plate I) approximately 2,000 feet (610 m) east of the town of Castaic. However, the fold is steeper in the Castaic Formation than in the overlying Saugus and older alluvium; most of the folding in this syncline is pre-Saugus.

Normal Faults East of the San Gabriel Fault

Six northwest-trending normal faults cut strata of the Castaic and Mint Canyon Formations east of the San Gabriel fault (Plate I). The Bitter Canyon fault dips 57 to 75° to the northeast. The northwest part of this fault is offset by east-west trending faults. The Bitter Canyon fault offsets the axis of the western part of the San Francisquito syncline. The Camp fault dips 70 to 80° to the southwest. The western part of the San Francisquito syncline terminates against the Camp fault to the east (Plate I).

In sections 13, 14, 15, and 24 of the T. 5N., R. 16W., an unnamed fault juxtaposes the Mint Canyon Formation against the Pelona Schist. The fault trends N 50 W to due west, dips southwest (Plate I), and exhibits normal separation. The fault may be a decollement surface, and the eastern parts of the Charlie Canyon anticline, Charlie Canyon syncline, and Castaic anticline may have formed in response to the faulting (Plate XVII).

Castaic Hills Fault

Near the eastern edge of the Castaic Hills oil field a fault was mapped in the subsurface which trends subparallel to and approximately 2,000 feet (610 m) southwest of the San Gabriel fault (Plates V, VII, X, and XII to XVI). This feature is named the Castaic Hills fault. Evidence for the fault includes: (1) poor electric log correlations within the Towsley Formation across the structure; (2) faunal repeats in some wells near the structure; (3) abrupt eastward thickening of the Towsley Formation across the structure. The overlying Saugus and Pico Formations are not affected by this fault (Plates III and IV).

The Castaic Hills fault may have been active during deposition of the Towsley Formation. It may have acted as a growth fault, permitting a thicker accumulation of the Towsley on the downthrown, eastern block. The possible growth faulting may also explain the poor electric log correlations within the Towsley Formation across the fault.

The Castaic Hills fault exhibits reverse separation of the base of the Towsley ranging from approximately 160 feet (50 m) on the south to approximately 450 feet (135 m) on the north. The fault does not exhibit strike-slip, as the northern edge of the Sterling sand in the Castaic Hills oil field is not offset horizontally across this structure.

San Gabriel Fault "C" (?)

A pre-Pico strand of theSan Gabriel fault zone is inferred in the subsurface west of the main San Gabriel fault "B" (Plates IV, V, and XI). It is named San Gabriel fault "C" (?). The fault is inferred because strata in three wells located west of the main trace of the San Gabriel fault contain strata are tentatively correlated with the Castaic Formation (wells #140, #141, and #150). The fault has no surface expression.

The fault cuts Morton and Dolley and MJM & M Radovich #1 (well #150) at 3,400 feet, and it separates the Towsley from the Castaic Formation (Plate XI). The fault dips to the southwest in this well and is inferred to steepen at depth.

The subcrop of San Gabriel fault "C" (?) against the base of the Pico Formation (Plate IV) is controlled only southeast of Morton and Dolley and MJM&M Radovich #1 (well #150). The Towsley Formation underlies the Pico in Conoco Harding #31 (well #208, Plate IV) and indicates that San Gabriel fault "C" (?) is north of this well. The trace of the subcrop of the fault against the base of the Pico north of Morton and Dolley and MJM&M Radovich #1 is not controlled in the subsurface. However, the fault cannot be present where the Towsley Formation begins to crop out west of the main San Gabriel fault. Therefore, San Gabriel fault "C" (?) is inferred to join San Gabriel fault "B" east of the first outcrops of Towsley along the surface trace of San Gabriel fault (Plates I and IV).

San Gabriel Fault "B"

San Gabriel fault "B" is a Stage II and Stage III structure (Figures 9 and 10). Schlaefer (1978) mapped two strands of the San Gabriel fault in the subsurface immediately southeast of the Castaic study area in Honor Rancho oil field. The western strand was named San Gabriel fault "A", and the main, eastern strand was named San Gabriel fault "B". The San Gabriel fault "A", like San Gabriel fault "C", brings the Castaic Formation into contact with the Towsley west of fault "B"; it apparently merges with fault "B" at the northern edge of section 6, south of the town of Castaic (Plate III). The San Gabriel fault "B" of Schlaefer (1978) is continuous with the main strand of the San Gabriel fault in the Castaic study area (e.g. Plate III), therefore the name San Gabriel fault "B" is used in the Castaic area.

Earlier workers have advanced conflicting interpretations of the movement history of the San Gabriel fault. Crowell (1952) first suggested that large right-lateral movement has occurred on the fault. Paschall and Off (1961) argued against a hypothesis of large right-slip based primarily on subsurface data in Honor Rancho oil field. Schlaefer (1978) restudied the subsurface geology of this field in detail, and her conclusions were consistent with the hypothesis of large-scale strike-slip on the San Gabriel fault. Weber (1979) suggested recently that limited right-slip (maximum of approximately

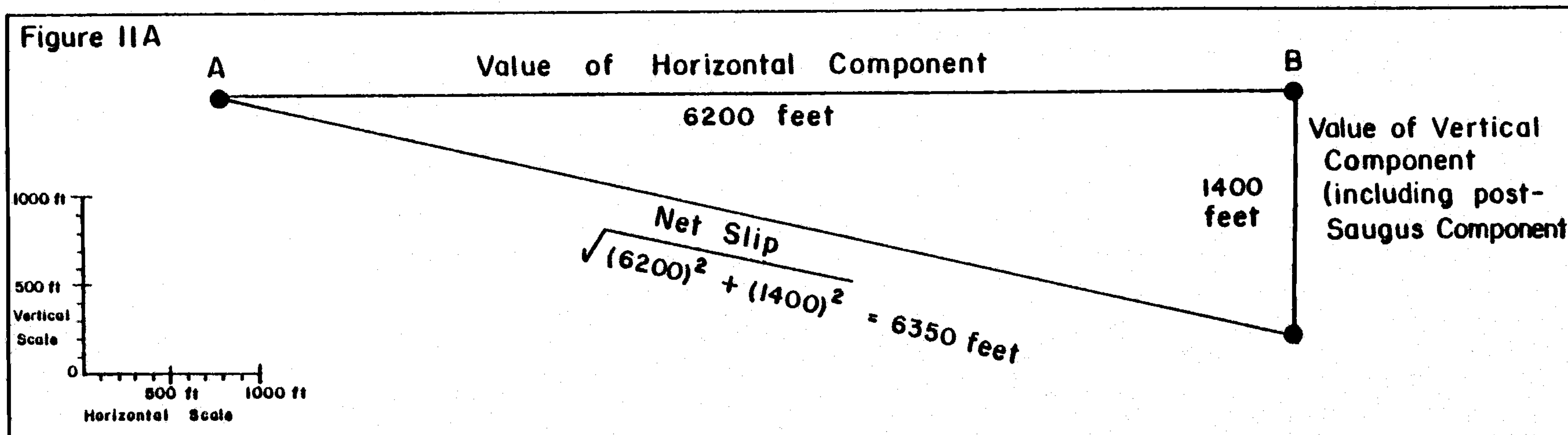
11 km) occurred on the San Gabriel fault, based primarily on surface geology.

Evidence for large right-lateral offsets on the San Gabriel fault includes: (1) 50 to 60 kilometers offset of Precambrian gneiss from the Alamo Mountain area to the western San Gabriel Mountains (Crowell, 1962); (2) approximately 23 kilometers offset of Mesozoic basement rocks of the central San Gabriel Mountains on the north branch of the San Gabriel fault (Ehlig, 1975a); (3) approximately 35 kilometers offset of Mesozoic basement rocks on the south branch of the San Gabriel fault in the central San Gabriel Mountains (Ehlig, 1975a); the combined offset on the two branches of the San Gabriel fault, in the central San Gabriel Mountains, approximates the 60 kilometers of offset proposed for basement rocks on the single trace of the fault further northwest; (4) approximately 60 kilometers offset of the Paleocene San Francisquito Formation in the Elizabeth Canyon area from similar Paleocene strata in the Caliente Range (Sage, 1973a); (5) approximately 60 kilometers offset of the Oligocene to early Miocene Vasquez Formation in the Soledad basin from the Oligocene to early Miocene Simmler and Plush Ranch Formations in the Caliente Range-Lockwood Valley region (Bohannon, 1975, 1976); (6) approximately 55 kilometers (no more than 80 km) offset of the St. Francis fault zone from the Morales fault, matching the Charlie Canyon Megabreccia with a possible source in the La Panza Range (Smith, 1977); (7) approximately 60 kilometers offset of the middle to late Miocene Mint Canyon Formation of Soledad basin from the Miocene Caliente Formation of the Caliente Range-Lockwood Valley region (Carman, 1964; Ehlig et al., 1975); (8) approximately 30 kilometers offset of late Miocene Modelo conglomerate which contains blocks of anorthosite from a probable source in the western San Gabriel Mountains (Crowell, 1952); (9) approximately 30 kilometers offset of late Miocene Violin Breccia in Violin Canyon from a gneiss source in the Alamo Mountain region (Crowell, 1952); (1) 11 to 32 kilometers offset of early to middle Pliocene sedimentary rocks near Newhall from a probable source in the San Gabriel Mountains (Ehlig, 1975a); (11) six to 19 kilometers offset of middle to late Pliocene Pliocene marine conglomerate near Newhall from a probable source in the San Gabriel Mountains (Ehlig, 1975a); (12) approximately two kilometers or more offset of the Pliocene Pico Formation in the subsurface near Honor Rancho oil field (Schlaefer, 1978).

In the Castaic study area, the San Gabriel fault juxtaposes Violin Breccia and Castaic Formation on the northeast against Palomas Gneiss, Towsley, and Pico Formations on the southwest. From the northern margin of the study area for approximately four miles (6.5 km) there is a single linear, main trace of the San Gabriel fault which trends northwest-southeast and dips 60 to 80° northeast. Along this segment of the fault, Weber (1979) mapped a minor strand of the San Gabriel fault which cuts Quaternary landslide material near the mouth of Palomas Canyon (Plate I). Near the mouth of Violin Canyon, the surface trace of the San Gabriel fault becomes sinuous, and the outcrop pattern in sections 22 and 23, T. 5N., R. 17W. suggests a southwest-dipping reverse fault (Plate I). The San Gabriel fault becomes a complex zone of anastomosing and en echelon segments where it cuts strata of the Saugus Formation. The extension of the fault zone across Castaic Creek has been mapped as two topographic lineaments (Weber, 1979; Plate I).

In the subsurface, the San Gabriel fault zone consists of a pre-Pico strand (San Gabriel fault "C" (?)), and a main strand (San Gabriel fault "B") (Plates V and XI). Because the main strand dips steeply to the northeast, only two wells in the study area cut the fault (Plate VII). In Conoco Alexander #1 (well #130), the fault is located at a subsea elevation of minus 430 feet where Violin Breccia is juxtaposed against Palomas Gneiss (Plate IX). In Texaco H. R. 'A'(NCT-2) #4 (well #72), the fault is located at a subsea depth of minus 3, 825 feet, where the Castaic Formation is juxtaposed to the Modelo Formation. The fault is constrained to a steep dip near Texaco H.R. 'A'(NCT-2) #32 (well #232), which bottoms in the Castaic Formation at a subsea elevation of minus 4, 177 feet (Plates XII, XIII, and XV). The San Gabriel fault "B" is contoured on the basis of these scattered control points (Plate VII).

The following observations from the subsurface of the Castaic study area support the hypothesis of large right-slip on the San Gabriel fault. (1) Coeval late Miocene strata of different lithologies are juxtaposed along the San Gabriel fault where these older rocks are covered by the Saugus Formation at the surface. The Modelo and Towsley Formations are conglomeratic and derived from the east whereas the adjacent Castaic Formation, presently east of these formations, is predominantly mudstone and siltstone (Plates X to XVI). The fine-grained clastics of the Castaic are not the source for the clasts in the Modelo and Towsley. The likely source for these clasts is the western San Gabriel Mountains, which contain a heterogeneous terrane of Precambrian gneiss and anorthosite and Mesozoic granitic rocks (Crowell, 1962). Right-slip of approximately 30 kilometers has separated the Modelo and Towsley conglomerates from this source area (Crowell, 1952). (2) The Pico Formation does not crop out east of the San Gabriel fault, but is present in the subsurface (Plates XIII, XIV, XVI, and XIX to XXII). The 700, 800, and 900 foot isopach lines indicate right-slip of 6,200 feet (two kilometers) of the Pico Formation on the San Gabriel fault (Plate VI). Based on Plate IV, the vertical component of piercing point offset of the 700 foot isopach of the Pico is approximately 1,400 feet. Thus, the net slip of the Pico Formation on the San Gabriel fault is 6,350 feet (net slip = $\sqrt{(6200)^2 + (1400)^2}$) in a right oblique sense (Figure 11A). The vertical component of separation of the base of the Saugus Formation at the 700 foot isopach line



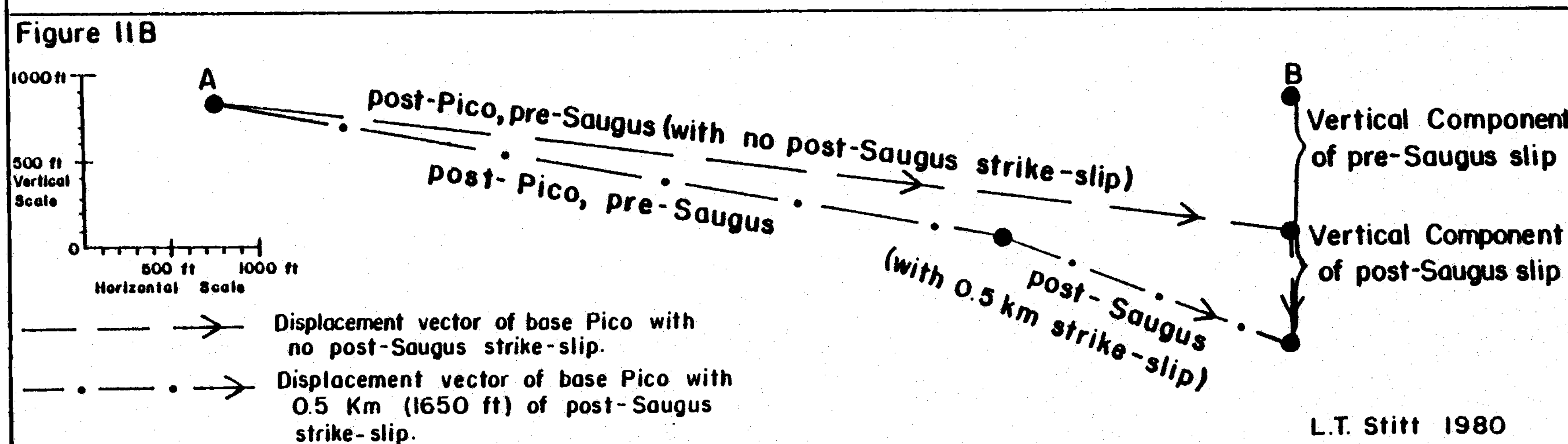


FIGURE 11A: Diagram parallel to the San Gabriel fault showing offset of the 700 foot isopach and the base of the Pico Formation. Points A and B located on Figure 9 (see Plate VI).

FIGURE 11B: Diagram parallel to the San Gabriel fault showing two possible displacement vectors of the base of the Pico Formation (700 foot isopach). One vector assumes no post-Saugus strike-slip. The other vector assumes 0.5 Km (1650 feet) of post-Saugus strike-slip as suggested by Weber (1979).

of the Pico east of the San Gabriel fault is 650 feet (Plate III). If there is no horizontal component of slip on the Saugus Formation, then the vertical component of pre-Saugus, post-Pico slip on the San Gabriel fault is 750 feet (1,400-650) (Figure 11B). This value is not changed by adding the 0.5 kilometers of right-slip on the Saugus suggested by Weber (1979) (Figure 11B).

Stage III Structures

Dry Canyon Syncline and Dry Canyon Anticline

The Dry Canyon syncline and Dry Canyon anticline trend east-west and plunge gently west. On the eastern end, the plunge of the Dry Canyon anticline within the Mint Canyon Formation is steeper than it is in the overlying Castaic and Saugus Formations. The folds die out to the west near the Tapia oil field.

Townsend Syncline

Beginning near the northwest corner of the study area, the Townsend syncline trends southeast and plunges approximately 25° southeast. West of the town of Castaic, near the head of Sloan Canyon, the fold changes to an east-west trend and plunges to the west (Plates I, and III to V). The plunge is steepest, approximately 15°, where the fold is truncated by the San Gabriel fault, and it gradually decreases to the west. The Townsend syncline appears to have had a pre-Towsley period of movement. The Modelo Formation is folded more steeply than the overlying Towsley, Pico, and Saugus Formations (Plates I, IX, X, XXIV).

Loma Verde Anticline

The Loma Verde anticline follows the trend of the Townsend syncline from northwest to southeast. Like the Townsend syncline, the Loma Verde anticline changes trend from southeast to northeast near Sloan Canyon (Plates I, and III to V). The fold plunges southwest approximately 20° where it is truncated by the San Gabriel fault; the plunge gradually decreases to zero 1,500 feet (455 m) east of Sloan Canyon. After changing to a northwest-southeast trend, the fold plunges approximately 25° to the southeast. The Loma Verde anticline is assymmetrical. It has a short north limb which abruptly becomes involved in the Townsend syncline, whereas the south limb enters the Hasley Canyon syncline more gradually (Plates III to V). The shortness of the north limb causes the axis of the anticline to migrate southward in the subsurface (Plate XXIV).

North and South Hasley Canyon Synclines

The North and South Hasley Canyon synclines of Plate I were mapped by Weber (1979). However, Pollard (1958) mapped only one continuous syncline in this area, and subsurface mapping indicates one major fold also (Plates III to V). In the subsurface, only the western end of the South Hasley Canyon syncline is present as a minor fold between Oak Canyon anticline and North Hasley Canyon syncline. The latter is analagous to the Townsend syncline and Loma Verde anticline; it is a doubly plunging fold which changes trend from southeast to northeast and plunge from southeast to southwest as it approaches the San Gabriel fault (Plates III to V).

Oak Canyon Anticline

The Oak Canyon anticline is present along the southwest margin of the study area. It trends northwest-southeast and plunges gently southeast (Plate I, and III to V). Oil is produced along this structure in the Oak Canyon and Hasley Canyon fields.

Normal Fault in Castaic Hills

Near the eastern edge of the Castaic Hills oil field, a normal fault was mapped which trends parallel to the Castaic Hills fault; it is located southwest of the San Gabriel fault and dips northeast (Plates III to V, VII, X, and XII to XVI). The normal fault cuts the base of the Saugus and all older formations. The only possible surface expression of the fault is an air photo lineament mapped by Weber (1979) in the southeast corner of section 26, T. 5N., R. 17W

(Plates I and VII), and this lineation is inferred to be the extension of this fault. The fault in the subsurface is inferred on the basis of normal separation, down to the northeast, of electric log markers in the Saugus and Pico Formations. Stratigraphic separation on the fault ranges from 150 to 350 feet (45 to 105 m). The Towsley Formation underlies the Pico Formation east of the normal fault, suggesting that major strike-slip movement on the fault is unlikely.

Hasley Fault

The Hasley fault (American Assoc. Petroleum Geologists, 1952) is a reverse fault which dips south approximately 55° at the surface (Pollard, 1958) and steepens to approximately 70° in the subsurface (Plates VIII and X). It produces a maximum of 300 to 500 feet (90 to 150 m) of stratigraphic separation in the Castaic study area (Plate X). Approximately 350 feet (110 m) of stratigraphic separation occurs on the Hasley fault in Oak Canyon oil field (American Assoc. Petroleum Geologists, 1952). Separation decreases eastward to zero, as shown on Plates III to V.

Marathon Douglas #1 (well #253, Plate II) contains approximately 2,800 feet (855 m) of Towsley, about 500 feet (150 m) more than in nearby wells. The Hasley fault produces the extra thickness by repeating approximately 500 feet (150 m) of the Towsley Formation.

In McCulloch Senegram #1 (well #254) the Hasley fault is picked at 9,000 feet (Plate X). Electric log characteristics within the Modelo Formation begin to change from regular alternations of high and low peaks on the spontaneous potential and resistivity curves to a broad, high resistivity curve and a relatively low, undeflected spontaneous potential curve. A dipmeter survey in the well indicates a change in bedding strike from S80E above 8,795 feet to N08W at 9,103 feet.

The Hasley fault is geometrically similar to the south-dipping Holser reverse fault which occurs south of the Castaic study area (Winterer and Durham, 1962). Like the Holser, the Hasley fault cuts the Saugus Formation. The fault has not been traced east of its offset of the Saugus-Pico contact. Its trace projects eastward into an area of alluvium in Hasley Canyon. Further east, the Villa Canyon structure of Weber (1979) may be in part related to the Hasley fault (Plates I and VIII).

Villa Canyon Structure of Weber (1979)

In his mapping of the San Gabriel fault zone, Weber (1979) recognized an east-west-trending lineament (fault ?) which follows Villa Canyon; he called this the Villa Canyon structure (Plate I). Evidence for the structure is mainly geomorphic. Weber (1979, p. 30) claims that south-flowing creeks (Romero and Sloan Canyons) exhibit apparent right-deflection along the Villa Canyon structure.

On an earlier map, Weber also noted questionable displacement of older or younger alluvium, aligned topographic features, questionable north-facing modified scarps, and a linear gulch along the course of the structure (Plate I of Weber, 1978). Geologic evidence for the structure is weak, as pointed out by Weber (1978), and consists of slight deformation of the Saugus Formation (see bedding attitudes on Plate I of this report), and apparent right-deflection of the QTss-QTsp contact in Villa Canyon (Weber, 1979; Plate I, this report).

Some of the features attributed to the Villa Canyon structure may be produced by the Hasley fault, especially those in Romero and Sloan Canyons (Plate I). However, east of the point where separtion on the Hasley fault diminishes to zero, there is no evidence for the Villa Canyon structure in the subsurface. Good correlation exists between wells on either side of the structure (Plates XXIII and XXIV). Also, in his surface mapping of the Hasley Canyon area, Pollard (1958) did not recognize any comparable structure in Villa Canyon. The surface geomorphic evidence of Weber (1978, 1979) is not compelling, and therefore the existence of a fault in Villa Canyon is doubtful.

San Gabriel Fault "B"

The San Gabriel fault "B" has moved since deposition of the Saugus Formation; therefore, it is both a Stage II and a Stage III structure.

There is no evidence of strike-slip offset on the San Gabriel fault of Pleistocene to Holocene strata in the San Gabriel Mountains (Ehlig, 1975a), or of the Plio-Pleistocene Hungry Valley Formation in the Ridge basin northwest of the Castaic study area (Crowell, 1975b). However, Weber (1979) suggested right-lateral offset on the San Gabriel fault of one kilometer of the Hungry Valley Formation and of 0.5 kilometers of the QTss-QTsp contact within the Saugus Formation near Honor Rancho.

In the Castaic study area, the Saugus Formation exhibits no strong evidence of having been affected by strike-slip on the San Gabriel fault (Plate I). In the subsurface, however, the Saugus is affected by normal separation on San Gabriel fault "B" (Plates III, and IX to XVI). Stratigraphic separation of the base of the Saugus Formation across the fault ranges from 250 to 750 feet (75 to 230 m).

Weber (1979, Figure 7) suggested normal separation of Quaternary alluvium, down to the northeast, across the San Gabriel fault in Castaic Creek. Weber (1979) also mapped traces of the San Gabriel fault zone which cut Quaternary landslides and terraces in the Castaic study area (Plate I).

SEISMICITY

Murdock (1979, Figure 2) located 42 small earthquakes ($M \geq 2.6$) in and near the Ridge basin from November, 1972 to March, 1973. Sixteen of the earthquakes are located near the surface trace of the San Gabriel fault for a distance of approximately six miles (ten kilometers). A composite fault plane solution for fourteen of the earthquakes has right-lateral strike-slip displacement on a vertical nodal plane which strikes northwest. Focal depths are 14 to 19 kilometers, and are therefore within basement. The other two earthquakes located near the San Gabriel fault yield solutions having northeast-striking nodal planes and reverse right oblique displacement (dip-slip component is 1.7 times the strike-slip). Murdock's (1979) interpretation for the earthquakes is that right-lateral strike-slip presently occurs on the San Gabriel fault. However, as Murdock pointed out, the composite focal mechanism solution (1979, Figure 3) is not unique and is based on the assumption that the San Gabriel fault is one of the nodal planes. Other solutions are possible with his data.

There are problems with Murdock's interpretation. Twelve of the earthquakes are located south of the San Gabriel fault and north of the Holser fault and form a zone parallel to Castaic Creek. They show no apparent relation to any known geologic structure including the San Gabriel fault. The other four earthquakes are located immediately northeast of the San Gabriel fault trace, which dips steeply northeast at the surface. However, two earthquakes yield solutions having right-lateral strike-slip; the other two earthquakes yield solutions having reverse displacement on northeast-trending planes. As discussed in the structure chapter of this report, the surface and subsurface geology near Castaic suggest that movement on the San Gabriel fault has been dip-slip only (normal displacement) since deposition of the Saugus Formation. Weber (1979, figure 7) showed that Quaternary alluvium in Castaic Creek may be offset by normal faulting, down to the northeast, across the San Gabriel fault. Thus, the near-surface geology along the San Gabriel fault near Castaic is in apparent conflict with the strike-slip interpretation of the San Gabriel fault of Murdock (1979).

The model of Whitcomb _et al_. (1973) for the 1971 San Fernando earthquake, indicated that the San Gabriel fault did not move during this shock. Their model showed that the San Gabriel fault was truncated by the San Fernando fault.

SEISMIC AND GROUND RUPTURE HAZARDS

(1) The San Gabriel fault cuts the Saugus Formation in the Castaic area. (2) Geomorphic evidence for faulting of late Quaternary deposits is convincing (Weber, 1979). (3) Although the Saugus and the younger Pacoima Formation (?) of Weber (1979) are folded, the San Gabriel fault does not appear to be folded in this area, which suggests that the fault has been active since folding of the Saugus and Pacoima (?) occurred. However, the San Gabriel fault may be oroclinally folded. When it was the main trace of the San Andreas fault, it may not have had a big bend; the broad bending to a more easterly trend in the San Gabriel Mountains may be a later phenomena, related to north-south shortening of the Transverse Ranges.

The San Gabriel fault probably poses a ground rupture hazard, but the nature of seismic activity on the fault is still unresolved.

GEOLOGIC HISTORY

Basement rocks of the Palomas Gneiss sliver and the Whitaker Granodiorite extend into the subsurface west of the San Gabriel fault. The Palomas Gneiss is correlated with Mendenhall Gneiss which crops out in the western San Gabriel Mountains. Similar gneiss and amphibolite occurs in the Alamo Mountain region and eastern Soledad basin. Radiometric dating of these rocks reveals that the protolith of the gneiss probably accumulated as volcanic and sedimentary strata which was metamorphosed between 1750 and 1680 My. Granodiorite and quartz monzonite intruded the metamorphic rocks between 1650 and 1680 My. During the interval 1425 to 1450 My, a major orogeny affected all the terranes, producing regional metamorphism to amphibolite and granulite facies (Silver, 1971).

The undated Whitaker Granodiorite was probably intruded during Mesozoic time. Major episodes of Mesozoic plutonism in the Transverse Ranges occurred at 160 to 170 My and 75 to 90 My (Silver, 1971).

Turbidites, volcanics, chert, and limestone of the Pelona Schist protolith were metamorphosed in greenschist and amphibolite facies at depths of 20 to 27 kilometers (Graham and England, 1976). Metamorphism accompanied major overthrusting by granitic and gneissic rocks between 47 and 59 My (Haxel and Dillon, 1978), during Paleocene and Eocene time.

During Paleocene time, while the Pelona Schist was being metamorphosed at depth, the San Francisquito Formation accumulated in a submarine fan to basin floor environment, with sediment transport primarily to the southwest (Sage, 1973a, 1975).

The Vasquez Formation of the study area accumulated as saline lake and alluvial fan deposits during Oligocene (?) time (Bohannon, 1976). Volcanic rocks interbedded with the Vasquez east of the study area are radiometrically dated as 20 to 25 My (Woodburne, 1975; Crowell, 1973a).

The Charlie Canyon Megabreccia was deposited as a major landslide derived from a nearby source to the south, possibly now displaced by right-slip to the La Panza Range (Smith, 1977).

After the Pacific Plate impinged against the North American Plate, beginning in late Oligocene time (approximately 30 My, Atwater, 1970), right-lateral strike-slip faulting began to affect the western margin of North America. At this time, the postulated Red Hills-San Juan-St. Francis-Russell-Chimeneas-Clemens Well fault (Smith, 1977; Crowell, 1979) may have accumulated approximately 175 kilometers of right-slip. This postulated fault is an older strike-slip fault which has been offset by the younger San Andreas fault. Movement on the fault system ended prior to movement on the San Francisquito fault, as the latter truncates the

St. Francis fault zone of Smith (1977) in the Castaic study area (Plate I).

Stage I structures formed during a period of northwest-southeast compression accompanying deroofing of the Sierra Pelona antiform. The San Francisquito Formation was thrust over the Vasquez Formation on the Bee Canyon fault, and the Vasquez was thrust over the Pelona Schist on the San Francisquito fault. Smith (1977) postulated 20 kilometers of left-lateral movement on the San Francisquito fault. There must also have been a large dip-slip component on the fault in order to juxtapose the Paleocene San Francisquito Formation against the coeval Pelona Schist.

During middle Miocene (?) time, the Pelona Schist began shedding detritus into the northern Soledad basin, forming the San Francisquito Canyon Breccia. The San Francisquito fault continued to be active, since it cuts rocks of the San Francisquito Canyon Breccia (Plate I).

In middle and late Miocene time, the Mint Canyon Formation accumulated as alluvial fan and lacustrine deposits adjacent to the Caliente Formation of Lockwood Valley (Ehlig et al., 1975).

Soon after Mint Canyon deposition, the San Gabriel fault began to move as the major right-lateral strike-slip fault of the Miocene

San Andreas system in the Transverse Ranges (Crowell, 1975a). The San Gabriel fault accumulated right-slip of about 30 kilometers, separating the Mint Canyon Formation from the Caliente Formation.

As the San Gabriel fault moved in late Miocene (lower Mohnian) time, the Violin Breccia began accumulating at the base of the San Gabriel fault scarp opposite gneissic terrane later displaced to the Alamo Mountain region (Crowell, 1952). At the same time, large blocks of anorthosite were being shed to the southwest from the western San Gabriel Mountains into the Ventura basin, forming the Devil Canyon conglomerate of the Modelo Formation. The Canton fault separating the Whitaker Granodiorite and Palomas Gneiss formed prior to deposition of most, if not all, of the Modelo Formation.

Late Miocene time was also marked by a significant eastward marine transgression into the eastern Ventura and Soledad basins. The Modelo and Castaic Formations onlapped eastward onto Whitaker Peak Granodiorite and Mint Canyon Formation, respectively. A narrow connection between the marine Ventura and Soledad basins may have existed in Mohnian time, as suggested by Winterer and Durham (1962, cf. figure 68). The Castaic Formation, exposed approximately 15 miles (24 km) southeast of the Castaic study area in the Sand Canyon-Placerita Canyon area (Morrison, 1958), contains

Mohnian conglomerate which is lithologically similar to, and may be the offset equivalent of, the Devil Canyon and/or Hasley conglomerates exposed in the study area. A connection between the Ventura and Soledad basins in late Miocene (Mohnian) time could also explain the presence of Charlie Canyon fauna west of the San Gabriel fault in the Honor Rancho area (Paschall and Off, 1961; Schlaefer, 1978).

The Modelo and Towsley Formations of the Castaic area represent shallow to deep water deposits near the margin of the late Miocene and earliest Pliocene Ventura basin. An angular unconformity separates these two formations and is most pronounced near the San Gabriel fault (Plates XXIII and XXIV). The unconformity may result from continuing movement on the San Gabriel fault.

Stage II folds formed in the Castaic Formation east of the San Gabriel fault, and in the Modelo Formation west of the fault. The folds may have formed during the second stage of movement on the San Gabriel fault under general north-south compression. The present northwest trends of the folds may be related to drag on the San Gabriel fault.

The Towsley Formation accumulated as a proximal submarine fan, and continuing movement on the San Gabriel fault beheaded this fan system, moving correlative conglomerates perhaps to the Sand Canyon-Placerita Canyon area, now located 15 miles (24 km) southeast of the Towsley Formation of the Castaic area.

In eastern Castaic Hills oil field, the Castaic Hills reverse fault was moving during Towsley deposition, resulting in a thicker sequence of Towsley on the downthrown (northeast) side of this fault. San Gabriel fault "C" (?) was also active, juxtaposing Towsley Formation against relatively fine-grained strata of the Castaic Formation (Plates V and XI).

Prior to deposition of the Pico Formation, 28 kilometers of right-slip occurred during the second stage of movement on the San Gabriel fault. The Devil Canyon conglomerate and Violin Breccia exhibit approximately 30 kilometers offset from their sources across the San Gabriel fault. Subtracting the two kilometers of right-lateral offset on the Pico Formation gives 28 kilometers of post-Modelo and Castaic, pre-Pico right-slip on the San Gabriel fault.

The relatively shallow-water Pico Formation accumulated in early to late Pliocene time as water depths shoaled in the eastern Ventura basin. Both San Gabriel fault "C" (?) and the Castaic Hills fault ceased activity prior to Pico deposition (Plate IV). The unconformity between the Pico and Castaic east of the San Gabriel fault is more pronounced than the unconformity between the Pico and Towsley west of the San Gabriel fault. After Castaic and prior to Pico deposition, in latest Miocene time, the Ridge basin had become separated from the marine Ventura basin. Perhaps the unconformity between the Castaic and Pico Formations represents tectonic activity which produced the isolation of the Ridge basin. Pico deposition may have occurred while the Stage II folds in the Castaic Formation were still positive features. After deposition, the Pico Formation was affected by approximately two kilometers of right-slip along the San Gabriel fault (Plate VI).

As marine waters of the Ventura basin regressed westward in late Pliocene time, Pico deposition was followed by marine to brackish-water deposits of the Sunshine Ranch member of the Saugus Formation, which are in turn overlain by alluvial fanglomerate of the nonmarine Saugus.

Major diatrophism has affected the Saugus Formation in the study area, forming the Stage III structures. Evidence of this diastrophic activity includes the following. (1) Folding of the Saugus and older formations produced the Dry Canyon syncline and Dry Canyon anticline east of the San Gabriel fault, and may have reactivated the southeast end of the Ridge Basin syncline (Plate III). The Townsend syncline, Loma Verde anticline, North and South Hasley Canyon synclines, and Oak Canyon anticline were formed west of the San Gabriel fault. (2) Upward relative movement of the block west of the San Gabriel fault may have produced the change in trend and plunge of the folds west of the fault (Plates I, and III to V). (3) Reverse faulting occurred on the Hasley fault. (4) Normal faulting affected the Saugus and Pico in eastern Castaic Hills oil field, southwest of the San Gabriel fault (Plates XII-XVI). (5) The Pico, Saugus, and Quaternary alluvium were affected by normal separation, down to the east, across the San Gabriel fault (Weber, 1979). Stage III structures are still in progress, forming under general north-south compression.

Quaternary erosion of the Castaic area has produced older, intermediate, and younger alluvial deposits (Plate I).

Geomorphic evidence and the possible normal separation of Quaternary alluvium in Castaic Creek indicate that the San Gabriel fault has probably continued activity in late Quaternary time. The Saugus Formation and younger strata are apparently only affected by normal separation, and not strike-slip, on the San Gabriel fault. The nature of seismic activity associated with the fault is still unresolved.

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APPENDICES

APPENDIX I

Wells Utilized in Study

Key to Abbreviations Used in Appendix I

TD	Total depth
KB	Kelly bushing
O.H.	Original hole
CCP	Crown Central Petroleum Corporation
CHU	Castaic Hills Unit
H.R.	Honor Rancho
Note	All elevation and total depths are in feet.

All townships, ranges, and sections are from the San Bernardino base and meridian

Well Number	Location	Well Name	Elevation KB	Measured TD
1	T. 5N. R. 16W. Sect. 2	Latimer Pictures Latimer #1	2326 ft.	2777 ft
2		Latimer Pictures Testhole #1	2222 ft	610 ft
3		Petro-Tek #1	2160 ft	4800 ft
4	T. 5N. R. 16W. Sect. 5	Dator Dev. Co. Lyons Ranch #1	1332 ft	433 ft
5		North Star Mining North Star Lyons #2	1353 ft	703 ft
6	T. 5N. R. 16W. Sect. 7	Chevron Lyons #1	1284 ft	2172 ft
7		Ember Oil & Gas Seattle-Toledo-Lyons #1	1489 ft	4027 ft
8		Edward W. Lang Rupy #1	1310 ft	803 ft
9	T. 5N. R. 16W. Sect. 8	Ember Oil & Gas Lyons #1	1326 ft	3476 ft
10		G & E Oil Co. G&E #1	1305 ft	1721 ft
11		John A. Kochergen Benson #1	1298 ft	2040 ft
12	T. 5N. R. 16W. Sect. 17	O'Kane & Brain, Inc. O'Kane & Brain & Barnsdale #1	1985 ft	3184 ft
13	T. 5N. R. 16W. Sect 18	Atlantic Oil Co. Behrendt Estate #1	1300 ft	2250 ft
14		Castaic Highlands W. W. #1	1209 ft	3772 ft
15		Castaic Oil Assoc. Well #1	1200 ft	1400 ft
16		Newhall Land & Farming Co. Daries #1	1377 ft	2387 ft
17		Rose Oil Co. Well #1	1200 ft	1700 ft
18		W. W. Stabler Jenkins #1	1135 ft	3404 ft
19		T & M Exploration Co. Kinler #1	1236 ft	2877 ft
20		U. S. Natural Resources, Inc. Kinler #43-18	1444 ft	2529 ft
21		L. R. Wilhite & C. Kavanaugh Wilhite-Jenkins #1	1207 ft	3489 ft
22		Worland Oil Co. Jenkins-Owens #1	1383 ft	2940 ft
23	T. 5N. R. 16W. Sect 19	George Allen Well #1	1206 ft	3700 ft
24		W. W. Stabler New Castaic #1	1255 ft	3352 ft
25	T. 5N. R. 16W. Sect. 20	Exxon Castaic #1	1535 ft	5064 ft
26	T. 5N. R. 16W. Sect. 24	Atlas Oil Co. Acosta #1	1895 ft	3939 ft
27	T. 5N. R. 16W. Sect. 25	Queen Oil Co. of Calif. Well #1	1654 ft	1175 ft

Well Number	Location	Well Name	Elevation KB	Measured TD
28	T. 5N. R. 16W. Sect 25	Queen Oil Co. of Calif. Well #1B	1667 ft	1163 ft
29	T. 5N. R. 16W. Sect. 26	Fowler & Oles Co. Robinett #1	1633 ft	2419 ft
30		H. P. & Irene L. Oates Well #1	1414 ft	969 ft
31	T. 5N. R. 16W. Sect. 27	Fox M. Boswell & Assoc. Ruix #1	1326 ft	2100 ft
32		B. A. Gillespie Well #1	1105 ft	3245 ft
33	T. 5N. R. 16W. Sect. 29	Joel Brandon Mark VII #1	1454 ft	1403 ft
34		Jesse M. Butler Butler-Mason #1	1424 ft	4018 ft
35		Jesse M. Butler Butler-Mason #2	1505 ft	1450 ft
36	T. 5N. R. 16W. Sect. 30	B & R Co. B & R #1	1149 ft	1090 ft
37		B & R Co. Benz #2	1154 ft	859 ft
38		B. B. Breckenridge Hartje-Kosloff #1	1259 ft	1112 ft
39		Crown-Huntington Oils, Ltd. Dodge #2	1318 ft	1348 ft
40		Dutch Oil Co. Howell #1	1435 ft	1820 ft
41		Henry King Urtasun #1	1174 ft	3511 ft
42		Phillip L. Pike Howell #2	1435 ft	645 ft
43		Phillip L. Pike Howell #3	1429 ft	798 ft
44a		Harold C. Ramser Charlie #1	1150 ft	3030 ft
44b		Texaco Yule #1	1139 ft	6010 ft
45		Paul O. Waggoner Queen #1	1224 ft	610 ft
46	T. 5N. R. 16W. Sect. 31	E. S. Arnn Arnn-Lackie #1	1294 ft	1531 ft
47		R. E. Bering Hartje #1 (O. H.)	1216 ft	1068 ft
		(Redrill)		892 ft
48		CCP Hartje #1	1170 ft	1102 ft
49		CCP Hartje #2	1246 ft	1195 ft
50		CCP Hartje #3	1184 ft	1143 ft
51		CCP Hartje #4	1282 ft	1312 ft
52		CCP Hartje #5	1329 ft	1417 ft
53		CCP Hartje #6	1321 ft	1410 ft
54		CCP Hartje #7	1321 ft	1900 ft
55		CCP Hartje #8	1216 ft	2110 ft
56		CCP Hartje #9	1276 ft	4600 ft

Well Number	Location	Well Name	Elevation KB	Measured TD
57	T. 5N. R. 16W. Sect. 31	CCP Lackie-USL #A-1	1289 ft	1320 ft
58		CCP Lackie-USL #A-2	1417 ft	1557 ft
59		CCP Lackie-USL #A-3	1247 ft	1470 ft
60		CCP Yule #1 (O. H.)	1128 ft	1490 ft
		(Redrill)		1406 ft
61		CCP Yule #2	1172 ft	1352 ft
62		CCP Yule #3	1152 ft	1070 ft
63		CCP Yule #4	1233 ft	1114 ft
64		Crown-Huntington Oils, Ltd. Dodge #3	1368 ft	1112 ft
65		Oilco Pet. Devt. Dodge #1	1230 ft	1367 ft
66		Oilco Pet. Devt. Louise #1	1250 ft	1127 ft
67		Oilco Pet. Devt. Louise #3	1194 ft	1067 ft
68		Oilco Pet. Devt. Royalty #1	1309 ft	1128 ft
69		Oilco Pet. Devt. Royalty #2	1309 ft	1100 ft
70		Planet Oil Co. Louise #2	1339 ft	1330 ft
71		M. I. Strehle Irene #1		
72		Texaco H. R. 'A' (NCT-2) #4	1141 ft	6510 ft
73		Texaco H. R. 'A' (NCT-2) #11	1267 ft	2492 ft
74		Texaco H. R. 'A' (NCT-2) #21	1254 ft	2498 ft
75		Texaco H. R. 'A' (NCT-2) #34	1280 ft	1425 ft
76		Texaco H. R. 'A' (NCT-2) #35	1160 ft	2800 ft
77		Texaco H. R. 'A' (NCT-2) #40	1329 ft	5587 ft
78		Texaco H. R. 'A' (NCT-2) #47	1320 ft	1525 ft
79		Texaco H. R. 'A' (NCT-2) #50	1302 ft	7309 ft
80		Texaco H. R. 'A' (NCT-2) #51	1322 ft	1500 ft
81		Texaco Wayside Canyon Unit #45	1362 ft	1700 ft
82		Woodland Oil Co. Charlie Wilder #1	1355 ft	1300 ft
83		Woodland Oil Co. Dodge-Tilley #1	1308 ft	1368 ft
84		Woodland Oil Co. North Wayside #1	1345 ft	1327 ft
85		Woodland Oil Co. North Wayside #2	1414 ft	1330 f5
86		Woodland Oil Co. North Wayside #3	1316 ft	1308 ft
87	T. 5N. R. 16W. Sect. 32	Coastal Energy Devt. Co. Withall #I-8	1665 ft	1475 ft

Well Number	Location	Well Name	Elevation KB	Measured TD
88	T. 5N. R. 16W. Sect. 32	Core Drill Ltd. Core #1	1658 ft	1170 ft
89		Richard M. Ferguson Safarik-Hansen #1	1664 ft	1623 ft
90		C. L. Fowler Dodge-Scott #1	1408 ft	1333 ft
91		Indian Oil Co. Dodge #13-32	1347 ft	1141 ft
92		Sun Oil Co. Dodge #1	1480 ft	5984 ft
93		Texaco Dodge #1	1610 ft	1425 ft
94		Texaco Hansen-Safarik-USL #1	1391 ft	1365 ft
95		Texaco Wayside Canyon Unit #1	1449 ft	1300 ft
96		Texaco Wayside Canyon Unit #46	1433 ft	1603 ft
97		Woodland Oil Co. Dodge #1	1363 ft	1032 ft
98		Woodland Oil Co. Dodge #2	1383 ft	1102 ft
99		Woodland Oil Co. USL #1	1454 ft	1302 ft
100	T. 5N. R. 16W. Sect. 33	Texaco De Nault #1	1713 ft	3500 ft
101	T. 5N. R. 16W. Sect. 34	International Oil Dev. Inc. Ltd. Powell #301	1280 ft	4339 ft
102		International Oil Dev. Inc. Ltd. Powell #302	1380 ft	2200 ft
103		Young Brothers Rentchler #1	1373 ft	2520 ft
104	T. 5N. R16W. Sect. 35	C. W. Colgrove Oates #24-35	1485 ft	3700 ft
105		Roy Gill & Assoc. Mittry #1	1396 ft	4205 ft
106		Mobil Oil Corp. Barstow #1	1515 ft	2136 ft
107		Mobil Oil Corp. Barstow #2	1445 ft	4040 ft
108		Mobil Oil Corp. Occidental #1	1565 ft	3115 ft
109		H. P. Oates Oates-Merritt Annex #1	1527 ft	2573 ft
110	T. 5N. R. 16W. Sect. 36	George R. Urich Burger #1	1445 ft	1893 ft
111	T. 5N. R. 17W. Sect. 2	Texaco Daries #1	1350 ft	4794 ft
112	T. 5N. R. 17W. Sect. 10	C. W. Ellsworth Paducah #1	1698 ft	
113	T. 5N. R. 17W. Sect. 13	British-American Oil Prod. Co. General #41-13	1766 ft	5818 ft
114		Gene Reid Drilling Inc. General American #81-13	1234 ft	3653 ft
115		Republic Operator Inc. Fee #1	1195 ft	4972 ft
116	T. 5N. R. 17W. Sect. 14	Neal Stivers Well #1	1672 ft	3392 ft
117a	T. 5N. R. 17W. Sect. 18	Bob Ferguson Hathaway #6	2292 ft	8325 ft
117b	T. 5N. R. 17W. Sect. 19	Gulf Oil Co. J. I. Hathaway #1	1986 ft	14437 ft

Well Number	Location	Well Name	Elevation KB	Measured TD
117c	T. 5N. R. 17W. Sect. 19	Gulf Oil Co. J. I. Hathaway #2	2212 ft	1979 ft
118		Marathon Oil Co. Hathaway #1		
		(O. H.)	2212 ft	4280 ft
		(Redrill)		7917 ft
119		Marathon Oil Co. Hathaway #2	1460 ft	5099 ft
120	T. 5N. R. 17W. Sect. 21	Shell Oil Co. Shell-Continental #86-20	1724 ft	7006 ft
121	T. 5N. R. 17W. Sect. 21	Aminoil USA HoCo-Romero Loma Verde		
		#55-21	2301 ft	4850 ft
122		Aminoil USA Romero-Loma Verde #77-21	2262 ft	4517 ft
123		Coastline Oil Co. Ltd. Well #1	1750 ft	2545 ft
124		Continental Oil Co. (Conoco)		
		Conoco Romero-Loma Verde #1	1863 ft	3500 ft
125		Marathon Oil Co. Romero #1	2280 ft	3048 ft
126	T. 5N. R. 17W. Sect. 22	Conoco Vier-Kenny #1	2161 ft	4612 ft
127		MJM&M Oil Co. Guyton #1	1633 ft	1539 ft
128		Union Oil Co. of Calif. Alexander #1	1520 ft	4051 ft
129	T. 5N. R. 17W. Sect. 23	Castaic Oil Co. Well #1	1445 ft	1000 ft
130		Conoco Alexander #1	1611 ft	4851 ft
131	T. 5N. R. 17W. Sect. 24	Pedro Pet. Corp. Oates #1	1170 ft	2207 ft
132		Max Pray Max Pray-NL&F #1	1212 ft	5500 ft
133		Temple & Lafever Well #1	1205 ft	2106 ft
134	T. 5N. R. 17W. Sect. 25	Atlantic Richfield Co. (Arco) Miller #1	1125 ft	1107 ft
135		Custom Drilling Co. Jones #1	1143 ft	3112 ft
136		Tesoro Pet. Corp. Fisher-USL #1	1118 ft	1223 ft
137		Texaco H. R. 'B' (NCT-2) #1	1115 ft	975 ft
138	T. 5N. R. 17W. Sect. 26	Aminoil USA Van Couvering #26-26	1622 ft	5920 ft
139		Atlantic Oil Co. Berryman #1	1590 ft	3902 ft
140		Macson Oil Co. Lindsay #1	1419 ft	3020 ft
141		Macson Oil Co. Radovich #1	1344 ft	3494 ft
142		Macson Oil Co. Radovich #2	1367 ft	1048 ft
143		Mangold & Morse Oil Co. Inc. McDermott #1	1475 ft	4313 ft
144		McFarland Energy Inc. Henning-Kennedy #0-2	1533 ft	925 ft
145		McFarland Energy Inc. Henning-Kennedy #101	1388 ft	995 ft

Well Number	Location	Well Name	Elevation KB	Measured TD
146	T. 5N. R. 17W . Sect. 26	McFarland Energy Inc. Henning-Kennedy #102	1360 ft	1050 ft
147		McFarland Energy Inc. Henning-Kennedy #103	1360 ft	1050 ft
148		Morton & Dolley & MJM&M Oil Co. Hall #1	1685 ft	5250 ft
149		Morton & Dolley MJM&M-Lindsay #1	1436 ft	1350 ft
150		Morton & Dolley MJM&M-Radovich #1	1464 ft	4155 ft
151	T. 5N. R. 17W. Sect. 27	L. H. Glaser Walker #1	1785 ft	2016 ft
152		Gulf Oil Co. Devils Canyon #1	1856 ft	7657 ft
153		Marathon Oil Co. Austin Estate #1	1871 ft	5507 ft
154	T. 5N. R. 17W. Sect. 28	Paul Benz Duignan #1	2162 ft	5516 ft
155		Superior Oil Co. Romero #51-28	2459 ft	7925 ft
156	T. 5N. R. 17W. Sect. 29	Amax Pet. Corp. Ayala #1	1692 ft	7416 ft
157		Amax Pet. Corp. Ayala #2	1481 ft	8398 ft
158		Rothschild Oil Co. Ayala #1	1563 ft	7506 ft
159		Shell Oil Co. Loma Verde #515-29	1712 ft	5000 ft
160	T. 5N. R. 17W. Sect. 32	Boeco Drilling Co. Gilmour #1	1716 ft	7592 ft
161	T. 5N. R. 17W. Sect. 33	Philip L. Pike Mark VII #2	1605 ft	3350 ft
162		Texaco Clara Stanley #1 (O. H.)	1527 ft	6652 ft
		(Redrill)		6200 ft
163	T. 5N. R. 17W. Sect. 34	Texaco Fischer #1	1585 ft	7322 ft
164		Texaco Fischer #2	1508 ft	7023 ft
165		Texaco Stanley #1	1673 ft	8747 ft
166		Texaco Wickham-USL #84-34	1670 ft	6174 ft
167	T. 5N. R. 17W. Sect. 35	Chevron Golden #175-4	1328 ft	3900 ft
168		Chevron Villa #15	1532 ft	6500 ft
169		Chevron Villa #26	1498 ft	6857 ft
170		Chevron Villa #36 (O. H.)	1407 ft	6800 ft
		(Redrill)		6640 ft
171		Conoco Rynne-Fisher #2	1614 ft	8973 ft
172		Decalta Intl. Corp. CHU #1-35	1524 ft	4742 ft
173		Decalta Intl. Corp. CHU #13-35	1661 ft	5618 ft
174		Decalta Intl. Corp. CHU #14-35	1612 ft	6101 ft
175		Decalta Intl. Corp. CHU #23-35	1644 ft	5584 ft
176		Decalta Intl. Corp. CHU #24-35	1570 ft	6004 ft
177		Decalta Intl. Corp. CHU #25-35	1484 ft	6505 ft

Well Number	Location	Well Name	Elevation KB	Measured TD
178	T. 5N. R. 17W. Sect. 35	Decalta Intl. Corp. CHU #32-35		
		(O. H.)	1737 ft	5955 ft
		(Redrill 1)		5552 ft
		(Redrill 2)		5551 ft
179		Decalta Intl. Corp CHU #33-35	1632 ft	5813 ft
180		Decalta Intl. Corp. CHU #34-35	1504 ft	6042 ft
181		Decalta Intl. Corp. CHU #35-35	1433 ft	6350 ft
182		Decalta Intl. Corp. CHU #43-35	1525 ft	5720 ft
183		Decalta Intl. Corp. CHU #44-35	1522 ft	6281 ft
184		Decalta Intl. Corp. CHU #45-35	1394 ft	6550 ft
185		Decalta Intl. Corp. CHU #52-35	1552 ft	5360 ft
186		Decalta Intl. Corp. CHU #53-35	1494 ft	7365 ft
187		Decalta Intl. Corp. CHU #54-35	1456 ft	6164 ft
188		Decalta Intl. Corp. CHU #55-35	1370 ft	6475 ft
189		Decalta Intl. Corp. CHU #62-35	1700 ft	5561 ft
190		Decalta Intl. Corp. CHU #63-35	1634 ft	6047 ft
191		Decalta Intl. Corp. CHU #64-35	1411 ft	6370 ft
192		Decalta Intl. Corp. CHU #72-35	1548 ft	5418 ft
193		Decalta Intl. Corp. CHU #73-35	1604 ft	5762 ft
194		Decalta Intl. Corp. CHU #74-35	1424 ft	6689 ft
195		Decalta Intl. Corp. CHU #75-35	1319 ft	8988 ft
196		Decalta Intl. Corp. CHU #83-35	1400 ft	6022 ft
197		Decalta Intl. Corp. CHU #84-35	1454 ft	6308 ft
198		Decalta Intl. Corp. CHU #85-35	1270 ft	6698 ft
199		Decalta Intl. Corp. Rynne-Fisher #82-35	1603 ft	6018 ft
200		Texaco Forst #1	1270 ft	7770 ft
201	T. 5N. R. 17W. Sect. 36	Atlantic Oil Co. Doyle #1	1093 ft	6215 ft
202		Atlantic Oil Co. Doyle #2 (O. H.)	1092 ft	6470 ft
		(Redrill)		6060 ft
203		Calif. -Time Pet. Inc. Ament-Dunn #4	1101 ft	6046 ft
204		Calif. -Time Pet. Inc. Ament-Dunn #5	1110 ft	5925 ft
205		Calif. -Time Pet. Inc. Ament-Dunn #6	1100 ft	5760 ft
206		Calif. -Time Pet. Inc. Ament #7	1100 ft	6950 ft

Well Number	Location	Well Name	Elevation KB	Measured TD
207	T. 5N. R. 17W. Sect. 36	Conoco Forst-Muller #36-36	1152 ft	6430 ft
208		Conoco Harding #31-36	1272 ft	7653 ft
209		Conoco Twomey #1	1086 ft	5907 ft
210		Conoco Twomey #2	1087 ft	5850 ft
211		Conoco Twomey #3	1086 ft	5780 ft
212		CCP Snow-USL #1	1113 ft	1020 ft
213		CCP Snow-USL #2	1125 ft	1145 ft
214		Decalta Intl. Corp. CHU #12-36	1612 ft	5392 ft
215		Decalta Intl. Corp. CHU #13-36	1563 ft	6273 ft
216		Decalta Intl. Corp. CHU #14-36	1361 ft	6334 ft
217		Decalta Intl. Corp. CHU #15-36	1276 ft	6506 ft
218		Decalta Intl. Corp. CHU #22-36		
		(O.H.)	1423 ft	6063 ft
		(Redrill)		5462 ft
219		Decalta Intl. Corp. CHU #24-36	1330 ft	5987 ft
220		Decalta Intl. Corp. CHU #25-36	1212 ft	6430 ft
221		Decalta Intl. Corp. CHU #33-36		
		(O.H.)	1377 ft	5706 ft
		(Redrill 1)		6097 ft
		(Redrill 2)		5896 ft
		(Redrill 3)		6100 ft
222		Decalta Intl. Corp. CHU #35-36	1223 ft	5920 ft
223		Decalta Intl. Corp. CHU #134-36	1247 ft	5803 ft
224		Decalta Intl. Corp. CHU #144-36	1182 ft	5779 ft
225		Decalta Intl. Corp. CHU #244-36	1203 ft	5905 ft
226		Decalta Intl. Corp. Forst-Muller #16-36	1230 ft	6929 ft
227		Decalta Intl. Corp. Harding #32-36	1385 ft	6650 ft
228		Decalta Intl. Corp. Rynne-Fisher #11-36	1643 ft	6193 ft
229		James Firchgrund Eskridge #1	1223 ft	6012 ft
230		Texaco H. R. 'A' (NCT-1) #10	1092 ft	6540 ft
231		Texaco H. R. 'A' (NCT-1) #13	1105 ft	7100 ft
232		Texaco H. R. 'A' (NCT-1) #32	1117 ft	5294 ft
233		Texaco H. R. 'A' (NCT-1) #1	1107 ft	5952 ft
234		Texaco H. R. 'B' (NCT-1) #2	1109 ft	5850 ft

Well Number	Location	Well Name	Elevation KB	Measured TD
235	T. 5N. R. 17W. Sect. 36	Texaco H. R. 'B' (NCT-1) #3	1207 ft	6000 ft
236		Texaco H. R. 'B' (NCT-1) #4	1092 ft	6050 ft
237		Texaco H. R. 'B' (NCT-1) #5	1097 ft	5825 ft
238		Texaco H. R. 'B' (NCT-1) #6	1091 ft	5950 ft
239a		Texaco H. R. 'B' (NCT-1) #7 (O.H.)	1099 ft	5970 ft
		(Redrill)		5795 ft
239b		Wood-Callahan Castaic #36-1	1092 ft	7003 ft
240	T. 4N. R. 17W. Sect. 1	Exxon NL & F #C-1	1062 ft	11440 ft
241		Texaco H. R. 'A' (NCT-1) #14	1092 ft	8022 ft
242	T. 4N. R. 17W. Sect. 2	Atlantic Oil Co. Good #1	1272 ft	8500 ft
243	T. 4N. R. 17W. Sect. 3	Federal Oil Co. Towle #1	1335 ft	5005 ft
244		G. R. Nance Inc. Towle #17	1506 ft	4321 ft
245		Petrominerals Corp. Mabel E. Strawn #1	1322 ft	6711 ft
246		Petrominerals Corp. Mabel Strawn #2	1374 ft	6100 ft
247		Petrominerals Corp. Mabel Strawn #3	1368 ft	5730 ft
248		Petrominerals Corp. Mabel Strawn #4	1314 ft	
249		Sands-American Corp. Hilgenfeld #1	1394 ft	4310 ft
250		Texaco Towle #1	1317 ft	7218 ft
251	T. 4N. R. 17W. Sect. 4	Chevron Videgain #1	1407 ft	8622 ft
252		Douglas Oil Co. Oak Canyon #1	1459 ft	4100 ft
253		Marathon Oil Co. Douglas #1	1416 ft	10503 ft
254		McCulloch Oil & Gas Corp.		
		McCulloch -Senegram #1	1703 ft	10865 ft
255		Porsco Operating Co.		
		Claiborne #88-4 (O.H.)	1345 ft	6010 ft
		(Redrill)		4015 ft
256	T. 4N. R. 17W. Sect. 10	Atlantic Oil Co. Strawn #1	1335 ft	6614 ft
257		Decalta Intl. Corp. Sterling #1-10	1345 ft	5810 ft
258		Decalta Intl. Corp. Sterling #2-10	1389 ft	5899 ft
259		Decalta Intl. Corp. Sterling #3-10	1403 ft	5830 ft
260		Fernando Oil Co. Well #1	1410 ft	3744 ft
261		Montara Pet. Co. Sterling #81X	1376 ft	6007 ft
262		US Natural Gas Corp. & Fred Manning Strawn #1	1352 ft	9435 ft
263	T. 4N. R. 17W. Sect. 11	Texaco Fernando #1	1260 ft	8034 ft

APPENDIX II

Key to Fossil Localities on Plate I

Fossil Locality	Location	Formation	Reference
F-1	T. 5N. R. 16W. Sect. 36	Castaic Formation	Stanton (1960), Locality 234
F-2		Castaic Formation	Stanton (1960), Locality 230
F-3		Castaic Formation	Stanton (1960), Locality 231
F-4		Castaic Formation	Stanton (1960), Locality 232
F-5		Castaic Formation	Stanton (1960), Locality 233
F-6		Castaic Formation	Stanton (1960), Locality 1624
F-7		Castaic Formation	Stanton (1960), Locality 1672
F-8		Castaic Formation	Stanton (1960), Locality 1674
F-9		Castaic Formation	Stanton (1960), Locality 1675
F-10		Castaic Formation	Stanton (1960), Locality 1676
F-11		Castaic Formation	Stanton (1960), Locality 1677
F-12		Castaic Formation	Stanton (1960), Locality 1678
F-13		Castaic Formation	Daviess (1942), Locality 1929
F-14		Castaic Formation	Daviess (1942), Locality 2050
F-15	T. 5N. R. 16W. Sect. 26	Castaic Formation	Stanton (1960), Locality 1670
F-16		Castaic Formation	Stanton (1960), Locality 1671
F-17		Castaic Formation	Stanton (1960), Locality 7-11-33
F-18		Castaic Formation	Stanton (1960), Locality 7-11-27
F-19	T. 5N. R. 16W. Sect. 9	Castaic Formation	Stanton (1960), Locality 9-8-1
F-20	T. 5N. R. 16W. Sect. 4	Castaic Formation	Stanton (1960), Locality 9-4-4
F-21	T. 5N. R. 16W. Sect. 7	Castaic Formation	Stanton (1960), Locality 279
F-22	T. 5N. R. 16W. Sect. 18	Castaic Formation	Stanton (1960), Locality 277
F-23	T. 5N. R. 17W. Sect. 12	Castaic Formation	Stanton (1960), Locality 7-6-9
F-24		Castaic Formation	Stanton (1960), Locality 2098
F-25	T. 5N. R. 17W. Sect. 1	Castaic Formation	Stanton (1960), Locality 2097
F-26	T. 5N. R. 17W. Sect. 5	Modelo Formation	Shepherd (1960), Locality A-20
F-27	T. 5N. R. 17W. Sect. 5	Pico Formation	Pollard (1958), Locality F-2
F-28	T. 5N. R. 17W. Sect. 32	Pico Formation	Pollard (1958), Locality F-4
F-29		Pico Formation	Pollard (1958), Locality F-5
F-30	T. 5N. R. 17W. Sect. 29	Pico Formation	Pollard (1958), Locality F-6
F-31		Pico Formation	Pollard (1958), Locality F-7
F-32		Saugus Formation	Pollard (1958), Locality F-8

Fossil Locality	Location	Formation	Reference
F-33	T. 5N. R. 17W. Sect. 28	Saugus Formation	Pollard (1958), Locality F-9
F-34		Saugus Formation	Pollard (1958), Locality F-10
F-35	T. 4N. R. 17W. Sect. 4	Saugus Formation	Pollard (1958), Locality F-11
F-36	T. 4N. R. 17W. Sect. 1	Older Alluvium	Pollard (1958), Locality F-12
F-37	T. 5N. R. 17W. Sect. 26	Pico Formation (?)	Pollard (1958), Locality F-13
F-38	T. 5N. R. 16W. Sect. 11	San Francisquito Canyon Breccia	Szatai (1961), No Locality Number
F-39	T. 5N. R. 16W. Sect. 10	San Francisquito Canyon Breccia	Sams (1964), No Locality Number