Geology of Southeastern Ventura Basin Los Angeles County California

By E. L. WINTERER *and* D. L. DURHAM

SHORTER CONTRIBUTIONS TO GENERAL GEOLOGY

GEOLOGICAL SURVEY PROFESSIONAL PAPER 334-H

A study of the stratigraphy, structure, and
occurrence of oil in the late Cenozoic
Ventura basin

U. S. DEPARTMENT OF THE INTERIOR
March 3, 1849

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1962

UNITED STATES DEPARTMENT OF THE INTERIOR

STEWART L. UDALL, *Secretary*

GEOLOGICAL SURVEY

Thomas B. Nolan, *Director*

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington 25, D.C.

CONTENTS

ILLUSTRATIONS

[Plates in pocket]

TABLES

GEOLOGY OF SOUTHEASTERN VENTURA BASIN, LOS ANGELES COUNTY, CALIFORNIA

By E. L. Winterer and D. L. Durham

ABSTRACT

The late Cenozoic Ventura basin, Ventura and Los Angeles Counties, Calif., is an elongate sedimentary trough which, together with its deformed structures, trends approximately east-west. The mapped area of this report lies entirely within Los Angeles County.

Most of the southeastern part of the Ventura basin is in the Santa Clara River watershed. Old high-level erosion surfaces, some more than 3,000 feet in altitude, and younger, topographically lower river-terrace surfaces and deposits are conspicuous. The river valley is now partly filled with alluvium which is being dissected during the present cycle of erosion.

Pre-Cretaceous basement rocks exposed in the San Gabriel Mountains are the oldest rocks in the area. These rocks include the fractured schist, gneiss, quartzite, and marble of the Placerita formation of Miller (1934) and also the somewhat gneissic Rubio diorite of Miller which intrudes them. Both of these rock units are intruded by quartz plutonites ranging in composition from granite to quartz diorite. Outside the mapped area a large body of anorthosite and norite makes up part of the basement rocks.

Within the mapped area, the oldest sedimentary rocks are well-indurated sandstone and siltstone containing a marine fauna indicative of a middle Eocene or early late Eocene age. Some wells in the area have penetrated several thousand feet of Eocene rocks.

Some wells drilled near San Fernando Pass have penetrated varicolored unfossiliferous beds that overlie Eocene rocks and are overlain by upper Miocene marine strata. These varicolored rocks have a thickness of nearly 2,000 feet but do not crop out in the area. They do not appear to interfinger with the overlying marine beds and are tentatively correlated with the Sespe formation of late Eocene to early Miocene age.

Near the Aliso Canyon oil field, wells have been drilled through as much as 2,500 feet of strata; predominantly sandstone but including a layer of amygdaloidal basalt, correlated tentatively with the Topanga formation of middle Miocene age. Rocks representing the Luisian (middle Miocene) stage of Kleinpell overlie these strata.

The nonmarine Mint Canyon formation of late Miocene age is present in the northeastern part of the area, north of the San Gabriel fault. This formation consists of fluviatile sandstone and conglomerate and lacustrine siltstone and tuff and has a thickness of at least 4,000 feet north of the mapped area.

The marine Modelo formation, of late middle and late Miocene age, is exposed in the southwestern part of the area but is not present in the subsurface section east of Newhall and Saugus and is not recognized north of the San Gabriel fault. Westward from the town of Newhall, its thickness increases to at least 5,000 feet at the Ventura County line. The formation is chiefly siltstone, mudstone, and shale, but it also contains sandstone and conglomerate.

The Towsley formation, of late Miocene and early Pliocene age, overlies and in places interfingers with the Modelo formation. Near Newhall and San Fernando Pass it overlaps the Modelo formation and lies directly on the Sespe(?) formation and on Eocene and pre-Cretaceous basement rocks. The formation ranges in thickness from about 4,000 feet in the southwestern part of the area to 0 where it is overlapped by younger rocks to the east. In the Santa Susana Mountains it grades upward into the Pico formation. Beds assigned to the Towsley formation rest unconformably on the Mint Canyon formation north of the San Gabriel fault.

The Towsley formation consists chiefly of interfingering lenticular beds of sandstone, mudstone, and conglomerate. Clasts in the conglomerate beds are of rock types found to the east and northeast in the San Gabriel Mountains. Sandstone and conglomerate beds in the Santa Susana Mountains contain many sedimentary structures, including graded beds, load casts, intraformational breccias, current ripples and lineations, slump structures, and convolute bedding. At several localities graded sandy beds contain mixed assemblages of shallow- and deep-water mollusks, the latter representing depths of more than 600 feet. The sedimentary structures and fossils, taken together, indicate that marine turbidity currents were major factors in the transportation and deposition of the sediments that now constitute the Towsley formation. A study of the molluscan fauna of the Towsley formation indicates that the shallow-water species are allied to Recent faunas now living south of the latitude of the Ventura basin.

The Pico formation, of Pliocene age, is distinguished from the Towsley formation largely by its soft olive-gray siltstone that generally contains small limonitic concretions. In the area near San Fernando Pass, the Towsley and Pico interfinger, but farther to the northeast there is an unconformity at the base of the Pico. Although the Pico is marine, it interfingers with brackish-water and nonmarine beds belonging to the basal part of the overlying Saugus formation. Near the west edge of the area it is at least 5,000 feet thick. Most of the sedimentary structures suggestive of turbidity currents found in the Towsley are also present in the lower part of the Pico in the Santa Susana Mountains. Abrupt lateral gradations from siltstone to sandstone and conglomerate are common in the Pico.

Molluscan faunas of mixed depth assemblage in the Pico formation suggest turbidity currents as a mode of deposition. The southern affinities of the shallow-water species suggest that the surface water temperature in the Ventura basin during the Pliocene was somewhat warmer than that prevailing now in the Pacific Ocean near Ventura. The northern affinities of the deeper water species indicate that the water was cold enough at depth to accommodate them. The vertical sequence of foraminiferal faunas suggests a gradual shoaling from water depths of about 2,500 feet in the deeper parts of the basin at the beginning to very shallow water depths at the close of Pico deposition. Lateral changes in foraminiferal faunas, shown by the crossing of foraminiferal correlation lines (water-depth lines) by lithologic units deposited by turbidity currents (time lines), indicate that at any one time the water was shallowest near Newhall and became deeper toward the west. Turbidity currents deposited coarse sand and gravel on this west-sloping bottom.

The Pico formation grades upward and laterally into the Saugus formation, of Pliocene and early Pleistocene age, which consists of interfingering shallow-water marine, brackish-water, and nonmarine beds that in turn grade into exclusively nonmarine beds. Sandstone, conglomerate, and reddish- and greenish-gray siltstone are characteristic of the formation. South of San Fernando Pass it is practicable to divide the Saugus formation into a lower member, the Sunshine Ranch member, characterized by greenish-gray siltstone beds, and an upper, coarser grained member. In this area the marine and brackish-water Sunshine Ranch member is separated from the upper nonmarine member by an unconformity. North and west of San Fernando Pass, the division of the Saugus formation into members is difficult, if not impossible. The thickness of the Saugus formation probably exceeds 7,000 feet in the west-central part of the area.

Stream-terrace deposits of late Pleistocene age are very similar lithologically to parts of the Saugus formation. East of Saugus these deposits are as much as 200 feet thick and lie with marked unconformity on the Saugus formation.

The Ventura basin is a narrow trough, filled with sedimentary rocks, whose axis approximately coincides with the Santa Clara River valley and the Santa Barbara Channel. The narrow troughlike form did not begin to develop until near the beginning of the Miocene epoch. Near the south margin of the Ventura basin the thick section of upper Cenozoic rocks has been thrust southward along the Santa Susana fault toward the older rocks of the Simi Hills. The southeastward-trending San Gabriel fault transects the northeastern part of the basin. Dissimilar facies in the pre-Pliocene rocks on opposite sides of this fault indicate a long period of continued movement along it. The major folds and faults between the San Gabriel and Santa Susana faults trend northwestward; most of the faults are southward-dipping reverse faults.

The first successful oil well in the area was completed in 1875. Most of the early development was in the Newhall oil field along the Pico anticline and near the southeast margin of the basin near the San Gabriel Mountains. Interest in the petroleum possibilities of the region was renewed with the discovery of the Newhall-Potrero oil field in 1937. Discovery of the Del Valle oil field (1940), Ramona oil field (1945), Castaic Junction oil field (1950), and a second period of development in the Placerita oil field (1948) followed. More than 80 million barrels of oil were produced from wells in the area, and at least 236 nonproductive exploratory wells were drilled prior to June 30, 1953.

INTRODUCTION

PURPOSE AND SCOPE

The Ventura basin (fig. 49) has long been one of the important oil-producing districts of California. The eastern part of the basin includes some of the oldest oil fields in California and also several of those most recently discovered. Since 1937 several new fields have been discovered in the area and undoubtedly more oil remains to be found.

The first work of the Geological Survey in this region was by Eldridge and Arnold (1907); Kew (1924) described part of the region studied by Eldridge and Arnold as well as much of the remainder of the Ventura basin. Since the publication of Kew's report, and especially since 1937 when the Newhall-Potrero oil field was discovered, interest in the eastern part of the Ventura basin has steadily increased.

The present report includes a small part of the area of Kew's report but on the larger scale of 1:24,000 (pl. 44; fig. 49). Attention is focused particularly on the surface stratigraphy. Subsurface data were collected where available, but they are necessarily incomplete.

FIELDWORK

Fieldwork was begun by Winterer in the summer of 1949 and carried on a few days each month until the summer of 1950, after which work was more continuous. Durham joined the project in the summer of 1951 and fieldwork was completed in September 1952. The areas mapped by each author are shown on an index map on plate 44. T. R. Fahy assisted in the collection of most of the foraminiferal samples.

The geology was mapped on aerial photographs, a few of which were 1:24,000 contact prints but most of which were 1:10,000 enlargements. The data on the photographs were transferred to the topographic base map, which consists of enlargements of the following Geological Survey 6-minute quadrangle maps: Pico and Newhall and parts of Santa Felicia Canyon, Castaic, Saugus, Humphreys, and Sylmar, all in Los Angeles County.

The stratigraphic sections of the Towsley formation (pl. 46) were measured with plane table and alidade; the stratigraphic sections of the Pico formation (pl. 47) were measured with tape and Brunton compass.

ACKNOWLEDGMENTS

Geologists on the staffs of oil companies operating in the region made much information available. Particular acknowledgment is due to E. J. Bartosh of the Bankline Oil Co.; T. L. Macleod of the Bell Petroleum

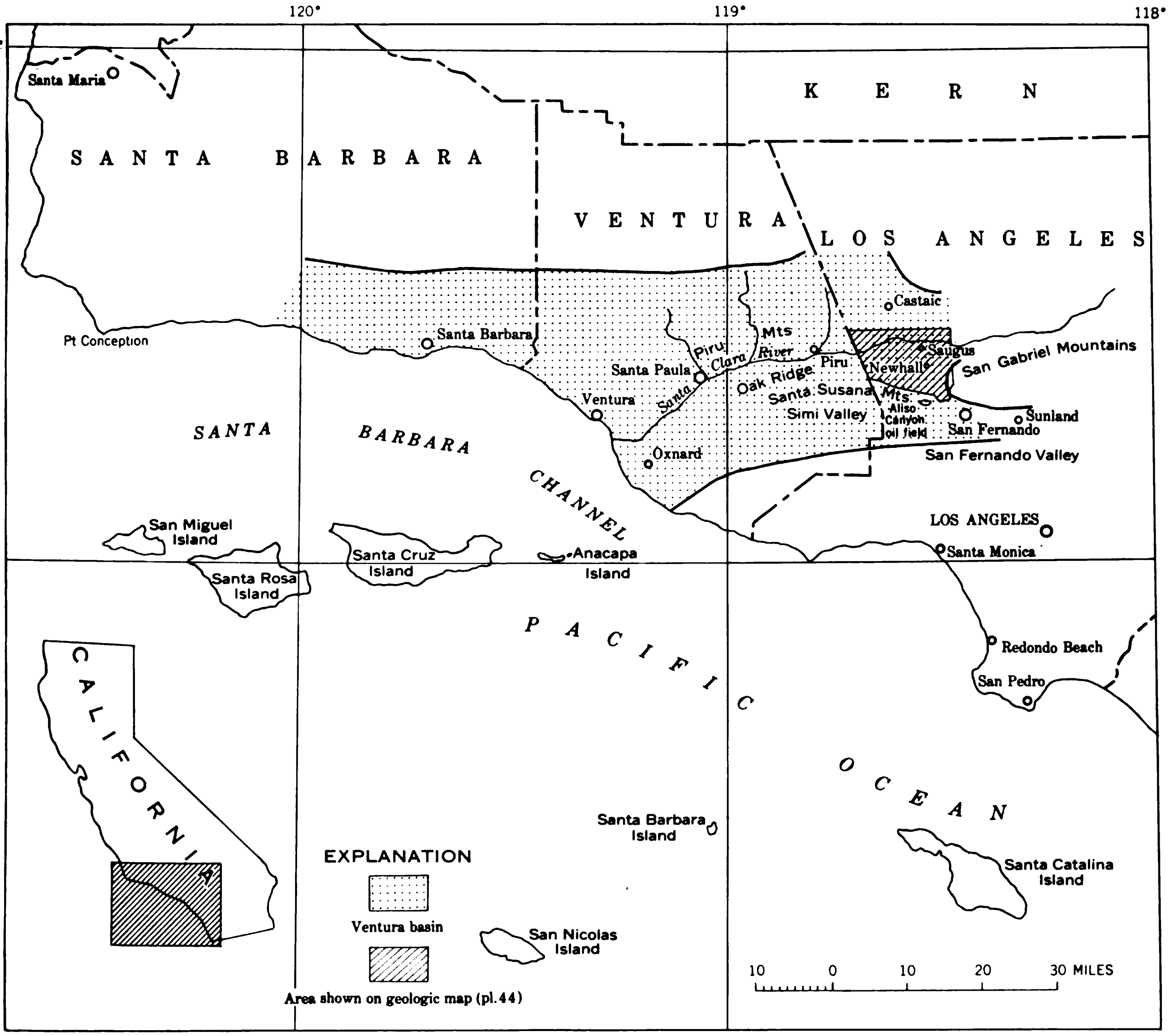

FIGURE 49.—Index map, showing area of report and general outline of Ventura basin.

Co.; K. S. Bishop and W. H. Corey of the Continental Oil Co.; R. S. Ballantyne, Jr., of the General Exploration Co. of California; D. B. Flynn, B. C. Lupton, and V. M. Smith of the General Petroleum Corp.; Hunter Yarborough, Jr., of the Humble Oil and Refining Co.; W. McKersey, formerly of the Kern Oil Co., now with the Seaboard Oil Co.; G. P. Gariepy and R. C. Shelton of the Ohio Oil Co.; Rollin Eckis, M. L. Natland, and W. T. Rothwell, Jr., of the Richfield Oil Corp., L. S. Chambers of the Seaboard Oil Co.; V. L. Crackel and P. L. Hayes of the Southern California Petroleum Corp.; O. W. Gilbert, W. H. Holman, J. B. Long, and E. H. Rader of the Standard Oil Co. of California; J. W. Sheller of the State Exploration Co.; R. J. Hindle, J. S. Loofbourow, and Robert Maynard of the Sunray Oil Corp.; G. Y. Wheatley of the Superior Oil Co.; F. D. Bode of the Texas Co.; R. F. Herron, formerly of the Texas Co., now with M. J. M. and M. Oil Co.; J. C. Hazzard and G. H. Quick of the Union Oil Co. of California; and P. H. Gardett, consulting geologist.

M. N. Bramlette, of Scripps Institute of Oceanography, who supervised the work in its early stages and who accompanied the authors in the field on several occasions, offered many valuable suggestions about stratigraphic problems and examined several foraminiferal faunas.

The micropaleontologic work was begun by Fahy and completed by Patsy B. Smith. Remains of a land mammal were identified by Remington Kellogg of the U.S. National Museum. The megafossils listed in this report were identified by W. P. Woodring, who was assisted by Ellen J. Trumbull and J. G. Vedder.

Woodring visited the field on several occasions to discuss stratigraphic problems and also made a special study of the *Calicantharus humerosus* group.

The courtesy of the Newhall Land and Farming Co. and of the many other land owners and residents in the region in granting access to their properties is gratefully acknowledged.

GEOGRAPHY

Most of the mapped area is in the eastern part of the Santa Clara River drainage basin. The southeastern part of the area is in the part of the Los Angeles River drainage area called the San Fernando Valley.

CLIMATE

The eastern part of the Santa Clara River valley is a semiarid region having a mean annual rainfall of about 16 inches. The rain is seasonal—most of it falls during the winter months.

Daily and seasonal records for the region show a wide temperature range. Temperatures on summer days often are above 100°F and temperatures on winter nights sometimes fall a few degrees below freezing.

VEGETATION

The vegetation varies with the underlying rock, the altitude, and the orientation of the slope. Areas underlain by fine-grained rocks commonly develop a soil that supports grass, a sage community, and oak and California walnut trees. Sandstone and conglomerate are commonly covered by the heavy brush locally called chaparral, which is especially heavy on north slopes. Bigcone-spruce trees grow at higher altitudes in the vicinity of San Fernando Pass.

SANTA CLARA RIVER

The Santa Clara River flows from its source on the north side of the western San Gabriel Mountains to the coast south of Ventura. The drainage area upstream from the water-stage recording station at the U.S. Highway 99 bridge 4 miles west of Newhall is about 355 square miles. The largest tributaries are west of Highway 99; they enter the river from the north. These tributaries include Piru, Sespe, and Santa Paula Creeks, whose combined drainage area and discharge are much greater than that of the main river upstream from the mouth of Piru Creek. The Santa Clara River bed is commonly dry in summer. All its tributaries in the mapped area are intermittent streams.

The average annual discharge of the river for the 16-year period from October 1929 to September 1945, as measured at the U.S. Highway 99 bridge water-stage recording station, was 19.7 cfs (cubic feet per second). The maximum discharge measured there during that period was 24,000 cfs on March 2, 1938, during a time of severe flood in southern California.

RELIEF

The eastern Santa Clara River valley region is one of bold relief. In the mapped area, the highest altitude, 3,747 feet, is in the Santa Susana Mountains. The western San Gabriel Mountains rise to an altitude of 3,119 feet within the mapped area and to altitudes of more than 4,000 feet only a short distance farther east. The Santa Clara River descends from 1,385 to 805 feet in the mapped area.

HUMAN ACTIVITIES

San Fernando Pass is located at the west end of the San Gabriel Mountains and is a convenient geographical boundary between them and the Santa Susana Mountains. The pass has been a natural entrance to the mountain-bordered Los Angeles region since early times. Evidence may still be seen of the pioneer wagon road through the pass. U.S. Highways 99 and 6, connecting Los Angeles with the San Joaquin Valley and the Mojave Desert, respectively, and the Southern Pacific railroad's main line from Los Angeles to the San Joaquin Valley, now traverse the pass area. The Los Angeles Department of Water and Power aqueduct from Owens Valley, as well as several power lines and pipe lines, use the San Fernando Pass area as a convenient gateway to the Los Angeles region. In addition to the highways and railroad already mentioned, a highway and railroad follow the Santa Clara River valley to the coast. Ranch, oil field, and forestry roads provide access to most of the area.

The towns of Newhall and Saugus, both along the Southern Pacific railroad, are the chief centers of population within the mapped area. The Santa Clara River valley, much of which is irrigated, supports farms, orchards, and cattle ranches. Numerous oil fields add to the economy of the region.

PHYSIOGRAPHY

The Santa Clara River follows the major structural depression of the region. The pattern of tributary streams and the shapes of the ridges are commonly determined by the varying resistance to erosion of the rocks.

Old erosion surfaces and river terraces are conspicuous. These may be conveniently divided into two groups: the older, topographically higher surfaces, remnants of which have been preserved in scattered localities; and the younger, topographically lower terrace surfaces, which are found along the Santa Clara River and its tributaries. The high surfaces extend to altitudes of more than 3,000 feet on the Santa Susana

Mountains. The younger terrace surfaces are at altitudes as low as 900 feet along the river at the western border of the area and as high as 1,900 feet on the hills near the eastern border.

Many small streams of the Santa Clara River drainage have their sources near the crest of the Santa Susana Mountains. Some of these streams have been beheaded by other streams which originate on the opposite side of the mountains and are tributary to the San Fernando Valley drainage.

Landslides are conspicuous. They are found in the Santa Susana Mountains on steep slopes underlain by shale and siltstone and in the northwestern part of the mapped area on high steep hills.

STRUCTURAL AND LITHOLOGIC CONTROL OF DRAINAGE

Because the Santa Clara River valley is developed more or less along the axial trend of the Ventura basin, the rocks exposed near the center of the valley are generally younger and less resistant to erosion than are those nearer the basin margins. The structural depression of the basin, together with its attendant faults, folds, and the accumulation of easily eroded younger rocks near the center, is largely responsible for the position of the valley.

The pattern of the tributaries to the Santa Clara River in several parts of the mapped area is controlled by lithology and structure. Sedimentary rocks exposed on the northeastern flank of the Santa Susana Mountains have a strike nearly parallel to the trend of the mountains themselves. The thicker conglomerate and sandstone units are represented by strike ridges and the thicker siltstone units have been eroded to form the intervening valleys. Dip and antidip slopes are commonly almost equally steep so that the longitudinal or strike valleys are narrow canyons. Some major drainage lines, such as Pico Canyon, begin in amphitheaters high on the north side of the main ridge of the Santa Susana Mountains, follow the strike for distances as much as 1 mile, and then alternately cut across the strike or follow it until they reach the lowland region west of Newhall. The canyons are narrowest where they cut through strike ridges. Towsley Canyon, for example, is deepest and narrowest where it crosses a unit of hard sandstone and conglomerate with a sequence of less resistant, finer grained rocks in the middle. The gorge crosses the resistant rocks, makes a right-angle bend to follow the softer intermediate beds along the strike for 400 feet, and then turns again at right angles to cross the remaining hard beds.

The positions of several valleys seem to be determined in part by the locations of major faults. In the northwestern part of the mapped area, San Martinez Chiquito Canyon follows closely the trend of the Holser fault for about 2 miles before making a bend, crossing the fault, and joining the Santa Clara River. Similarly, the course of the upper part of San Martinez Grande Canyon may have been originally determined by the position of the nearby Del Valle fault. The canyon parallels this fault for nearly 2 miles before crossing it to join the Santa Clara River.

RIVER TERRACES AND OLD EROSION SURFACES

Several river-terrace levels and old erosion surfaces are exposed along the Santa Clara River and its tributaries. The hills north of the river between Bouquet Canyon and the eastern border of the mapped area are marked by remnants of seven distinct river terraces. Figure 50 shows diagrammatically the spatial distribution of these terrace remnants and their correlation. The terrace surfaces are formed on both river-terrace deposits and rock of the Saugus formation. The geologic map (pl. 44) shows the extent of river-terrace deposits but not necessarily the extent of surfaces formed on these deposits. Inasmuch as the river-terrace remnants depicted on figure 50 have only a thin veneer of terrace deposits, the limits of the deposits as shown on the map approximate closely the extent of the terrace surfaces as well. The lowest terrace surface is about 40 feet and the highest more than 400 feet above the present river bed. These terrace surfaces are generally nearly planar with gentle slopes toward the river, but some steepen against the hills. The highest terrace surface extends back into the highlands up gently sloping valleys unrelated to the present drainage. Surfaces reconstructed from the remnants of various terrace levels slope in approximately the same direction as the present river valley. A comparison of the gradient of the river that formed the terraces with the gradient of the present river is difficult to make because of the limited extent and distribution and the possible deformation of these terrace remnants; however, the gradients of the streams that formed the two highest terrace levels appear to have been flatter in this area than that of the present river (fig. 50).

Remnants of an old erosion surface are found above the river terraces north of the Santa Clara River. This surface is on and near the tops of the highest hills and is as much as 520 feet above the present river bottom. South of the Santa Clara River, directly opposite the area of extensive terraces, only one terrace remnant is preserved. No correlation between it and those north of the river is apparent. Between Dry Canyon, just west of Bouquet Canyon, and Castaic Valley, no terraces are present along the north side of the central, alluvium-filled valley of the Santa Clara River.

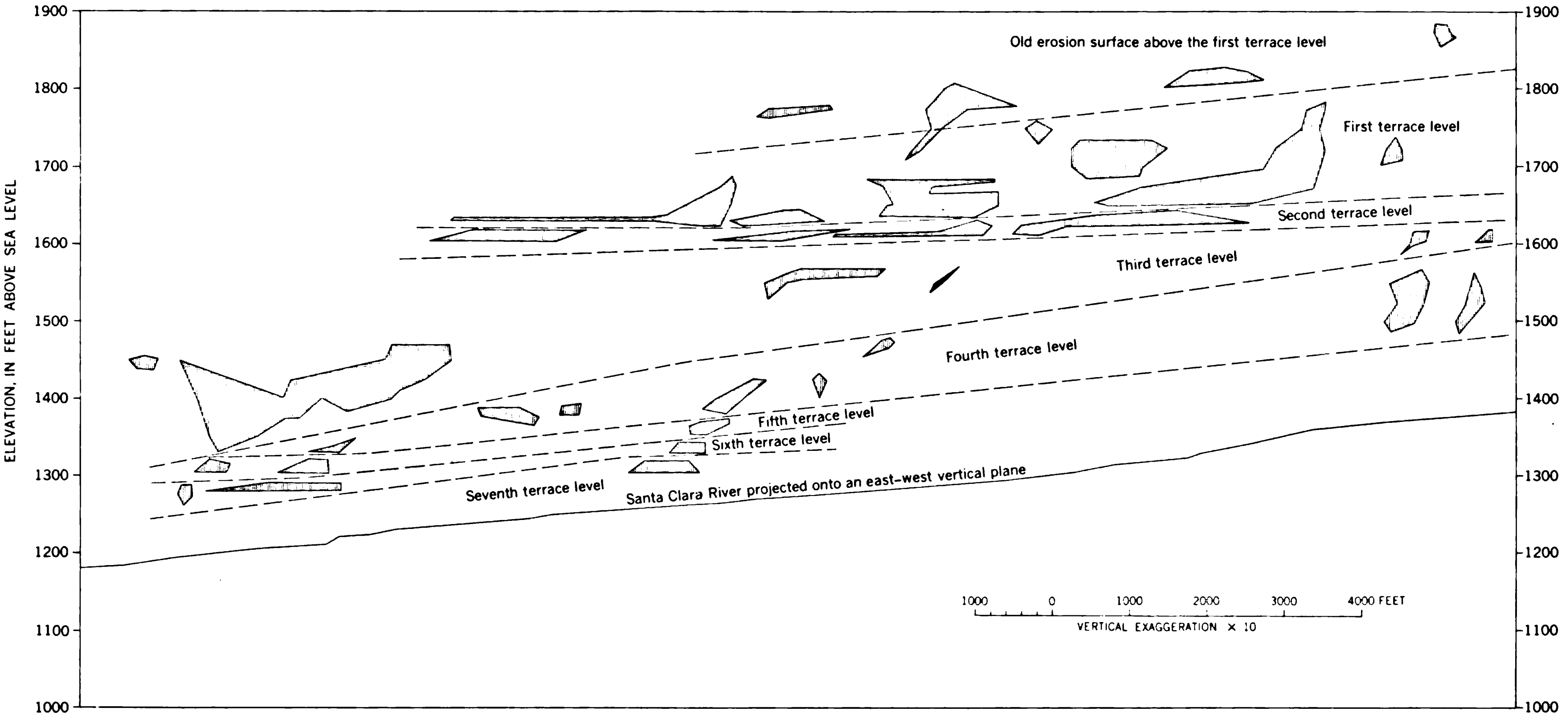

Figure 50.—Erosion and river-terrace surfaces on the north side of the Santa Clara River east of the mouth of Bouquet Canyon, projected horizontally onto an east-west vertical plane. Each of the polygons in the figure represents an individual terrace-surface remnant. Because only selected points around the perimeter of each terrace-surface remnant were projected, the projections have a polygonal outline. The length of a polygon is proportional to the east-west extent of the terrace remnant that it represents; its vertical position represents the elevation of the remnant, and its height represents the difference in elevation of the front and back of the remnant. Thus, inasmuch as each remnant has a slope toward the river, the upper margin of each polygon represents the edge of the surface farthest from the river and the lower margin of the polygon represents the edge of the surface nearest the river. The correlations of terrace remnants, shown graphically in the diagram, were made in the field. The down-stream slopes that may be inferred for each of the old surfaces are indicated by dashed lines.

Remnants of several terrace and erosion surfaces are present east of Saugus and Newhall, in La Placerita Canyon and along Newhall Creek. The most extensive of these surfaces is on the hills north and south of the lower part of La Placerita Canyon, where its lowest altitude is about 150 feet higher than the altitude of the adjacent canyon bottom. This surface increases in altitude to merge with an old erosion surface on the hills in the vicinity of the Placerita oil field. The highest part of this erosion surface has an altitude of over 1,900 feet, or more than 500 feet above the lowest part of the extensive surface. At its western end, the terrace surface is formed on a thick accumulation of river-terrace material but toward its eastern end it is underlain by only a thin mantle of terrace material covering rocks of the Saugus formation. This same surface is correlated with the extensive surface on the west side of the wide valley west of Newhall and Saugus and with surfaces of less extent near the Castaic Junction and Del Valle oil fields.

In La Placerita Canyon, near U.S. Highway 6, the three lowest terrace levels are about 50, 125, and 175 feet above the adjacent canyon bottom. Along the Santa Clara River several somewhat similar terrace levels can be distinguished below extensive higher terraces.

Just east of Saugus are remnants of two small valleys formed during an earlier cycle of erosion. The lower parts of these valleys are being destroyed by streams of the present erosion cycle, but their upper parts are still preserved.

A nearly undissected erosion surface, cut on the crystalline rocks of the western flank of the San Gabriel Mountains in the vicinity of Elsmere Canyon, is a resurrected pre-Pliocene surface exposed by the recent removal of the sedimentary rock cover.

The Santa Susana Mountains are made up of a continuous northwestward-trending ridge with steep, deeply dissected flanks. The relatively narrow summit region has rounded knolls and gentle slopes; streams there have gentle gradients but steepen markedly where they begin to descend the mountain flank. At one time these streams must have had gentle gradients throughout their length comparable to those now found along the uppermost parts of their courses. The crest of the Santa Susana Mountains is a remnant of the old surface across which they flowed.

At the head of Rice Canyon, near the eastern end of the mountains at an altitude of 2,750 feet, boulders of granitic rocks rest on the Modelo formation. These boulders are the remains of a river-terrace deposit—the oldest such deposit recognized in the area. At other places on the flanks of the mountains, gently sloping bench areas and accordant ridge levels give further evidence of the former existence of an old surface of erosion.

PRESENT EROSION CYCLE

The Santa Clara River is a graded stream. The river normally occupies only a comparatively narrow, sinuous channel, but during floods it may cover its entire flood plain.

The Santa Clara River valley in this area and the valleys that are tributary to it were alluviated just prior to the present cycle of erosion. The river and its tributaries now flow in channels that have been cut as much as 25 feet into the older alluvial deposits. At a point about 1 mile west of the Los Angeles-Ventura County line the Santa Clara River valley floor narrows abruptly. According to local residents, bedrock was exposed continuously across the river channel at this point immediately following a flood in 1938. Along the river between Bouquet Canyon and Castaic Creek, broad paired alluvial terraces are about 5 feet above the present river bed. This terrace level merges into the alluvium of the present river bottom both upstream and downstream from the area of its distinct development. At the mouths of numerous small valleys and gullies, fans with comparatively steep slopes are forming on the surface of the older alluvium that veneers the floors of the Santa Clara River valley and its major tributaries.

LANDSLIDES

On the flanks of the Santa Susana Mountains and in the hills in the northwestern part of the area, the shale and siltstone of the Modelo and Pico formations are exposed in steep slopes. Soil creep, slumping, and landsliding are prevalent in these areas. Many of the hills near the Del Valle and Ramona oil fields have dip slopes that are especially susceptible to movements of the superficial rock and soil cover. This has been the source of much trouble in the maintenance of oil-well drill sites and roads.

STRATIGRAPHY

The area described in this report includes parts of three depositional provinces; each province has a different geologic history, but the three are now crowded close together along faults of large displacement.

Northeast of the San Gabriel fault a thick succession of pre-late Miocene nonmarine strata comprising the Vasquez and Mint Canyon formations overlies pre-Cretaceous igneous and metamorphic rocks. Southwest of the fault, strata of roughly equivalent age are chiefly marine. The thick conformable upper Miocene, Pliocene, and lower Pleistocene section southwest of the fault is represented northeast of the fault by a greatly thinned section that contains several unconformities.

Within the province between the San Gabriel and Santa Susana faults, the formations of late Tertiary age thin markedly and become coarser grained toward the east, where successively younger formations rest directly on the lower Tertiary and pre-Cretaceous rocks of the San Gabriel Mountains. The Modelo and the Towsley formations and the lower part of the Pico formation were deposited in a marine environment, probably at depths greater than 600 feet. During deposition of the Pico the water became gradually shallower, and the overlying Saugus formation represents chiefly nonmarine conditions. The contact between the Pico and the Saugus, that is, the marine-nonmarine interface, rises stratigraphically toward the west.

South of the Santa Susana fault system the strata of late Cenozoic age are thin or even absent in many places, although a very thick succession of Pliocene and Pleistocene strata is present in a narrow belt along the southern margin of the San Gabriel Mountains.

PRE-CRETACEOUS ROCKS

The San Gabriel Mountains consist of a complex assemblage of igneous and metamorphic rocks that constitute the oldest rocks in the mapped area. No attempt was made during fieldwork to distinguish units within these rocks for this report, and statements concerning them result from incidental observations made along their contacts with the younger sedimentary rocks, from brief reconnaissance trips into the San Gabriel Mountains, and from a perusal of published and unpublished maps and reports on the area.

The oldest exposed rocks in the mapped area are assigned to the Placerita formation of Miller (1934) and consist of schist, gneiss, quartzite, and marble. This formation of metamorphosed sedimentary rocks has been intruded by the Rubio diorite of Miller (1934) which consists chiefly of hornblende and biotite diorite gneiss. In many places the diorite and metamorphic rocks are so intimately associated that separation into mappable units is impossible. Miller (1934) included such mixed rocks in his San Gabriel formation (1931). These older rocks are intricately crumpled and fractured, but some of the marble units can be traced continuously for many hundreds of feet. At some places, particularly in the Grapevine Canyon area, dark mylonite is common.

Plutonic igneous rocks that are probably much younger than the Placerita formation of Miller (1934) and the Rubio diorite of Miller (1934) intrude the older formations. These younger rocks are medium to coarse grained and range in composition from granite to quartz diorite.

An important unit of the sequence of pre-Cretaceous crystalline rocks, present on the northeast side of the San Gabriel fault but not present in the mapped area, is a large body of anorthosite and norite containing irregular-shaped magnetite-ilmenite bodies. This occurrence of the anorthosite-norite suite is unique in California, with the exception of a possible occurrence in a small area in or near the San Andreas fault zone more than 100 miles southeast, on the north side of Coachella Valley. The anorthosite-norite suite is easy to recognize as clasts in conglomerates, and its presence in a conglomerate is presumptive evidence of a San Gabriel Mountains provenance, even though by a circuitous and interrupted route.

TERTIARY SYSTEM

EOCENE SERIES

Eocene rocks exposed in a small area in Elsmere Canyon are the oldest sedimentary rocks that crop out within the area shown on the geologic map. The possible Eocene age of these rocks was first realized by Homer Hamlin, who directed W. L. Watts to the outcrops. Watts (1901, p. 56–57) noted the resemblance of these rocks to sandstones of the Sespe district now assigned to the Domengine stage, but he apparently found no fossils.

The rocks consist chiefly of light- to medium-gray well-indurated fine- to medium-grained sandstone that weathers grayish orange, interbedded with medium- to dark-gray siltstone that weathers light to moderate brown, and grayish-orange conglomeratic sandstone that weathers light gray. The coarser beds are generally very thick bedded. Graded bedding is a prevalent feature in the sandstone layers.

In Elsmere Canyon the Eocene rocks are in fault contact with the pre-Cretaceous crystalline rocks and are overlain unconformably by rocks of early Pliocene age. Neither the base nor the top of the Eocene sequence is exposed. Many wells near Newhall have penetrated Eocene rocks. One well, Continental Oil Phillips 1, was drilled about 6,500 feet through Eocene rocks (pl. 45) before reaching crystalline rocks. The dip of the beds in this well is mainly between 20° and 60°, but the possibility that reverse faults repeat parts of the succession makes it difficult to estimate the thickness of the sequence.

Some of the more friable sandstone beds in Elsmere Canyon are saturated with tar, and heavy oil oozes from some fractures. Shows of oil in the Eocene rocks have been reported from many wells, and a few wells in Whitney Canyon have produced high-gravity light-green oil, apparently from Eocene rocks.

FOSSILS

Fossils collected from outcrops in Elsmere Canyon and from cores of two wells, Union Oil Needham 3 in sec. 12, T. 3 N., R. 16 W., and North Star Mining and Development Shepard 1 in sec. 1, T. 3 N., R. 16 W., are listed in table 1.

TABLE 1.—*Fossils from Eocene rocks*

[Identifications by Ralph Stewart]

Fossil	Locality (table 11)				
	F1	F2	F3	F4	F5
GASTROPODS					
Amaurellina cf. *A. clarki* Stewart	X	X			
cf. *A. lajollaensis* Stewart	X				
?*Bonnelitia* sp			X		
Calyptraea cf. *C. diegoana* (Conrad)	X	X			
Conus remondii? Gabb		X			
aff. ?*C. warreni* "Hendon" Turner, sm. inc		X			
Cylichnina cf. *C. tantilla* (Anderson and Hanna)			X	X	
sp	X	X			
?*Diodora stillwaterensis* (Weaver and Palmer)		X			
Ectinochilus aff. *E. elongatus* (Weaver)	X	X			
?*E.* sp			X		
Ficopsis cf. *F. remondii* (Gabb)		X			
Galeodaria? sp		X			
?*Gegania arnoldi* (Dickerson)	X	X			
Harpa sp		X			
Perissolax? n. sp				X	
Pleurotomid				X	
Sinum? sp		X			
?*Solariella dibitata* Hanna	X				
?*Surculites* sp	X				
Tornatellaea aff. ?*T. vacarillensis* Palmer				X	
Turritella sp	X	X			
SCAPHOPOD					
Dentalium sp		X		?	
PELECYPODS					
Brachidontes cf. *B. cowlitzensis* (Weaver and Palmer)	X	X			
Corbula cf. *C. parilis* Gabb		X			
?*C.* sp	?	X			
Cuspidaria n. sp				X	
Gari cf. *G. texta* Gabb		X			
Jupitaria? sp				X	X
Macrocallista cf. *M. hornii* (Gabb)	X	X			
Miltha cf. *M. gyrata* (Gabb)		X			
Nemocardium cf. *N. linteum* (Conrad)		X			
Ostraea sp	X	X			
?*Pitar californianus* (Conrad)		X			
P. uvasanus (Conrad)	cf.	?			
Plagiocardium (*Schedocardia*) cf. *P. brewerii* (Gabb)	X				
Propeamussium sp	X			X	
Saccella sp			X		
Solen? sp		X			
?*Spondylus* sp	X				
?*Taras politus* (Gabb)	X	X			
T. sp					X
Tellina cf. *T. longa* Gabb	X				
cf. *T. soledadensis* Hanna		X			
Teredo sp.?	X		X		
Venericardia n. sp	X	X			
ECHINOIDS					
Cassiduloid		X			
Schizaster?			X		?
Spatangoid			X		

AGE AND CORRELATION

According to Stewart (written communication, 1952):

> The fauna is comparable to that of the Santiago formation of the Santa Ana Mountains (Woodring and Popenoe, 1945) and is probably middle Eocene or lower part of the upper Eocene. This age determination agrees fairly well with that based on the Foraminifera, that is, the B-1 zone of Laiming reported from cores of some wells in this area.

UPPER EOCENE TO LOWER MIOCENE

SESPE(?) FORMATION

Numerous wells in the area between San Fernando Pass and Newhall have penetrated a sequence of unfossiliferous light-gray, green, red, and bluish sandstone, siltstone, and claystone that does not crop out anywhere in the region (pl. 45, sections *A–A′*, *B–B′*). In wells that were drilled through this sequence the variegated beds directly overlie Eocene rocks. These beds of supposed continental origin are overlain in the Tunnel area of the Newhall oil field by lower Pliocene marine strata and farther west by marine strata representing the Delmontian and upper Mohnian stages of Kleinpell (1938). So far as the writers know, no evidence of interfingering between the variegated beds and the marine upper Miocene beds has been discovered.

The sequence ranges in thickness from nearly 2,000 feet at the British American Oil Edwina 1 well in sec. 11, T. 3 N., R. 16 W., to 0 between the Tunnel area and Elsmere Canyon (pl. 45, section *A–A′*).

In the past, these variegated beds have been correlated with the Mint Canyon formation of late Miocene age, but at least two considerations are opposed to this correlation. First, the apparent lack of interfingering with upper Miocene rocks and the absence of similar strata in a thick middle Miocene through lower Pliocene outcrop section suggest the beds are not only post-middle Eocene but pre-middle Miocene. Second, the lithology of the variegated beds, especially the presence of red beds and the bluish-green montmorillonitic clay, is not typical of the Mint Canyon formation; furthermore, the Mint Canyon formation is exposed only north of the San Gabriel fault. Crowell (1952a, p. 2026–2035) advanced several arguments in favor of a post-Mohnian right-lateral displacement of from 15 to 25 miles on the San Gabriel fault. If Crowell's hypothesis is correct, the main area of deposition of the Mint Canyon formation during middle Miocene time would have been many miles to the northwest of Newhall. The stratigraphic relations and the lithology of the continental beds make a correlation with the Sespe formation of late Eocene to early Miocene age seem much more likely than a correlation with the Mint Canyon formation.

MIOCENE SERIES

TOPANGA(?) FORMATION

In the hanging-wall block of the Santa Susana fault in the vicinity of the Aliso Canyon oil field, south of the area shown on the geologic map (pl. 44), a thickness of about 900 feet of light- to medium-brown thick-bedded fine- to medium-grained sandstone, with occasional thin lenses of pebble and cobble conglomerate, lies beneath shale of middle Miocene age. Locally, the upper part of the unit contains an amygdaloidal basalt flow. The Standard Oil of California Ward 3-1 well, about half a mile north of the area of outcrop of this sequence in sec. 27, T. 3 N., R. 16 W., penetrated a thickness of about 2,500 feet of similar rocks, including at least one thin layer of amygdaloidal basalt.

Both at the outcrop and in the well the unit is overlain by rocks representing the Luisian stage (upper middle Miocene) of Kleinpell. Because of their stratigraphic position below upper middle Miocene rocks and because of the presence of a basalt flow, these beds are tentatively correlated with the Topanga formation of middle Miocene age.

MINT CANYON FORMATION

NOMENCLATURE

Hershey (1902, p. 356–358) gave the name "Mellenia series" to the sequence of rocks that includes the Mint Canyon formation. Because the term Mellenia is not a place name, Kew (1924, p. 52) designated these rocks the Mint Canyon formation in recognition of their excellent development in the Mint Canyon region. Jahns (1939, p. 819) demonstrated that north of the area of this report the rocks that Kew named the Mint Canyon formation consist of two formations rather than one; he suggested that the lower part be called the Tick Canyon formation and the term Mint Canyon formation be retained for the upper beds. Only rocks from the upper part of the Mint Canyon formation as defined by Kew, and hence also from the Mint Canyon formation as restricted by Jahns, are exposed in the area shown on the geologic map (pl. 44). The older Tick Canyon formation of Jahns (1939) is not exposed, nor is it known to be present in the subsurface in the mapped area.

DISTRIBUTION

The Mint Canyon formation crops out on the north side of the Santa Clara River valley between Agua Dulce and Elizabeth Lake Canyons (outside the mapped area) and south of the valley between Sand Canyon and Honby (partly in the mapped area). It is not found south of the San Gabriel fault. Possible large right-lateral displacement along this fault (Crowell, 1952a) may explain the restriction of the known extent of the formation to the area north of the fault.

GENERAL LITHOLOGY

The lithologic character of the Mint Canyon formation has been discussed in detail by Kew (1924, p. 52–53) and Jahns (1940, p. 154–163). Jahns (p. 163) noted that "The beds in the lower half of the section are characteristically fine-grained, thin-bedded, and of variegated colors, whereas those higher up are more irregular, coarser, and subdued in color." The conglomerates are typically lenticular, cross-stratified, poorly sorted, and locally sandy. An abundance of gneiss, schist, and volcanic clasts is characteristic of the formation. Both well and poorly consolidated sandstones, which are arkosic and commonly cross-stratified, occur in the formation. Tan, gray, green, and pink siltstone and clay beds as well as white and gray vitric and crystal tuff beds are interstratified with coarser deposits. Some fine-grained units grade laterally into coarser grained beds; this gradation, together with the lenticular nature of the coarser grained beds, makes it difficult to trace lithologic units and horizons within the formation. Tuff beds are useful marker beds even though many of them are less than 4 feet thick.

THICKNESS

Jahns (1940, p. 162) ascribed an aggregate thickness of about 4,000 feet to the Mint Canyon formation in the Bouquet Canyon region. Oakeshott (1950, p. 53) reported the formation to be more than 2,400 feet thick in the area south of the Santa Clara River. A complete section is not exposed in the area shown on the geologic map.

STRATIGRAPHIC RELATIONS AND AGE

The first discovery of vertebrate remains in the Mint Canyon formation was made by Kew in 1919 during reconnaissance mapping Following the discovery of additional material, Maxson (1930) compared the fauna with those of other regions, and, after considering the position of the Mint Canyon formation unconformably below marine strata regarded by Woodring (1930, p. 155) as the approximate equivalent of the Cierbo sandstone of northern California, he concluded that the Mint Canyon was deposited during approximately the middle part of the late Miocene.

In a critical review of Maxson's work, Stirton (1933, p. 569–576) differed with him on the identification of the mammalian forms and advocated an early Pliocene age for the fauna. Subsequent papers by Teilhard de Charden and Stirton (1934), Stirton (1936; 1939), McGrew and Meade (1938), Lewis (1938), and Maxson (1938 a,b) have dealt with the paleontological aspect of the age of the Mint Canyon formation. As Reed and Hollister (1936, p. 40, 43) pointed out, the basic problem in the assignment of an age to the Mint Canyon fauna is the equivalence of the lower Pliocene of most vertebrate paleontologists and the upper Miocene of most California invertebrate paleontologists. There are two major considerations in determining the age of the Mint Canyon formation: (a) the occurrence of *Hipparion* in the Mint Canyon fauna, and (b) the occurrence of marine beds unconformably overlying the formation. The presence of *Hipparion* indicates an early Pliocene age to many vertebrate paleontologists. Stirton (1933) adhered to this concept, but Maxson (1930), largely because of the stratigraphic relationships of the Mint Canyon formation to the younger marine rocks, believed the range of the genus extends to the Miocene.

Although Kew (1924, p. 52) recorded a marked unconformity between the marine rocks and the Mint Canyon formation in Haskell Canyon, Stirton (1933, p. 569–576) and later Clements (1937, p. 215) indicated that the relationship is an interfingering or gradational one. Jahns (1939, p. 822) was able to demonstrate a distinct, though in places slight, angular discordance between the marine rocks and the Mint Canyon formation. He agreed with Eaton (1939, p. 534) that the Mint Canyon formation thins to the northwest by a loss of basal beds.

Grant's examination of additional collections of invertebrates from the marine rocks (Maxson, 1938a, p. 1716–1717) permitted a more exact determination than had previously been possible of their age as Neroly (uppermost Miocene). Kleinpell (1938, p. 71) referred meager foraminiferal faunas collected from the marine rocks to the Delmontian stage and agreed with the concept of the contemporaneity of the marine rocks and the Mint Canyon formation. Later, M. N. Bramlette [1] examined foraminiferal collections from the lower part of the marine sequence and considered the faunas as indicative of a late Mohnian (pre-Delmontian late Miocene) age.

The Mint Canyon formation is undeniably older than marine rocks deposited during at least part of late Miocene time, based on the invertebrate time scale of California. Jahns (1940, p. 172) considered the Mint Canyon formation to be of late Miocene age, a designation consistent with the stratigraphic position of the formation in the marine sequence. He also pointed out that the faunal gradation within the formation indicates that the deposition took place over a considerable time interval.

The Mint Canyon formation (restricted) of Jahns (1939) unconformably overlies his Tick Canyon and older formations. Jahns (1940, p. 174–175) regarded his Tick Canyon formation as late early Miocene or possibly earliest middle Miocene in age.

The Mint Canyon and Tick Canyon formations of Jahns (1939) overlie with pronounced unconformity beds called the Escondido series by Hershey (1902, p. 349–372), referred to the Sespe(?) formation by Kew (1924, p. 38–39), and named Vasquez series by Sharp (1935, p. 314) since Hershey's term is preoccupied. The Vasquez is of continental origin, is unfossiliferous, and has been tentatively referred to the Oligocene by Jahns (1940, p. 170–171). The Mint Canyon formation also unconformably overlies Eocene sedimentary rocks and the crystalline basement complex, considered to be pre-Cretaceous.

STRATIGRAPHY AND LITHOLOGY IN THE MAPPED AREA

In the northeastern part of the mapped area, the Mint Canyon formation crops out in a predominantly fine-grained sequence of greenish-gray siltstone units and interstratified sandstone, conglomerate, and thin tuff beds. The formation has been compressed into a series of comparatively tight, nearly westward trending folds. Resistant sandstone and conglomerate beds form prominent hills and ridges; less resistant siltstone units form a more subdued topography that includes the hummocky landscape typical of landslide areas.

Greenish-gray siltstone units include beds of mudstone and claystone and thin beds of sandstone and tuff. The siltstone commonly has sharp contacts with interstratified sandstone and conglomerate, although at some places the contacts are gradational. Bedding in the siltstone is generally indistinct or contorted due to the folding of the beds. Gypsum, found along the bedding planes and in fractures, and small bits of carbonaceous matter are conspicuous in the siltstone. Fresh-water fossils are abundant in some horizons. The fresh-water gastropod *Paludestrina imitator* Pilsbry has been identified (Kew, 1924, p. 54) in the formation.

The vitric and crystal tuff beds are massive and white to gray; they break with a blocky or conchoidal fracture. The tuffs are commonly finely laminated, cross-stratified, and ripple marked.

Most of the sandstone beds are light tan or yellowish brown but some are greenish gray. They are arkosic, and generally poorly sorted, and show cross-stratification, channeling, and local erosion of beds. Pebbly sandstone beds and sandstone beds with pebble stringers and lenses are common; the beds are from a few inches to several tens of feet thick.

Pebble, cobble, and boulder conglomerates contain clasts that range from angular to well rounded, but the majority are subrounded. A count of 430 clasts from one pebble conglomerate showed the following percentages of rock types:

Gneiss	58. 5
Volcanic rocks	34. 8
Anorthosite (and related rocks)	3. 0
Quartzite	1. 4
Schist	. 2
Miscellaneous	2. 1
	100. 0

The igneous and metamorphic rock types are like those found in the nearby San Gabriel Mountains and

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[1] Davless, S. N., 1942, Contact relationship between Mint Canyon formation and upper Miocene marine beds in eastern Ventura basin, Los Angeles County, California: Unpublished M. S. thesis, California Univ. at Los Angeles.

Sierra Pelona. The volcanic rocks are similar to flows in the Vasquez, east and northeast of the area.

The lithologic nature of the Mint Canyon formation in the mapped area is not characteristic of the entire formation in adjacent areas. The "light-gray to nearly white gravel interbedded with greenish clay or fine sand" (Kew, 1924, p. 52) in the upper part of the formation does not occur in significant amounts in the mapped area. A thickness of about 1,500 feet of the Mint Canyon formation is exposed in the mapped area. The base is not exposed.

ENVIRONMENT OF DEPOSITION

The Mint Canyon formation was deposited under subaerial conditions. The coarse, unsorted, and lenticular sand and conglomerate beds appear to have been large alluvial fan deposits. Fresh-water lakes were present in the area concurrently with the development of the alluvial fans. Thick sections of siltstone with interstratified mudstone, tuff, sandstone, and conglomerate are lake deposits. The presence of fresh-water mollusks and of a turtle possibly related to *Clemmys* (Maxson, 1930, p. 82, 87) is evidence of a lacustrine environment during deposition of part of the formation. Maxson regarded the abundant remains of hypsodont horses, antelopes, camels, and rabbits as an indication that the vegetation of the region must have been at least as abundant as that supported by a semiarid region. The grazing types of mammals occupied grass-covered plains, while *Parahippus*, peccaries, and possibly the oreodonts and mastodons also found in the formation frequented wooded areas along streams and lakes. Axelrod (1940, p. 577–585) made a study of fossil plants from tuff beds of the Mint Canyon formation in the vicinity of Bouquet and Sand Canyons. He found elements in the flora indicative of at least four distinct habitats: rush- or reed-like plants suggestive of shallow lakes, desert scrub from the drier slopes of the lower basin, an oak assemblage from the savanna area surrounding the general basin and probably also from the borders of streams, and a woodland community found at higher altitudes and on cooler slopes. Comparison with similar modern floras indicates that the region had an annual rainfall of from 15 to 20 inches, that precipitation was distributed as summer thundershowers and winter rains, and that temperatures were similar to those now prevailing in the region, except that the winters were slightly warmer.

The source of a large part of the Mint Canyon sedimentary beds was probably to the east, where rocks similar to the types represented as clasts in conglomerates of the Mint Canyon formation occur in the San Gabriel Mountains. Anorthosite and related rocks present as clasts in the conglomerates of the Mint Canyon formation are especially indicative of an easterly derivation of the sediments, but the presence in some of the conglomerates of schist and sandstone clasts similar to the Pelona schist and sandstones of Eocene age in the mountainous region north of the Santa Clara River valley indicates a northerly source for part of the formation.

During deposition of the Mint Canyon formation, the region was probably a large alluvium-covered valley or plain with scattered lakes, tree-bordered streams, and grass- and brush-covered alluvial-fan surfaces leading up to the adjacent mountainous areas.

MODELO FORMATION

The Modelo formation was named by Eldridge and Arnold (1907, p. 17–19), who described as typical its exposures in Hopper Canyon and at the head of Modelo Canyon in Ventura County. As originally defined, the formation consisted at the type area of from 1,700 to 6,000 feet of strata, divided into four members: a lower sandstone member, 200 to 2,000 feet thick; a lower shale member, 400 to 1,600 feet thick; an upper sandstone member, about 900 feet thick; and an upper shale member, estimated to be between 200 and 1,500 feet thick. Eldridge and Arnold described the formation as overlying a shale sequence correlated with the Vaqueros formation and underlying rocks of the Fernando group. Kew (1924, p. 55–69) redefined the Modelo formation to include the underlying beds correlated by Eldridge and Arnold (1907) with the Vaqueros. As thus redefined, the Modelo formation at the type area consisted of five members: a lower shale member, a lower sandstone member (the basal unit as defined by Eldridge and Arnold), a middle shale member, an upper sandstone member, and an upper shale member. The aggregate thickness of this sequence was given by Kew as about 9,000 feet.

Hudson and Craig (1929) redefined and restricted the Modelo formation at the type area. They correlated the lower shale, lower sandstone, and middle shale members of Kew's Modelo formation with the Topanga formation, largely on paleontological evidence. They also excluded from their restricted Modelo the uppermost beds of Kew's Modelo formation at the type area.

The members of the Modelo formation at the type area are not recognizable in the Santa Susana Mountains. In the area included on the geologic map (pl. 44), the Modelo formation consists mainly of rocks that Kew (1924) mapped as a shale member of the Modelo. Strata mapped by him as an overlying sandstone member of the Modelo are included in the Towsley formation.

Rocks of the Modelo formation crop out in a band along the crest of the Santa Susana Mountains and along the axis of the Pico anticline. Although the base of the formation is not exposed within the area shown on the geologic map (pl. 44), the Modelo formation rests unconformably on the Topanga(?) formation a short distance south of the mapped area in the Aliso Canyon oil field (White and others, 1952). The Modelo is present in the subsurface in all parts of the eastern Ventura basin except for the area northeast of the San Gabriel fault and the area east of a line approximately through the towns of Newhall and Saugus. In the subsurface near Newhall the Modelo formation wedges out and is overlapped by the Towsley formation. Westward from Newhall the thickness of the Modelo increases to at least 5,000 feet, but because no wells in the western part of the area have reached the base of the formation, the total thickness is not known. In the subsurface throughout most of the region the Modelo formation cannot consistently be differentiated from the overlying Towsley formation because of the lithologic similarity and lenticular nature of the sandstone and conglomerate lenses in both formations.

STRATIGRAPHY AND LITHOLOGY

Near the crest of the Santa Susana Mountains, in the area of Aliso and Rice Canyons, a complete section of the Modelo formation is exposed. In Aliso Canyon (outside the mapped area), the Topanga(?) formation is overlain by a unit about 300 feet thick of gray to grayish-orange medium- to coarse-grained well-sorted sandstone with lenses of pebble- to cobble-conglomerate. Above the basal sandstone of the Modelo a sequence of grayish-brown, brownish-gray, and grayish-black, poorly indurated, thinly laminated to thin-bedded silty and sandy shale about 400 feet thick is overlain by about 800 feet of pale yellowish-orange hard platy, thinly laminated to thin-bedded cherty shale, clay shale, and porcellaneous shale. The upper part of the formation, about 1,500 feet thick near Rice Canyon, consists chiefly of softer fine-grained rock. The siltstone, claystone, and mudstone are laminated to thick bedded, light brownish gray or grayish orange when fresh, medium brown when weathered. The thinly laminated, platy to punky silty shale is grayish brown to light brownish gray, grayish orange, pale red, or pale red purple. At many places fractures and bedding planes are encrusted with gypsum and coated with a yellow powdery mineral that is probably jarosite.

Occasional beds of gray impure limestone, which commonly weathers pale yellowish orange and is probably of concretionary origin, are interstratified in the shale. Elliposidal limy concretions, some more than 6 feet long, are scattered through the shale. At most places concretions are alined along definite horizons. Thin lenses and small nodules of nearly white phosphatic material occur in the shale at several stratigraphic levels. The nodules commonly contain fish bones and scales.

Layers of light-colored silty to coarse-grained sandstone are interbedded in the shale at many places. The layers range from laminae to beds several feet thick. The sandstone beds are generally graded from coarse at the bottom to fine grained at the top and are like the sandstone beds in the overlying Towsley formation in every important respect.

The upper part of the Modelo formation is exposed in a belt along the axis of the Pico anticline from East Canyon to Big Moore Canyon. In the vicinity of Rice Canyon a thickness of about 1,000 feet of Modelo formation is exposed below the Towsley formation. The lithology is similar to that of the upper part of the formation described above. Several deep exploratory wells that were drilled along the Pico anticline show that the thickness of the Modelo formation increases from about 3,000 feet at the crest of the Santa Susana Mountains to at least 5,000 feet near the axis of the anticline.

FOSSILS AND AGE

The only mollusks found in the Modelo formation are valves of a small *Delectopecten*. Fish bones and scales are common, especially in the more platy shales, and foraminifers are plentiful in some layers. The lower part of the Modelo formation in Aliso Canyon contains a foraminiferal fauna representative of the Luisian stage of Kleinpell (White and others, 1952). Foraminiferal faunas from several localities in the upper part of the Modelo formation in the Santa Susana Mountains region are given in table 2. The faunas that have any age significance seem to represent the Mohnian stage of Kleinpell, including the *Bolivina hughesi* zone, except for the faunas from localities f10 and f11, between Rice and East Canyons, which may represent the Delmontian stage (Patsy B. Smith, oral communication, 1954).

UPPER MIOCENE AND LOWER PLIOCENE

TOWSLEY FORMATION

DISTRIBUTION

Along the north slopes of the Santa Susana Mountains the fine-grained sedimentary rocks of the Modelo formation are overlain by and interfinger with a sequence of light-colored sandstone, conglomerate, and interbedded brown-weathering mudstone beds. This sequence was named the Towsley formation by the authors (1954) for its good exposures in the vicinity

TABLE 2.—*Foraminifera from Modelo formation*

[Identifications by Patsy B. Smith]

	Locality (table 11)						
	f6	f7	f8	f9	f10	f11	f12
Baggina cf. *B. subinequalis* Kleinpell	X						
Bolivina adrena striatella Cushman	X						
cf. *B. cuneiformis* Kleinpell							X
hootsi Rankin				X			
pseudobeyrichi Cushman				X			
pseudospissa Kleinpell	X						
pygmea Brady				X			
rankini Kleinpell					X		
sinuata Galloway and Wissler	X				X		
woodringi? Kleinpell		X					
Bulimina ovula pedroana Kleinpell	X						
pagoda hebespinata R. E. and K. C. Stewart				X			
rostrata H. B. Brady							X
cf. *B. uvigerinaformis*? Cushman and Kleinpell					X		
Buliminella curta Cushman					X		
subfusiformis Cushman				X		X	
Cassidulina delicata Cushman				X		X	
cf. *C. limbata* Cushman and Hughes					X		
Cassidulinella renulinaformis Natland		X	X				
Chilostomella grandis Cushman				X	X		
Cibicides basilobus? (Cushman)					X		
mckannai Galloway and Wissler					X		
Discorbis valmonteensis Kleinpell			X				
Epistominella bradyana (Cushman)						X	
cf. *E. evax* Bandy				X			
subperuviana (Cushman)				X			
Eponides cf. *E. exigua* (H. B. Brady)	X						
Globobulimina sp					X		
Gyroidina rotundimargo R. E. and K. C. Stewart					X		
Hopkinsina magnifica Bramlette		X					
Nonion labradoricum (Dawson)	X						
Nonionella miocenica Cushman				X			
Uvigerina hootsi Rankin	X						
subperegrina Cushman and Kleinpell	cf.				X		
Valvulineria araucana (d'Orbigny)					X		
californica Cushman							X
Virgulina californiensis Cushman	X					X	
californiensis grandis Cushman and Kleinpell				X			
cornuta Cushman				X		X	

of Towsley Canyon. The lithology and thickness of the Towsley formation change markedly from place to place so that the designation of a section truly typical of the formation as a whole is impossible. However, the section exposed along the north limb of the Pico anticline at Towsley Canyon is a representative one (pl. 46). At Towsley Canyon, the base of the Towsley formation is the base of the first unit of thick-bedded coarse-grained sandstone that lies above the typically fine-clastic rocks of the Modelo formation. The lower contact is not everywhere at the same stratigraphic horizon. The upper part of the Towsley formation closely resembles the lower part of the overlying Pico formation. The contact between the two is drawn at the base of the first conspicuous sandstone and conglomerate unit below the lowest concretion-bearing olive-gray siltstone typical of the Pico formation. The upper contact too is not everywhere at the same stratigraphic horizon. In the area around Newhall and San Fernando Pass the Towsley formation overlaps the Modelo formation and rests on pre-Cretaceous crystalline rocks, on the Sespe(?) formation, and on Eocene rocks. Where it rests unconformably on older rocks, the basal part of the formation contains a shallow-water molluscan fauna.

In two small areas north of the San Gabriel fault, beds of siltstone and sandstone that rest unconformably on the Mint Canyon formation and are overlain unconformably by the Sunshine Ranch member of the Saugus formation are assigned to the Towsley formation. North of the belt of outcrops along the Santa Susana Mountains the Towsley formation can be traced in the subsurface by electric log correlations. The distinctiveness of the formation decreases as correlations are extended farther and farther from the belt of outcrops because numerous lenticular units of sandstone similar to those in the Towsley formation occur in the Modelo formation.

DISTINCTION FROM MODELO FORMATION

The many lenticular units of sandstone and conglomerate in the Towsley formation distinguish it from the underlying Modelo formation. The base of the Towsley formation is much lower, stratigraphically, on the south limb of the Oat Mountain syncline than it is 1 or 2 miles farther north on the north limb of the Pico anticline. The interfingering between the Towsley and Modelo formations is particularly evident in the vicinity of the headwaters of Rice Canyon. The position of the base of the Towsley formation in the upper reaches of Rice Canyon is more than 1,500 feet stratigraphically below the horizon of the base of the Towsley on the north limb of the Pico anticline 1½ miles to the north. Similarly, in the area between Little Moore Canyon and Pico Canyon, along the Pico anticline, the base of the Towsley formation is at lower and lower stratigraphic horizons as the formation is traced westward.

The thickness of the Towsley formation ranges from about 4,000 feet in the southwestern part of the mapped area to a thin edge where the formation is unconformably overlapped by younger strata in the eastern part of the area.

PREVIOUS ASSIGNMENT

In the Santa Susana Mountains, most of the strata assigned to the Towsley formation were mapped by Kew (1924) as a sandstone member of the Modelo formation; he included a few of the uppermost beds of the Towsley there in the overlying Pico formation. Kew included in the Pico most of the rocks in the eastern part of the area, near Elsmere Canyon, here assigned to the Towsley; however, he assigned some of the higher beds to the Saugus formation. Oakeshott (1950) assigned the beds of the Towsley in the eastern part of the area to the Repetto formation and distinguished two members: his basal Elsmere member, which includes all the lower Pliocene in the vicinity of Elsmere Canyon, and a siltstone member, exposed in the two small areas north of the San Gabriel fault. Willis (1952) included all the Pliocene strata in the eastern part of the area in the Pico and termed the lower parts of the sequence, which corresponds to the Towsley, the Repetto formation and the Repetto equivalent. Because the type locality of the Repetto is in the Los Angeles basin, which was not connected with the Ventura basin during Pliocene time, and because the Towsley does not resemble the type Repetto lithologically, the term Repetto formation is not used for rocks described in this report.

In the Santa Susana Mountains local names for the Towsley formation include: Elsmere, Delmontian sands, and Miocene-Pliocene transition zone. Productive intervals in the formation have been given local names in the various oil fields in the area (see p. 340–347).

STRATIGRAPHY AND LITHOLOGY

Santa Susana Mountains

Relation to Modelo formation—The Towsley formation is exposed in a continuous belt extending along the north slope of the Santa Susana Mountains to and beyond the west border of the area. Throughout this belt the Towsley overlies and interfingers with the Modelo formation and is overlain by the Pico formation along a gradational contact. The lithology and thickness of the Towsley at seven places is shown in the columnar sections on plate 46. The dashed lines between the columns indicate correlations based on the tracing in the field of mappable units. The stratigraphic relations of the Towsley in the Santa Susana Mountains area are also shown on plate 45.

Fine-grained sedimentary rocks—Units of brown-weathering mudstone, siltstone, and shale make up the greater part of the Towsley formation, especially in the western and central parts of the mapped area. They are interbedded with lenticular units of sandstone and conglomerate as shown on the geologic map (pl. 44). The mapped units include many individual beds too thin or too limited in extent to be shown on the geologic map but whose lithology differs from that of the unit as a whole. In particular, beds and laminae of siltstone and mudstone are present in the sandstone and conglomerate units.

In the lower part of the formation the fine-grained rocks tend to be somewhat fissile, but at higher levels fissility is generally lacking. Fractures and bedding planes in the fine-grained rocks are commonly encrusted with gypsum crystals and lightly coated with films of jarosite(?). The general impermeability and high sulphate content of these rocks produce an unfavorable medium for plant growth. Belts conspicuously barren of vegetation mark the outcrops of mudstone units in many areas.

Ellipsoidal limy concretions similar to those in the Modelo formation are scattered sparcely in the mudstone and, as in the Modelo, are generally alined along definite horizons. At many places bedding planes in the mudstone pass without interruption through the concretions. The concretions are generally about a foot long, although a few are as much as 4 feet long. Occasional beds of hard fine-grained gray limestone that weathers yellowish gray are intercalated in the mudstone. These beds, some of which may be traced for several hundred yards, are as much as 18 inches thick, but any one bed is generally of variable thickness. In some places the limestone beds contain foraminifers. Because of their similarity to the ellipsoidal concretions, the limestone beds are thought to be concretionary in origin rather than primary deposits.

The most common fine-grained rock is massive light brownish-gray sandy mudstone that weathers a darker brown. In well cores this rock is generally dark greenish gray. Typically, the mudstone is poorly sorted. Mechanical analyses of representative samples showed medium and coarse silt (0.0156–0.0625 mm) to be the most abundant size classes. In most samples the clay fraction amounted to only about 5 percent by weight, but this low percentage of clay may reflect incomplete dispersion of the samples rather than a real scarcity of material in this size. Fine-grained sand was present in all samples analyzed. Many hand specimens contain very coarse angular sand grains scattered in a muddy matrix. The lack of clear bedding in, and poor sorting of, the sandy mudstone may be due to the disturbance of the sediments by burrowing and mud-eating organisms at the time of deposition.

Fossils are scarce in the mudstone. Foraminiferal faunas were meager, except for a few collected from the surfaces of concretions. Fish scales and fragments of fish bones are the most plentiful organic remains. Fossils may be scarce because conditions were not favorable for the development of a benthonic fauna. The gypsum and jarosite(?) on weathered surfaces might be interpreted as indicative of sulphurous bottom waters; however, the presence of benthonic Foraminifera in some of the limy concretions indicates that living conditions were suitable, at least at times. The fact that beds containing Foraminifera within concretions are generally not only barren outside the concretions but closely similar in appearance to most other barren mudstone beds suggests that Foraminifera were living on the bottom during deposition of the mudstone, but that their remains were later destroyed. In places where the rocks are very poorly sorted and poorly bedded, mud-eating scavengers may have partly destroyed the foraminiferal tests. Where the rocks are well bedded or where foraminiferal concretions are present, interstratal solution probably destroyed all calcareous shells except those protected within concretions.

At a few places in the Towsley formation thin units of yellowish-gray shale with paper-thin laminations crop out. In these laminae fish bones and scales are abundant, and well-preserved mud pectens (*Delectopecten* sp.) are common.

Sandstone and conglomerate—In many areas, the sandstone and conglomerate units are firmly cemented so that they produce bold topographic forms. Many streams have waterfalls in their courses where they cross these resistant units. The dense cover of brush that grows on most sandy slopes is nearly impenetrable in some areas, especially along the Santa Susana Mountains in the upper reaches of Towsley and Pico Canyons. Many of the sandstone and conglomerate units contain large concretions such as those shown in figure 51. Bedding planes pass through the concretions without interruption. Individual beds within these mappable units range from thin laminae to beds at least 5 feet thick. At many exposures single beds several feet thick pinch out completely in a few tens of feet. The beds of conglomerate tend to be the most variable in thickness.

Some of the mappable sandstone and conglomerate units can be traced laterally for only a few hundred yards. Others, like the resistant unit that is so well exposed north of the axis of the Pico anticline where Towsley Canyon narrows to a gorge, can be traced for several miles. Even this persistent unit is variable in both lithology and thickness from place to place. At the narrows in Towsley Canyon it is about 225 feet thick and consists largely of conglomerate. Clasts near the base of the unit are as large as 18 inches in diameter. One mile northwest of Towsley Canyon, near Little Moore Canyon, the unit is only a few feet thick and consists of sandstone. At Little Moore Canyon the unit thickens and coarsens abruptly again, then gradually thins toward Pico Canyon. South of the axis of the Pico anticline in Towsley Canyon the same unit consists of coarse-grained sandstone.

The clasts of pebble or larger size in the conglomerate represent a great variety of rock types. At most places gneiss and leucocratic plutonic rocks constitute about 80 percent of the clasts. Dark volcanic rocks, chiefly andesite but representing a wide range in composition, generally make up about 15 percent, and a host of other rock types, including quartzite, vein quartz, chert, aplite, gabbro, norite, and anorthosite, constitute the remainder.

FIGURE 51.—Concretionary sandstone unit in the Towsley formation on the crest of the Santa Susana Mountains.

The only place where anorthosite and norite crop out in the region of the Ventura basin is northeast of the San Gabriel fault in the San Gabriel Mountains, east and northeast of the easternmost outcrops of the Towsley formation. Gneiss and granitic rocks are exposed over extensive areas in both the San Gabriel Mountains and in the Traverse Ranges north of the eastern Ventura basin. Flows and sills of andesite lithologically similar to some of the clasts in the conglomerate of the Towsley formation occur in the Vasquez formation about 12 miles northeast of Newhall (Kew, 1924, p. 39). Many of the clasts in the Towsley formation are probably at least second generation, having been eroded from older conglomeratic formations. The clasts show almost every degree of rounding, although most rocks fall within Pettijohn's rounded class (Pettijohn, 1949, p. 51–53).

Boulders larger than 1 foot in diameter, although generally rare, are common in some places, as for example in the basal part of the conglomeratic unit that crops out at the narrows in Towsley Canyon. On the divide between Rice and Towsley Canyons on the south limb of the Oat Mountain syncline a bed containing many 3-foot boulders crops out near the base of the formation. Nearly all boulders consist of gneiss or light-colored plutonic rock. Beds of cobble conglomerate occur throughout the Towsley formation in the Santa Susana Mountains, but boulder-bearing beds are confined chiefly to the area between Pico and Wiley Canyons, on the north limb of the Pico anticline, and to the area near the divide between Rice and Towsley Canyons, south of the axis of the anticline. This distribution is suggestive of a northern or northeastern source for the conglomerate.

Graded bedding—The most prevalent sedimentary structure in the sandstone and conglomerate beds of the Towsley formation is graded bedding. Except for the lower part of the formation that rests unconformably on older rocks in the vicinity of Elsmere Canyon, nearly all sandstone beds and most conglomerate beds of the Towsley formation are graded. Generally the grading is conspicuous, the contrast between average grain size at the base and at the top of most beds being marked. In some beds, however, the grading is obscure; these beds have a nearly uniform grain-size distribution through more than 90 percent of their thickness but show distinct grading in the uppermost parts. Other beds, thought to be ungraded when examined in the field, were found to be graded when sequences of samples from single beds were analyzed in the laboratory. The relatively few ungraded sandstone beds are generally thin and contain evidence that reworking may have destroyed any original grading.

Typically, a graded bed is very poorly sorted, especially in its lower part. The finest material is present throughout the entire thickness of such a bed, even in the coarsest basal part; the median diameter of the grains, however, decreases steadily from the base of the bed to the top. Near the top of many graded beds the sandstone grades into siltstone, and commonly the sequence continues to grade upward into claystone. This upward reduction in grain size near the top of a graded bed is accompanied by a steadily darkening color.

Most commonly the contact of a graded bed with the overlying bed is distinct and abrupt. The interface between some beds is an even surface with no sign of any erosion or disturbance of the underlying bed. At many places where pebbles at the base of one graded bed rest directly on claystone of the underlying bed no evidence of channeling of the claystone can be detected. Where recent erosion stripped away part of the pebbly bed and exposed the surface of contact, the upper surface of the claystone is dimpled with the impressions of the eroded pebbles.

At many places graded beds of sandstone contain angular fragments of finer grained rocks similar to the fine-grained strata interbedded with the sandstone. Most fragments are only an inch or two in diameter, but clasts with a diameter as great as 10 feet also occur (fig. 63). Carbonaceous material, commonly in the form of dark-brown or black angular fragments, is abundant in some beds. The fragments are generally arranged in laminae near the top of graded beds. Most fragments are sand or granule size, but pieces as large as 1 inch are present. The material has a low density and resembles charcoal. The angular shapes and charcoal-like appearance of the material suggest that it is burnt wood. According to Shepard (1951, p. 56–57), similar material has been found in Recent sand layers in one of the inner basins in the continental borderland off southern California.

Other characteristic sedimentary structures in the Towsley strata in the Santa Susana Mountains area include load casts, small cut-and-fill structures, current ripples, slump structures, and convolute bedding. Detailed descriptions of the sedimentary structures in the Towsley strata and a discussion of their origin and significance are given on pages 333–334.

San Fernando Pass and Elsmere Canyon Area

In the region southeast of Newhall, near San Fernando Pass and Elsmere Canyon, strata assigned to the Towsley formation include beds deposited in water shallower than that farther west where the rocks of the Santa Susana Mountains proper were deposited. The formation thins eastward and northeastward, probably partly because of successive overlap of lower parts of the formation by beds higher in the formation. An unconformity at the base of the overlying Pico formation truncates strata of the Towsley formation near Elsmere and Whitney Canyons.

From Whitney Canyon south to Grapevine Canyon the basal beds of the Towsley formation lie directly on pre-Cretaceous igneous and metamorphic rocks. The crystalline rocks near the contact generally show no evidence of pre-Towsley weathering. The degree of fracturing in the crystalline rocks is not perceptibly more intense near the contact than at places farther away. The surface of contact is jagged in detail but local relief on the surface is generally not greater than 1 or 2 feet. Viewed more broadly, the contact is very even.

At most places the basal bed of the Towsley formation is a well-indurated conglomerate containing, in addition to well-rounded clasts of a great variety of rock types, angular blocks of crystalline rock of very local derivation. In Elsmere Canyon the coarse basal beds are about 15 feet thick; in places in Grapevine Canyon the conglomerate or breccia is only a few inches thick and is overlain by fine-grained silty sandstone. In Whitney Canyon and on the divide between Whitney and Elsmere Canyons the entire exposed thickness of the formation consists chiefly of conglomeratic sandstone interbedded with relatively minor amounts of siltstone and mudstone. Figure 52 shows the basal part of the Towsley formation where it rests on quartz diorite on the divide between Elsmere and Whitney Canyons. The lowest part of the Towsley formation here consists of large, closely spaced blocks of quartz diorite. The interstices between blocks are filled with sand and rounded pebbles and cobbles of a variety of rock types. Lying above the basal rubble are lenticular beds of conglomerate and sandstone. The upper beds overlap the rubble and rest directly on the quartz diorite in the upper part of the figure. At some places, particularly in the area near the southeast corner of section 18, T. 3 N., R. 15 W., mound-shaped lenses of light-gray hard calcareous fine-grained sandstone occur near the base of the formation. They are a few yards in diameter, as much as 10 feet thick, and interfinger with softer sandstone and pebbly sandstone beds. Erosion of the softer beds has left some of the hard lenses standing as prominent knobs. The lenses are generally very fossiliferous; specimens of *Lucinoma annulata* (Reeve), identified by Winterer, are particularly abundant.

In Elsmere Canyon the lower conglomeratic beds are overlain by a sequence about 150 feet thick of fossilif-

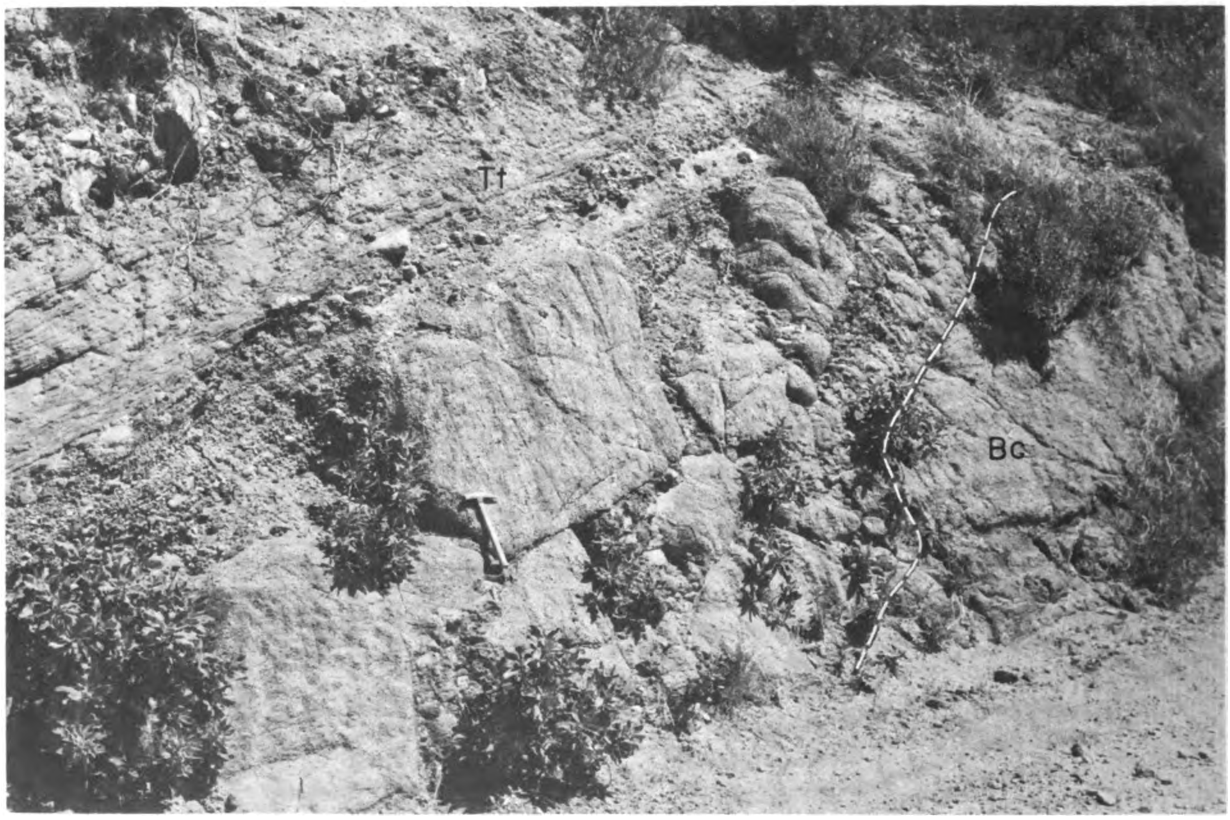

FIGURE 52.—Contact of Towsley formation (Tt) with quartz diorite of pre-Cretaceous basement complex (Bc) on ridge between Whitney and Elsmere Canyons.

erous moderately indurated, poorly bedded sandstone, siltstone, mudstone, and occasional thin lenses of conglomerate. The sandstone commonly contains concretions that are especially fossiliferous. The sequence is tar stained and has oil seeps. It has been productive in wells in the Elsmere, the Tunnel, and the Whitney Canyon areas, and in the Placerita field where it is known as the lower Kraft zone.

This sequence of beds grades upward into a unit of moderate yellowish-brown to dark yellowish-brown massive sandy siltstone. This unit is about 150 feet thick at the place where the Whitney Canyon fault intersects Elsmere Canyon. It thins northeastward and pinches out near the divide between Elsmere and Whitney Canyons. The unit can be traced in the subsurface, by means of drillers' logs and electric logs, into the Tunnel area, where it is about 300 feet thick. An unconformity at the base of the overlying Pico formation truncates the unit so that its original thickness cannot be measured at Elsmere Canyon.

South and west of Elsmere Canyon the Towsley formation thickens markedly and the upper conglomeratic beds interfinger with brown sandy siltstone and mudstone. In Grapevine Canyon the formation is at least 1,500 feet thick and consists of yellowish-brown mudstone, siltstone, and fine-grained sandstone interbedded with lenticular units of light-colored sandstone and conglomerate. In the area south of the Weldon syncline the beds of sandstone and conglomerate in the Towsley formation, excepting only the lowest, are similar in all important respects to the sandstone and conglomerate beds of the Towsley in the Santa Susana Mountains. The fine-grained beds are likewise very similar to those in the Santa Susana Mountains area. The increase in the thickness of the formation as it is traced westward may be due to the presence in the lower part of the formation of beds older than those resting on the crystalline rocks at the outcrops in Elsmere and Grapevine Canyons. The numerous faults in the San Fernando Pass area make correlations between various sedimentary units uncertain.

In the area where the axis of the Weldon syncline crosses U.S. Highway 6, the siltstone in the upper part of the Towsley grades northwestward in a very short distance into cross-stratified conglomerate and sandstone assigned to the Pico formation. The cross-stratification is very well exposed near San Fernando Pass (fig. 53).

North of the San Gabriel fault

Beds assigned to the Towsley formation crop out north of the San Gabriel fault in sections 20 and 32, T. 4 N., R. 15 W. The correlation of these beds with the Towsley formation south of the fault is based on lithologic similarity to the beds in Elsmere Canyon and on stratigraphic position. North of the fault the beds unconformably overlie the Mint Canyon formation and are in turn unconformably overlain by the Sunshine Ranch member of the Saugus formation. The rocks are chiefly light olive-gray, sparsely fossiliferous silty sandstone and sandy siltstone. Beds of light-colored fossiliferous pebbly sandstone are near the base of the formation. About 700 feet of Towsley strata are exposed in sec. 20, and a short distance beyond the east border of the area, in sec. 32, the formation is about 300 feet thick.

Subsurface development

The Towsley formation loses its identity as it is traced in the subsurface northward from the Santa Susana Mountains. Numerous lenses of sandstone and conglomerate occur in the Modelo formation as well as in the Towsley, and the fine-grained rocks in the lower part of the Towsley are not distinguishable from those of the Modelo, a combination of circumstances that makes the differentiation of the two formations in that area impracticable if not impossible. Valid correlations can be made from electric logs of wells drilled fairly close together, but in the absence of such data, correlations are best made on the basis of foraminiferal faunas. Because of the highly competitive nature of the oil industry in this area, many operators find it inadvisable to release detailed subsurface information, especially details about foraminiferal correlations. Consequently, different species have been used by different paleontologists as index fossils for the same time-stratigraphic unit. Thus the top of the Miocene, as determined by different paleontologists, may vary as much as 1,000 feet in the same well. The correlations shown in the structure sections (pl. 45, sections *A–A'* through *F–F'*) are therefore subject to the errors inherent in adjusting conflicting views.

FOSSILS

Santa Susana Mountains

Foraminifera are relatively scarce in the Towsley formation in the Santa Susana Mountains. Foraminiferal faunas from localities in the Santa Susana Mountains as well as from Elsmere Canyon and from north of the San Gabriel fault are listed in table 3.

The only mollusks found in the pelitic rocks of the Towsley formation in the Santa Susana Mountains are specimens of *Delectopecten*, generally with paired valves. These mud pectens are common in the fissile shale. Unidentifiable fragments of mollusks occur in many places in the sandstone and conglomerate, and at a few places whole shells occur. Collections from two localities have been identified; the species are listed in table

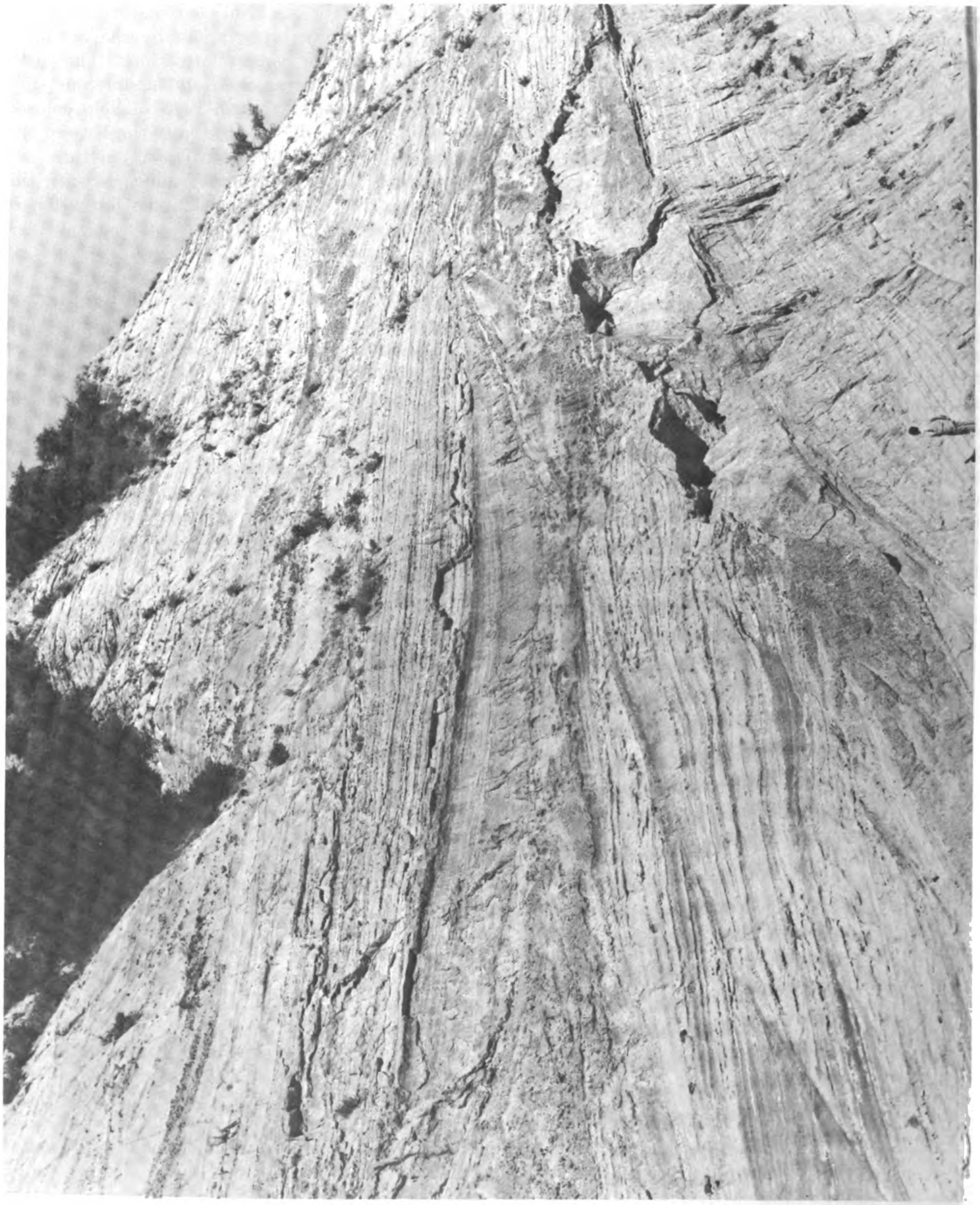

FIGURE 53.—Large-scale sets of cross-strata in the lower part of the Pico formation exposed in cut on U.S. Highway 6 in San Fernando Pass.

TABLE 3.—*Foraminifera from Towsley formation*

[Identifications by Patsy B. Smith]

	Locality (table 11)													
	Santa Susana Mountains									Elsmere Canyon	North of San Gabriel fault			
	f15	f28	f29	f30	f31	f32	f33	f34	f35	f36	f37	f38	f39	f40
Angulogerina sp													×	
Bathysiphon sp								×						
Bolivina adrena Cushman var	×			×		×								
hootsi Rankin		×				cf.								
imbricata Cushman var													×	
cf. *B. imbricata* Cushman			×											
pisciformis Galloway and Morrey										×				
pseudobeyrichi Cushman														×
rankini Kleinpell	×			×	cf.									
seminuda Cushman												×	×	×
sinuata Galloway and Wissler	×													
spissa Cushman	×													
tumida Cushman			×											
Bulimina cf. *B. ætnea* Seguenza											×			
pagoda Cushman var					×									
rostrata H. B. Brady			×	×										
subacuminata Cushman and R. E. Stewart										×				
Buliminella curta Cushman		×								×			×	×
elegantissima (d'Orbigny)												×	×	×
subfusiformis Cushman			×	×										
Cassidulina californica Cushman and Hughes														×
cushmani R. E. and K. C. Stewart			×									×	×	
delicata Cushman	×													
translucens Cushman and Hughes										×				
Chilostomella sp				×										
Cibicides basilobus (Cushman)													×	
lobatulus (Walker and Jacob)														×
mckannai Galloway and Wissler										×				
var. (flat)														×
Cyclammina sp				×				×						
Epistominella bradyana (Cushman)		×												
pacifica (Cushman)										×				
subperuviana (Cushman)												×	×	×
Eponides peruviana (d'Orbigny)											×		×	×
Frondicularia foliacea Schwager				×										
Globigerina spp											×	×	×	
Globobulimina spp			×	×										
Gyroidina altiformis R. E. and K. C. Stewart	×													
rotundimargo R. E. and K. C. Stewart	×	×	×			×								
Nodosaria sp				×										
Nonion cf. *N. costiferum* (Cushman)										×			×	×
cf. *N. incisum* (Cushman) •												×		
sp											×			
Quinqueloculina sp											×		×	
Robulus cushmani Galloway and Wissler				×									×	
Textularia sp										×			?	×
Trochammina pacifica Cushman														×
Uvigerina cf. *U. hispido-costata* Cushman and Todd				×										
hootsi Rankin	×	×	×	×										
peregrina Cushman										×				
subperegrina Cushman and Kleinpell	×		×											
Valvulineria araucana (d'Orbigny)			×											×
ornata Cushman											×	×		
Verneuilina sp				×	×				×					
Virgulina californiensis Cushman							×							
californiensis grandis Cushman and Kleinpell							×							

4. **At a locality (F17) outside the area shown on the** geologic map but near the top of the Towsley formation (see pl. 46) and along the line of the measured stratigraphic section between Tapo and Salt Canyons, fossils occur in several graded beds of pebbly sandstone interbedded with conglomerate. Fossils identified by Woodring and Trumbull from this locality (written communication, 1952), which have not been previously reported from the Ventura basin are:

"*Nassa*" *hamlini* Arnold, subsp.
Fulgoraria orgeonensis Dall
Glyptostoma cf. *G. gabrielense* Pilsbry
Yoldia aff. *Y. beringiana* Dall
Cyclocardia aff. *C. barbarensis* (Stearns)
Calyptogena lasia (Woodring)

Elsmere Canyon region

The fauna of the Towsley formation from the Elsmere Canyon area has been described or listed by a number of workers (Gabb, 1869, p. 49; Ashley, 1896, p. 337; Watts, 1901, p. 56; Eldridge and Arnold, 1907, p. 25; English, 1914, p. 203–218; Kew, 1924, p. 77–80; and Grant and Gale, 1931).

No attempt was made to collect new material from the area during the course of the fieldwork for this report. Fossils are abundant in the lowest part of the formation, and especially abundant in concretions. The fossils are well preserved by the tar that impregnates the rocks. Paired pelecypod valves are very common at most localities, suggesting that the shells

TABLE 4.—*Fossils from*

[Identified by W. P. Woodring, J. G. Vedder, and E. J. Trumbull, unless otherwise specified. Geographic and bathymetric data compiled by E. L. Winterer. AA, very
form; cf., similar form; sp., presumably

	Locality (table 11)															
	Towsley formation				Pico formation											
	Santa Susana Mountains		North of San Gabriel fault		North of Santa Clara River valley											
	F16	F17	F18	F19	F41	F42	F43	F44	F45	F46	F47	F48	F49	F50	F51	F52
Bryozoa:																
Unidentified worn specimen				×												
Brachiopods:																
Glottidia cf. *G. albida* (Hinds)								sp.R								
Terebratalia occidentalis Dall, including *T. occidentalis obsoleta* Dall.			×													
Chiton:																
Ischnochiton sp								R								
Gastropods:																
Acmaea? cf. *A. mitra* Eschscholtz			×													
Solariella peramabilis Carpenter		aff.					aff.R		?			sp.				aff.
Calliostoma coalingense catoteron Woodring?																
aff. *C. coalingense* Arnold		×			R		sp.R	sp.R								
sp			?													
C.? n. sp.? [2]					R											
Tegula aff. *T. aureotincta* (Forbes)																
gallina (Forbes)?						×										
ligulata (Menke)		cf.	sp.				cf.R		×						sp.	
Norrisia norrisi (Sowerby)?				×												
Pomaulax gradatus (Grant and Gale)		?		sp.	C		cf.R	cf.R	×					?		
Lacuna sp	×							R								
Capulus? cf. *C. californicus* Dall					R											
Crepidula princeps Conrad					R		?R	?R								
onyx Sowerby		cf.			cf.C		cf.R	cf.C	cf.							cf.
aculeata (Gmelin)								cf.R	aff.							
Calyptraea cf. *C. fastigiata* Gould			×					R								
filosa (Gabb)		cf.			cf.R		cf.R	A	×			×	×		?cf.	
Crucibulum cf. *C. spinosum* (Sowerby)				?sp.											sp.	×
Cryptonatica aleutica Dall, medium-sized form.		?sp.					C	cf.R	cf.							cf.
aleutica Dall, small form					C											
Neverita reclusiana (Deshayes)		×		×	AA	×	C	R	×							×
Lunatia lewisii (Gould)							R		cf.							
Sinum scopulosum (Conrad)					?R		?R	C	?			?				
Turritella cooperi Carpenter, subsp	×	×	×	?	AA	×	C	R	×				×			
gonostoma hemphilli Applin		cf.				cf.	?cf.R		?							
Aletes squamigerus Carpenter		?					R	R	×				×			
squamigerus Carpenter?, smooth form.					R											×
Petaloconchus montereyensis Dall								R								
Unidentified Vermetid												×				
"*Cerithium*" sp																×
simplicus Grant and Gale?																
Bittium rugatum Carpenter					cf.R	?		cf.C	?			cf.				
sp		×	×		R		R	AA			×		×			
"*Gyrineum*" cf. "*G.*" *elsmerense* English									×							
mediocre lewisii Carson					R		R			?						

See footnotes at end of table.

Towsley and Pico formations

abundant (more than 100); A, abundant (50-100); C, common (10-50); R, rare (less than 10); X, occurrence in nonbulk collections; ?, doubtful occurrence; aff., comparable similar form; ?sp., genus doubtful]

Locality (table 11)—Continued												Present habitat	
Pico formation—Continued													
North of Santa Clara River valley—Continued				South of Santa Clara River valley								Geographic range	Bathymetric data (depth in fathoms)
F59	F60	F61	F62	F76	F77	F78	F79	F80	F81	F82	F85		
											X		
									X			Monterey Bay, Calif., to Magdalena Bay, Baja California (Hertlein and Grant, 1944, p. 14).	Low water to 80 (Hertlein and Grant, 1944, p. 14).
cf.					X	X						San Francisco, Calif., to Cape San Lucas, Baja California (Hertlein and Grant, 1944, p. 129).	45-113 (Hertlein and Grant, 1944, p. 127-132).
							sp.					Bering Sea to San Martin Island, Baja California (Burch, No. 57, p. 6).[1]	Usually near lowtide mark, but 20 off Monterey, Calif., and 75 off Redondo Beach, Calif. (Burch, No. 57, p. 6).[1]
												Forrester Island, Alaska, to San Diego, Calif., also Japan (Burch, No. 58, p. 5).[1]	Alaska, 20-50; southern California (Burch No. 58, p. 5),[1] 32-239 (Woodring, Bramlette, and Kew, 1946, p. 90).
		X										Extinct	
			X							?		do	
		X										Extinct	
		X										Santa Barbara Islands, Calif., to Santa Margarita Island, Baja California (Burch, No. 57, p. 38).[1]	Not uncommon in medium tidal zone (Burch, No. 57, p. 38).[1]
												San Francisco Bay, Calif., to Gulf of California (Burch, No. 57,, p. 35).[1]	At high-tide line and intertidal, on rocks (Woodring, Bramlette, and Kew, 1946, p. 93).
												Monterey, Calif., to Acapulco, Mexico (Burch, No. 57, p. 38).[1]	Shallow to moderate depths (Woodring and Vedder, written communication), commonly in rocky rubble (Burch, No. 57, p. 38).[1]
												Monterey, Calif., to Cedros Island, Baja California (Burch, No. 57, p. 34).[1]	Commonly on kelp (Burch, No. 57, p. 34).[1]
		?sp.	X			cf.			?			Extinct	
		?											
												Redondo, Calif., to Cape San Lucas, Baja California (Burch, No. 56, p. 9).[1]	20-25, off San Pedro, Calif. (Commensal on *Pecten diegensis* Dall) (Burch, No. 56, p. 9).[1]
sp.			?									Extinct	
	?		cf.	cf.			?cf.		cf.	?cf.[3]	sp.[3]	Monterey, Calif., to Chile (Burch, No. 56, p. 12).[1]	Shallow (including estuaries) to moderate depths; 50 off Redondo Beach, Calif. (Burch No., 56, p. 12).[1]
			cf.	cf.		cf.	cf.		cf.			Port Harford, Calif., to Chile (Burch, No. 56, p. 14).[1]	Commonly on kelp holdfasts (Burch, No. 56, p. 15).[1]
												Port Etches, Alaska, to Rodondo Beach, Calif. (Burch, No. 56, p. 22).[1]	50-75 off Redondo Beach, Calif.; 10-30 in Puget Sound (Burch, No. 56, p. 22).[1]
	sp.	cf.	X				sp.		X	sp.[3]	sp.[3]	Extinct	
sp.								X				Trinidad, Calif., to Chile (Burch, No. 56, p. 21).[1]	Shallow (including estuaries) to moderate depths. 10-15 off Malaga Cove, Calif. (Burch, No. 56, p. 21).[1]
												Bering Sea to Washington and perhaps to southern California (Woodring and Bramlette, 1950, p. 72).	48-795 off California coast for *C. russa* (Woodring, Bramlette, and Kew, 1946, p. 90), which Woodring (Woodring and Bramlette, 1950, p. 72) treats as *C. aleutica.*
												do	Do.
	X	X	X			cf.		X	?	X	?	Pt. Conception, Calif., to Tres Marias Island, Mexico (Burch, No. 56, p. 30).[1]	Shallow (including estuaries) to 25 (Burch, No. 56, p. 30).[1]
			X							cf.[3]	cf.[3]	Duncan Bay, British Columbia, to Todos Santos Bay, Baja California (Burch, No 56, p. 29).[1]	Common in estuaries; down to 25 off Monterey and Redondo Beach, Calif. (Burch, No. 56, p. 29, 30).[1]
			X									Monterey, Calif., to Todos Santos Bay, Baja California (Burch, No. 56, p. 32.)[1]	In bays and estuaries, lower limit not listed (Burch, No. 56, p. 32).[1]
X	X	X	X	X		X	X	X	X	X		Monterey, Calif., to Cedros Island, Baja California (*T. cooperi*) (Burch, No. 54, p. 47).[1]	10-50 off Calif.; 14-30 off Cedros Island, Baja California (Burch, No. 54, p. 47).[1]
		cf.					cf.					Cape San Lucas, Baja California to Acapulco, Mexico (Woodring and Bramlette, 1950, p. 98).	
						?cf.						Forrester Island, Alaska, to Peru (Burch, No. 54, p. 43).[1]	Littoral to perhaps 20 off Monterey, Calif. (Burch, No. 54, p. 43).[1]
		X											
												Crescent City, Calif. (Burch, No. 54, p. 48)[1] to Catalina Island, Calif. (Burch, No. 54, p. 45).[1]	20 off Monterey, Calif. (Burch, No. 54, p. 45).[1]
								X				Extinct	
							cf.	cf.	cf.			San Pedro, Calif., to Todos Santos Bay, Baja California (Burch, No. 54, p. 31).[1]	50-181 off California (Woodring, Bramlette, and Kew, 1946, p. 90).
	X		X					X					
												Extiuct	
												do	

TABLE 4.—*Fossils from Towsley*

	Locality (table 11)															
	Towsley formation				Pico formation											
	Santa Susana Mountains		North of San Gabriel fault		North of Santa Clara River valley											
	F16	F17	F18	F19	F41	F42	F43	F44	F45	F46	F47	F48	F49	F50	F51	F52
Gastropods—Continued																
Fusitriton oregonensis (Redfield)		×			R		aff.A							?sp.		?
Cymatid?					R		R									
Eulima cf. *E. raymondi* Rivers							R	C				sp.	sp.			
Pyramidella sp									×							?
Turbonilla sp								R								
Epitonium hemphilli (Dall)?		×						sp.R								
Architectonica sp																×
Jaton cf. *J. festivus* (Hinds)																×
Maxwellia gemma (Sowerby)							R	cf.R								cf.
Tritonalia? sp								R								
Boreotrophon cf. *B. stuarti* (Smith)				×				sp.R				?sp.	?sp.			
B.? n. sp.?					R											
Muricid?													×			
Nucella elsmerensis (Grant and Gale)		sp.			R											
Forreria cf. *F. belcheri* (Hinds)																
cf. *F. magister* (Nomland)					R											
Acanthina spirata (Blainville), round-shouldered form.							R		×							
spirata (Blainville), angulate form									×							
Mitrella carinata gausapata (Gould)	×				R		aff. R	R			sp.		?			
cf. *M. tuberosa* (Carpenter)				sp.				R				sp.				
M.? sp								C			×					
Neptunea cf. *N. lyrata* (Gmelin)									×							
sp		×					R			×						×
Plicifusus sp							R									
Calicantharus humerosus (Gabb), slender form.																×
humerosus (Gabb), intermediate form.															×	
humerosus (Gabb), typical form		×			C		R		×				×	×		
cf. *C. humerosus* (Gabb)								R								
cf. *C. fortis* (Carpenter)																
cf. *C. fortis angulata* (Arnold)					R		R									
kettlemanensis (Arnold)					R		aff. R	cf. R	?							
Kelletia cf. *K. kelletii* (Forbes)		?					?R		×							
Cantharus? cf. *C. elegans* (Gray)					R											
C. sp					R											
"*Nassa*" aff. "*N.*" *moraniana* Martin	×	×	sp.	×	AA		A	AA	×		sp.	×	×			
hamlini Arnold	×	sp. ×			sp. C		?R	A					×			
cf. *N. mendicus* Gould																
sp					?R	?						×				×
Barbarofusus aff. *B. arnoldi* (Cossmann)		×			A				cf.							
cf. *B. barbarensis* (Trask)							R	R	×			sp.	sp.			
Fulgoraria oregonensis (Dall)		×						sp. R	cf.							
Olivella pedroana (Conrad)			cf.	×			cf. R		?							
biplicata Sowerby																
"*Cancellaria*" aff. "*C.*" *tritonidea* Gabb	×	×		sp.	sp. R		R	R								×
n. sp.? cf. "*C.*" *tritonidea* Gabb					R											
rapa perrini Carson							R		×							
hemphilli Dall		×					R	R	×			×	×			
arnoldi Dall		?cf.			R aff.											

See footnotes at end of table.

and Pico formations—Continued

Locality (table 11)—Continued												Present habitat	
Pico formation—Continued													
North of Santa Clara River valley—Continued				South of Santa Clara River valley								Geographic range	Bathymetric data (depth in fathoms)
F59	F60	F61	F62	F76	F77	F78	F79	F80	F81	F82	F85		
												Pribiloff Islands, Bering Sea, to Catalina Island, Calif. (Woodring, Bramlette, and Kew, 1946, p. 88).	80–1081 off California coast (Woodring, Bramlette, and Kew, 1946, p. 90).
												Probably close to *E. californica* which ranges from Santa Cruz Island, Calif. to Todos Santos Bay, Baja California (Burch, No. 53, p. 16).[1]	*E. californica* ranges from 20 to 75 (Burch, No. 53, p. 16).[1]
												Extinct	
		×										Santa Barbara, Calif., to San Ignacio Lagoon, Baja California (Burch, No. 51, p. 36).[1]	In almost all rocky localities; common on mudflats; as deep as 75 off Redondo Beach, Calif. (Burch, No. 51, p. 36).[1]
		?cf.										Santa Barbara, Calif., to San Hipolito, Baja California (Burch, No. 51, p. 36).[1]	Common in all rocky localities; in 30 off Catalina Island, Calif. (Burch, No. 51, p. 36).[1]
												Shumagin Islands, Alaska, to San Diego, Calif. (Burch, No. 51, p. 58).[1]	50–202 off California (Woodring, Bramlette, and Kew, 1946, p. 90); low tide to 25 in Alaska (Burch, No. 51, p. 58).[1]
												Extinct	
			×							×		Mugu Bay, Calif., to Scammon's Lagoon, Baja California (Burch, No. 51, p. 54).[1]	In bays and estuaries to 15 off Redondo Beach, Calif. (Burch, No. 51, p. 54).[1]
												Extinct	
												Monterey, Calif., to Socorro, Baja California (Burch, No. 52, p. 9).[1]	Shallow to moderate depths (Woodring and Vedder, written communication). Common on rocks between tides (Burch, No. 52, p. 9).[1]
												Puget Sound to Socorro Island, Baja California (Burch, No. 52, p. 9).[1]	Common above high-tide mark on rocks and pilings; estuaries on *Mytilus* beds (Burch, No. 52, p. 9).[1]
		aff.										Forrester Island, Alaska, to Salina Cruz, Mexico (Burch, No. 51, p. 14, 15).[1]	Commonly on rocky shores, not uncommon in bays on eel grass; a favorite habitat is on floating kelp; as deep as 35 at Catalina (Burch, No. 51, p. 15).[1]
							sp.		×		sp.[3]	Forrester Island, Alaska, to Gulf of California (Burch, No. 51, p. 16).[1]	7–35 off southern California (Burch, No. 51, p. 16).[1]
												Icy Cape, Arctic Ocean, to Pt. Pinos, Calif. (Burch, No. 50, p. 22).[1]	755–958 off Pt. Pinos, Calif.; 0–50 in Alaskan waters (Burch, No. 50, p. 22; No. 51,p. 30).[1]
										×			
												Circumboreal genus except for *P. griseus*, which was dredged off San Diego, Calif. (Burch, No. 50, p. 16–18).[1]	*P. griseus* in 414 and 636 off southern California coast (Burch, No. 50, p. 17).[1]
												Extinct	
		?		×				×	×	×		do	
			×									do	
×	×											do	
×						×						do	
												do	
						?						do	
×		?										Santa Barbara, Calif., to San Quintin Bay, Baja California (Burch, No. 50, p. 11).[1]	Abundant between 10 and 35 off Redondo, Newport, and Santa Monica, Calif. (Burch, No. 50, p. 11).[1]
												Gulf of California to Peru (Burch, No. 50, p. 12).[1]	
×		×	×	×		×	×	×	×			Extinct.	
												do	
										×		Kodiak Island, Alaska, to Magdalena Bay, Baja California (Burch, No. 51, p. 8).[1]	Shallow, including littoral, to moderate depths; as deep as 40 off Monterey, Calif. (Burch, No. 51, p. 8).[1]
		cf.	cf.									Monterey, Calif., to Cedros Island, Baja California (Burch, No. 50, p. 7, 8).[1]	15–108 (Burch, No. 50, p. 8).[1]
			×					sp.	×	?		Heceta Bank, Oregon, to San Diego, Calif. (Burch, No. 50, p. 9).[1]	30–218 off California coast (Woodring, Bramlette, and Kew, 1946, p. 90).
	cf.											Extinct	
		cf.										Alaska to Cape San Lucas, Baja California (Burch, No. 49, p. 17, 21).[1]	Shallow (including lagoons seasonally) to moderate depths; in 40 off Monterey, Calif. (Burch, No. 49, p. 21).[1]
											×	Vancouver Island, B.C., to Magdalena Bay, Baja California (Burch, No. 49, p. 19).[1]	Shallow (including lagoons seasonally) to moderate depths. Dredged in 25 off Redondo Beach, Calif. (Burch, No. 49 p. 20).[1]
		×	?							?	×[3]	Extinct	
												do	
												do	
		?					×	×				do	
												do	

TABLE 4.—*Fossils from Towsley*

	Locality (table 11)															
	Towsley formation				Pico formation											
	Santa Susana Mountains		North of San Gabriel fault		North of Santa Clara River valley											
	F16	F17	F18	F19	F41	F42	F43	F44	F45	F46	F47	F48	F49	F50	F51	F52
Gastropods—Continued																
Progabbia cf. *P. cooperi* (Gabb)								C				×				
Crawfordina cf. *C. fugleri* (Arnold)																
Admete cf. *A. gracilior* (Carpenter)					×			R								
Conus californicus Hinds					R		R		cf.							
Turricula? sp								R								
Antiplanes perversa (Gabb)							R									
sp							R									
Megasurcula carpenteriana (Gabb)		cf.			C											
aff. *M. cooperi* (Arnold)		×			R		R	cf.R	×							
Propebela sp								R								
Pseudomelatoma aff. *P. semiinflata* Grant and Gale		?sp.			R											
Crassispira? sp		×														
Elaeocyma empyrosia (Dall)		?sp.			AA aff.		C aff.	cf.R	?				cf.			
Ophiodermella aff. *O. quinquecincta* (Grant and Gale)		?sp.			R			cf.R	cf.							
"*Drillia*" cf. "*D.*" *graciosana* Arnold				×												
Clavine? turrid, genus?					R		R									
Mangelia aff. *M. variegata* Carpenter								R								
Glyphostoma conradiana (Gabb)								C								
Strioterebrum martini (English)		×		?	A		C	R	×							
Acteon aff. *A. grandior* Grant and Gale					cf.R		cf.R	cf.R								cf.
Acteocina cf. *A. culcitella* (Gould)					R		R	C				×				
Scaphander aff. *S. jugularis* (Conrad)								R								
Bulla cf. *B. gouldiana* Pilsbry							R		×							
cf. B. *punctulata* (Adams)								R								
Melampus cf. *M. olivaceus* Carpenter							R									×
Glyptostoma cf. *G. gabrielense* Pilsbry		×						sp.R								
Scaphopods:																
Dentalium neohexagonum Pilsbry and Sharp					R				cf.							
cf. *D. pretiosum* Nuttall								R				sp.				
Cadulus sp					?R		R	C								
Pelecypods:																
Acila castrensis (Hinds)						?	C		cf.				?		?	
castrensis (Hinds), small form								AA								
semirostrata (Grant and Gale)		×			R		?R					×				×
Nuculana cf. *N. hamata* (Carpenter)		sp.										×				
cf. *N. leonina* (Dall)							R									
cf. *N. extenuata* (Dall)												×				
Saccella taphria (Dall)		×		cf.	C	×	C	C	×		sp.	×			×	?
cf. *S. orcutti* (Arnold)					R											
cellulita (Dall)								R								
Yoldia beringiana Dall		aff.					R aff.	cf. C				cf.			×	
cooperi Gabb								cf. R							?	

See footnotes at end of table.

and Pico formations—Continued

Locality (table 11)—Continued												Present habitat	
Pico formation—Continued													
North of Santa Clara River valley—Continued				South of Santa Clara River valley								Geographic range	Bathymetric data (depth in fathoms)
F59	F60	F61	F62	F76	F77	F78	F79	F80	F81	F82	F85		
			?									Monterey, Calif., to Coronados Islands, Baja California (Burch, No. 49, p. 6).[1]	15-300 (Burch, No. 49, p. 6).
						×						Extinct. Possibly related to *C. crawfordiana* (Woodring and Bramlette, 1950, p. 77), which ranges from Forrester Island, Alaska, to San Diego, Calif. (Burch, No. 49, p. 9).[1]	*C. crawfordiana:* 46-70 off California coast (Burch, No. 49, p. 9).[1]
												Aleutian Islands to Todos Santos Bay, Baja California (Burch, No. 49, p. 10, 11).[1] Probably identical with *A. rhyssa* (Woodring, Bramlette, and Kew, 1946, p. 90).	20 (Burch, No. 49, p. 11) [1] to 81 (Woodring, Bramlette, and Kew, 1946, p. 90) off southern California coast.
?		?										Farallon Islands, Calif., to Ballenas Lagoon, Baja California (Burch, No. 48, p. 23).[1]	Far up in estuaries; down to at least 25 along open coast (Burch, No. 48, p. 23).[1]
												Alaska to San Diego, Calif. (Burch, No. 62, p. 15).[1]	In 50-200 off California coast (Burch, No. 62, p. 15).[1]
			cf.							?		Bodega Bay, Calif., to Cedros Island, Baja California (Burch, No. 62, p. 5).[1]	15-50 (Burch, No. 62, p. 5).[1]
		×										Extinct	
												Alaska to California (Woodring and Bramlette, 1950, p. 79).	60-870 off California (Woodring and Bramlette, 1950, p. 80).
												Extinct	
		aff.	aff.			cf.		?				Redondo Beach, Calif. (Burch, No. 62, p. 8) [1] to Todos Santos Bay, Baja California.	Dredged from 25-50 (Burch, No. 62, p. 8).[1]
		?cf.										Extinct	
												do	
												Alaska to Gulf of California (Burch, No. 62, p. 29).[1]	Littoral to 50 (Burch, No. 62, p. 30).[1]
							×					San Pedro and Redondo Beach, Calif. (Burch, No. 62, p. 24).[1]	20-50 (Burch, No. 62, p.24).[1]
		×	×			×	×	×	×			Extinct	
		?						cf.	cf.			Extinct(?)	May be related to *A. painei* (Grant and Gale, 1931, p. 444), dredged in 30-50 off Catalina Island, Calif. (Burch, No. 47, p. 10).[1]
			×				sp.				sp.[3]	Alaska? to San Martin Island, Baja California (Burch, No. 47, p. 12).[1]	10-25 off California coast (Burch, No. 47, p. 12, 13).[1]
												Extinct	
								sp.				Santa Barbara, Calif., to Mazatlan, Mexico (Burch, No. 48, p. 2).[1]	Commonly in bays and sloughs; as deep as 25 off Catalina Island, Calif. (Burch, No. 48, p. 2).[1]
		sp.										Ensenada, Baja California, to Peru (Burch, No. 48, p. 2).[1]	
												Monterey Bay (Salinas River), Calif. to Mazatlan, Mexico (Burch, No. 48, p. 11).[1]	On mud flats in bays (Burch, No. 48, p. 11, 12).[1] Air breathing.
												Los Angeles region, Calif. (Burch, No. 4, p. 3, Oct. 7, 1941).[1]	Land snail, usually in hilly areas (Burch, No. 4, p. 3, Oct. 7, 1941).[1]
		sp.	×	×					×			Monterey, Calif. to Guacomayo, Colombia (Burch, No. 46, p. 9).[1]	5-100 off California (Burch, No. 46, p. 9).[1]
											?[3]	Forrester Island, Alaska to San Diego, Calif. (Burch, No. 46, p. 12).[1]	20-80 off California coast (Burch, No. 46, p. 12).[1]
												Sitka, Alaska, to Cedros Island, Baja California (Burch, No. 33, p. 8).[1]	15-233 off California coast (Woodring, Bramlette, and Kew, 1946, p. 90).
										×	?[3]		
												Extinct	
												Puget Sound to Panama Bay (Burch, No. 33, p. 11).[1]	25-158 off California (Burch, No. 33, p. 11).[1]
												Straits of Juan de Fuca to lat 35° N. (Burch, No. 33, p. 11).[1]	152-766 off Monterey, Calif. (Burch, No. 33, p. 11).[1]
												Sitka, Alaska (Burch, No. 33, p. 11).[4]	1569 off Sitka, Alaska (Burch, No. 33, p. 11).[1]
	×	×	×							×		Bodega Bay, Calif., to Baja California (Burch, No. 33, p. 11).[1]	3-51 off southern California (Burch, No. 33, p. 11).[1]
												Extinct	
												Craig, Alaska, to Puget Sound (Burch, No. 33, p. 10).[1]	30-40 at Craig, Alaska (Burch, No. 33, p. 10).[1]
									?			Bering Sea to Anacapa Island, Calif. (Burch, No. 33, p. 13).[1]	152-1041 off Monterey, Calif. (Burch, No. 33, p. 13).[1]
												San Francisco, Calif., to Todos Santos Bay, Baja California (Burch, No. 33, p. 13).[1]	5-15 (Burch, No. 33, p. 13).[1]

Table 4.—*Fossils from Towsley*

	Locality (table 11)															
	Towsley formation				Pico formation											
	Santa Susana Mountains		North of San Gabriel fault		North of Santa Clara River valley											
	F16	F17	F18	F19	F41	F42	F43	F44	F45	F46	F47	F48	F49	F50	F51	F52
Pelecypods—Continued																
Tindaria? sp												X				
Anadara camuloensis (Osmont)							C	C	X				X	?		?
trilineata (Conrad)	sp.											cf.			?	
trilineata (Conrad), short form, cf *A. trilineata canalis* (Conrad)		X		sp.	AA						sp.					
Anomia? sp								R								
Pododesmus macroschisma (Deshayes)									X							
Volsella sp																
Pecten hemphilli Dall															X	X
stearnsii Dall					cf.R		sp.R	cf.R							?	
Aequipecten circularis (Sowerby)			?sp.						aff.				sp.		?	?
circularis (Sowerby), small form		X														
cf. *A. purpuratus* (Lamarck)																
Chlamys islandicus hindsii (Carpenter)			X		?sp.R							sp.			cf.	
opuntia (Dall)																
Patinopecten healeyi (Arnold)		?	?	?	?cf.R										X	
Lyropecten cerrosensis (Gabb)		?			?R			?R	?							
Ostrea vespertina Conrad		X				sp.	R	R	X			cf.			X	
vespertina Conrad, strongly plicate form.																X
Eucrassatella aff. *E. fluctuata* (Carpenter)			X													
Cyclocardia aff. *C. barbarensis* (Stearns)		X			cf.A	X	cf.R	cf.AA	X				cf.			
cf. *C. ventricosa* (Gould)																
Calyptogena lasia (Woodring)		X			?sp.R											
Lucina excavata Carpenter		X			R		R		X							
Lucinisca nuttallii (Conrad)		X			R	X										
Lucinoma cf. *L. annulata* (Reeve)		X			R			R				X				
Parvilucina tenuisculpta (Carpenter)					cf.R			cf.C			sp.	?				
Miltha xantusi Dall					sp.R											
Tellina idae Dall		X			?R											
Macoma cf. *M. calcarea* (Gmelin)	?sp.						R									X
cf. *M. calcarea* (Gmelin), small form						?sp.	?sp.C	R			sp.	sp.		sp.		
indentata Carpenter?					R											
secta (Conrad)							cf.R	?R								
Apolymetis biangulata (Carpenter)																?
Spisula hemphilli (Dall)?		?sp.					?sp.R									
Schizothaerus nuttallii (Conrad)		?cf.					?sp.R	?sp.R	?sp.							
Dosinia ponderosa (Gray), subsp		X			R	sp.	aff.R		X				cf.?			
Compsomyax subdiaphana (Carpenter)				?cf.	R		R	C			?cf.	X			?sp.	X
Pachydesma crassatelloides (Conrad) [*Tivela stultorum* (Mawe)].							R									X
Macrocallista aff. *M. squalida* (Sowerby)									cf.							
M. ? sp								R								
Amiantis callosa (Conrad)		?cf.			R		?cf.R		cf.							
Chione fernandoensis English	X	X	cf.	X	C	X	R	C					?			
Protothaca cf. *P. staminea* (Conrad)		X		?sp.			R				sp.	sp.				

See footnotes at end of table.

and Pico formations—Continued

Locality (table 11)—Continued												Present habitat	
Pico formation—Continued												Geographic range	Bathymetric data (depth in fathoms)
North of Santa Clara River valley—Continued				South of Santa Clara River valley									
F59	F60	F61	F62	F76	F77	F78	F79	F80	F81	F82	F85		
													A deepwater genus (Burch, No. 33, p. 14)
		×	×									Extinct	
	?		?cf.			?				cf.		do	
												do	
		×											
cf.	?									×		Southern Bering Sea to south end of Baja California (Burch, No. 36, p. 3).[1]	On stones, pilings, etc., near low-tide line; as deep as 35 off Redondo Beach, Calif. (Burch, No. 36, p. 3).[1]
						×							
										?	×	Extinct	
cf.	cf.									cf.	cf.	Extinct. Possibly related to *P. diegensis*, which ranges from Monterey, Calif., to San Benito Islands, Baja California (Burch, No. 35, p. 4).[1]	*P. diegensis* dredged in 14–266 off California (Woodring, Bramlette, and Kew, 1946, p. 90).
aff.			?	aff.			?sp.	?	sp.			Monterey, Calif., to Peru (Burch, No. 35, p. 10).[1]	Sloughs to 25 (Burch, No. 35, p. 11).[1]
	×									×		Some varieties living off South America (Grant and Gale, 1931, p. 208–210).	
	×									cf.		Alaska to San Diego, Calif. (Burch, No. 35, p. 6).[1]	50 (one record) (Burch, No. 35, p. 6).[1]
	×											Extinct	
	?		?	?	?	?				?		do	
×	×		×	×	?							do	
			×				sp.	×		×	×	Baja California and Gulf of California (Grant and Gale, 1931, p. 152).	
×	×			×					×	×			
												Santa Barbara Islands, Calif., to San Pedro, Calif. (Burch, No. 39, p. 8).[1]	25–30 off Catalina Island, Calif. (Burch, No. 39, p. 8).[1]
										sp.		Santa Barbara Channel, Calif., to San Diego, Calif. (Burch, No. 39, p. 13).[1]	62–276 in Santa Barbara Channel (Woodring, Bramlette, and Kew, 1946, p. 90).
sp.				×								Belkoffski Bay, Alaska, to Coronados Islands, Baja California (Burch, No. 39, p. 14).[1]	35–149 off Monterey, Calif. (Burch, No. 39, p. 14).[1]
												Extinct(?)	
×	cf.		×	×		×						San Pedro, Calif., to Mazatlan, Mexico (Burch, No. 40, p. 6).[1]	Upper reaches of bays down to 20 (Burch, No. 40, p. 6).[1]
		aff.	×	×								Monterey, Calif., to Mazatlan, Mexico (Burch, No. 40, p. 6).[1]	Littoral to 25 off southern California (Burch, No. 40, p. 7).[1]
	×		×									Port Althorp, Alaska, to Coronados Islands, Baja California (Burch, No. 40, p. 7).[1]	*f. annulata* var. *densilineata* dredged from 8 to about 75 off California (Burch, No. 40, p. 7).[1]
				×			cf.					Bering Sea to Coronados Islands, Baja California (Burch, No. 40, p. 8).[1]	19 off Monterey, Calif. (Burch, No. 40, p. 8).[1]
				×								Gulf of California to Mazatlan, Mexico (Grant and Gale, 1931, p. 291).	
		cf.	?	?sp.								Santa Barbara Islands, Calif., to Newport, Calif. (Burch, No. 43, p. 6).[1]	In Newport Bay, Calif., and as deep as 50 off Redondo, Calif. (Burch, No. 43, p. 6).[1]
										×	sp.[3]	Arctic Ocean to Monterey Bay, Calif. (Burch, no. 43, p. 11).[1]	15–60 (Burch, No. 43, p. 11).[1]
	sp.												
												Puget Sound to Baja California (Burch, No. 43, p. 15).[1]	Lagoons (for example, Playa del Rey, Calif.) to as deep as 25 off Redondo Beach, Calif. (Burch, No. 43, p. 15).[1]
			?	×								Vancouver Island, British Columbia to Gulf of California (Burch, No. 43, p. 16).[1]	Bays, sloughs, and beaches. As deep as 25 off Redondo Beach, Calif. (Burch, No. 43, p. 16).[1]
			×	cf.								Santa Barbara, Calif., to Ensenada, Baja California (Burch, No. 43, p. 9).[1]	Bays to as deep as 25 off Redondo Beach, Calif. (Burch, No. 43, p. 10).[1]
	×											Redondo Beach, Calif., to Nicaragua (Burch, No. 44, p. 19).[1]	Immature in bays and lagoons, full-grown offshore in shallow water (Burch, No. 44, p. 20).[1]
×												Bolinas, Calif., to Scammons Lagoon, Baja California (Burch, No. 44, p. 22).[1]	Common in lagoons. Young living specimens in 20–25 off Redondo Beach, Calif. (Burch, No. 44, p. 20).[1]
		×	×						?	?sp.		Scammons Lagoon, Baja California, to Peru (?) (Woodring, Bramlette, and Kew, 1946, p. 88).	
?			×								?[3]	Sannakh Islands, Alaska, to Todos Santos Bay, Baja California (Burch, No. 42, p. 11).[1]	1 (Burch, No. 42, p. 11).[1] to 270 (Woodring, Bramlette, and Kew, 1946, p. 90) off California.
										×	?	Half Moon Bay, Calif., to Baja California (Burch, No. 42, p. 6).[1]	In surf (Burch, No. 42, p. 6).[1]
								×	cf.			Scammons Lagoon, Baja California, to Peru (Grant and Gale, 1931, p. 347).	
			×	cf.								Santa Monica, Calif., to Gulf of Tehuantepec (Burch, No. 42, p. 7).[1]	Just below low-tide line on sandy beaches, in surf (Burch, No. 42, p. 7).[1]
?	×	cf.	×	×			×	×	×	?		Extinct	
												Aleutian Islands to San Quintin Bay, Baja California (Burch, No. 42, p. 13).[1]	

TABLE 4.—*Fossils from Towsley*

	Locality (table 11)															
	Towsley formation				Pico formation											
	Santa Susana Mountains		North of San Gabriel fault		North of Santa Clara River valley											
	F16	F17	F18	F19	F41	F42	F43	F44	F45	F46	F47	F48	F49	F50	F51	F52
Pelecypods—Continued																
P. tenerrima (Carpenter)								cf.R					?			cf.×
Psephidia lordi (Baird)?								C								
Petricola carditoides (Conrad)?																
Trachycardium quadragenarium (Conrad)			cf.		cf.R	cf.		?sp.R								cf.
Laevicardium cf. *L. substriatum* (Conrad)																
Pratulum centifilosum (Carpenter)					C			C			cf.	×	×			
Chama pelludica Broderip?									×							
Pseudochama exogyra (Conrad)?									×							
Gari edentula (Gabb)													?			
Mya arenaria Linné?																×
Cryptomya californica (Conrad)																×
Sanguinolaria? cf. *S. nuttallii* Conrad					R											
Tagelus subteres (Conrad)?																
Panomya sp.											×					
Corbula luteola Carpenter		×														
(*Varicorbula*) *gibbiformis* Grant and Gale.								R	×			×				
Solen cf. *S. perrini* Clark					R		R	C	×		sp.	sp.				
Siliqua sp.											×					
Panope generosa Gould			?		sp.R		sp.R	cf.R				?sp.			?	
Thracia trapezoides Conrad									?							
Pandora punctuata Conrad								cf.R								
Cardiomya cf. *C. planetica* Dall								R								
Echinoids:																
Dendraster cf. *D. diegoensis diegoensis* Kew.																
D.? sp. indet															×	
Brissopsis pacifica (A. Agassiz)?									×							
Barnacles:																
Balanus cf. *B. aquila* Pilsbry																
sp.									×			×				
Mammal (identified by Remington Kellogg):																
Illium of unidentified small cat					×											

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[1] From unpublished minutes of the Conchological Society of Southern California, compiled by J. Q. Burch.
[2] A smooth species unlike any described fossil of Recent trochid from Pacific coast.
[3] Identified in the field by J. G. Vedder.

and Pico formations—Continued

Locality (table 11)—Continued												Present habitat	
Pico formation—Continued													
North of Santa Clara River valley—Continued				South of Santa Clara River valley									
F59	F60	F61	F62	F76	F77	F78	F79	F80	F81	F82	F85	Geographic range	Bathymetric data (depth in fathoms)
		?cf.		cf.					cf.		cf.	Vancouver, British Columbia to Cape San Lucas, Baja California (Burch, No. 42, p. 12).[1]	Littoral to 25 off Redondo Beach, Calif. (Burch, No. 42, p. 12).[1]
											?sp.[3]	Unalaska, Alaska, to Coronados Islands, Baja California (Burch, No. 42, p. 16).[1]	4–30 (Burch, No. 42, p. 16; No. 43, p. 34).[1]
				×								Vancouver Island, British Columbia, to Magdalena Bay, Baja California (Burch, No. 42, p. 19).[1]	Littoral to 40 (Burch, No. 42, p. 19).[1]
cf.	cf.	?sp.	×	cf.		cf.			sp.			Santa Barbara, Calif., to Todos Santos Bay, Baja California (Burch, No. 41, p. 21).[1]	Upper reaches of estuaries to as deep as 75 off Redondo Beach, Calif. (Burch, No. 41, p. 21, 22).[1]
								×				Point Mugu, Calif., to Acapulco, Mexico (Burch, No. 41, p. 26).[1]	Common in sloughs and bays. As deep as 25 off Redondo Beach, Calif. (Burch, No. 41, p. 26).[1]
		?cf.				?			?			Bodega Bay, Calif., to Baja California (Burch, No. 41, p. 27).[1]	16–108 off California (Woodring, Bramlette, and Kew, 1946, p. 90).
												Oregon to Chile (Burch, No. 39, p. 18) [1]	On rocks, pilings, etc. from just below low-tide mark to 25 off Redondo Beach, Calif. (Burch, No. 39, p. 18).[1]
				×								Oregon to Panama (Burch, No. 39, p. 19).[1]	Intertidal (Burch, No. 39, p. 19).[1]
			×									Redondo Beach, Calif., to San Diego, Calif. (Burch, No. 43, p. 22).[1]	Shallow water, perhaps 15 off Redondo Beach, Calif. (Burch, No. 43, p. 22).[1]
												Circumboreal, south to Vancouver Island(?); introduced into San Francisco Bay (Burch, No. 44, p. 26).[1]	Commonly on mud flats at low-tide line (Ricketts and Calvin, 1952, p. 303, 304).
												Chicagoff Island, Alaska, to Topolobampo, Mexico (Burch, No. 44, p. 26).[1]	Common in bays and lagoons, but also along open coast (Burch, No. 44, p. 27).[1]
												Monterey, Calif., to Magdalena Bay, Baja California (Burch, No. 43, p. 22).[1]	Mainly estuarine and lagoonal (Burch, No. 43, p. 22).[1]
										×		Santa Barbara, Calif., to Panama (Burch, No. 43, p. 23).[1]	Intertidal in bays (Burch, No. 43, p. 23).[1]
												Monterey, Calif., to Acapulco, Mexico (Burch, No. 44, p. 28).[1]	Littoral to 25 (Burch, No. 44, p. 29).[1]
		×						×		×		Extinct	
×	sp.	sp.	×	sp.			?sp.		sp.			do.	
?		cf.×	?	?					?		×[3]	Forrester Island, Alaska, to Scammons Lagoon, Baja California (Burch, No. 44, p. 29).[1]	Deep mud, especially in lagoons and bays (Burch, No. 44, p. 30).[1]
			×									Craig, Alaska, to Redondo Beach, Calif. (Burch, No. 45, p. 9).[1]	16 (Woodring, Bramlette, and Kew, 1946, p. 90) to 75 (Burch, No. 37, p. 13).[1]
			cf.								×	Vancouver Island, British Columbia, to Gulf of California (Burch, No. 38, p. 3).[1]	Below lowest tide line to 25 off southern California (Burch, No. 38, p. 3).[1]
												Bering Sea to Coronado Islands, Baja California (Burch, No. 38, p. 13).[1]	35–202 off California (Burch, No. 39, p. 5).[1]
											×	Extinct	
	×												
												Off southern California; Gulf of California (Grant and Hertlein, 1938, p. 126).	20–780 (Woodring and Vedder, written communication, 1953).
		×											
									×		×		

have not been transported. Shark teeth, not noted in previous lists of fossils, are numerous at some places.

North of San Gabriel fault

Collections were made from two localities, F18 and F19, in the Towsley formation in sec. 20, T. 4 N., R. 15 W. The species are listed in table 4. This list includes *Norrisia norrisi* (Sowerby)?, "*Drillia*" cf. "*D*". *graciosana* Arnold, and *Eucrassatella* aff. *E. fluctuata* (Carpenter) not previously recorded from the Ventura basin (Vedder and Woodring, written communication, 1953).

Kew (1924, loc. 3591) lists fossils collected from the Towsley formation in sec. 32, T. 4 N., R. 15 W. including the following species[2]: *Chione fernandoensis* English, *Phacoides annulatus* Reeve (=*Lucinoma annulata* (Reeve)), *P. nuttalli* Conrad (=*Lucinisca nuttalli* (Conrad)), *P. sanctaecrucis* Arnold? (=?*Miltha xantusi* Dall), *Tellina idae* Dall?, *Actaeon* (*Rectaxis*) cf. *A. punctocoelata* Carpenter, *Cancellaria elsmerensis* English, *C. fernandoensis* Arnold (=?"*C.*" *tritonidea* var. *fernandoensis* Arnold), *C. tritonidea* Gabb, *Columbella* (*Astyris*) cf. *C. tuberosa* Carpenter (=*Mitrella* cf. *M. tuberosa* (Carpenter)), *Mitra tristis* Swainson, *Nassa californiana* Conrad (=?"*N.*" *moraniana* Martin), *Natica recluziana* Petit (=*Nererita reclusiana* (Deshayes)), *Terebra simplex* Cooper (=?*Strioterebrum pedroanum* Dall), *Trophosycon nodiferum* (Gabb) (=?*T. ocoyana* var. *ruginodosa* Grant and Gale), *Turris* (*Bathytoma*) *cooperi* Arnold (=*Megasurcula cooperi* (Arnold)), and *Turritella cooperi* Carpenter.

About 1 mile east of the area shown on the geologic map (pl. 44), in sec. 27, T. 4 N., R. 15 W., Gale (Grant and Gale, 1931, p. 30) collected *Patinopecten healeyi* var. *lohri* (Hertlein) and *Trophosycon ocoyana* (Conrad) from beds of lithology similar to those in sec. 32.

Environment Suggested

Attempts to define the environments that were occupied by fossil assemblages involve the assumption that the ecologic requirements of a species remain fairly constant through time, or that living close relatives of extinct species have habitats similar to those of their fossil relatives. It is further assumed that any physiological changes that develop in the species during the course of time will be reflected in some morphological change. That these assumptions may not be entirely valid is suggested by many instances in California and elsewhere of late Tertiary assemblages which contain at one locality and in one bed a mixture of species whose modern representatives live in habitats greatly different from one another. At many places a part of the mixing stems from the fact that remains of organisms that lived under many different ecologic conditions were transported and brought together after death. Just as streams carry plant remains from many different altitudes and deposit these remains together on a flood plain, so also waves and longshore currents and particularly submarine slides and turbidity currents may transport organic remains far from the places where the organisms lived. The opportunities for mixing of assemblages from various depths are especially favorable where sliding or turbidity currents are operative.

It is well known that some animals that live in shallow water in northern regions are found only in deeper water in more southerly regions, owing, apparently, to the temperature requirements of the animals. The presence of shallow-water fossils in coarse-grained rocks has led some workers to conclude, sometimes incorrectly, that the environment of deposition was necessarily in shallow water. Inferences about water temperatures that do not take into account the possible mixing of species from several depth zones are therefore not realistic. Even after mixing of species from several depth zones is considered, some fossil faunas still show a residue of anomalous associations of species. Many of the anomalies can be understood by considering the variety of environments available to marine organisms, even in shallow water. Such factors as salinity, exposure to waves, character of the bottom, and temperature, to mention but a few, vary irregularly within short distances along a coast. For example, the local upwelling of cold water, a very common phenomenon along the California coast, permits species generally found only in cool deep water to live locally in shallow water. The great variety of ecologic niches occupied by organisms within a small area and the possibility of faunas from several of these habitats being mixed mean that inferences about past environments must be based on communities rather than on selected individual species.

As pointed out by Woodring and Trumbull who identified the collection (written communication, 1952), the fauna from locality F17 in the Santa Susana Mountains is a mixture of species whose modern representatives live in different depth zones. In table 4 the bathymetric distribution of the Recent forms is shown;[3]

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[2] The names in parentheses are translations by Winterer of the nomenclature used by Kew into more recently accepted terminology.

[3] The data for both the bathymetric and geographic distribution of Recent forms were compiled by E. L. Winterer, who prepared the discussion of paleoecological interpretations, except where otherwise noted.

the bathymetric range of mollusks from locality F17 is given in the table below:

[Compiled by E. L. Winterer from data on referred fossils by Woodring and Trumbull (written communication, 1952)]

Water depth (feet)	*Mollusk*
Deep (more than 600)	*Yoldia* aff. *Y. beringiana* Dall
	Calyptogena lasia (Woodring) (related to *C. pacifica*)
Moderate (60–600, but ranging into deep).	*Solariella* aff. *S. peramabilis* Carpenter
	Fusitriton oregonensis (Redfield)
	Barbarofusus aff. *B. arnoldi* (Cossmann)
	Cyclocardia aff. *C. barbarensis* (Stearns)
Moderate (60–600)	*Turritella cooperi* Carpenter
	Kelletia cf. *K. kelletii* (Forbes)
Shallow (less than 60, but ranging into moderate).	*Tegula* cf. *T. ligulata* (Menke)
	Crepidula cf. *C. onyx* Sowerby
	Neverita reclusiana (Deshayes)
	Aletes squamigerus Carpenter?
	Sacella taphria (Dall)
	Aequipecten circularis (Sowerby)
	Lucina excavata Carpenter
	Lucinisca nuttalli (Conrad)
	Lucinoma cf. *L. annulata* (Reeve)
	Tellina idae Dall
	Schizothaerus nuttalli (Conrad)
	Corbula luteola Carpenter
Shallow (less than 60)	*Ostrea vespertina* Conrad
	Amiantis? cf. *A. callosa* (Conrad)
Terrestrial	*Glyptostoma* cf. *G. gabrielense* Pilsbry

According to Woodring and Trumbull (written communication, 1952), "The shallow-water species and those ranging from shallow water to moderate depths * * * are represented for the most part by a few incomplete or worn specimens. Other species, however, also are represented by a few incomplete or worn specimens." The megafauna collected at locality F17 is obviously an assemblage of shells brought together after death; the presence of the shells in association with graded beds suggests that the agent of transportation was a turbidity current. The depth of water at the site of deposition was probably in excess of 600 feet. The modern representatives of the molluscan assemblage at locality F17 live either in shallow water or at moderate depths.

Foraminiferal faunas from the Towsley formation of the Santa Susana Mountains contain such species as *Bulimina rostrata* and *Gyroidina rotundimargo*, suggesting water depths of perhaps 3,000 feet. Forms such as *Robulus cushmani* are known from Recent collections from depths as shallow as 100 feet, while *Bulimina rostrata* ranges downward to 11,000 feet.

The modern representatives and relatives of the fauna of the Towsley formation in the Elsmere Canyon area live in shallow water or in water ranging from shallow to moderate depths. The abundance of paired pelecypod valves and the stratigraphic position of the fossils, near the base of the formation where it rests unconformably on older rocks, seem to indicate that the shells were not transported far, if at all, from their life habitats, and that the water was shallow or only moderately deep during deposition of the fossiliferous part of the formation.

One foraminiferal fauna from the Towsley formation at Elsmere Canyon (loc. f36) is difficult to evaluate bathymetrically. Depth ranges of some of the species in that fauna, based upon the range of closely allied modern forms living off California, are; *Cassidulina translucens*, 400–6,000 feet, *Cibicides mckannai*, 300–3,330 feet, *Epistominella pacifica*, 700–6,500 feet, and *Uvigerina peregrina*, 500–8,000 feet. Locality f36 is little more than 150 feet above the base of the formation and only 100–140 feet above numerous shallow-water mollusks.

The fauna at locality F18, north of the San Gabriel fault near the base of the Towsley formation, consists of moderate-depth species such as *Terebratalia occidentalis*, *Calyptrea* cf. *C. fastigiata*, *Turritella cooperi* subsp., and *Eucrassatella* aff. *E. fluctuata;* species that range from shallow to moderate depths such as *Acmaea?* cf. *A. mitra*, *Olivella* cf. *pedroana*, and *Trachycardium* cf. *T. quadragenarium;* and shallow-water species such as *Panope generosa?*.

At locality F19, several hundred feet stratigraphically above locality F18, no strictly shallow-water species were collected. Species that range from shallow into moderate depths include *Neverita reclusiana*, *Olivella pedroana*, and *Saccella* cf. *S. taphria*. Two species, *Boreotrophon* cf. *B. stuarti* and *Compsomyax?* cf. *C. subdiaphana* range from moderate depths into deep water.

Foraminiferal faunas from localities f37 to f40 (close to locality F18) are dominated by species whose Recent relatives can nearly all be found at depths of from 500 to 1,000 feet. Some species, for example, *Buliminella elegantissima*, range into quite shallow water, while several others range to depths of more than 3,000 feet.

The geographic range of the Recent close relatives of the fossils found in the Towsley formation provides a basis for inferences about environments during the time the formation was being deposited. Table 5 shows the geographic affinities of fossils in the Towsley formation having living close relatives.

The southern affinities of all the species collected from the Towsley formation that are confined strictly to a very shallow habitat are further emphasized by the fact that their modern relatives range at least as far

TABLE 5.—*Geographic range of Recent species related to fossils from the Towsley formation*

[Data compiled by E. L. Winterer]

Water depth	Present status in relation to latitude of Ventura, Calif.	Fossil	Locality		
			Santa Susana Mountains	Elsmere Canyon	North of San Gabriel fault
Shallow or ranging from shallow to moderate.	Recent species and Recent relatives extinct, but now living farther south.	*Turritella* cf. *T. gonostoma* var. *hemphilli* Applin	X		
		Bittium cf. *B. asperum* (Gabb)		X	
		Ostrea vespertina Conrad	X		
		Miltha xantusi Dall		X	
		Lucina excavata Carpenter	X	X	
		Spisula hemphilli (Dall)	X	X	
		Dosinia ponderosa (Gray)	X	X	
		Amiantis callosa (Conrad)	X	X	
	Recent species and Recent relatives living at or near northern limits of their range.	*Neverita reclusiana* (Deshayes)	X	X	X
		Maxwellia gemma (Sowerby)		X	
		Kelletia cf. *K. kelletii* (Forbes)	X	X	
		Tellina idae Dall	X	X	
		Apolymetis biangulata (Carpenter)		X	
		Trachycardium quadragenarium (Conrad)		X	X
	Recent species extinct, but now living farther north	*Mya truncata* Linné		X	
	Recent relative living at or near southern limits of its range.	*Megasurcula* cf. *M. carpenteriana* (Gabb)	X	X	
Moderate and deep	Recent relative extinct, but now living farther south	*Elaeocyma* aff. *E. empyrosia* (Dall)	X		
	Recent relatives living at or near northern limits of their range.	*Eucrassatella* aff. *E. fluctuata* (Carpenter)			X
		Cyclocardia aff. *C. barbarensis* (Stearns)	X		
	Recent species and Recent relatives extinct, but now living farther north.	*Cryptonatica aleutica*? Dall	X		
		Chlamys islandicus hindsii (Carpenter)			X
		Macoma cf. *M. calcarea* (Gmelin)	X		
	Recent species and Recent relatives living at or near southern limits of their range.	*Calyptraea* cf. *C. fastigiata* Gould			X
		Fusitriton oregonensis (Redfield)	X		
		Yoldia beringiana Dall	X		
		Calpytogena lasia (Woodring)	X		

south as Todos Santos Bay, Baja California. This range indicates that temperatures in shallow water during deposition of the Towsley formation were probably several degrees warmer than they are at Ventura today. *Mya truncata*, however, which is in the shallow-water assemblage at Elsmere Canyon and also at some other shallow-water Pliocene localities in California, does not range south of Puget Sound today. The anomalous occurrence of this circumboreal species in a "southern" fauna may have an explanation similar to that given for some of the anomalous associations recorded in late Tertiary floras. Axelrod (1941) reviewed the floral problem and concluded that in the past some species may have had a tolerance for a broad range of environments, but that "ecotypes" adapted to certain of these environments may later have been eliminated. The modern representatives of the species may occupy a narrow ecologic niche greatly different from those occupied by some of the fossil members. Woodring (Woodring, Bramlette and Kew, 1946, p. 102; Woodring and Bramlette, 1950, p. 99) has warned against blind reliance on present geographic and bathymetric distribution as an index to the environmental conditions under which a species may have lived in the past.

PLIOCENE SERIES

PICO FORMATION

Throughout most of the eastern Ventura basin the Towsley formation is overlain by the marine Pico formation. The Pico formation consists chiefly of light olive-gray and medium bluish-gray siltstone and fine-grained silty sandstone, containing small reddish-brown concretions, and light-colored sandstone and conglomerate. In the western part of the area the sandstone and conglomerate constitute a minor portion of the formation. In the easternmost part of the area the converse is true; there the formation consists largely of sandstone and conglomerate.

The Pico formation is distinguished from the Towsley formation largely by the presence in the Pico of olive-gray soft siltstone that generally contains small limonite concretions. The lower part of the Pico very closely resembles the upper part of the Towsley formation; the contact is drawn at the base of the first prominent sandstone or conglomerate unit below the lowest bed of olive-gray concretion-bearing soft siltstone. The stratigraphic level of the contact is not exactly the same everywhere. In the area around San Fernando Pass the characteristic siltstone of the Pico formation is present only in minor amounts; there the base of the Pico is placed at the base of the sandstone and conglomerate units that overlie the brown-weathering siltstone and fine-grained sandstone of the Towsley. The Towsley and Pico formations interfinger in the area near San Fernando Pass. At Elsmere and Whitney Canyons the base of the Pico formation is an unconformity.

The Pico formation is entirely marine but interfingers at the top with normal marine, brackish-water, lagoonal, and nonmarine beds of the Sunshine Ranch member of the Saugus formation. Figure 54 illustrates dia-

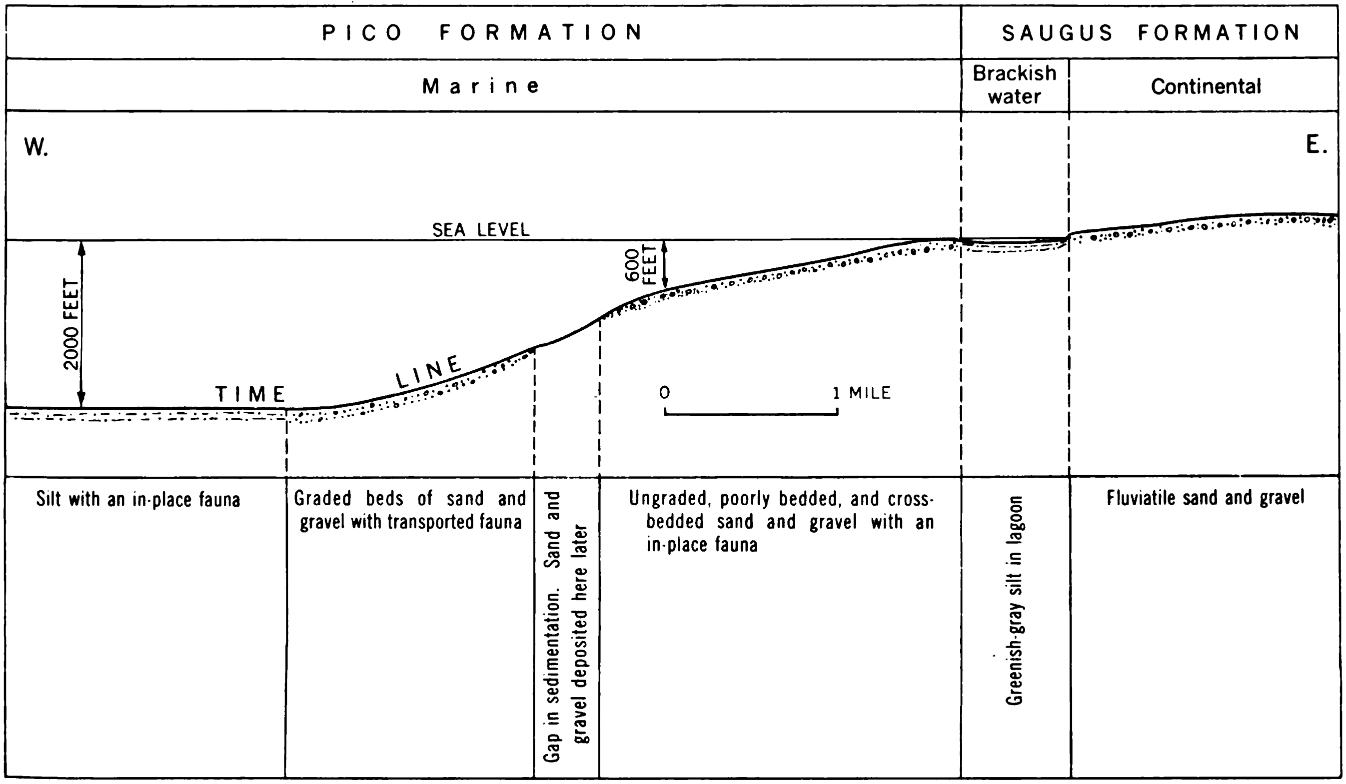

FIGURE 54.—The relation between contemporary upper Pliocene deposits of the Saugus and the Pico formations.

grammatically the conditions resulting in the contemporaneous deposition of the marine Pico formation and the nonmarine Saugus formation. Minor fluctuations in the position of the shoreline together with the general retreat of the sea westward as the basin filled resulted in an interfingering relationship of the marine and nonmarine beds. In the western part of the area the Pico formation is about 5,000 feet thick; in the eastern part of the area, near the Placerita oil field, it is only a few hundred feet thick.

STRATIGRAPHY AND LITHOLOGY

Newhall-Potrero Area

South of the Santa Clara River in the area between the Los Angeles-Ventura County line and the Newhall-Potrero oil field the Pico formation is 5,000 or more feet thick and consists chiefly of light olive-gray, generally poorly bedded soft siltstone. Potrero Canyon, a broad lowland containing the Newhall-Potrero oil field, is formed in this soft siltstone.

The siltstone generally contains many ellipsoidal concretions, most about 1 inch, but some as much as 6 inches in diameter. The concretions are dark yellowish orange and weather to light brown and moderate brown. The cementing material in the concretions is a carbonate. Closely similar concretions occur in the Santa Barbara formation, of early Pleistocene age, in the Ventura region. In well cores the concretions in the Santa Barbara formation contain ankerite (Bailey, 1935, p. 492). Slopes developed on weathered siltstone of the Pico formation are commonly strewn with concretions.

The siltstone contains Foraminifera but not in great abundance. A few hundred individuals can be recovered from an average 100 cc sample. Paired valves of small thin-shelled pelecypods, such as *Yoldia scissurata* and *Macoma*, and poorly preserved mollusks, as well as echinoid spines and external molds of echinoids, are scattered in the siltstone.

Interbedded with the siltstone are layers a few inches thick of pale-olive fine-grained silty sandstone that weathers to a dark yellowish orange. In the lower part of the formation many of the sandstone beds are graded and closely resemble graded beds in the Towsley formation. In the upper part of the formation the beds of sandstone are commonly not noticeably graded. Occasional thin beds of grayish-olive brittle claystone are interbedded in the siltstone.

In the lower third of the formation, units of light brownish-gray sandy mudstone that weather to a moderate brown alternate with units of siltstone. The brown-weathering jarositic mudstone is indistinguishable from the mudstone in the upper part of the Towsley formation (p. 289) with respect to lithology and weathering characteristics.

Lenses of interbedded conglomerate and sandstone ranging in thickness from a few inches to as much as 500 feet are common in the lower half of the formation. These lenses tend to form bold topographic features, and a few can be traced for several miles; other lenses extend for less than 100 yards. Very abrupt lateral gradations from conglomerate to siltstone are common. At places a thickness of as much as 20 feet of sandstone and conglomerate grades laterally into siltstone in a distance of less than 20 yards.

The conglomeratic lenses closely resemble the conglomeratic units of the Towsley formation. The coarsest beds, consisting chiefly of cobbles, are generally several feet thick and nearly homogeneous in texture throughout their thickness. Beds consisting of pebbles and sand grains are commonly graded. Load casts are not uncommon in the graded beds, and at many places shallow channels were cut into the underlying beds. Sets of small-scale cross laminae, so common in the Towsley formation, are only in the lower beds in the Pico formation. Slump structures occur at a few places in the sandstone beds, but convolute bedding is not known. Beds containing small angular bits of charcoallike material are common, especially in the lower part of the formation. The sandstone and conglomerate beds contain mollusks at many places, but the shells are generally concentrated in local lenses and pods. Paired pelecypod valves do not occur at these localities and many of the shells are broken or worn. Counts of pebbles from conglomerate beds at several places in the Pico formation in the mapped area showed that the conglomerate is very similar to that in the Towsley formation with respect to kinds of clasts and to their relative abundances (p. 290).

In the uppermost parts of the Pico formation the olive-gray soft siltstone is more fossiliferous than similar rocks lower in the formation and is interbedded with nearly white or cream-colored massive thick-bedded conglomeratic sandstone and dusky-yellow silty sandstone. Paired valves of large pelecypods such as *Saxidomus* and *Panope* are not uncommon in the uppermost siltstone beds. The silty sandstone beds are very fossiliferous in some places, with *Ostrea vespertina*, *Pecten hemphilli*, *P. stearnsii*, and paired valves of *Cyclocardia* cf. *C. ventricosa* especially abundant at some places. The beds of pebbly sandstone contain *Dendraster*, oysters, and pectens at many places (identifications by Winterer).

Newhall-Potrero oil field to East Canyon

Eastward from the southeastern part of the Newhall-Potrero oil field the siltstone beds in the upper three-fifths of the Pico formation grade laterally into marine sandstone and conglomerate beds which in turn grade into brackish-water and nonmarine beds of the Saugus formation. The contact between the two formations occurs at lower and lower stratigraphic levels eastward beyond Pico Canyon. Near the southeast end of the Newhall-Potrero oil field the Pico formation is about 5,300 feet thick; 4 miles farther southeast, near East Canyon, the rocks assigned to it are only about 2,000 feet thick. The decrease in the thickness results wholly from lateral gradation in the upper part of the formation, as can be demonstrated by tracing several persistent units of conglomerate and sandstone eastward from the oil field. These beds in the middle of the Pico near the oil field extend eastward into the Saugus. The mapping of these persistent units showed that the thickness of the part of the formation below the traced beds actually increases eastward, and that all the decrease in thickness of the formation as a whole takes place in its upper part.

The most abrupt lateral graduation from siltstone to sandstone and conglomerate is at the southeast end of the Newhall-Potrero oil field, where a sequence of siltstone beds about 800 feet thick grades eastward into sandstone and conglomerate in a horizontal distance of about 1,000 feet. The exposure in the transition zone between the sandstone and conglomerate beds and the siltstone beds are sufficient to exclude the possibility of major faulting.

Many of the sandstone and conglomerate beds in the transition zone are graded. Figure 55 shows thick beds of conglomerate and sandstone alternating with thinner beds of dark-colored siltstone and fine-grained sandstone exposed near the southeast edge of the Newhall-Potrero oil field. The sandstone and conglomerate beds are graded, show marked changes of thickness, channel underlying beds, and contain slump structures and angular siltstone fragments. The conglomerate grades upward without a break into sandstone that contains scattered blocks of siltstone. The next overlying bed likewise grades from conglomerate to sand; in fact, all the sandstone and conglomerate beds at this exposure are graded.

Eastward the graded bedding in the transition zone becomes more obscure, and in a distance of about half a mile the beds show no grading and are slightly more conglomeratic. Scattered fragments of marine mollusks occur in the sandstone and conglomerate beds near the transition zone, but farther east fossils are lacking. Still farther east equivalent strata are mapped as part of the Saugus formation. The conditions of deposition are discussed on pages 309, 319, 320, and 325.

In the area between Little Moore Canyon and San Fernando Pass, the upper part of the Pico formation is quite fossiliferous. At some places, especially in the

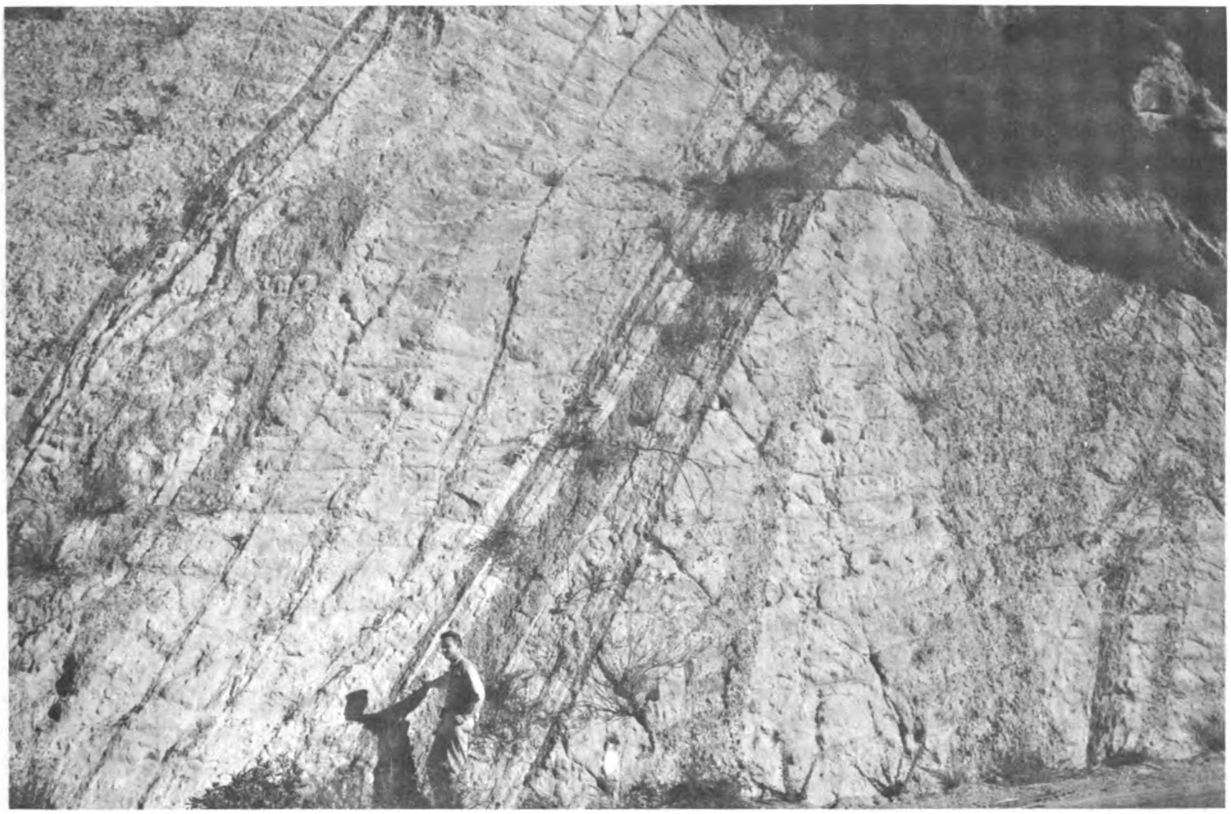

FIGURE 55.—Conglomerate, sandstone, and siltstone beds of the Pico formation near the southeast end of the Newhall-Potrero oil field. Near right edge of photograph, a thick bed of conglomerate rests on an eroded surface; beds beneath the conglomerate are cut out to depths of at least 4 feet. Sandstone beds in the center have marked changes of thickness, a very characteristic feature of the beds in this area. In the upper left, conspicuous slump structures are shown.

more conglomeratic beds, the fossils are broken and worn, but at many places paired pelecypod valves are common. Near the mouth of Towsley Canyon several beds yield numerous specimens of a smooth form of *Terebratalia occidentalis* (identified by Winterer).

Mouth of East Canyon to San Fernando Pass

Beginning at a point near the mouth of East Canyon, many tongues of sandstone and conglomerate appear in the Pico formation throughout its thickness. These tongues thicken eastward at the expense of the intervening units of siltstone and fine-grained sandstone. In the uppermost part of the formation near East Canyon some of the more sandy units are cross-stratified. Eastward large-scale cross-stratification appears in units progressively lower in the formation. At San Fernando Pass even the lowest part of the formation contains large-scale sets of cross-strata (fig. 53).

The lower part of the formation consists of the typical light olive-gray soft siltstone and fine-grained silty sandstone alternating with lenticular units of resistant conglomerate and sandstone. Graded bedding is prevalent in the coarse-grained units from East Canyon to the divide between Gavin and Weldon Canyons.

Megafossils are very abundant in some of the fine-grained beds in the upper part of the formation and are locally abundant in a few conglomerate lenses.

In the southeast corner of the mapped area (pl. 44), the Pico formation is represented by nearly white, very thick bedded conglomeratic sandstone and minor amounts of gray siltstone. Several 1- to 2-foot beds of reddish-brown to nearly black, hard fine- to coarse-grained sandstone in the upper part of the formation near San Fernando Pass consist almost entirely of magnetite and ilmenite with minor amounts of quartz, feldspar, red garnet, and zircon.

San Fernando Pass to San Gabriel fault

At San Fernando Pass, south of the Beacon fault, the cross-stratified conglomeratic beds in the lower part of the Pico formation interfinger with the brownish siltstone beds of the Towsley formation. North of the Beacon fault an unconformity separates the two formations. Near Elsmere Canyon the Pico formation consists almost entirely of lenticular units of cream-colored and yellowish-brown cross-stratified coarse-grained sandstone and light-brown conglomerate. The conglomeratic beds in the lower part of the formation are tar soaked. The formation is about 1,000 feet thick in the Elsmere Canyon area.

In La Placerita Canyon the base of the Pico formation overlaps the Towsley formation and rests directly on the pre-Cretaceous crystalline rocks. The lower part of the Pico here consists chiefly of lenses of brownish-gray conglomerate and cross-stratified cream-colored pebbly sandstone with minor amounts of fine-grained sandstone and brownish-gray siltstone. In the upper part of the formation, conglomerate beds are less numerous and there are more beds of brownish-gray siltstone and silty sandstone. The upper part of the formation is best developed north of La Placerita Canyon, east of the Placerita oil field.

Santa Clara River to Del Valle fault

The Pico formation is exposed north of the Santa Clara River in three fault blocks: one south of the Del Valle fault, a second between the Del Valle fault and the Holser fault, and a third north of the Holser fault.

A thickness of about 6,000 feet of the Pico formation is exposed in the southward-dipping homocline on the south or hanging-wall side of the Del Valle fault. The gradational contact between the Pico and the underlying Towsley formation is exposed for a short distance near the intersection of the county line and the trace of the fault. The lowest beds of the Pico formation consist of brown-weathering jarositic mudstone alternating with light-brown hard thick-bedded conglomeratic sandstone, light-brown and cream-colored thin-bedded friable fine- to coarse-grained silty sandstone, and light olive-gray siltstone.

In the lower 2,000 feet of the formation the proportion of brown-weathering mudstone to olive-gray siltstone steadily decreases upward to zero. Lenses of sandstone and conglomerate occur throughout the formation, but they are most numerous in the middle part. Graded bedding is common in the sandstone. The lenses are locally very fossiliferous and the fossils are commonly worn and broken although some beds contain very well preserved specimens. Paired pelecypod valves do not occur in the coarse-grained beds but are very common in the siltstone. Throughout the formation the siltstone contains Foraminifera and scattered generally poorly preserved mollusks and echinoids.

The section exposed in this part of the area does not extend to the top of the Pico formation, although the conglomerate in the trough of the syncline near the county line is probably near the top of the formation.

Del Valle fault to Holser fault

The base of the Pico formation is not exposed in the area between the Holser and Del Valle faults. However the beds exposed immediately south of the trace of the Holser fault, in the steep amphitheater just west of the divide between Holser and San Martinez Chiquito Canyons, are very similar in lithology to the lowest part of the Pico south of the Del Valle fault. These beds probably are within 1,000 feet of the base of the formation. In the area of the Ramona oil field a unit that constitutes the lower 2,000 feet of the Pico formation and that lies above the trace of the Holser fault consists chiefly of olive-gray siltstone with a few lenticular units of sandstone and conglomeratic sandstone and brown-weathering mudstone beds in its lower half. In the area near the county line a sequence of nearly white, very thick bedded sandstone and minor lenses of conglomerate overlies the siltstone.

Eastward from the county line, tongues of sandstone, which thicken and coarsen, appear in the Pico at progressively lower stratigraphic levels. Beginning at about the east line of sec. 17, T. 4 N., R. 17 W., mollusks occur in abundance in many of the silty layers between the sandstone beds. The slender form of *Calicantharus humerosus* is very abundant in some beds. Near the divide between San Martinez Chiquito and San Martinez Grande Canyons, beds consisting almost wholly of closely packed shells of *Ostrea vespertina* var. *sequens* are interbedded with the sandstone and siltstone. The oyster reefs are traceable across San Martinez Chiquito Canyon and to the Holser fault. An oyster reef that crops out about 200 feet east of the Texas Malis 1 well in sec. 10, T. 4 N., R. 17 W., yielded a few horse teeth (loc. V84) that Chester Stock identified as *Pliohippus* (oral communication, 1950). East of San Martinez Chiquito Canyon the siltstone beds have a greenish-gray color, rather than the typical olive-gray color of the Pico formation. Beds of reddish-brown sandy claystone are intercalated with the greenish-gray siltstone beds and oyster reefs. Some of the sandstone beds contain numerous sand dollars. Although it is recognized that the red beds may represent nonmarine deposits and that the beds east of San Martinez Chiquito Canyon could be assigned to the Sunshine Ranch member of the Saugus formation, the prevalence of definitely marine fossils, such as *Dendraster*, at so many places is believed to be justification for including in the Pico formation all the beds below the uppermost echinoid-bearing beds.

Area north of Holser fault

North of the Holser fault near the head of Holser Canyon the Pico formation consists of light-tan fine- to medium-grained sandstone and gray siltstone, with a minor amount of conglomerate. The sandstone is, for the most part, well bedded, individual beds being a few inches to several tens of feet thick. The siltstone contains thin hard limy beds and, on the north side of Holser Canyon near its head, both the siltstone and the hard limy beds contain abundant marine fossils.

Fossils are also present, but not abundant, in the sandstone.

FOSSILS

Foraminifera

Several sections across the Pico formation were sampled systematically to determine the faunal succession at various places in the eastern Ventura basin. Plate 47 shows four such sections in graphic form. Plates 48 and 49 show the fauna from each sample, 102 species from 343 localities. The locations of the sections are shown on the geologic map (pl. 44); the numbers at the ends of the traverse legs on the map correspond to the numbers on the columnar sections (pl. 47). At some places the traverse legs are tied by key beds; at other places, where key beds are lacking, the relative stratigraphic position of the partial sections was determined by projection of strike lines. The positions of the samples were determined in the field with tape and Brunton compass. Where no relatively fresh rock was at or near the surface, holes were dug with a hand auger to obtain less weathered material.

Nearly all the faunas from Pico Canyon (pl. 48) were picked by T.R. Fahy. Identifications and abundance counts were made by Patsy B. Smith on both picked and unpicked material. Where Foraminifera were especially abundant, samples were split by hand, all specimens in a split fraction counted, and the totals multiplied by the number of splits.

Temperature and depth information for Recent species was compiled and charted by Patsy B. Smith. The following faunal and paleoecologic discussion involving Foraminifera is taken from written and oral communications from her (1953–1954).

In the lower part of the Pico Canyon section are found *Bolivina pisciformis*, *B. seminuda*, *Bulimina subacuminata*, *Cassidulina cushmani*, *C. delicata*, *Cibicides mckannai*, *Gyroidina rotundimargo*, *Epistominella pacifica*, *E. bradyana*, *Uvigerina peregrina*, and *Bolivina argentea*. Several species, including *Cibicides mckannai*, *Uvigerina peregrina*, and *Epistominella pacifica*, are present to the top of the section. *Gyroidina rotundimargo* is not present above sample fP66. *Nonion pompilioides* is not in the lower part of the section but is in samples fP59 through fP153. *Cassidulina limbata* occurs in sample fP98 and continues nearly to the top of the section. *Gaudryina arenaria* comes in abundantly near sample fP97. *Angulogerina angulosa* becomes abundant at sample fP120 and continues to the top. *Cassidulina californica* has its base at sample fP139.

The succession in the Towsley Canyon section seems to be a rather compressed version of the Pico Canyon succession. Samples stratigraphically below number fT16 were nearly all barren. The base of the Pico formation is near the horizon of sample fT14. Some of the species present in the lower part of the Pico Canyon section, such as *Bolivina seminuda* and *Bulimina subacuminata*, do not occur in the Towsley Canyon section. *Gyroidina rotundimargo* and *Cibicides mckannai* are present below sample fT32, and *Bolivina argentea* ranges from sample fT29 through fT35. *Bolivina pisciformis*, *Uvigerina peregrina*, *and Epistominella pacifica* are present throughout the section. *Cassidulina limbata* does not occur in the section, but *Angulogerina angulosa*, *Nonion scaphum*, and *Bulimina pagoda* are present in the upper part of the column.

The Gavin Canyon section, which includes only the upper part of the Pico formation, has even fewer species than the Towsley Canyon section. *Cibicides mckannai* is absent and *Nonion pompilioides* occurs only in the lowest sample. The fauna is similar to that in the upper part of the Towsley Canyon section.

The Weldon-Gavin Divide section, barren below sample fW16, contains a rather meager fauna, consisting chiefly of *Epistominella pacifica*, *E. subperuviana*, and *Uvigerina peregrina*. The fauna resembles that in the Gavin Canyon section.

All the foraminiferal species present in all sections also occur in Recent sediments, with the exception of *Bolivina pisciformis*. No foraminiferal species represented is a guide fossil in any restricted sense. On the other hand, the assemblages have ecologic significance. The sequence of faunas in the Pico Canyon foraminiferal section suggests a shallowing of the water during deposition of the Pico formation. However, the Pico formation in this area does not have the orderly progression of faunas indicative of a continually shallowing sea that was inferred by Natland (1933, p. 225–230), Natland and Kuenen (1951, p. 76–107), and Bandy (1953b, p. 200–203) for the formation in the western part of the Ventura basin.

In an effort to determine the temperature and depth of water during the deposition of the Pico formation, comparison was made of the conditions under which the Pico foraminiferal species must have lived with those off the coast of California under which Recent forms of the same species now live. The temperature and depth information for Recent species compiled by Patsy B. Smith from Natland (1933), Crouch (1952), Butcher (1951), and Bandy (1953a) is given in column *C* on plates 48 and 49. The maximum and minimum temperatures and depths reported for Recent species in these sources are used as maximum and minimum ranges for the species on the checklist. No distinction was made in the studies between empty tests and live Foraminifera from the various depth and temperature regions. The possibility of shallow-water species being transported into much deeper water after death should not be discounted when evaluating the depth and temperature ranges for Recent forms. The isopleth maps prepared by Butcher for population density of *Cassidulina limbata* are instructive in that they show the depth at which tests of that species are most abundant off San Diego. This depth is near the top of the total depth range of tests collected.

The maximum and minimum depth and temperature ranges are plotted on plates 48 and 49, diagrams *E* and *F*, for species with five or more individuals in the sample. Samples with the largest faunas are plotted, and with few exceptions there is found to be a depth and temperature range common to all species plotted. The main exceptions to this common range are *Nonion pompilioides* and *Pullenia bulloides*, whose minimum depths in the Eastern Pacific Ocean are reported to be 6,500 feet. They occur abundantly from sample fP59 to sample fP147 of the Pico Canyon section, as do 18 other species whose common depth is around 3,000 feet.

The association of these two very deep-water forms with such forms as *Cassidulina limbata*, *C. quadrata*, *Bulimina denudata*, and *Gaudryina arenaria* is puzzling. It is possible that the shallow-water forms are not indigenous and that the tests were transported into deep water after the death of the animals. However, evidence that at least part of the Pico Canyon section was deposited in shallow water or water of moderate depth is furnished by the presence of a few paired valves of *Schizothaerus*, a shallow- to moderate-depth pelecypod, in the upper part of the section in geographic and stratigraphic positions close to the two deep-water species of Foraminifera. It is unlikely that the deep-water forms were reworked, as the sources of the Pico sediments lay generally to the east of the Pico Canyon section, and in that region there is no other evidence to indicate erosion in Pico time of deposits which would contain these two deep-water species. It seems more likely that *Nonion pompilioides* and *Pullenia bulloides* ranged into shallower water in this region during the Pliocene than they do today. *N. pompilioides* has been reported in Recent beach sands on the east coast of Japan in association with "*Rotalia*" *beccarii* (Linné) var. (Harrington, 1955, p. 126).

Ignoring the few aberrant species, a range of probable water depth and temperature during deposition of the Pico Canyon section can be postulated (pl. 48 diagrams *E* and *F*): Apparently, the water shallowed from a depth of 2,000-3,000 feet during deposition of the lower part of the section, to a depth of 600–1,600 feet during deposition of the upper part.

The possible depth and temperature range indicated by the Towsley Canyon section is much greater than that indicated by the Pico Canyon section (pl. 49, diagrams *E* and *F*), although it seems probable, from the geographic position of the Towsley Canyon section, that the water there would be shallower at any particular time.

During deposition of the Gavin Canyon section the water was probably never much deeper than 1,500 feet and may have been considerably shallower. The Gavin Canyon section, too, shows evidence of shallowing water and of increasing temperatures toward the top (pl. 49 diagrams *E* and *F*).

The fauna in the Weldon-Gavin Divide section is too sparse to give significant information about depth and temperature of deposition, although the abundance of cross-stratified coarse sediments suggests a near-shore deposit.

The Holser-Del Valle section is west and north of the previously discussed sections. It, like the Towsley Canyon section, shows wide and indefinite depth and temperature ranges.

On plate 47, dashed lines are drawn between the four columnar sections to relate the highest or lowest occurrences of certain species. The solid double lines connect key horizons that can be correlated from one section to another. The correlations between sections were made by tracing a mappable conglomerate and sandstone unit as far as possible, offsetting a known stratigraphic distance to another mappable conglomerate and sandstone unit, and then tracing it as far as possible. This process was repeated as many times as necessary until the next section was reached. The correlation point then was located by compensating for the amount of stratigraphic offset made in tracing mappable lithologic units between the sections. The conglomerate and sandstone beds probably were deposited almost instantaneously by currents and they may therefore be treated as time lines. The crossing of faunal lines, marking depth of water, and time lines, represented by key beds between the Towsley Canyon and Pico Canyon sections, is interpreted to mean that the individual beds were deposited on a slope that extended from relatively shallow water at Towsley Canyon to relatively deep water at Pico Canyon.

The range of depth of water represented by any foraminiferal sample in the sections shown on plate 47 can be approximated by an inspection of data on diagram *F* on plates 48 and 49. For the Pico, Towsley, and Gavin Canyon sections, the diagram shows a general trend from deeper water faunas at the base of the sections to shallower water faunas at the top. If a nearly uniform rate of shoaling is assumed for each section, a nearly straight line that stays always within the upper and lower depth tie lines can be drawn through the depth-range diagram (*F* of pls. 48 and 49) for each section. Using this line, an estimated depth for each sample can be inferred. The dotted lines on plate 47 connect points of equal depth facies as estimated by this method. A crude parallelism with the dashed lines is at once apparent. It should be emphasized, however, that no great confidence is placed on the exact position of the depth lines, and very little if any confidence is placed on the 1,500 and 2,000-foot lines, since the depth-range diagrams show no discernible trend in their middle portions.

The angle at which the depth and faunal lines cross the lithologic lines changes gradually from a very large angle in the upper part of the Pico formation to a very small angle in the lowest parts of the formation. This change indicates that the difference in water depth between Towsley and Pico Canyons increased during the time of deposition of the Pico formation. At Pico Canyon the thickness of the Pico is about 5,000 feet; the depth of water at the beginning of deposition was probably about 2,500 feet. The amount of subsidence indicated is about 2,500 feet. At Towsley Canyon the thickness of the Pico formation is about 2,000 feet; if the estimate of 2,500 feet for the water depth at the beginning of deposition is correct, then there was no subsidence. Subsidence at Towsley Canyon at a later time, however, is necessary before deposition of the overlying Saugus formation.

Megafossils

Although megafossils are present in the siltstone in the lower part of the Pico formation, they are generally widely scattered and poorly preserved. Small pelecypods (identified by Winterer), including *Yoldia scissurata*, *Spisula*, and *Macoma?*, seem to be the most common forms.

Several large faunas were collected from lenticular beds of sandstone and conglomerate in the lower part of the Pico formation north of the Santa Clara River. These collections (from loc. F41–48, F50, F51, F59, and F60) come from graded beds or from beds intimately associated with graded beds; the faunas probably were transported to their place of final deposition by turbidity currents or submarine slides. The checklist (table 4) shows the species that occur at the various localities, which are listed in stratigraphic sequence. At localities F41, F43, and F44 blocks of fossiliferous rock were collected. The relative abundance of the species obtained from these bulk collections is shown on the checklist. The material at locality F49 occurred as float in a stream bottom and its true stratigraphic position could be anywhere between locality F42 and locality F50, although the distribution of shell fragments along the stream indicates that the material came from a horizon no lower than locality F46.

According to Woodring, Trumbull, and Vedder (written communications, 1952 and 1953), the following species from the Pico formation have not previously been reported from the Ventura basin:

Crepidula cf. *C. aculeata* (Gmelin)
Petaloconchus montereyensis Dall
Eulima cf. *E. raymondi* Rivers
"*Gyrineum*" *mediocre lewisii* Carson
Neptunea cf. *N. lyrata* (Gmelin)
Calicantharus kettlemanensis (Arnold)
"*Nassa*" *hamlini* Arnold
Progabbia cf. *P. cooperi* (Gabb)
Mangelia aff. *M. variegata* Carpenter
Melampus cf. *M. olivaceus* Carpenter
Nuculana cf. *N. hamata* (Carpenter)
Nuculana cf. *N. extenuata* (Dall)
Saccella cellulita (Dall)
Pachydesma crassatelloides (Conrad)
Macrocallista cf. *M. squalida* (Sowerby)
Cardiomya cf. *C. planetica* Dall

Scaphander aff. *S. jugularis* (Conrad) was known previously only from Miocene rocks, and *Brissopsis pacifica* (A. Agassiz)? has not previously been reported from Tertiary rocks of the west coast.

The uppermost few hundred feet of the Pico formation are very fossiliferous at most places. Because the interfingering contact between the Pico and the Sunshine Ranch member of the Saugus formation is time-transgressive, this fossiliferous zone, which Gale (Grant and Gale, 1931) termed the middle Pliocene San Diego zone, is not of the same age everywhere but rather represents a facies fauna. Collections were made from this so-called zone near San Fernando Pass (loc. F76) and near the mouth of Towsley Canyon (loc. F77–F81).

Locality F61, near Val Verde Park, is in siltstone slightly below the upper fossiliferous zone of the Pico formation.

According to Woodring and Vedder (written communication, 1953), *Laevicardium* cf. *L. substriatum* (Conrad), from locality F80, has not previously been reported from the Ventura basin.

Some of the collections from the lower part of the Pico are from localities where field evidence suggests deposition by turbidity currents, and these collections contain a mixture of species indicative of various depth zones (shallow, less than 60 feet; moderate, 60 to 600 feet; deep, more than 600 feet). Other collections from similar rocks consist of species that could have lived together in the same depth zone.

Localities at which there is a mixture of species from different depth zones and localities at which there is no apparent mixing are listed below. Ecologic interpretations for both groups were compiled by Winterer from data that includes reports of Woodring, Trumbull, and

Vedder, who identified the collections; all data in quotation marks are from Woodring and Vedder (written communication, 1953).

Localities with species from different depth zones

Locality	*Remarks*
F42	*Tegula gallina?* suggests shallow water. *Cyclocardia* aff. *C. barbarensis* suggests moderate to deep water. The rest of the species live in moderate depths or range from shallow into moderate depths. "A mixed ecologic facies is suggested by this fauna: shallow water and moderate depth."
F43	"The air-breathing *Malampus olivaceous* lives above high tide level in the vegetation surrounding shallow bays and mud flats. The Pismo clam, *Pachydesma crassatelloides*, lives in surf. *Cyclocardia* cf. *C. barbarensis* suggests a moderate to deep-water environment."
F44	"A land snail, *Glyptostoma* sp., * * * is represented. *Crepidula onyx*, *Mitrella carinata gausapata*, *Bulla* cf. *B. punctulata*, *Anadara camuloensis*, *Ostrea vespertina*, *Schizothaerus?* sp., *Protothaca tenerrima* and *Panope* cf. *P. generosa* indicate shallow water to moderate depths. The majority of the species suggest moderate depths. *Yoldia* cf. *Y. beringiana*, *Cyclocardia* aff. *C. barbarensis* and *Cardiomya* cf. *C. planetica* indicate moderate depths to deep water."
F45	"*Tegula ligulata*, *Crepidula* cf. *C. onyx*, *Acanthina spirata*, *Olivella pedroana?*, *Bulla* cf. *B. gouldiana*, *Anadara camuloensis*, *Aequipecten* aff. *A. circularis*, *Ostrea vespertina*, *Schizothaerus?* sp., *Dosinia ponderosa* subsp., *Amiantis* cf. *A. callosa*, *Pseudochama exogyra?*, and *Chama pellucida* indicate shallow to moderate depths. The remaining mollusks suggest moderate depths, with the exception of *Cyclocardia* aff. *C. barbarensis*, which ranges into deep water. The echinoid *Brissopsis pacifica* has been recorded from depths of 120 to 4680 feet."
F48	"*Mitrella* sp., *Anadara* cf. *A. camuloensis*, *Ostrea vespertina* indicate shallow water to moderate depths. Most of the species indicate moderate depths. *Nuculana* cf. *N. hamata* suggests moderate depths to deep water. *Nuculana extenuata?* and *Yoldia* cf. *Y. beringiana* suggest deep water. The only specimens of the living *Nuculana extenuata* in the U.S. National Museum collections were dredged at a depth of 1,569 fathoms."
F49	Shallow to moderate depths are indicated by *Mitrella carinata gausapata*, *Dosinia* cf. *D. ponderosa* subsp.?, *Protothaca tenerrina*, and *Gari edentula*?. *Cyclocardia* cf. *C. barbarensis* suggests moderate depths to deep water. "The fauna suggests a mixed-depth facies of shallow, moderate-depth, and deep water. The majority of species indicate moderate depths."
F50	"Shallow to moderate depths are indicated by the few species in this collection, other than *Fusitriton*?, which suggests moderate depths to deep water."
F51	"The majority of species indicate shallow to moderate depths with the exception of *Yoldia beringiana*, which suggests deep water."

Localities at which there is no apparent mixing of species from different depth zones

Locality	*Remarks*
F41	This very large fauna "*** represent[s] a uniform moderate-depth environment within the range of 10 to 50 fathoms." The cat bone from this locality seems no more anomalous than the chunks of wood that are in adjacent beds.
F46	"The meager fauna *** indicates moderate depth."
F47	All the specimens in this collection are incomplete, immature, or worn. "Shallow to moderate depths are indicated by the poorly preserved fauna."
F59	"These species suggest shallow to moderate depth ranges."
F60	"The fossils in this collection indicate an environment of shallow to moderate depths."

The same generalization holds for the geographic distribution of the modern representatives or close relatives of the species at localities F41 to F51, as for the fauna of the Towsley formation: the shallow-water species either include the latitude of Ventura in their present range or are restricted to areas south of Ventura. All the exclusively shallow water species range southward at least as far as Todos Santos Bay, Baja California. This distribution suggest that surface water temperatures were slightly warmer than they are now at Ventura.

The fact that all the species now extinct in the latitude of Ventura but living in areas north of Ventura are moderate-depth or deep-water species could be interpreted to mean that the water in the eastern Ventura basin was cold enough at depth to allow these forms to range southward from their present habitats.

The fossils from locality F61, near Val Verde Park, are interpreted by Woodring and Trumbull (written communication, 1952) as suggesting a moderate-depth facies of about 60 to 180 feet.

The collections from localities F77 to F81 consist of species that live in water of moderate depths and species that live in water that ranges from shallow to moderate depths. According to Woodring and Vedder (written communication, 1953), *Yoldia beringiana*? from locality F81 indicates deeper water.

Only one collection (from loc. F95) was made from a specific locality high in the Pico formation, but at several places, particularly around the northeast side of the Newhall-Potrero oil field, the beds in the upper part of the Pico stratigraphically higher than localities F77 to F81 commonly yield a fauna consisting chiefly of sand dollars, pectens, and oysters. This fauna is interpreted to represent a gradual shoaling of the water during deposition of the upper part of the Pico formation.

UPPER PLIOCENE AND LOWER PLEISTOCENE

SAUGUS FORMATION

DEFINITION AND SUBDIVISION

The marine Pico formation grades upward and laterally into the Saugus formation, which comprises interfingering shallow-water marine, brackish-water, and nonmarine deposits that in turn grade upward and laterally into exclusively nonmarine beds. Conditions resulting in the contemporaneous deposition of the two formations are illustrated diagrammatically in figure 54. South of San Fernando Pass it is practicable to divide the formation into a lower member, termed the Sunshine Ranch member, and an upper, coarser grained nonmarine member. A similar division was attempted for the formation north and west of San Fernando Pass but was finally abandoned as impractical or misleading.

The Saugus formation was first described by Hershey (1902, p. 359–362) as the "Saugus division of the upper Pliocene series," the name stemming from the exposures in Soledad Canyon not far from the town of Saugus.

Eldridge and Arnold (1907, p. 22–28) restricted the term Saugus to the Pleistocene terrace deposits and applied the name Fernando formation to all the rocks younger than the Modelo formation and older than the Pleistocene terrace deposits in the Santa Clara River valley region. Kew (1924, p. 81), in raising the Fernando formation to group status, defined the Saugus formation as the upper part of the Fernando group that rests unconformably on the Pico formation in most places. Kew assigned to the Saugus many beds which are referred to the Pico in the present report.

The term Sunshine Ranch was introduced as a formation name by J. C. Hazzard (Oakeshott, 1950, p. 59) for interfingering marine, brackish-water, and nonmarine beds lying above the Pico formation in the vicinity of the San Fernando Reservoir, a few miles south of the area shown on the geologic map (pl. 44). These beds were designated the Sunshine Ranch member of the Saugus formation by the authors (Winterer and Durham, 1958). At the type locality described by Hazzard the Sunshine Ranch member is about 3,000 feet thick and consists chiefly of interbedded "* * * gray, coarse-grained to pebbly, friable sandstone and gray to greenish-gray very fine grained sandstone, silty sandstone or sandy siltstone. These fine-grained greenish-gray beds are the most characteristic lithologic type in the formation. As a rule, their mere presence, even in thin beds, is indicative of their stratigraphic position. * * *" At the type locality marine fossils occur as high as the middle of the member. Oakeshott (1950, p. 59–61) adopted the name Sunshine Ranch for "* * * upper Pliocene continental beds lying below the continental lower Pleistocene Saugus formation and above marine beds commonly called Pico * * *" north of the San Fernando Pass in the vicinity of the Placerita oil field; he designated these beds as the uppermost member of the Pico formation. The Sunshine Ranch is here treated as the lower member of the Saugus formation.

STRATIGRAPHY AND LITHOLOGY

San Fernando Valley

Both the Sunshine Ranch and the unnamed upper member of the Saugus formation are present in the San Fernando Pass area. Near the south end of the pass the Sunshine Ranch member is represented by a thickness of about 800 feet of greenish-gray soft siltstone and fine-grained sandstone intercalated with light-gray sandstone and conglomeratic sandstone. Figure 56 shows an exposure of these beds in a road cut on U.S. Highway 99 (old road).

Fossils are abundant at some horizons in the Sunshine Ranch member but generally the fauna at any one locality consists almost wholly of numerous individuals of one species. Three species of mollusks dominate the fauna in this area: *Cryptomya californica*, *Ostrea vespertina*, generally small individuals of the var. *sequens*, and a slender form of *Calicantharus humerosus*. A few fragments of the echinoid *Dendraster* were noted at one locality (identifications by Winterer).

The Sunshine Ranch member is separated by an unconformity from the upper member of the Saugus formation in the area east of U.S. Highway 99. The upper member consists mainly of lenticular beds of light-gray and brown sandstone and conglomerate intercalated with lesser amounts of reddish-brown sandy mudstone. West of Highway 99, where a fault separates the Sunshine Ranch member from the upper member of the Saugus, the younger beds consist chiefly of grayish-orange sandstone and light-gray conglomerate. Some beds, especially in an area near the Santa Susana fault zone, are very firmly cemented by calcium carbonate.

A thickness of about 1,500 feet of the upper member of the Saugus formation is exposed on the north limb of a syncline near the south end of San Fernando Pass. According to Oakeshott (1950, p. 62) the Saugus formation (the unnamed upper member of this report) is at least 3,000 feet thick on the south limb of this syncline, the axial parts of which are covered by alluvium. Oakeshott also reported the finding of a horse tooth about 800 feet stratigraphically above the top of the Sunshine Ranch member of the Saugus. The tooth was tentatively identified by Stock as that of a Pleistocene horse.

That the Saugus formation may be very thick in some places in this area is attested by evidence from Sunray

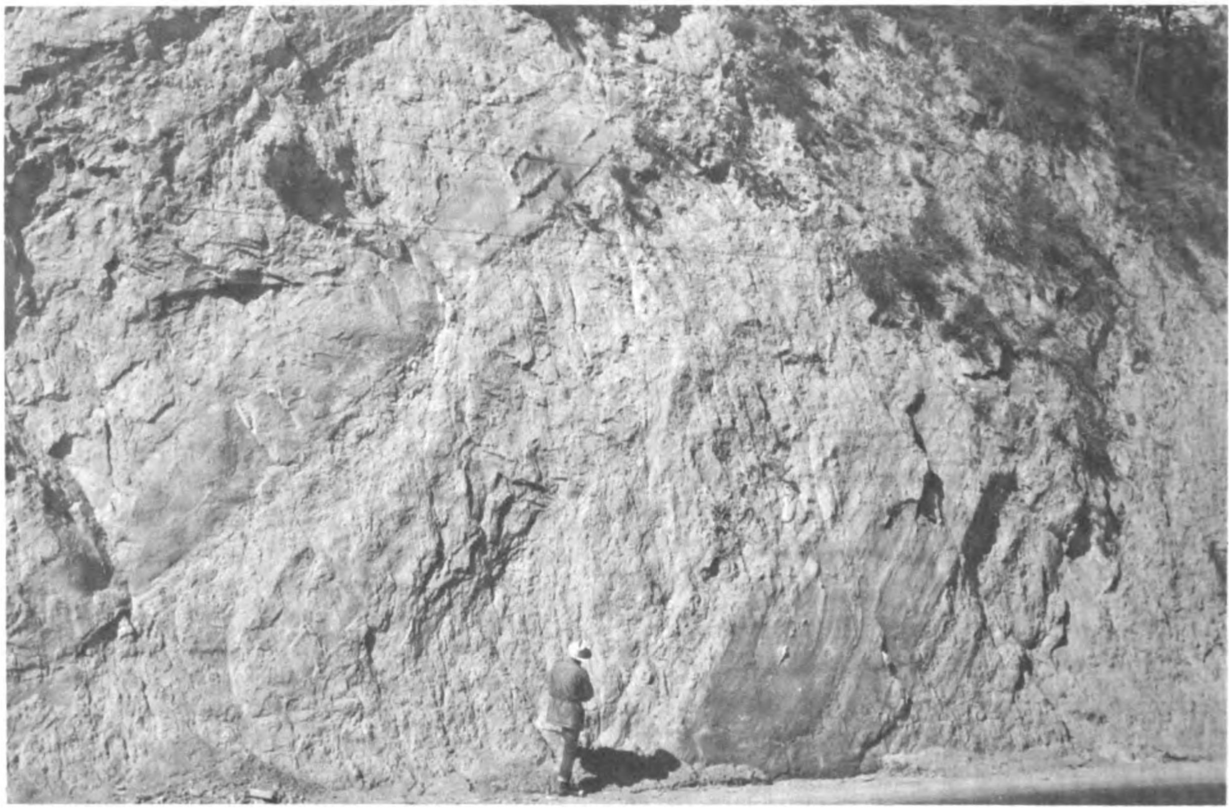

FIGURE 56.—Soft greenish-gray siltstone and fine-grained sandstone beds of the Sunshine Ranch member of the Saugus formation exposed along U.S. Highway 99 south of San Fernando Pass.

Oil Stetson-Sombrero well 1, drilled in sec. 21, T. 3 N., R. 15 W., about 100 yards east of the area shown on the geologic map (pl. 44) and about 300 yards north of Foothill Boulevard. This well entered the Saugus formation beneath a cover of alluvium and remained in the Saugus to the bottom of the hole at a depth of nearly 12,000 feet. The strata dip south at angles between 20° and 45°.

Area south of San Gabriel and Holser faults

Within the belt of outcrops extending in a large arc from the Placerita oil field to the Del Valle oil field, the Saugus formation is not easily divided into members. In some parts of this area, such as the vicinity of Whitney Canyon, north of the Placerita oil field, southwest of Newhall, and near the Del Valle oil field, a twofold division into a lower member characterized by numerous beds of greenish-gray siltstone and sandstone and an upper member that lacks the greenish beds would be possible; however, over most of the area of outcrop the upward change in lithology is very gradual and greenish-gray beds occur even in the uppermost exposed parts of the formation. For this reason, the Saugus is not subdivided in this area.

The contact between the Saugus formation and the marine Pico formation is gradational and interfingering in many places, the chief distinction between the two formations being a change in the color of the siltstone beds from olive gray or light bluish gray in the Pico to greenish gray in the Saugus.

Near the southeast end of the Newhall-Potrero oil field the contact of the Saugus and Pico formations is, for a short distance, an angular unconformity. This unconformity can be traced for only about 2 miles as an angular discordance. In the vicinity of La Placerita Canyon also the Saugus formation rests nonconformably on the Pico formation. Elsewhere the contact is placed rather arbitrarily at the upper limit of the abundantly fossiliferous beds of the Pico formation.

In the area south of the San Gabriel and Holser faults the Saugus formation consists of lenticular units of light-colored, loosely consolidated, poorly bedded, ill-sorted conglomerate (fig. 57), conglomeratic sandstone, and sandstone alternating with beds of greenish-gray siltstone, silty sandstone, and light-brown to moderate reddish-brown sandy siltstone and claystone. The proportion of greenish-gray beds is greater in the lower part and the proportion of reddish-brown beds is greater in the upper part of the formation.

At a few places between Towsley Canyon and Newhall the lower part of the formation includes beds especially

FIGURE 57.—Conglomeratic sandstone of Saugus formation exposed along U.S. Highway 6 south of La Placerita Canyon.

rich in plant remains. These lignitic beds occur in units as much as 6 feet thick, but they are generally very lenticular and sandy.

The clasts in the conglomerate beds of the Saugus formation are nearly all rounded to well rounded. Pebble counts made at several places show that the same rock types are represented in about the same abundance as in the conglomerate beds of the Pico formation. In fact, the variation within either formation is greater than the difference between the two formations. The average diameter of clasts decreases gradually from east to west. Near Newhall, beds containing boulders are not common; near Pico Canyon, boulders are scarce, but cobbles are abundant; near the Del Valle oil field, cobbles are less common and most of the conglomerate beds contain pebble-size clasts.

Because an unknown thickness of beds from the upper part of the Saugus formation has been removed by erosion, the original thickness of the formation is not known. In the area between the Newhall-Potrero oil field and the syncline north of the Castaic Junction oil field, however, the Saugus formation is about 7,000 feet thick.

FOSSILS

In the area south of the Holser and San Gabriel faults, as well as in the San Fernando Valley, marine or brackish-water megafossils occur sparsely in the lower part of the formation. These consist mainly of *Ostrea vespertina* var. *sequens*, *Cryptomya californica*, and *Calicantharus humerosus*, as well as fragments of unidentified naticids and fragments of *Dendraster* (identifications by Winterer).

In the area north of the Santa Clara River and south of the Holser fault, W. H. Corey (oral communication, 1951) collected horse teeth from the Saugus formation at localities which are shown on the geologic map (locs. V92 and V93). According to Corey, Chester Stock identified the teeth as probably belonging to *Pliohippus*.

Two samples, stratigraphically only a few feet apart (locs. f90 and f91), were collected from greenish-gray siltstone in the Pico formation just below the base of the Saugus formation north of the Newhall-Potrero oil field and were examined for microfossils. The lower sample contained an abundance of *Nonion scaphum* along with *Rotalia* sp., *Gaudryina* sp., and ostracodes. The higher sample contained only gastropods, ostracodes, a barnacle, and charaphytes. A sample collected higher in the formation (loc. f89), near the Castaic Junction oil field, contained fresh-water gastropods, ostracodes, and charaphytes.

The mollusks and Foraminifera in the uppermost part of the Pico formation, which in many places interfingers with the Saugus formation, are interpreted as indicating a shallow-water marine environment. The meager molluscan fauna from the lower part of the Saugus is suggestive of a shallow-water marine, or perhaps even an estuarine or lagoonal environment (fig. 54), as living *Ostrea* (related to *O. vespertina sequens*) and *Cryptomya californica* have a wide salinity tolerance. *Dendraster* could also live in a somewhat brackish-water environment.

The microfauna from the Pico formation at locality f90, a short distance stratigraphically below the base of the Saugus, indicates shallow-water marine conditions. The fauna at locality f91, only a few feet higher stratigraphically, suggests a change to brackish-water conditions. The fauna from locality f89, in the Saugus formation, suggests a lacustrine environment.

The upper part of the formation is unfossiliferous except for the horse teeth and presumably represents nonmarine deposition. The conglomeratic beds are doubtless stream deposits, and the unfossiliferous greenish and reddish siltstone may represent lacustrine or flood plain deposits.

AGE OF YOUNGEST FORMATIONS OF MAPPED AREA

Because of the gradational and interfingering relation between each successive pair of the four youngest formations in the mapped area, the age assignment for each of the last three is dependent on the ages assigned to the adjacent formations. Marine fossils in the three youngest formations are better guides to depth or other facies than to precise ages.

The guide lines for relative ages are furnished by the outcrops of thin graded conglomerate and sandstone beds which persist over long distances. Each of these beds was probably deposited quickly, almost instantaneously, by a turbidity current. Using such a bed as a base line, it was found that the upper three-fifths of the Pico formation at the southeast end of the Newhall-Potrero oil field grades southeast into the lower part of the Saugus formation (cf. p. 310). Where persistent mappable graded beds were not found, or where the effect of faulting is complex or obscure, time lines are correspondingly uncertain. Both difficulties were encountered near San Fernando Pass.

TOWSLEY FORMATION

The oldest beds in the Towsley formation, which crop out near the crest of the Santa Susana Mountains, interfinger with the Modelo formation. A foraminiferal fauna from a bed in the Modelo about 50 feet stratigraphically below the base of the Towsley near Oat Mountain (loc. f12; see table 2) appears to represent the lower part of Kleinpell's Mohnian stage (upper Miocene). The base of the Towsley formation on the south limb of the Pico anticline near East Canyon is about 1,500 feet stratigraphically higher than at Oat Mountain, and foraminiferal faunas collected from the Modelo formation a short distance below the base of the Towsley formation there (loc. f10 and f11) suggest Kleinpell's Delmontain stage (uppermost Miocene) for the basal beds of the Towsley at that place; the lower part of the formation in the Pico Canyon oil field area (loc. f29–f32) yielded Foraminifera assigned to the Delmontian stage (Patsy B. Smith, written communication, 1953).

The exact stratigraphic relation of the beds of the Towsley formation in Elsmere Canyon to the Towsley in the Santa Susana Moutains is not known because of the complex faulting near San Fernando Pass and the apparent thickening of the Towsley westward from near Elsmere Canyon. The horizon represented by the base of the Towsley formation where it rests unconformably on older rocks near Elsmere and Grapevine Canyons probably corresponds approximately with the horizon of the conglomeratic beds that crop out below the oil-stained sandstone in the road cuts at the junction of U.S. Highways 6 and 99. If this correlation is correct, the fossils at locality F16, near East Canyon in the middle of the Santa Susana Mountains section of the Towsley, are at very nearly this same horizon. The base of the Towsley formation at Towsley Canyon would be about 1,500 feet stratigraphically below this horizon. The position of the horizon of locality F17 with respect to the beds of the Towsley formation in Elsmere Canyon is even more uncertain, but it is probably slightly higher.

The molluscan and echinoid fauna from the Towsley formation in the Elsmere Canyon area has long been regarded as indicating an early Pliocene age (English, 1914, p. 214; Grant and Gale, 1931, p. 29–32; Kew, 1924, p. 77–80; Woodring, 1938, p. 20). This age assignment is based on several facts: First, the fauna contains a large number of species not known in other parts of the California Coast Ranges from beds older than Pliocene. Second, the fauna includes such forms as *Astrodapsis* and *Trophosycon*, known elsewhere only in beds no younger than early Pliocene. Third, the fauna has a large number of species in common with the fauna of the Jacalitos formation of the Coalinga region and with the fauna of the lower part of the San Diego formation. The Jacalitos formation and also the lower part of the San Diego formation are probably considered early Pliocene in age (Woodring, Stewart, and Richards, 1940, chart facing p. 112).

The Santa Susana Mountains localities both contain "*Nassa*" *hamlini* and locality F17 yielded *Acila semirostrata*. These two species occur only in lower Pliocene strata outside the Ventura basin. Within the basin, *A. semirostrata* occurs well up in the Pico formation (loc. F52). Specimens of *Turritella cooperi*, a species reported elsewhere from only two localities in beds older than Pliocene (Merriam, 1941, p. 118), were noted by Winterer about 1,000 feet above the base of the Towsley formation near Towsley Canyon. The boundary between the Pliocene and Miocene is probably, therefore, between the *Turritella cooperi* horizon and the beds (loc. f32) containing the foraminiferal fauna of Delmontain age near the Pico Canyon oil field, that is, in the interval from about 500 to 1,000 feet above the base of the Towsley at Towsley Canyon. This part of the formation contains few foraminifers.

PICO FORMATION

The Pico formation within the mapped area undoubtedly is entirely of Pliocene age in terms of the California subdivisions of the Cenozoic era. The beds along the northeast side of the Newhall-Potrero oil field are probably the youngest in the formation and contain *Patinopecten healeyi* and *Lyropecten cerrosensis*, both of which occur in rocks no younger than Pliocene elsewhere in California.

Just how much of the Pliocene is represented by the Pico formation is not known. The lower part of the formation, from which "*Nassa*" *hamlini* was collected, is regarded as lower Pliocene. *Acila semirostrata* is known from a few localities in the lower part of Pliocene strata in the Los Angeles basin (for example, Woodring, 1938, p. 28). In the Ventura basin, *A. semirostrata* occurs at least as high as the middle of the Pico formation (loc. F52). At all localities in the eastern Ventura basin where these two species are found, evidence of transportation after death indicates that the animals may have lived far from the places where their remains are found. The true depth facies of these two species is not known, although a moderate depth facies appears most likely.

The strongly plicate variety of *Ostrea vespertina*, which occurs at localities in the uppermost part of the Pico formation, has not been found in association with either *Acila semirostrata* or "*Nassa*" *hamlini*. Although the presence of this form of *O. vespertina* may suggest a late Pliocene age, correlations between fossil localities by means of key beds suggest that the stratigraphic range of the strongly plicate oyster partly overlaps the ranges of *A. semirostrata* and "*N.*" *hamlini*.

TABLE 6.—*Distribution of forms of* Calicantharus humerosus (*Gabb*)

[Identification by W. P. Woodring]

Formation	Area	Locality (table 11)	Form		
			Typical	Intermediate	Slender
Sunshine Ranch member of Saugus formation.	Santa Susana Mountains.	F87	--------	--------	×
		F86	--------	--------	×
	South of San Fernando Pass.	F85	--------	--------	×
Pico formation	South of Del Valle fault.	F41	×	--------	--------
		F43	×	--------	--------
		F45	×	--------	--------
		F49	×	--------	--------
		F50	×	--------	--------
		F51	--------	×	--------
		F52	--------	--------	×
		F68	--------	--------	×
	Between Del Valle and Holser faults.	F65	×	--------	--------
		F61	--------	?	--------
		F66	×	--------	--------
		F74	--------	--------	×
		F69	--------	--------	×
		F72	--------	--------	×
		F70	--------	--------	×
		F75	--------	--------	×
		F71	--------	--------	×
		F73	--------	--------	×
	North of Holser fault.	F64	?	--------	--------
		F63	×	--------	--------
		F67	--------	--------	×
		F62	×	--------	--------
	Santa Susana Mountains.	F76	--------	×	--------
		F83	--------	×	--------
		F80	--------	×	--------
		F81	--------	×	--------
		F82	--------	×	--------
Towsley formation.	Elsmere Canyon.	F21	×	--------	--------
		F22	×	--------	--------
		F23	×	--------	--------
		F24	?	--------	--------
		F25	--------	×	--------
		F26	--------	?	--------
		F27	--------	?	--------
	Santa Susana Mountains.	F20	×	--------	--------
		F17	×	--------	--------

Table 6 shows the stratigraphic distribution of forms of *Calicantharus humerosus* in the Pliocene rocks of the area. The table presents the result of a special study of the species by Woodring, who used University of California at Los Angeles collections as well as Geological Survey collections. The form termed by Woodring as typical, which is strongly inflated and has a strong angular shoulder, occurs in the Towsley formation at Elsmere Canyon and in all except the uppermost part of the Pico formation. A form that Woodring called intermediate, which is moderately inflated, has a strong angular shoulder, and is more or less intergraded with the typical form, occurs in the Towsley and Pico formations. The form that Woodring termed slender, which is round shouldered, occurs in the Pico formation and in the lower part of the Saugus formation. The different forms do not occur together except at one poorly described University of California at Los Angeles locality in the Towsley formation in Elsmere Canyon, where the typical and intermediate forms may occur together. The typical form has a somewhat longer stratigraphic range than *Acila semirostrata* and "*Nassa*" *hamlini*, the intermediate form occurs in the upper part of the stratigraphic range of the typical form, and the slender form occurs mainly above both the other forms.

Woodring (written communication, 1953) suggested that, "Inasmuch as the typical form occurs at Elsmere Canyon in an early Pliocene shallow-water association and the slender form occurs in the same kind of association in the late Pliocene part of the Pico formation, at least those two forms evidently are not ecologic varieties adapted to different environments * * *. The stratigraphic distribution strongly suggests a typical-intermediate-slender chronologic lineage in decreasing age sequence."

Field evidence (Winterer) also suggests that the slender form may range into brackish-water deposits. At several places in the uppermost part of the Pico formation, or in the lower part of the Saugus formation, the slender form of *Calicantharus humerosus* is associated with abundant *Cryptomya californica* or with a small form of *Ostrea vespertina sequens*.

Paleontologic evidence may warrant a division of the Pliocene in the southwestern Ventura basin into the lower Pliocene, characterized by "*Nassa*" *hamlini* and *Acila semirostrata*, and the upper Pliocene, characterized by the strongly plicate form of *Ostrea vespertina* and the slender form of *Calicantharus humerosus*.

SAUGUS FORMATION

The Saugus formation interfingers with the upper Pliocene part of the Pico formation in the area south of the Holser fault. The *Pliohippus* teeth more than 1,000 feet above the base of the Saugus near the Del Valle oil field, where the base is relatively young with respect to the same horizon farther north or east, indicate a Pliocene age for at least the lower half of the Saugus formation. The horse tooth collected by Oakeshott from the upper member of the formation in the San Fernando Valley indicates that the upper member is in part of Pleistocene age. Near the town of Castaic, several miles north of the mapped area, W. H. Corey collected a *Bison* jawbone and teeth from reddish-brown clay beds near a large fault. The beds containing the vertebrate fossils dip about 30° and were tentatively assigned by Corey to the Saugus formation (oral communication). Chester Stock examined the material and told him that the *Bison* is a very late one, possibly even Recent. It may be that the dipping beds do not belong to the Saugus formation but are stream-terrace deposits of late Pleistocene age that were deformed during movements along the nearby fault. If, on the contrary, the beds containing *Bison* are within the Saugus formation, then the age range of that formation must be extended at least into the late Pleistocene.

QUATERNARY SYSTEM

PLEISTOCENE SERIES

TERRACE DEPOSITS

Stream-terrace deposits are widely distributed in the Ventura basin but are most extensive near the town of Saugus and in the immediate vicinity of the Santa Clara River. The deposits consist of crudely stratified, poorly consolidated reddish-brown gravel, sand, and silt. In some areas where terrace deposits rest on the Saugus formation, the contact between the two units is difficult to locate accurately because of the similarity of the gravels to loosely consolidated conglomerate beds in the Saugus formation.

The extensive terrace deposits east of Saugus are as much as 200 feet thick. Farther west, near the Castaic Junction and Del Valle oil fields, the deposits are as much as 75 feet thick. At many places the former presence of a cover of gravel on stream terraces is indicated by isolated large boulders resting like glacial erratics on remnants of erosion surfaces. One notable occurrence of such residual boulders is at an altitude of 2,850 feet near the headwaters of Rice Canyon, where rounded granitic boulders as much as 2 feet in diameter are scattered on ridge tops on shale of the Modelo formation.

The thick terrace deposits exposed in the vicinity of Saugus, near the Castaic Junction and Del Valle oil fields, and near the mouth of Potrero Canyon, are apparently remnants of a once continuous cover of alluvium. The altitude of the base of this series of terrace deposits is about 150 feet above the Santa Clara River valley near the Del Valle oil field, but near Saugus, farther upstream, the base is lower than the present river bed. An erosion surface on this same series of terrace deposits likewise shows a lesser gradient than the present Santa Clara River valley. The downstream divergence of the long profiles of the present Santa Clara River valley and the former valley is probably due to broad warping after the formation of the terrace deposits.

The terrace deposits are assigned a late Pleistocene age because they lie with marked unconformity on the Saugus formation, the upper part of which is of probable early Pleistocene age. At a few places faults of small displacement cut the higher terrace deposits, and the large terraces near the east end of the Del Valle oil field and just southwest of the Castaic Junction oil field may have been slightly folded; the terrace deposits are otherwise not obviously deformed. The oldest undeformed rocks in the western part of the Ventura basin are assigned a late Pleistocene age on faunal evidence.

The only faunal evidence for the age of the terrace deposits in the southeastern Ventura Basin is doubtful. A bison tooth was collected by Corey at an outcrop near the junction of Castaic Creek and the Santa Clara River (loc. V94). At this place terrace gravels lie unconformably on the Saugus formation. The tooth was collected at the surface of the Saugus outcrop, and Corey reported (oral communication, 1951) that he could not be certain whether the tooth came from the Saugus formation or was washed from the over-lying terrace gravel. Chester Stock identified the tooth as belonging to a very late Pleistocene or even Recent *Bison* (See "Saugus formation" above).

ALLUVIUM

A blanket of alluvium covers the Santa Clara River valley floor and extends far up many of the tributary valleys. The present flood plain of the Santa Clara River is entrenched in this alluvial fill to a depth that ranges from about 20 feet near the Los Angeles-Ventura County line to about 5 feet near the eastern edge of the area shown on the geologic map (pl. 44). The deposits consist of poorly bedded, unconsolidated gravel, sand, and silt.

TURBIDITY CURRENT FEATURES IN THE TERTIARY ROCKS

The presence of graded sandstone and conglomerate beds in the Eocene rocks and in the Modelo, Towsley, and Pico formations has been noted in the discussions of the lithology of those formations, but the possible origin and significance of this prevalent sedimentary structure has not been discussed directly. Anomalous depth associations in the molluscan faunas from the Towsley and Pico formations have been described also, and the suggestion has been made (p. 306 and 315) that turbidity currents may account for the mixed faunas.

Analysis of foraminiferal faunas from the Pico formation showed that a large part of that formation in the western half of the mapped area was deposited in water more than 600 feet deep, and that the depth may have been as much as 3,000 feet. However, siltstone beds containing deep-water Foraminifera are interstratified with beds of sandstone and coarse conglomerate. Unless the Foraminifera have no depth significance, some mechanism of transportation must be found to explain the presence of large volumes of coarse material in deep water. Otherwise, a kind of "springboard tectonics" must be invented, alternately to raise the sea floor into the realm of strong wave and current action for deposition of the sandstone and conglomerate beds, and then to lower it again to depths at which the Foraminifera can live. Significantly, the sandstone and conglomerate beds in the midst of the deep-water siltstone contain sedimentary structures, notably size grading, that suggest turbidity currents as the probable agent of transportation of the sediments that formed these beds.

NATURE OF TURBIDITY CURRENTS

A turbidity current, as the term is used in this report, is a sediment-laden current that flows in a body of standing clear water. It stays more or less segregated as a distinct layer because of a difference in density between the turbid water and the clear water. It is a special kind of density current. Depending on the difference in density, a turbidity current can flow along the top of, within, or along the floor of the body of standing water. A thin surface layer of sediment-laden river water often extends for many miles out to sea opposite river mouths, even though the fresh water contains a greater concentration of suspended sediment than sea water (Scruton and Moore, 1953). Surface turbidity currents, or overflows, are driven mainly by winds and to a lesser extent by ocean currents and river flow. Overflows of turbid water occur in the upper part of Lake Mead, Ariz.-Nev., during late spring and early summer when, due to its lower salinity, the incoming Colorado River water is lighter than the surface water of the lake (Gould, 1951, p. 38, 39). Turbidity currents that flow at some intermediate level in a body of standing water are termed interflows; they can be produced in laboratory tank experiments and have been observed in Lake Mead (Gould, 1951, p. 39) but not in the sea. Turbidity currents that flow along the floor of a body of standing water have been investigated in the laboratory by Bell (1942a, b) and Kuenen (1937; 1938; 1951; Kuenen and Migliorini, 1950) and have been observed and studied in lakes (Gould, 1951, p. 38, 39). Turbidity currents flowing along the bottom have not been actually observed in the sea, although many writers have called upon marine turbidity currents to explain the deposition of beds of sand (Shepard, 1951; Ericson, Ewing, and Heezen, 1951; 1952) or of graded beds of sand (Bramlette and Bradley, 1942; Kuenen, 1950, p. 367) in Recent deep-sea sediments. The presence of faunas consisting of shallow-water or mixed shallow- and deep-water species of Foraminifera recovered from cores of Recent deep-sea sands has been ascribed to transportation by turbidity currents (Phleger, 1951).

The velocity of material in suspension in a flow is greatest at the nose of the current and the coarsest material in the flow at any one time is found there. As the head of the flow advances, the velocity is reduced owing to the resistance of the stagnant water and to dilution by mixing with clear water. A loss of velocity and turbulence leads to deposition of the coarsest material from the mixture at the head of the flow. Thus a horizontal grading is established. Behind the nose of the current the suspension is progessively more dilute and slower moving. A pronounced vertical gradient in both density and velocity can be observed in experimental flows. In flows containing a mixture of various sizes of grains, the vertical and horizontal velocity and density gradients caused corresponding average grain-size gradients in the flows, and thus provide an explanation of the formation of graded beds by turbidity currents. Deposition is rapid enough to lay down and bury a mixture of particles of all sizes at the base of the flow before the current can winnow out the finer particles.

Turbidity currents in Lake Mead (Gould, 1951) transport for great distances much of the finer material introduced at the head of the lake by the Colorado River. Many flows have travelled the entire length of the lake to the face of Hoover Dam, a distance of more than 70 miles, over an average bottom slope of from 3 to 5 feet per mile. The velocities of the flows, which transport chiefly clay-size material, range from about 1.0 foot per second near the upper end of Lake Mead to less than 0.25 foot per second farther down the lake. Measurements indicate that the flows are only a few feet thick and have a vertical density gradient. Effective differences in density measured in one flow ranged from 0.001 at the top to 0.200 at the bottom.

Indirect evidence of the existence and importance of marine turbidity currents comes from several sources. Layers of sand interbedded with typical deep-water sediments have been observed in cores of Recent sediments recovered from deep water at a very large number of localities in many parts of the world (Shepard, 1951). Many of these areas are in middle and low latitudes where ice rafting of the sand is improbable. Some of the sand layers are well sorted and others are graded. Remains of shallow-water organisms, especially Foraminifera, are present in some layers. The sand layers are interbedded with deep-water sediments in some areas hundreds of miles from the nearest land or even from the nearest known appreciable submarine slope. The large number of cores from the North Atlantic obtained during cruises of the research vessel *Atlantis* show that coarse-grained sediments are distributed over thousands of square miles in deep ocean basins (Ericson, Ewing, and Heezen, 1952). The sand layers in the Atlantic range in thickness from thin films to beds several feet thick. Some of the cores were about 30 feet long and contained as many as 20 layers of sand. Many of the layers are graded from coarse clastics at the bottom to fine clastics at the top, with abyssal red clay at the top of some layers.

Turbidity currents acting in conjunction with submarine slumping and sliding have been envoked as possible agents for the erosion of submarine canyons (Daly, 1936; Kuenen, 1950, p. 485–526; Woodford, 1951; Crowell, 1952b) and deep sea channels (Dietz, 1953; Ewing and others, 1953).

Ludwick[4] showed that in the San Diego trough, off the coast of southern California, sand layers, although present in many parts of the trough, are most abundant near the outer part of submarine La Jolla Canyon. Near the distal part of the canyon, wide shallow channels with gentle gradients have been found extending part way across the floor of San Diego trough. A fathogram (Menard and Ludwick, 1951, fig. 1) across one of these channels shows levees on both sides of it.

Marine turbidity currents provide an explanation for the presence of layers of coarse-grained sediment in deep water, for their grading, for their alternation with typical deep-water sediments, for their abundance near the ends of submarine canyons, for their occurrence in depressions and below slopes, and for their content of the remains of displaced Recent shallow-water organisms. Many other theories have been advanced to explain the deep-water occurrences of sand, the most important of which are rafting by ice or floating vegetation and transportation by wind and by currents in shallow waters during a time of drastic lowering of sea level. Doubtless ice rafting is an important agent in the transportation of coarse-grained material into deep water, especially in high latitudes; during the Pleistocene epoch this mechanism probably was of even greater importance and was effective in lower latitudes than it is today (Bramlette and Bradley, 1942, p. 4). However, it is difficult to see how this mechanism can produce well-sorted or graded beds; furthermore, the distribution of the rafted sediment or wind-blown sand would not have any special relation to the topography of the sea bottom. Sufficient lowering of sea level to bring the sea bottom within the range of shallow-water currents, even if the mechanism responsible for such a lowering were known, would not explain the layers of interstratified sand and fine-grained sediment containing remains of deep-water Foraminifera.

Evidence bearing on the existence and importance of marine turbidity currents is provided by phenomena associated with the Grand Banks earthquake of 1929 (Heezen and Ewing, 1952). Submarine cables lying downslope from the epicentral area, which was on the continental slope of Newfoundland, were broken in an orderly succession after the earthquake. The farthest cable was more than 300 miles from the epicenter, and the average slope of the sea floor below the epicentral area is 1°50′; many of the breaks were on a slope of less than 1°. Heezen and Ewing concluded that a large slide or slump was triggered by the earthquake and as the material moved down the slope it was converted into a turbidity current which broke the lower cables in succession. Because about a 200-mile length of the last cable was destroyed and buried deeply, it is reasonable to assume that the flow traveled even farther into the ocean basin. Heezen and Ewing (1952, p. 865–866) stated that deposits left by the flow are graded.

Although earthquakes may initiate submarine slides or slumps that later are transformed into turbidity

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[4] Ludwick, J. C., 1950, Deep-water sand layers off San Diego, California: Unpublished doctor's thesis, Scripps Inst. Oceanography.

currents, the flow might be triggered by other means. Shepard (1951, p. 58–59) reported that frequent surveys of the nearshore end of Scripps Canyon, which is a branch of submarine La Jolla Canyon, show that tributaries at the head of the canyon are constantly being filled with sand and then reopened. The fills contain an abundance of soft slimy decaying marine vegetation, which may make the sand less cohesive and more likely to slide down the canyon. The immediate cause of the slides is not known, although heavy storm waves may be an initiating force. Slides moving in canyons, if composed largely of incoherent sediment, may become transformed into turbidity currents by mixing with adjacent clear water. A flow of large volume, moving down a steep canyon, may have sufficient momentum to spread far out onto the sea floor at the mouth of the canyon.

The graded beds of sandstone in the Modelo, Towsley, and Pico formations exhibit characteristics that are suggestive of marine turbidity current deposits. The evenly graded beds are similar to those produced by Kuenen in tank experiments in which a quantity of material is introduced suddenly into the standing water. The beds that are nearly homogeneous throughout most of their thickness and that show grading only in their uppermost parts are similar to those produced (Kuenen and Menard, 1952, p. 83–96) in the laboratory by introducing the coarser material, not in one sudden slide, but in a continuous stream. In a small turbidity current induced by sudden introduction of material, the coarsest material is in the nose of the flow, owing to the greater velocities and turbulence prevailing there, and the average grain size gradually diminishes toward the tail of the flow. When a supply of sediment is fed continuously into the current, no such horizontal grain-size gradient can be established; the current deposits an ungraded bed until the supply is cut off, at which time the horizontal gradient in the flow is established and vertical grading of the deposit begins. In nature a continuous feeding might result from a large slide originating over a large area (Kuenen and Menard, 1952, p. 94). Slumping of sediment that has accumulated for some distance along the headward parts of a submarine canyon appears to be a possible mechanism for maintaining continuous feeding. The greater than average thickness of most of the beds of sandstone in the Towsley formation that are graded only in their uppermost parts indicates that they were deposited by currents of large volume.

A very well sorted supply of sediment also might lead to the near absence of grading, but the nearly homogeneous beds in the Towsley formation are commonly not sorted well enough to make this explanation the most likely. Many beds have uniform grading from sand or coarser material at the base up into fine or very fine grained sand near the top; claystone rests abruptly on the fine sand with a smooth contact. The part of the bed that is normally represented by siltstone in a bed perfectly graded from sandstone to claystone is missing. The sediment that would have formed the absent layers was probably carried past this site of deposition by currents at the tail of the turbidity current. The fact that beds with these layers missing generally contain sets of cross-laminae near their tops suggests reworking by currents.

The next succeeding flow may have eroded the missing layers or may have followed so closely behind the first that its rapidly moving head overtook the dilute slow-moving tail of the first current and began depositing its load before the first bed was completed. A succession of flows following closely behind one another might be started by a succession of slumps on a submarine slope.

Many thick beds of conglomerate are not graded. The larger the average clast size the less well developed is the grading. Ungraded beds of coarse conglomerate may represent deposits of undersea slides.

INTERRUPTED GRADATIONS

Although most beds grade upward into siltstone or even claystone, many consist only of sandstone and are overlain by another sandstone bed whose base generally is not conspicuous because of the lack of a striking contrast in grain size or color across the contact. The degree of induration is commonly the same in both beds and the contact is not necessarily a surface of fissility, as is the surface between fine-grained and coarser beds. In some sandstone outcrops, however, graded bedding is conspicuous, and what may appear at a distance to be a single thick bed of sandstone may prove to comprise several beds when examined closely.

Within many graded beds the median grain size does not decrease upward in a uniform fashion. Thin dark streaks and wisps of micaceous silt (fig. 58) produce interruptions in the otherwise orderly sequence. The lower parts of graded beds are free of these fine laminae. The laminae may have been formed as a result of pulsations in the velocity or amount of turbulence in the current, although the common association of the laminae with sets of cross laminae suggests that they were formed by a current that moved its load at least partly by traction, rather than wholly in suspension.

ANGULAR FRAGMENTS IN SANDSTONE

A notable exception to uniform grading is the position of mudstone fragments that are commonly incorporated in the sandstone beds. These fragments are generally well up in a graded bed rather than at its base. In

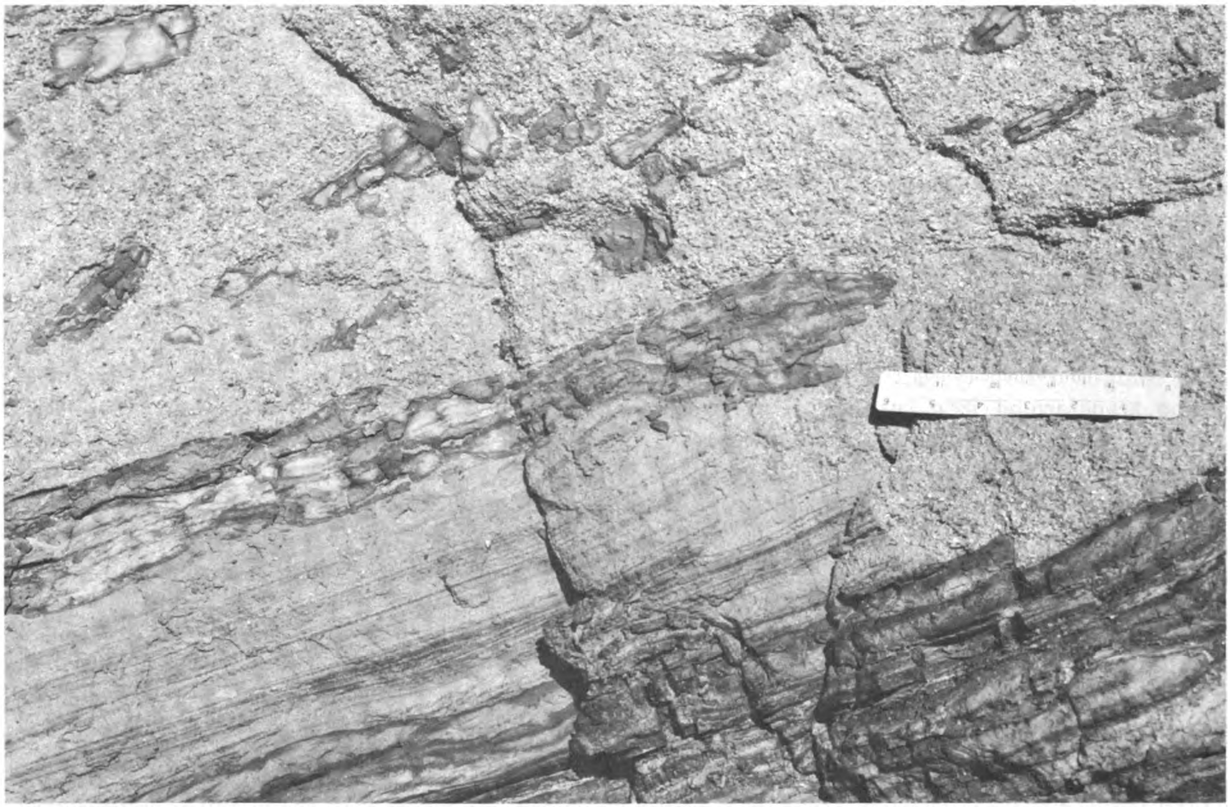

FIGURE 58.—Sandstone and siltstone beds in the Towsley formation, Santa Susana Mountains. The dark siltstone bed and the lighter colored siltstone bed with dark streaks and wisps of micaceous silt to the left of the 6-inch scale are channeled by the sandstone on which the scale rests. Angular clasts of siltstone lithologically identical with the dark siltstone bed that has been partially eroded are scattered in the channeling sandstone.

some places they are scattered at various levels, but in other places they are chiefly at one level. Their low density and their slab shape probably combined to give the fragments a slow settling velocity as compared to igneous or metamorphic clasts of the same dimensions. The alinement of these fragments along fairly definite planes within a graded bed suggests that a layer of mudstone was broken up and carried away from its place of origin on the sea floor a very short distance upslope and that this erosion proceeded concurrently with, and perhaps because of, the passage of a turbid flow. The fragments thus may not even have been available for transport until the lower part of the graded bed had been deposited downslope. Intermittent erosion during passage of the current could have produced trains of fragments which would have been deposited in distinct layers a short distance downslope (fig. 62).

IRREGULAR CONTACTS

Many contacts between two graded beds, although abrupt, are irregular. In some places there is clear evidence of channeling of the underlying beds. Thin wisps and laminae in the channeled bed are truncated at the contact. Generally the channel extends only a few millimeters into the bed beneath, but deeper channels, such as the one illustrated in figure 58 are not rare.

Irregularities in the shape of the surface of contact are generally not due to erosion of parts of the underlying beds but rather to deformation of the interface during deposition, probably due to unequal loading. Figure 59 shows several varieties of such deformation.

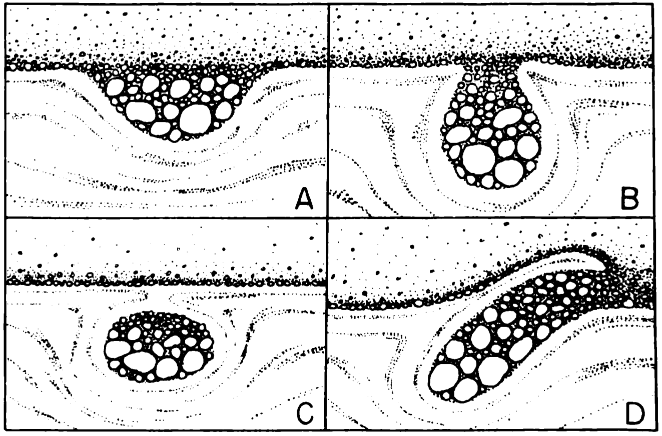

FIGURE 59.—Types of deformation of sandstone-siltstone interface, resulting from unequal loading, by which load casts are formed: A, shallow depression; B, deep depression with narrow connection with overlying bed; C, isolated pocket in lower bed; D, depression modified to an asymmetrical form by slumping, perhaps due partly to the drag of the passing turbidity current, and by unequal loading.

These features have been called load casts (Kuenen, 1953, p. 1048). The load casts are pockets of coarse-grained material projecting down into an underlying bed. Laminae in the bed beneath are not truncated as in an erosional channel but are bent around the pocket. The material in the pocket is generally markedly coarser than the material at the base of the overlying bed outside the pocket. This contrast is most noticeable where the overlying bed is pebbly. The material in the pockets generally grades evenly upward into the overlying material.

Most of the casts are shallow depressions but some are much deeper and have a narrow connection with the overlying bed; in some places the pocket is isolated within the lower bed (fig. 59).

Figure 60 shows load casts at the base of a bed of sandstone above siltstone beds. The attenuated form of the prongs of siltstone separating the load casts is evidence of the mobility of the substratum at the time of loading.

Figure 61 shows load casts at the base of a sandstone bed that rests on siltstone. The siltstone has been eroded away so that the configuration of the lower surface of the load casts can be seen. The current that transported the material in the overlying bed must have distributed its load gently but unevenly on a very plastic substratum, perhaps into small shallow original depressions. The weight of the unequally distributed material would cause it to sink in the underlying plastic mud wherever the larger, and therefore heavier, grains were concentrated. The coarsest material in a small turbidity current is at the nose of the current and would be the first to settle out. If the supply of new material is continuous, the sinking process is to a degree self-sustaining. The depth to which a pocket can grow is dependent on the strength of the substratum and the rate at which new material is supplied. A rapid supply, or a relatively stiff substratum, would cause the depression to be filled and a more equal load distribution to be developed before the pocket sank very deep.

INTRAFORMATIONAL BRECCIAS

Intraformational breccias are abundant throughout the Towsley formation (figs. 58, 62). The record of the formation of such breccias is preserved in the rocks. Deformed chips and slabs are common. Figure 58 shows a bed of coarse-grained sandstone containing siltstone fragments. In the center of the picture, the 2-inch layer of siltstone that underlies the sandstone has been eroded and the sandstone bed rests on a lower siltstone layer. The fragments in the sandstone bed are lithologically identical with the siltstone in the eroded

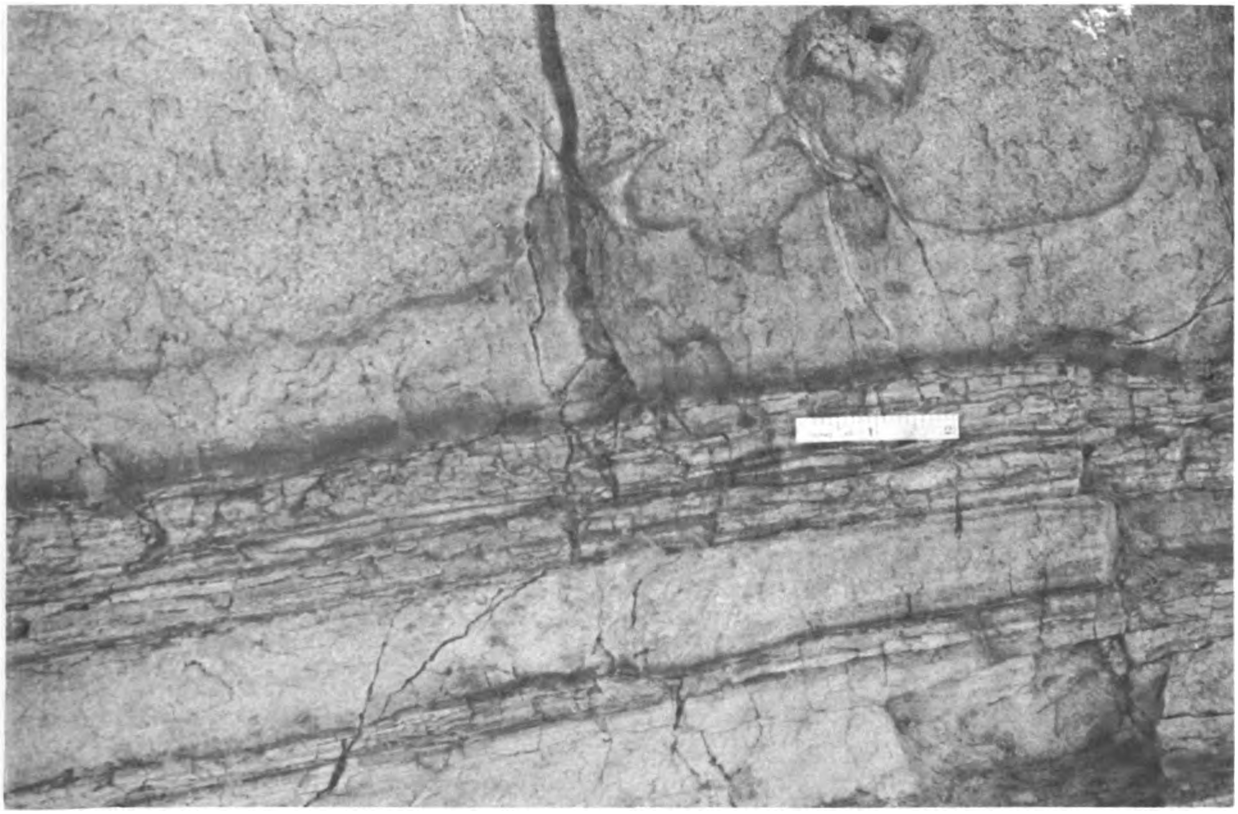

FIGURE 60.—Load casts in the Towsley formation, Santa Susana Mountains. The small block of siltstone near the top margin of the photograph apparently has been completely detached from the parent bed below.

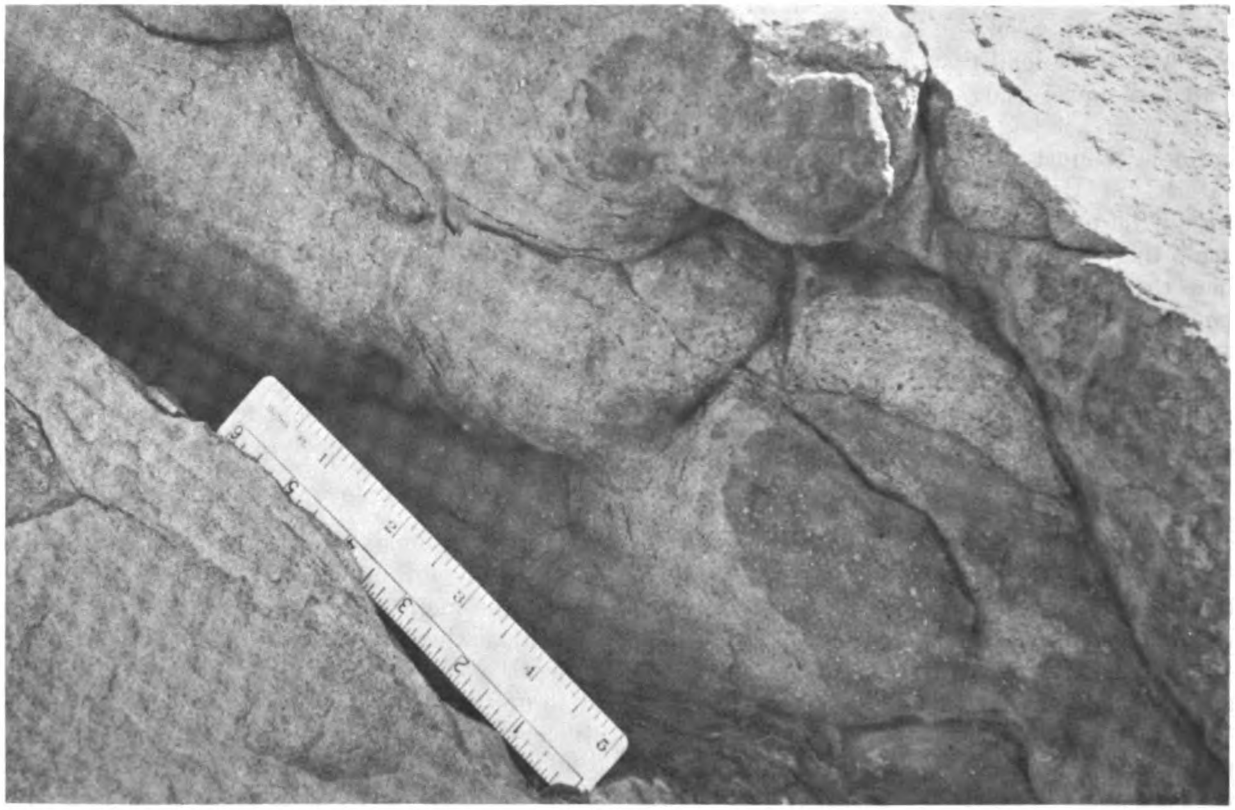

FIGURE 61.—Load casts developed on the basal surface of a sandstone bed in the Towsley formation, Santa Susana Mountains. The underlying siltstone bed has been eroded away.

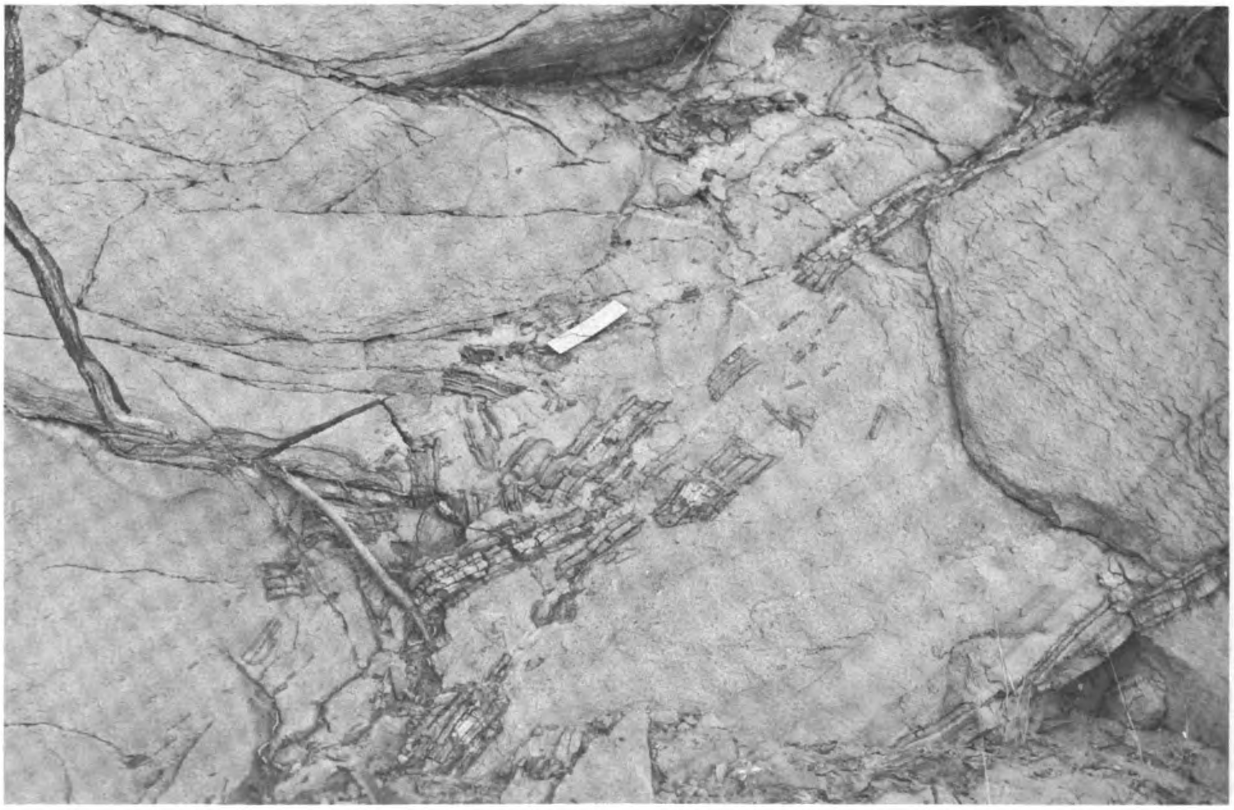

FIGURE 62.—Intraformational breccia in the Towsley formation, Santa Susana Mountains. The siltstone blocks below the 6-inch scale have the same thickness and lithology as the undisturbed siltstone bed in the upper right corner of the photograph and were apparently derived from it.

interval. The channeling sandstone bed actually underlies the siltstone for a distance of about 2 inches to the left of the broken end of the siltstone layer. The numerous dark laminae below the siltstone layer in the left half of the figure terminate against the sandstone-filled channel. The overhanging bed is bent downward slightly and was apparently the next unit that would have been eroded. Fragments in the sandstone were probably derived chiefly from a part of the siltstone layer that lies beyond the exposure shown on the photograph.

The intraformational breccia shown on figure 62 has siltstone blocks scattered to the left of the parent layer that match it in thickness and lithology.

A very large angular block of shale, more than 10 feet long in its largest exposed dimension (fig. 63) occurs with sandstone beds near the base of the Towsley formation. The block is exposed in the cut made for Standard Oil of California Brady Estates well 1, in sec. 13, T. 3 N., R. 17 W., near the summit of the Santa Susana Mountains. The base of the block lies a few inches above the base of a sandstone bed. Several other beds of sandstone and mudstone abut against higher parts of the shale block. Lack of deformation in beds adjacent to the block indicates that the upper part of the block projected above the sea floor and sediment filled in around it after the block arrived at its final destination. The shale in the block is phosphatic although no phosphatic shale in this part of the Towsley formation crops out nearby. The block therefore is not like those in the intraformational breccias described above for it does not have a nearby source. A unit of very similar phosphatic shale in the Modelo formation, a few hundred feet stratigraphically below the rocks in which the shale block occurs, crops out a few hundred feet to the south. The sandstone beds that enclose the shale block interfinger northward with phosphatic shale of the Modelo formation and are stratigraphic equivalents of the beds exposed near the axis of the Pico anticline, about 2 miles distant. Evidence from a study of the sedimentary structures indicates that the direction of transport of the sediment of the Towsley formation in this area was from the east or northeast. The nearest land in those directions during Towsley time probably was no closer than 5 miles. Regardless of actual source, however, the block must have travelled a considerable distance to reach its present site. Because the shale in the block is very brittle and crumbly, it is difficult to understand how such a large block, even if it were firmer and more cohesive at the time of its transportation, could survive a long journey along the sea floor. A very powerful current is needed to move an angular block of such large size, yet this current must be of such a nature

FIGURE 63.—Large angular erratic block of shale in the Towsley formation, Santa Susana Mountains.

as to prevent the block from breaking as it moves along. Extrapolation of the results of laboratory experiments by Kuenen indicates that a large swift turbidity current of moderately high density could move the block by suspension. Because of the long distance to land, as compared to the distance to possible submarine sources of phosphatic shale, it is more likely that the block was derived from a submarine source.

The block was obviously coherent when eroded and transported. It may have been derived from some nearby submarine slide that involved a sequence of compacted beds thick enough to produce a block of this size. It is notable, however, that no other shale blocks of comparable dimensions were observed near this one or anywhere else in the Towsley or Pico formations.

CURRENT MARKS

Currents have left their impress on the rocks, not only in the form of cut-and-fill structures, but also as current bedding, current lineation, and ripple marks. A typical succession involving current bedding is illustrated in figure 64. The base of the bed on which the scale rests is its coarsest part and the basal contact is irregular but very distinct. The middle part of the bed is banded by discontinuous streaks and wisps of dark silt and clay. Near the top of the bed are several small-scale lenticular trough sets of concave high-angle thin cross laminae (McKee and Weir, 1953, p. 381–390). Resting with an abrupt contact on the sets of cross laminae is a band of dark siltstone and claystone. The contact between the siltstone and the underlying sandstone is wavy. The siltstone is thicker in the troughs of the waves than at the crests, and sets of cross laminae are either thin or missing under the wave troughs. In the sandstone bed that lies on the siltstone band, the coarsest material lies in the wave troughs. These facts indicate that the wavy form is a primary feature and is a cross section of a series of ripple marks. The average wavelength of ripples observed in the Towsley formation is about 10 inches.

The apparent dip of the laminae is to the left in all beds shown in figure 64, but not all cross laminae are so regular. In some places beds containing cross laminae are slumped and contorted.

Many determinations of the true dip of cross laminae in the Towsley formation were made and compared with the dip of the enclosing strata. Observations at numerous places from Rice Canyon westward to and beyond the border of the mapped area showed that the direction of current flow indicated by cross laminae is remarkably constant. Along the belt of outcrops on the north slope of the Santa Susana Mountains the cross laminae were produced by currents flowing from the sector between east and northeast.

In only one place, in a road cut in the Pico Canyon oil field area, was a bedding plane seen that had been stripped over a large enough area to show the pattern of the ripple marks. The current that produced the ripples flowed from the northeast.

The persistence of the same direction of inclination of the cross laminae over such a large area and throughout the thickness of the formation can make the cross laminae useful in determining the direction of dip of beds penetrated by wildcat oil wells. It would be relatively easy to determine the direction of inclination of cross laminae from a series of cores from wells in areas where the dip of the strata is known. The direction of cross-stratification, and hence the direction of currents, would probably be different in various parts of the eastern Ventura basin, but it should not be difficult to establish a pattern of variation. Because recovering well-oriented cores or measuring the direction of dip with electrical devices is sometimes expensive and time-consuming, attention to cross-stratification in cores might be rewarding.

The ripples and cross-stratification indicate currents that moved material by traction. The sets of cross laminae near the tops of many graded beds and the relative constancy of the direction of current flow indicated by the inclination of the cross laminae suggest that the dilute tail of the turbidity current that deposited a bed produced the ripples. The rather consistent direction of currents required to explain the uniformity of the direction of inclination of the cross laminae over a large area and through a considerable thickness of strata is not compatible with a shallow-water environment, where the direction of currents is generally subject to rapid shifting. In a basin deep enough to prevent normally fluctuating wind, wave, and tidal currents from stirring the sediment on the bottom, turbidity currents originating along a submarine slope on a side of the basin could not only transport coarse-grained material into the basin, but could also produce a rather uniform orientation of directional features such as ripple marks.

The existence of such a submarine slope during late Miocene time is suggested by subsurface data showing that both the Modelo and Towsley formations thin very markedly eastward toward Newhall and Saugus from the intersection of U.S. Highway 99 with Pico Canyon. Structure section *A–A′* (pl. 45) shows that this eastward thinning is so pronounced, especially in the Modelo formation, that it seems reasonable to assume that either a submarine slope against which the layers of basin sediment thinned existed in that area, or a very unequal rate of subsidence prevailed

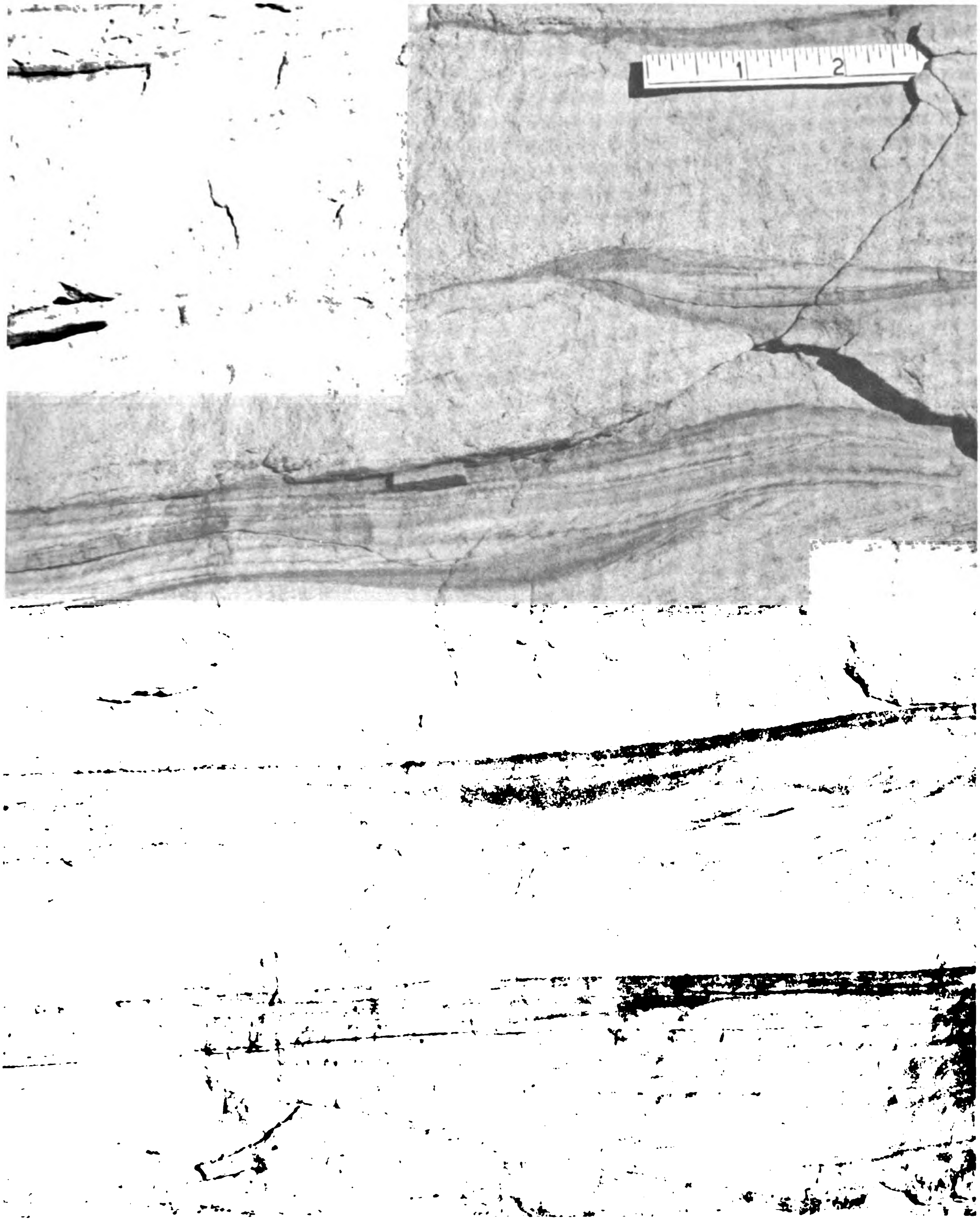

FIGURE 64.—Current bedding in the Towsley formation Santa Susana Mountains. The bed on which the 3-inch scale rests and others below it have an irregular basal contact, coarser material at the base, discontinuous streaks and wisps of dark silt and clay in the middle part, and cross laminae near the top.

in two areas of equal depth on either side of the zone of thinning. The former possibility is consistent with the direction of the source of turbidity currents indicated by the inclination of the cross laminae.

The geographic distribution of the lowest conglomerate beds in the Towsley formation is not consistent with the source direction indicated by the study of crossbedding. The change in facies from the conglomerate and sandstone of the lowest beds of the Towsley along the crest of the Santa Susana Mountains to shale in beds of equivalent age in the Modelo formation farther northeast in the Rice Canyon area means that finer, rather than coarser grained rocks, occur toward the supposed source. The best examples of current bedding in this geographic and stratigraphic part of the Towsley formation definitely indicate a northeastern source for the sediments. The conclusion seems warranted that gravel-loaded turbidity currents moved across a mud bottom for a mile or more without depositing coarse sediment and without leaving clear evidence of erosion. Channeling may have been obliterated from the structureless mudstone of the Modelo where not even bedding is apparent. The area of deposition of the Towsley may have been separated from the source area by a belt of mud. Though no evidence of erosion channels was seen in the field, the pronounced thinning of the Towsley and Modelo formations toward the northeast, in the direction of Newhall, may be partly due to penecontemporaneous erosion.

That the same general source direction may have been predominant during deposition of the Pico formation is indicated by the lateral change in foraminiferal faunas from deep-water types at the longitude of the Newhall-Potrero oil field to much shallower water types at the longitude of Towsley Canyon. Single mappable units of conglomerate and sandstone may be traced continously from the shallow- to the deep-water area. In the deep-water area, graded beds are prevalent (fig. 54).

Well-preserved current lineation was seen at only one place in the Towsley formation, probably because current lineations are not readily preserved in friable sandstones such as those in the Towsley. Figure 65 shows current lineation, a number of nearly parallel narrow low ridges, on the base of a block of sandstone removed from a sandstone bed overlying a layer of siltstone. The base of the sandstone bed in place also is marked by ridges like those in the figure. The ridges are casts of narrow grooves that score the upper part of the surface of the underlying siltstone layer. Because the orientation of the lineation corresponds to the direction of current flow indicated by cross laminae in adjacent beds, the lineation is believed to have been produced by a current. Similar short, narrow, and shallow grooves formed by sand grains rolling and sliding along the silty or clayey bottom of a present-day shallow stream near Newhall were observed by the authors. Flow markings similar to those shown in figure 65 were described by Rich (1950, p. 717–741; 1951, p. 1–20) and by Kuenen (1953).

SLUMP STRUCTURES AND CONVOLUTE BEDDING

The most common type of slump structure is postdepositional in origin; it generally involves more than one bed, and cross-stratification, where present, is equally well developed over troughs and crest of folds. Slump structures such as this are common in the Towsley formation. Figure 66 shows a slump structure that involves a sequence of beds about 8 feet thick. The mudstone bed probably provided the slipping base on which the slumping began. The light-colored banded rock is sandstone. The darker bands within the sandstone are discontinuous wisps of micaceous siltstone. Two large prongs project up into the sandstone from the lower mudstone layer.

Individual beds having only the middle parts crumpled are rare in the Towsley formation, but folds truncated by the next overlying bed are more common. This feature, termed convolute bedding (Kuenen, 1952, p. 31), is commonly very difficult to distinguish from an ordinary slump structure. The folds in convolute bedding die out downward and the folding is confined to one bed; ideally, the folds of convolute bedding die out upward also. Convolute bedding has laminae that are commonly attenuated on the crests of the folds and thickened in the troughs, as in ordinary slump structures, but the sets of cross laminae commonly associated with the laminae near the top of the bed are generally more prevalent and thicker in the troughs than on the crests. Convolute bedding characteristically extends for considerable distances along a bed. The thickness of the bed, the steepness and asymmetry of folds within the bed, and the distance between the crests of the folds, as well as the relative width of the troughs and crests of the folds, remain constant. A particular pattern of crumpling may remain nearly the same for many yards along an exposure. One convoluted bed about 5 inches thick was traced for about 50 yards, showed no appreciable change in thickness, and retained a distinctive pattern of crumpling. Crumpling confined to the center of a bed is the result of movement that began and ceased during, not after, the deposition of the bed. If the top part of a crumpled bed is missing as a result of erosion, the dating of the movement is more uncertain.

The crumpling of beds during deposition could be due to frictional drag of a current, but the currents producing the sets of cross laminae associated with the

FIGURE 65.—Current lineations in the Towsley formation, Santa Susana Mountains. Scale is about 7 inches long.

FIGURE 66.—Slump structures in the Towsley formation, Santa Susana Mountains. The dark siltstone in the upper left truncates the contorted beds below. The lowest bed, at the extreme right edge of the figure, is mudstone. The dark, diamond-shaped block of mudstone near the hammer was probably derived from the mudstone layer.

convolute bedding are probably not swift enough to accomplish the task. A more plausible explanation is that the deposition took place on a slope sufficiently steep to permit the water-saturated incoherent sand to continue to creep downslope even after deposition. The thin laminae of clay in the convoluted beds might be helpful in promoting the creep.

STRUCTURE

REGIONAL RELATIONS

The Ventura basin is a deep narrow trough filled with a thick prism of sedimentary rocks of late Cenozoic age. The axis of the basin trends east-west and coincides approximately with the center of the Santa Clara River valley and Santa Barbara Channel. Although the Ventura basin has been an area of subsidence and accumulation of sediment since the beginning of the Tertiary period, the narrow troughlike form did not develop until near the beginning of the Miocene epoch. At that time the Oak Ridge uplift developed as a more or less linear positive element that bordered the Ventura basin on the south and extended eastward from Oxnard through the Simi Hills to the north side of San Fernando Valley (fig. 49). Strata of late Cenozoic age thin toward this persistent high and are dissimilar on its north and south sides.

The axis of the late Cenozoic trough north of the Oak Ridge high extends westward from the vicinity of Sunland (fig. 49) along the north edge of San Fernando Valley and through the Newhall-Potrero oil field to Piru. The narrow easternmost part of the basin is bordered on the north by highlands of pre-Cretaceous rocks of the San Gabriel Mountains. Near Newhall the trough increases in width, and its margin of crystalline rocks trends northwestward near the trace of the San Gabriel fault. Farther west, the north border of the trough is ill defined, but the northward thinning of the upper Cenozoic section north of the Oak Canyon oil field indicates that the margin of the trough must have been only a short distance north of that area during Pliocene time and probably only 7 or 8 miles north of there during Miocene time. In the Ventura basin the Miocene sea was, in general, more widespread than the Pliocene sea.

Near the south margin of the Ventura basin the thick section of rocks of late Cenozoic age has been thrust southward along the Santa Susana fault toward the older rocks of the Simi Hills. The zone of thrust faulting extends northeastward, obliquely across the axis of the depositional trough near San Fernando Pass. The zone continues as a series of high-angle northward-dipping faults along which the pre-Cretaceous rocks of the San Gabriel Mountains are thrust southward over the nothern margin of the basin.

The San Gabriel fault zone transects the northeastern part of the Ventura basin. This fault can be traced from the Frazier Mountain area, about 30 miles northwest of Saugus, to the eastern part of the San Gabriel Mountains, a distance of about 90 miles. Dissimilar facies in the pre-Pliocene rocks on opposite sides of the fault indicate a long history of continue movement. Evidence of 15 to 25 miles of right-lateral displacement along the fault after late Miocene time was presented by Crowell (1952a).

Major folds and faults between the San Gabriel and Santa Susana fault zones trend northwestward. Mos of the faults are southward-dipping reverse faults.

STRUCTURAL HISTORY

PRE-LATE CRETACEOUS

During the course of field work no attempt was made to differentiate rocks unit within the crystalline complex of the San Gabriel Mountains; therefore, no inference are made regarding the structural history of these older rocks.

LATE CRETACEOUS AND EARLY TERTIARY

Cretaceous rocks are unknown in the area north o the Santa Susana fault, but their thickness (5,500± feet in the nearby Simi Hills and their presence in well immediately south of the fault suggest that the Cretaceous sea may have covered at least part of the region north of the fault. Paleocene rocks likewise crop ou in the Simi Hills and are reported from the Aliso Canyon oil field, just south of the Santa Susana fault Paleocene rocks also crop out between branches of th San Gabriel fault about 10 miles southeast of Newhal (Hill, 1930, pl. 15) and over a large area north of th San Gabriel fault near Elizabeth Lake Canyon and about 5 miles north of Castaic. Even if large latera displacements have occurred along the San Gabrie fault, it is still probable that the southeastern Ventur basin was a depositional basin during Paleocene time

Eocene rocks exposed in Elsmere Canyon are a least in part equivalent in age to the Llajas formation of McMasters (1933) in Simi Valley. This formation rests with slight unconfromity on older beds in th Simi Valley area. In the region north of the Sant Susana fault a similar unconfromity may be presen between crystalline rocks and rocks of Eocene ag penetrated in Continental Oil Phillips 1 well.

The Sespe formation is reported to rest conformabl on the Llajas formation of McMasters (1933) in th Simi Valley (Stipp, 1943, p. 422), and no evidence wa discovered to disprove a similar relationship betwee the Sespe(?) formation and marine Eocene rocks i the Newhall area.

EARLY AND MIDDLE MIOCENE

Lower Miocene marine rocks are not known in the southeastern Ventura basin but they may have been present at one time. South of the Santa Susana fault, middle Miocene strata assigned to the Topanga formation rest with angular unconformity on the Llajas formation of McMasters. The unconformity at the base of the Topanga formation is inferred to be associated with the beginning of the uplift of Oak Ridge and the Simi Hills.

The most widespread unconformity in the Miocene section is at the base of the Modelo formation. In the Aliso Canyon oil field, the Modelo formation rests on Cretaceous and Eocene rocks; in the same area, but north of the Santa Susana fault zone, the Modelo formation rests unconformably on the Topanga formation. This unconformity, together with the southward thinning of the Modelo formation, suggests that the Oak Ridge-Simi area was a positive tectonic element at the time the Modelo formation was deposited.

LATE MIOCENE

Subsidence in the trough continued during the late Miocene, and the change from predominantly fine-grained clastic material in the Modelo formation to predominantly sandstone and conglomerate in the Towsley formation suggests the uplift of adjacent land areas to a higher altitude. The distribution of coarse anorthosite-bearing conglomerate in rocks of Kleinpell's upper Miocene Mohnian stage northwest of Castaic was interpreted by Crowell (1952a) as suggestive of their derivation from a nearby area across (northeast of) the San Gabriel fault. The change from the finer grained rocks of the Modelo to the coarser grained rocks of the younger Towsley, especially considering the eastern derivation of the material, may well be correlated with the beginning of important movement along the San Gabriel fault.

The angular unconformity at the base of the upper Miocene Castaic formation of Oakeshott (1954) north of the San Gabriel fault records local, but intense, post-Mint Canyon (latest Miocene) deformation. The Whitney Canyon fault may have been active during late Miocene time also, but its movement cannot be dated more precisely than post-Eocene and pre-Plicoene.

PLIOCENE AND EARLY PLEISTOCENE(?)

Lower Pliocene strata overlap older formations near the southeastern margin of the basin, but no unconformity separates Miocene and Pliocene rocks in its central part. Although subsidence continued in the central part of the basin during the Pliocene, the rate of subsidence was less than the rate of sedimentation. Unconformities between the Pico and Towsley formations and between the Saugus and Pico formations near the margins of the basin reflect the tectonic activity in these areas. That these disturbances also affected areas at some distance from the edges of the basin is indicated by the angular discordance between the Pico and Saugus formations southeast of the Newhall-Potrero oil field. Continued intermittent activity along the San Gabriel fault zone is inferred from the increased angularity of unconformities in areas near the fault.

PLEISTOCENE

After the deposition of the Saugus formation, which may include beds as young as late Pleistocene, the entire region was intensely deformed and the present structural features of the region were developed. The deformation in the mapped area cannot be dated precisely, but presumably it is the same one that affected the Ventura region in the middle Pleistocene (Bailey, 1935, p. 491).

LATE PLEISTOCENE

The erosion surfaces and stream-terrace deposits that exist at various altitudes between the floor of the Santa Clara River valley and the top of the Santa Susana Mountains record continued vertical uplift of the entire region. The terrace surface that lies across the axis of the Del Valle anticline appears to have an exceptionally flat profile, rather than the valleyward-sloping profile that would be expected, suggesting that the fold is still being formed. Similarly, the profile of a terrace surface that lies across the axis of the syncline southwest of Castaic Junction oil field appears to be concave. Further evidence of continued tectonic activity in the region is found in the displacement of terrace deposits by minor faults at several places.

STRUCTURAL DETAILS

SANTA SUSANA MOUNTAINS AND SAN FERNANDO VALLEY

Faults.—The part of the Santa Susana Mountains shown on the geologic map (pl. 44) lies on the north or upthrown side of the Santa Susana fault. Southwest of the mapped area on the southwestern flank of the mountains, this fault has a very sinuous trace with an average trend of about N. 60° W. The fault south of San Fernando Pass that is labeled Santa Susana on the map does not have the general strike and low dip which are characteristic of the Santa Susana fault outside the area shown on the map. The northeastward-trending segment of the fault on the map is interpreted as a tear fault at the southeastern end of the Santa Susana fault proper.

Southwest of the mapped area the Santa Susana fault commonly dips gently northward at the surface, although at some localities the fault surface is flat or even dips southward. At moderate depths the fault dips steeply to the north (pl. 45), but whether it continues to dip steeply at greater depth is uncertain. The dissimilarity of the stratigraphic sections on either side of the fault, as revealed at the surface and in wells, suggests that the rocks on opposite sides of the fault were deposited in areas remote from one another and were brought into closer proximity by movement on the Santa Susana fault. If this movement was, as believed, chiefly thrust rather than strike slip in character, the fault surface must flatten northward at depth. Leach (1948) suggested 5 miles, and Hazzard (1944) a minimum of 1½ miles of thrust movement on the Santa Susana fault.

The zone of southward thrusting continues eastward along the south front of the San Gabriel Mountains as a series of reverse faults that bring rocks of pre-Cretaceous and Pliocene age into contact. The outlier of crystalline rocks east of Grapevine Canyon is probably a klippe related to the nearby thrust faults. The fault trending northwestward across Grapevine Canyon truncates a thick section of Pliocene rocks on the poorly formed eastward continuation of the Pico anticline. It is interpreted as a tear fault related to the faults along the south front of the San Gabriel Mountains.

The Salt Creek fault (pl. 45), a reverse fault which dips steeply toward the northeast, truncates the west end of the Pico anticline. A horizontal component in the movement of this fault is demonstrated by right-lateral displacement of conglomerate beds of the Pico formation. Since no evidence was found that the fault continues north of Potrero Canyon, it is postulated that it may terminate there against an eastward-trending fault.

Folds.—Eastward from Salt Canyon the general northerly dip of the strata above the Santa Susana fault is disrupted by the Pico anticline and the parallel Oat Mountain syncline (pl. 45). The axial plane of the Pico anticline is nearly vertical in exposures in the canyon bottoms but dips southward in exposures high on the ridges. Subsurface information suggests that the axial plane dips steeply southward at depth. The rapid northward thickening of the Modelo formation near Rice and East Canyons greatly reduces the structural relief of the anticline in the subsurface.

The asymmetric anticline in the subsurface in the Newhall-Potrero oil field (pl. 45) is represented at the surface in the central part of the field only by a broad structural terrace that changes toward the northwest to a northwestward-plunging nose. No unconformity is known which would explain the marked difference in surface and subsurface structure. The steep south limb of the anticline may have been caused by a fault in the subsurface. Although steep dips on the divide between Pico Canyon and Potrero Canyon and in the area southeast of the mouth of DeWitt Canyon may indicate the presence of such a fault, no important displacement of beds was observed at the surface.

SANTA CLARA RIVER TO SAN GABRIEL FAULT

Faults.—The Del Valle and Holser faults are two of the most important structural features north of the Santa Clara River in the western part of the area. The Del Valle fault trends eastward from the Los Angeles-Ventura County line for nearly 2 miles and turns southward before crossing San Martinez Grande Canyon. The eastward-trending part of the fault trace is a southward-dipping reverse fault (pl. 45); the southward-trending part of the fault trace is interpreted to be a tear fault. On the geologic map (pl. 44) these two segments are shown to be connected, but their true relationship is obscured in the field by landslides and creep.

The Holser fault can be traced from near Piru Creek, several miles west of the Los Angeles-Ventura County line, to Castaic Creek. Subsurface information and conspicuous southward-dipping fractures in outcrops of the Saugus formation just east of the U.S. Highway 99 bridge over the Santa Clara River indicate that the fault extends eastward beneath the alluvium-covered river valley (pl. 45). The Holser fault is inferred to intersect the San Gabriel fault east of the town of Saugus. Subsurface data in the Del Valle and Ramona oil fields demonstrate that the Holser fault is a southward-dipping, rather sharply folded reverse fault (pl. 45). It is offset by cross-faulting in at least one place near the east boundary of sec. 9, T. 4 N., R. 17 W.

Folds.—Folds near the Ramona and Del Valle oil fields (pl. 45) have an east-west trend, plunge gently eastward, and have almost vertical axial planes. The east-west trend of the folds changes to a southeasterly trend near the Castaic Junction oil field. Folds south of the Holser fault between San Martinez Chiquito Canyon and Castaic Creek are more closely spaced near the fault.

SAN FERNANDO PASS AND NEWHALL AREA

Rocks of Pliocene age near Newhall and San Fernando Pass have a regional dip to the west; southward-dipping thrust and reverse faults have deformed these strata into gentle westward-plunging folds. "Legion fault" and "Beacon fault" are local names commonly used by geologists for two of these faults. The Legion fault, the northernmost of the reverse faults (pl. 45), is named for its exposure behind the American Legion Hall, about 1 mile east of Newhall. The fault is mostly concealed by alluvium, but it is inferred to connect with a system of reverse faults exposed on the ridge south of Elsmere Canyon. The Beacon fault is named for its exposure near an airway beacon in San Fernando Pass. It is a thrust fault that dips about

30° southward at the surface along the eastern part of its trace (pl. 45) but apparently steepens to the west. At its east end it is apparently parallel to the bedding of the strata and could not be traced.

The Weldon fault, which parallels the Beacon fault to the south, does not steepen westward but rather flattens and the direction of its trace changes from west-northwest to nearly south. A klippe lies just west of the north-southward-trending part of the fault trace. The Weldon and Beacon faults are both believed to steepen at depth. The pre-Pliocene stratigraphy is very dissimilar in the subsurface on either side of the Weldon fault (pl. 45). Wells drilled south of the fault penetrate a thick section of the Modelo formation, whereas north of the fault the Modelo is very thin. This difference in thickness could be explained by the presence of a strike-slip fault along which there has been considerable displacement, most probably left-lateral. Many small west-northwestward-trending faults, some of which have horizontal slickensides, are exposed in Weldon and Gavin Canyons; however, none of these faults appear to have sufficient displacement to explain the dissimilarity of rocks of pre-Pliocene age on either side of the Weldon fault. It is possible that different pre-Pliocene stratigraphic sequences may have been brought into juxtaposition along a strike-slip fault whose movement was chiefly of pre-Pliocene age.

The nature and age of movements along the Whitney Canyon fault are not definitely known. No Eocene rocks are present east of this fault, but the Continental Oil Phillips 1 well (well 42 on pl. 44), which was drilled only 1,600 feet west of the surface trace of the fault, penetrated a very thick section of Eocene rocks between 1,300 and 7,911 feet (pl. 45). The difference in depth to crystalline rocks on opposite sides of the fault would indicate a vertical displacement of about 6,000 feet on the Whitney Canyon fault if the movement were entirely vertical. The base of the Pliocene section, however, has a vertical displacement of only about 400 feet across the fault, and, in a sense, opposite to the displacement of the top of the crystalline rocks. From this evidence it seems probable that the Whitney Canyon fault may have had at least two periods of activity: pre-Pliocene movement, which may have been either dip-slip or strike-slip, and post-Pliocene movement, which was perhaps mainly dip-slip, as suggested by the similarity in thickness and facies of the rocks of Pliocene age on opposite sides of the fault.

SAN GABRIEL FAULT TO NORTH EDGE OF MAPPED AREA

Faults.—The San Gabriel fault is a major right-lateral strike-slip fault that trends in a northwesterly direction across the northeastern part of the mapped area. The rock sequences of pre-Pliocene age on opposite sides of the fault are quite dissimilar (pl. 45). The Miocene rocks south of the fault are chiefly marine, and those north of it are chiefly nonmarine. The Pliocene rocks, however, particularly the Saugus formation, are similar on both sides of the fault. Although the postlate Miocene (Mohnian stage of Kleinpell) movement along the San Gabriel fault may have been large (Crowell, 1952a), the major movement occurred before the deposition of the Saugus formation. The trace of the fault through the Saugus is marked only by a zone where the beds have abnormally steep dips and relatively minor faults and fractures.

Folds.—South of the Santa Clara River, the Mint Canyon formation is compressed into a number of tight folds (pl. 45). East of U.S. Highway 6 these folds have a northwesterly trend, but west of the highway they trend nearly due west. This change in trend, together with the poor correlation of the folds across the small valley west of U.S. Highway 6, suggests that a northeastward-trending fault may be present beneath the alluvium of the valley. Since no evidence of it was found in exposures of the Saugus formation, such a fault, if it exists, is pre-Saugus.

The Saugus formation north of the San Gabriel fault is warped into a number of broad folds. The trend of some of the folds is at slight variance with the regional trend of folds in other parts of the mapped area.

GEOLOGIC HISTORY

Fundamental to an understanding of the Cretaceous and Tertiary history of almost any area in southern California is the realization that large lateral movements along faults can drastically alter the distribution of rock units, separating formerly contiguous rocks and placing together rocks originally deposited in different areas or even in different basins. The San Gabriel fault is apparently a strike-slip fault that has brought together two formerly distinct depositional provinces. The area northeast of the fault appears to have had a depositional history more or less independent of that of the area southwest of the fault until late Tertiary time, when movements along the fault began to bring the two areas into closer proximity.

The earliest event in the region for which there is a record in the rocks was the deposition of the Placerita formation of Miller (1934) which was later intruded by the Rubio diorite of Miller (1934). Both of these formations were intruded before Late Cretaceous time by quartz plutonites.

Late Cretaceous and Paleocene events are not recorded in the mapped area, but marine deposits of those epochs in areas close by suggest that seas of these ages may have extended across the mapped area.

Middle or late Eocene seas undoubtedly covered the area south of the San Gabriel fault, and in these seas were deposited several thousand feet of sandstone, siltstone, and conglomerate. Graded beds suggest that turbidity currents may have been operative in transporting and depositing sediment.

In the Ventura basin deposition of nonmarine variegated strata of the Sespe(?) formation followed withdrawal of the Eocene sea. Whether a period of erosion intervened between the marine and nonmarine periods of deposition is not clear, nor is the time extent of the nonmarine deposition known. Beds of montmorillonitic clay in the nonmarine strata suggest volcanic activity accompanied by ash falls.

During an unknown interval of time between the Paleocene and the beginning of the Miocene epoch, nonmarine deposits were laid down in the region northeast of the San Gabriel fault. These sediments, which now make up the Vasquez formation, include conglomerates, derived in part from an anorthosite terrane, as well as lacustrine deposits, lava flows, and tuff beds. The area of deposition of the Vasquez formation may have been separated from the area of deposition of the Sespe(?) formation by a ridge of pre-Cretaceous rocks, chiefly anorthosite.

Sometime between the end of the deposition of the Sespe(?) formation and middle Miocene time a positive element, the Oak Ridge-Simi Hills uplift, began to rise and to divide into two separate basins a former single area of accumulation of Cretaceous and early Tertiary sediments. The rocks in the uplifted area were folded and partly eroded before the deposition of the marine Topanga(?) formation in middle Miocene time, for the Topanga(?) formation rests unconformably on the older formations.

Deformation northeast of the San Gabriel fault during the time between the end of deposition of the Vasquez formation and the early part of the Miocene epoch is recorded by the angular unconformity at the base of the Tick Canyon formation of Jahns (1939). The deformations in the Simi Hills area and in the area of deposition of the Vasquez formation may be related to each other, but uncertainties about the age ranges of both the Sespe(?) and the Vasquez formations and doubts concerning the exact ages of Jahns' Tick Canyon formation and the Topanga(?) formation makes a correlation of tectonic activity in the two regions dubious.

Nonmarine conditions of deposition prevailed in the area northeast of the San Gabriel fault during deposition of the Tick Canyon formation of Jahns (1939). Lower Miocene marine deposits of the Vaqueros formation near the fault a few miles northwest of Castaic indicate that the region southwest of the fault was at least in part in a marine environment. However, early Miocene seas probably did not cover much of the mapped area.

The generally coarse texture of the clastic material in the Topanga(?) formation suggests nearby land as source areas, but the local paleogeography of middle Miocene time is obscure. The sea probably covered the area now occupied by the Simi Hills, but deposition there was very slow compared with that in the area now occupied by the Santa Monica Mountains to the south and the Ventura basin to the north. The middle Miocene sea extended eastward through the San Fernando Pass area at least as far as the present site of the town of Sunland, but how far the sea spread to the north is not known. Fine-grained marine rocks assigned to the Rincon formation, a part of which is equivalent in age to the Topanga(?) formation, are exposed about 15 miles northwest of outcrops of the Topanga(?) in the Santa Susana Mountains. The Topanga(?) may grade laterally into these finer grained beds in the subsurface. Minor eruptions of basalt accompanied deposition of the Topanga(?) in the area now occupied by Aliso Canyon.

Deposition of the Topanga(?) formation was followed by tilting and erosion, at least in the Aliso Canyon area, that perhaps reflected renewed uplift in the Simi Hills area. Deposition may have been continuous in areas farther north in the Ventura basin.

During late middle Miocene time the sea extended southward again into the Aliso Canyon area, where the sandstone at the base of the Modelo formation represents near-shore deposits of this sea. Either the Luisian (late middle Miocene) sea was widespread and the Santa Susana Mountains area was far from land, or else nearby land areas were low lying, for the siliceous and organic shales of the lower part of the Modelo formation record slow deposition in an area receiving little land-derived detritus. Deposition of mud continued in the Santa Susana Mountains area into late Miocene time, but the rate of deposition increased, and from time to time sand and gravel were swept into the basin by turbidity currents.

The probable main geographic features of the region in the early part of late Miocene time are represented in figure 67. A moderately deep trough extended in an east-west direction along the general line of the Santa Clara River valley from at least as far west as the town of Ventura through the Fillmore and Piru areas into the Santa Susana Mountains and Newhall areas. South of this trough was the Oak Ridge-Simi Hills uplift, which, even if not actually emergent, was not an area receiving important amounts of sediment. North of the trough, perhaps 10 or 12 miles north of the Del Valle oil field, a land area (the Piru Mountains) was probably con-

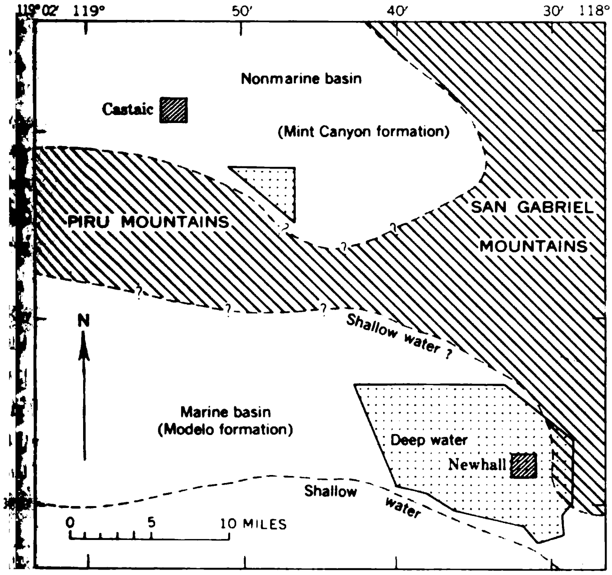

FIGURE 67.—Paleogeography of beginning of late Miocene time, eastern Ventura basin.

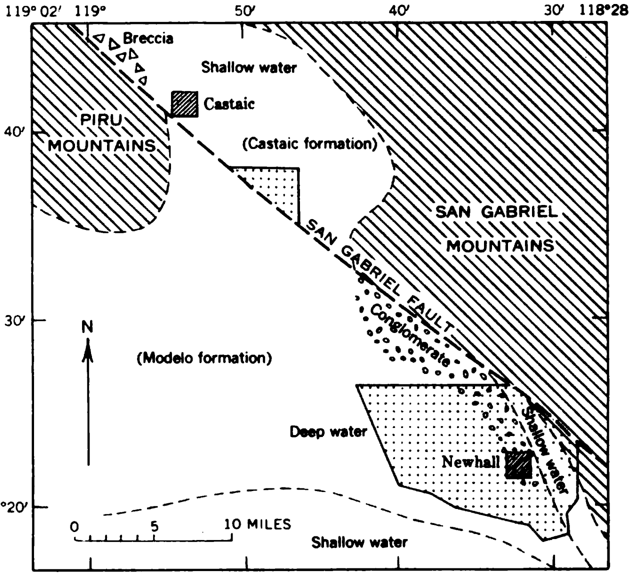

FIGURE 68.—Paleogeography of part of late Miocene (late Mohnian) time, eastern Ventura basin.

tributing detritus to the northern part of the basin. A fairly steep submarine slope bordered the basin from the Newhall area northward through Saugus, where the strike of the slope may have swung northwestward to become parallel to the present San Gabriel fault.

Northwest of the San Gabriel fault pre-Cretaceous rocks, including anorthosite, were exposed on a land area. This mass possibly extended as far north as Castaic and perhaps connected with the land area rimming the basin of deposition on the north.

On the north side of the ridge of crystalline rocks, in the same general area where the Vasquez formation was deposited at an earlier time, the fluviatile and lacustrine Mint Canyon formation was being deposited. The Mint Canyon basin may have drained southward into the Ventura basin or perhaps northwestward into the Cuyama Valley area.

Movements along the San Gabriel fault apparently began at least as long ago as early late Miocene (Mohnian) time and influenced sedimentation during much of the later part of the Tertiary period. During later Miocene time, after deposition of the Mint Canyon formation, the sea spread northeastward across the former barrier between the Ventura and Mint Canyon basins of deposition (fig. 68). In the shallow basin northeast of the fault, sand and silt were deposited that now constitute the Castaic formation of Oakeshott (1954). Northwest of Castaic very coarse gneissic breccia accumulated, possibly as talus at the base of steep scarps along the San Gabriel fault. On the opposite side of the fault, and for many miles farther southeast, coarse gravel accumulated near the submarine slope leading from the shoreline near the fault into the deeper waters of the ancient Ventura basin. Occasionally sand and gravel were carried far out into the basin by undersea slides and turbidity currents. Through the remainder of the Miocene epoch, and probably through most of the Pliocene epoch as well, lateral movement along the San Gabriel fault continued. Vertical movements along this or other nearby faults kept the land area high enough so that coarse material was nearly always being brought to the sea by streams. Near the close of Miocene time the area close to the fault was probably uplifted sufficiently so that the Castaic formation of Oakeshott (1954) was partly eroded away, but in the central parts of the basin deposition was continuous.

During the early Pliocene much of the marginal uplifted area was resubmerged and the sea extended not only into the region northeast of the San Gabriel fault but also into the Elsmere Canyon area. The general pattern of deposition established in the late Miocene in the Ventura basin continued. Shallow-water deposits accumulated in the area around Newhall while deeper water deposits accumulated farther west. Turbidity currents were intermittently active in transporting coarse material into deep water. Through Pliocene time the basin continued to subside, but the rate of subsidence was less than the rate of deposition and the basin gradually shallowed. Near the margins of the basin, shallow-water marine conditions of deposition gradually gave way to lagoonal and estuarine and finally to fluviatile conditions. The shore line of the basin of deposition was pushed farther and farther westward until fluviatile deposition prevailed over the entire area. Subsidence and deposition continued through the Pliocene and into the early Pleistocene.

Near the middle of the Pleistocene epoch the entire Ventura basin, along with the rest of coastal southern

California, was strongly compressed, and most of the present structural features of the area were produced. The main period of compression was apparently of short duration, although some deformation is probably going on in the region at present.

Following this orogenic episode slow uplift of the region began. Erosion surfaces were cut during the uplift, and stream terrace gravels were deposited locally on these surfaces.

OCCURRENCE OF OIL

Early travelers in California found that the Indians were using oil and tar collected from many natural seepages near the present town of Newhall. By 1850, oil from seepages in Pico Canyon was being distilled at nearby San Fernando Mission to produce "burning oil" for illuminating purposes (Prutzman, 1913). After 1859 the numerous oil seepages in the area attracted the attention of persons familiar with petroleum development in Pennsylvania. As early as 1869–70, Sanford Lyon drilled a spring-pole hole to a depth of 140 feet near oil seeps on the axis of the Pico anticline in Pico Canyon. The well is reported to have flowed from 70 to 75 barrels of oil per day while being drilled (Standard Oil Co. of California, 1918), but the tools were lost in the hole and drilling was suspended. Not until 1875 was another attempt made to drill a well in the area. In that year C. C. Mentre drilled on the axis of the Pico anticline a spring-pole hole that had an initial daily production of 2 barrels of 32° Bé (Baumé) gravity oil at 30 feet (Orcutt, 1924, p. 65). This well is generally considered to mark the beginning of the California oil industry.

After the successful completion of Mentre's well, California Star Oil Works Co. was organized to develop the oil resources of the Pico Canyon area. This company built the first oil refinery in California near Newhall in 1876. The refinery had a daily capacity of 20 barrels and the oil was hauled to it in wooden barrels.

In 1877 steam-driven equipment was installed on well Pico 4 (Standard Oil Co. of California C.S.O.W. 4) and was used successfully to deepen the well from 370 to 610 feet.[5] This first success with the use of steam-driven equipment marked the end of the spring-pole method of drilling in the area.

The Pacific Coast Oil Co. was incorporated in 1879 and began operations in the Pico Canyon area where, by acquiring the holdings of the California Star Oil Works Co., it became the principal oil producer in the region. A new refinery with a greater capacity was built near Newhall and a 2-inch gravity pipeline, the first in California, was constructed to it from Pico Canyon. After the Newhall refinery was closed in 1883, the oil was shipped by rail to the Pacific Coast Oil Co.'s refinery at Alameda, near San Francisco. During 1884 and 1885 a combination 2- and 3-inch gravity pipeline was laid from Pico Canyon to a refinery at Santa Paula. Shortly afterward the line was extended to the seacoast at Ventura where the oil was taken aboard ships for transit to San Francisco.

Development of the oil resources of Pico Canyon, as well as those of adjacent areas to the east along the Pico anticline was actively carried out even though the market for the oil was limited. Walling reported (1934) that well Pico 2 was permitted to flow freely for about a year because the poor market did not warrant the marketing of the oil. Activity along the Pico anticline was greatest from 1875 to 1900.

Exploration was begun in De Witt Canyon in 1882–83, in Wiley Canyon prior to 1883, in Towsley Canyon prior to 1893, and in Rice and East Canyons in 1899. Development outside the Pico anticline area began in Elsmere Canyon in 1889, in Whitney Canyon in 1893, and in the Tunnel area in 1900. No new discoveries of importance were made until the Newhall-Potrero field was found in 1937. The major discoveries in the area from 1938 to 1953 were the Del Valle field in 1940, the Ramona field in 1945, the Placerita field in 1948, and the Castaic Junction field in 1950.

The nomenclature used in this report for the various oil fields is similar to that used by the California Department of Natural Resources, Division of Oil and Gas. The small fields along the Pico anticline, together with those east and southeast of Newhall, are collectively called the Newhall field. The other fields are treated separately. The names of oil-producing zones used here conform with those used by most of the petroleum geologists who work in the region and with published reports. The oil-producing zones are listed in table 7 and the production statistics of the oil fields in the area are shown in table 8. The location of wells referred to in the text and of wildcat wells drilled prior to July 1953, whose locations are known to the authors, are shown on the geologic map (pl. 44).

OIL FIELDS

NEWHALL

Newhall oil field is the term applied to a number of relatively small oil-producing areas on the northern flank of the Santa Susana Mountains along the Pico anticline and on the western flank of the San Gabriel Mountains east and southeast of Newhall. The earliest development in the Newhall field was along the Pico anticline with its many oil seepages. Attention was focused on a number of canyosn which afforded access through the rugged terrain to the axis of the anticline.

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[5] The names of operators and wells given in parentheses after the names of a few of the wells mentioned in the text refer to a later designation of the well where the well name or operator has been offically changed.

TABLE 7.—*Oil- and gas-producing zones in four major fields west of Newhall*

Age	Field			
	Ramona	Del Valle	Castaic Junction	Newhall-Potrero
Early Pliocene		Sepulveda 20		
Delmontian stage of Kleinpell	Black Kern Del Valle	Kinler Sepulveda Vasquez 13 Vasquez Videgain Intermediate Del Valle		1st 2d 3d
Late Mohnian stage of Kleinpell		Anderson Bering	Reservoir 10 Reservoir 15	5th 6th
Early Mohnian stage of Kleinpell		Barnes Lincoln	Reservoir 21	7th 9th

PICO CANYON AREA

The Pico Canyon area is located about 5 miles west of Newhall in secs. 1 and 2, T. 3 N., R. 17 W. With successive well completions, development gradually spread from its beginning near the oil seepages in the broken shales in the canyon bottom to the adjacent hillsides. Twelve wells were drilled south of the anticlinal axis in Pico Canyon, but only 6 produced commercial quantities of oil, and these were soon abandoned because of low production. By the end of 1887, 31 wells had been drilled, of which 11 had been abandoned and the remaining 20 were producing an average daily total of 491 barrels of oil (Walling, 1934, p. 9). Several wells have been drilled in the area since 1902; however, none of these newer wells has produced more than a few barrels per day.

Wells C.S.O.W. (California Star Oil Works Co.) 12 and P.C.O. (Pacific Coast Oil Co.) 28 had the highest initial production records in the Pico Canyon area. Well C.S.O.W. 12, about 100 feet north of the axis, was completed at a depth of 1,400 feet in 1883; it produced 85 barrels of oil the first 24 hours. Well P.C.O. 28, about 1,000 feet north of the axis of the Pico anticline, was completed at a depth of 1,610 feet in 1893; it produced an average of 88 barrels per day during the first week. Sustained production showing a slow decline that is typical of the area is exemplified by well C.S. O.W. 13, which was completed in 1884 at a depth of 1,500 feet and produced 80 barrels of oil per day. During March 1891, well 13 produced a daily average of only 16 barrels. Production was increased to 24 barrels a day after the well was cleaned out and placed on pump in May 1891, but by July 1893 production had declined again to only 15 barrels per day (Walling, 1934, p. 17).

Approximately 80 wells were drilled in the area. Of these, 37 were still producing in 1934, with a daily average per well of 1.8 barrels of 38.2°API (American Petroleum Institute) gravity oil. In May 1940, 26 wells were producing only 50 barrels per day (Kew, 1943, p. 414). In 1953, a couple of wells were still pumping a few barrels of oil per day.

The Pico Canyon area is at the west end of the northwestward-trending Pico anticline. Shale of the Modelo formation is exposed in places along the axis of the anticline east of the field, but all the wells in the field are spudded in the Towsley formation. The somewhat lenticular nature of the strata, together with faulting, makes the recognition of definite oil-producing zones in the Pico Canyon area difficult. However, Walling (1934, p. 15) recognized a top, central, and lower zone. The first wells were completed at depths of from 120 to 170 feet, depending on their structural position; they produced from the central zone. Although some oil was reported in the fractured shales, most of the central-zone production probably came from sandstone. Well C.S.O.W. 32 is the only one to produce oil from the lower zone. This well, which was drilled to a depth of 3,445 feet and was completed in 1905, produced from between 2,588 and 3,000 feet. As late as April 1917, it was still producing a daily average of 12 barrels of 33.6° Bé gravity oil, with 69 percent water.

TABLE 8.—*Oil-production statistics for period January 1 to June 30, 1953*

[From: California State Oil and Gas Supervisor, 1953]

Field	Average number actual producing wells	Production (bbls)	Cumulative production, June 30, 1953 (bbl)	Average production per well per producing day (bbls)		Acreage	
				Oil	Water	Proved, June 30, 1953	Maximum potential
Castaic Junction	10	278, 761	1, 112, 287	169. 9	1. 2	315	315
Del Valle	80	518, 093	16, 485, 040	38. 8	61. 9	630	640
Newhall	40	74. 017	6, 205, 622	11. 8	12. 5	395	645
Newhall-Potrero	91	1, 587, 141	30, 184, 760	101. 8	6. 2	1, 170	1, 170
Placerita	326	1, 442, 314	19, 976, 443	25. 0	9. 3	660	685
Ramona [1]	122	545, 199	11, 204, 267	25. 1	4. 2	585	585
Total	669	4, 445, 525	85, 168, 419	62. 3	15. 8	3, 755	4, 040

[1] Only part of the Ramona field is within the area covered in this report.

In 1942, Standard Oil Co. of California drilled a deep test, P.C.O. 42, very near the axis of the anticline in the eastern part of the field. After penetrating the base of the Towsley formation, the well encountered steeply dipping fractured shales of the Modelo formation. The well bottomed at 8,758 feet in rocks assigned to the lower part of Kleinpell's Mohnian stage. The few sandstone beds encountered had low porosity.

DE WITT CANYON AREA

The De Witt Canyon area is about 2 miles east of Pico Canyon in the north half of sec. 7, T. 3 N., R. 16 W. A total of 7 wells were drilled there near the axis of the Pico anticline between the years 1882 and 1897. The first well, Hardison and Stewart 1, was drilled on the south flank of the structure near the axis; it is reported to have been completed at a depth of 1,000 feet and to have produced 1 barrel per day of black 24.1° Bé gravity oil (Walling, 1934, p. 18). The deepest well, Hardison and Stewart 3, was drilled to a depth of about 1,600 feet and was abandoned, although some oil was reported. There is no record of any commercial production in the De Witt Canyon area. A deep test well, the Los Nietos Oil Odeen 1, was drilled about 1 mile southwest of the De Witt Canyon area on the south limb of the Pico anticline in 1951–52. The well, which was abandoned at a depth of 9,215 feet, bottomed in rocks assigned to the lower part of Kleinpell's Mohnian stage.

TOWSLEY CANYON AREA

The Towsley Canyon area is about 3 miles southeast of Pico Canyon on the Pico anticline in the north half of sec. 17 and the south half of sec. 8, T. 3 N., R. 16 W. (pl. 45). The first well was drilled prior to 1893 by the Temple Oil Co., but it was abandoned without record. A number of shallow wells have been drilled since, none of which produced more than 30 barrels a day of low gravity oil.

In 1929 Consolidated Oil Co. began one of the few attempts to find a deep producing zone along the Pico anticline. This well, which was later designated the Community Oil of Nevada 1, was drilled a short distance north of the anticlinal axis; it was drilled to a depth of 5,225 feet, and for most of its depth the dips in cores were greater than 70°. The best oil show was in the interval between 3,915 and 3,990 feet, where a pumping test gave 20 to 75 barrels per day of 24° Bé gravity oil with 60 to 75 percent cut.

In 1941–42 Barnsdall Oil Co., Bandini Petroleum Co., and Ambassador Oil Co., drilled a deep test, the Limbocher 1, on the south limb of the anticline. Oil sands were cored but in a formation test only a small amount of gassy mud was recovered. The well bottomed at 7,071 feet in steeply dipping shale beds of the Modelo formation containing Foraminifera assigned to the lower part of Kleinpell's Mohnian stage.

Intermittent production has continued in the Towsley Canyon area to the present time. From January 1923 to January 1927 about 4,000 barrels was produced. During July 1935, 5 wells produced a daily average per well of 1.9 barrels of 20.5° API gravity oil and 2.2 barrels of water (Walling, 1934, p. 21).

WILEY CANYON AREA

The Wiley Canyon area is on the Pico anticline about 1 mile east of Towsley Canyon in sec. 16, T. 3 N., R. 16 W. Oil development was begun by a Mr. Davis, who in 1868 leased Wiley Springs and collected seepage oil which he shipped to the Metropolitan Gas Works in San Francisco. Two tunnels were dug into the side of Wiley Canyon for distances of 300 and 400 feet in an attempt to obtain increased seepage production (Walling 1934), but these proved unsuccessful.

The first well with a record of production was the Pacific Coast Oil well Wiley 4, which was placed on production May 31, 1884, and which pumped 2 barrels a day of 30° Bé gravity oil from a total depth of 1,275 feet.

In 1909–10 Standard Oil Co. of California drilled the first two wells in the area to produce oil in commercial quantities. These wells, Wiley 18 and 19, were drilled about 200 feet south of the axis of Pico anticline and were completed at depths of 1,528 and 1,509 feet, respectively. Wiley 18 was completed in 1910 and pumped a daily average of 83 barrels during the first 8 days. This well was deepened in 1913 and when recompleted it pumped 89 barrels per day of 29° Bé gravity oil. The Wiley 19 had an initial production of 109 barrels a day, the highest in the area.

The deepest well was Standard Oil of California Wiley 25, drilled in 1910–12 on the north flank of the anticline and abandoned at a depth of 3,835 feet.

Of the 29 wells drilled in the Wiley Canyon area, 8 were still producing a daily average per well of 1.7 barrels of 28.2° API gravity oil and 3.7 barrels of water in 1934. Nearly all production in the area came from wells that are less than 2,000 feet deep and are near the axis of the Pico anticline. When shut down in 1940, 9 wells were producing less than 1 barrel a day per well.

RICE CANYON AREA

The Rice Canyon area had 10 productive acres on the Pico anticline 1 mile southeast of Wiley Canyon in sec. 22, T. 3 N., R. 16 W. The first well was drilled by Pacific Coast Oil Co. in 1899 to a depth of 550 feet. In 1900 it was producing 3 barrels a day. Ten wells were drilled, altogether, to depths ranging from 300 to 1,580 feet. All the wells are either on the axis of Pico anticline or within a few hundred feet south of it. The deepest well, Inspiration Oil 1, was drilled by Rice Canyon Oil Co. in 1902; drilling was suspended at 1,580 feet because of mechanical difficulties. More than 30 years later, the well was cleaned out; it produced a daily average of 4.8 barrels of 25° API gravity oil and 48 barrels of water during July 1935 (Walling, 1934).

Three wells were drilled on the Pico anticline in East Canyon, one-half mile southeast of Rice Canyon. The first, Occidental Petroleum 1, drilled by Bradshaw and Beville to a depth of 800 feet in 1899, had a good show of 18° Bé gravity oil near the bottom but was never pumped. There are no records of the second, Grapevine Cañon Oil 1.

A deep test was made by General Petroleum Corp. with their Mendota 1 well in 1943. This well, which bottomed in rocks of the lower part of Kleinpell's Mohnian stage at 6,834 feet, encountered no productive sands.

TUNNEL AREA

The Tunnel area, named for a former highway tunnel through San Fernando Pass, is about 2 miles southeast of Newhall, in sec. 13, T. 3 N., R. 16 W. and sec. 18, T. 3 N., R. 15 W. Most of the production is obtained from sandstone and conglomerate beds of the Towsley formation, accumulation of oil being controlled by faulting and by the lenticularity of the beds.

The first wells, Zenith Oil 1–5 (E. A. Clampitt Zenith 1–5), were drilled along Newhall Creek from 1900 to 1902. They ranged in depth from 645 to 760 feet. Well 1 penetrated oil sand from 640 to 650 feet and produced about 7 barrels a day of 14° Bé gravity oil.

Sixteen wells were drilled between 1900 and 1909 by small companies to depths ranging from 645 to 2,100 feet, all but 3 having total depths less than 1,000 feet. They had little or no oil production. Between 1922 and 1932, 9 wells were drilled by, or later acquired by, Southern California Drilling Co. The best initial production was 200 barrels a day of 19.5° Bé gravity oil with 10 percent water from Southern California Drilling Needham 1 (Airline Oil C. C. Herwick, Needham 1), which had a total depth of 1,952 feet. From 1929 to 1931, York-Smullin Oil Co. drilled 6 wells ranging in depth from 1,184 feet to 1,490 feet and with initial productions from 76 to 220 barrels of 19° to 22.7° Bé gravity oil per day. York-Smullin Oil 1, which was drilled to a depth of 1,490 feet, had the highest initial production of 220 barrels of 21.6° Bé gravity oil with 3.2 percent water.

Several wells have been drilled through the Pliocene section into rocks of the Sespe(?) formation, where oil-stained sands occur throughout an interval of more than 300 feet. Southern California Drilling Needham 4 (Airline Oil C. C. Herwick, Needham 4) penetrated the Sespe(?) formation; it was drilled in Eocene rocks from 2,747 feet to the bottom at 4,400 feet. Thirty-one wells were drilled in the area prior to 1943, 20 of which were producing 4 to 10 barrels per day of 16° to 22° API gravity oil. In the early 1950's, several small operators, chiefly Morton and Dolley, entered the area and completed a number of relatively shallow wells with modest records of low-gravity oil production. Morton and Dolley Hilty 1 and Needham 2 are examples of the later wells in the Tunnel area. Well Hilty 1, in sec. 12, T. 3 N., R. 16 W. was completed at a depth of 2,280 feet late in 1952; it flowed an estimated 135 barrels per day of 18.5° API gravity oil with 1.0 percent water. When put on pump several days later, it produced 33 barrels per day of 19.9° API gravity oil with 0.1 percent water. Well Needham 2, in sec. 12, T. 3 N., R. 16 W., was also completed late in 1952 and was drilled to a depth of 1,578 feet. Several days after completion it was pumping 30 barrels per day of 19.0° API gravity oil with 2.0 percent water.

ELSMERE AREA

The first successful drilling for oil in the eastern part of the Newhall field was in the Elsmere area about 1½ miles southeast of Newhall in sec. 12, T. 3 N., R. 16 W. and sec. 7, T. 3 N., R. 15 W. The productive area covers about 60 acres in Elsmere Canyon and on the ridge south of the canyon. Rocks of the Towsley formation are at the surface; production is from the Towsley formation and possibly also from rocks of Eocene age, at depths of less than 1,500 feet. The oil accumulation is controlled by the lenticularity of the beds.

The first well, Elsmere 1, was begun in 1889 by Pacific Coast Oil Co. Although it did not produce, oil shows were sufficiently good to encourage more drilling. Pacific Coast Oil Co. drilled 20 wells, 420 to 1,376 feet deep, in the Elsmere area before its holdings were acquired by Standard Oil Co. of California in 1902. The highest initial production was in Standard Oil of California Elsmere 2, which was completed in 1891 with a daily average production of 54 barrels per day during the first four days.

Between 1900 and 1903, Alpine Oil Co. and Santa Ana Oil Co. drilled three wells each, to depths of 1,000 feet or less, in the Elsmere area; at least four of them produced some oil. From 1918 to 1920 E. A. and D. L. Clampitt drilled three wells to 660, 690, and 1,040 feet. The first two had initial productions of 15 barrels per day of 13° Bé gravity oil and 20 barrels per day of 14° Bé oil, respectively. The third produced heavy tar only.

Standard Oil Co. of California drilled two wells in 1916 and 1917 to depths of 1,611 and 691 feet; these wells had only poor oil shows. Republic Petroleum Corp. drilled wells Fink 3 and 4 in 1920 and 1921 as offsets to the north line of the E. A. and D. L. Clampitt property. Well Fink 3 was drilled to 1,242 feet; when completed it produced 25 barrels of 17° Bé gravity oil and 2.5 barrels of water a day. Fink 4, which was drilled to 1,383 feet, had no commercial oil production.

Thirty-three wells were drilled in the field. Of these, six were still pumping in June 1949. The oil produced varied from 14° to 16° API gravity and averaged about 14.2° API gravity.

WHITNEY CANYON AREA

The Whitney Canyon area is ¼ to 1¼ miles northeast of the Elsmere area in secs. 6, 7, and 8, T. 3 N., R. 15 W. The first well was drilled by Banner Oil Co. in 1893. It was completed at a depth of 850 feet with an initial production of about 100 barrels of oil per day. After a short time water broke in the hole and the well was shut down. A total of 13 wells were drilled by small companies between 1893 and 1933, but only four were drilled to a depth of more than 1,100 feet, the deepest being Southern Production Co. 1 (later Republic Petroleum Price 4), which was drilled to 2,842 feet in 1930–33. This well is of special interest as it produced oil of 27°API gravity and higher from rocks of Eocene age. Most of the wells have rather low production records of 14° to 17° Bé gravity oil.

A deep wildcat well near Whitney Canyon, the Continental Oil Phillips 1, drilled in sec. 6, T. 3 N., R. 15 W. (pl. 45), penetrated the entire thickness of rocks of Eocene age in this vicinity before being abandoned in crystalline rocks at 8,253 feet.

NEWHALL TOWNSITE

Recent exploration in the vicinity of Newhall resulted in the discovery of several new pools in that area. Late in 1948, the R. W. Sherman well Newhall-Community 3-1 was completed in sec. 2, T. 3 N., R. 16 W., at a total depth of 5,846 feet, with a rated initial production of 265 barrels of oil per day from rocks of latest Miocene age (pl. 45). A total of 10 wells were drilled near the R. W. Sherman Newhall-Community 3-1 but none produced commercial quantities of oil. The Sherman well itself was subject to many production difficulties and was not commercially successful. In 1951, the Talisman Oil Braille 1, in sec. 1, T. 3 N., R. 16 W., was completed at a depth of 3,195 feet, with a rated initial production of 101 barrels per day. This new pool is in rocks of earliest Pliocene age (pl. 45).

PLACERITA

The Placerita field is about 1 mile northeast of Newhall and centers in sec. 31, T. 4 N., R. 15 W. The field has had two periods of development; the first, and minor, period was from 1920 to 1933, the second after 1948. The first well in the field was Equity Oil Daisy 1 (York Oil York 1), drilled in 1920 to a depth of 975 feet. It was deepened to 1,394 feet in 1921, and in 1925 was producing 6 barrels a day of 14° Bé gravity oil. Four wells drilled during this first period (the deepest to 1,598 feet) were producing an average of 8.9 barrels a day of 11.8° Bé gravity oil with 18.8 percent water in April 1935.

The second period of development of the Placerita field began in April 1948, when Nelson-Phillips Oil Kraft 1 (Tevis F. Morrow Kraft 1) was completed at a depth of 2,220 feet, flowing with a rated initial production of 60 barrels a day of 16.4° API gravity oil from a sand between the depths of 585 and 718 feet (Moody, 1949, p. 819). This well marked the beginning of low-gravity production development in the southern part of the field. In February 1949, the northern or high-gravity part of the field was opened with the completion of Somavia and Yant Juanita 1, approximately 1 mile north of Nelson-Phillips Kraft 1. This well produced 340 barrels a day of 22.8° API gravity oil from 100 feet of sand below 1,737 feet. The completion of this well marked the beginning of the most spectacular townlot boom in California in 30 years. A highly subdivided area of 80 acres was opened to practically unrestricted drilling by a ruling of the California Superior Court which declared the State Well Spacing Act unconstitutional. Approximately 140 wells were drilled on about 60 acres, with a peak production of 28,950 barrels of oil a day being reached during September 1949. By the end of 1951, Tevis F. Morrow had purchased the three largest undeveloped holdings in the area and drilled 46 wells, most of which are in the part of the field which produced low-gravity oil. This completed development of the field. By the end of November 1951, the northern part of the field had produced 11,611,670 barrels of high-gravity oil as compared with 2,973,313 barrels of lower gravity oil produced in the southern part of the field.

The oil in the Placerita field accumulated in a homoclinal structure bounded by the San Gabriel fault on the north and the Whitney Canyon fault on the east. The northern high-gravity oil-producing area is separated from the southern low-gravity area by a northwestward-trending normal fault of relatively small displacement.

Two producing zones are recognized in the field, the lower and upper Kraft zones. The lower Kraft zone, which is unproductive in the southwestern part of the field, is in the Towsley formation of late Miocene and early Pliocene age. This zone is reported to have thicknesses of 200 feet near the east margin and is 480 feet thick in the northwestern part of the field (Willis, 1952, p. 38). The lower Kraft zone yields 20° to 25° API gravity oil in the northern high-gravity area, 16° API gravity oil in the southeastern part of the field, and 12° API gravity oil elsewhere. The upper Kraft zone in the Pico formation is of Pliocene age and produces oil only in the southern part of the field where accumulation appears to be controlled largely by the lenticularity of the beds. The oil from this zone is of 10° to 12° API gravity.

NEWHALL-POTRERO

The Newhall-Potrero oil field is about 5 miles west of Newhall in secs. 25, 27, 35, and 36, T. 4 N., R. 17 W. The field was discovered by Barnsdall Oil Co. with the completion of well Rancho San Francisco 1 (Sunray Oil R.S.F. 1) in March 1937. The well was drilled to a depth of 6,472 feet and had an initial production per day of 208 barrels of 34° API gravity oil, with 4.0 percent water, and 500M cu ft of gas. It produced from 312 feet of oil sand between the depths of 6,160 and 6,472 feet.

The Newhall-Potrero field has seven producing zones: the first, second, third, fifth, sixth, seventh, and ninth. The first zone is in rocks assigned to Kleinpell's Delmontian stage. It is lenticular, has several members, and lenses out to the southwest in the vicinity of wells R.S.F. 89, 78, and 83. Its maximum thickness is 375 feet in the western part of the field.

The second zone, which is also in rocks of the Delmontian stage, has a maximum thickness of 340 feet at the southeast end of the field and pinches out in a northerly direction near a line between wells R.S.F. 22, 11, 99, and 91.

The third zone, which is the most important oil-producing zone in the field, is also in rocks assigned to the Delmontian stage. It has a maximum thickness of 400 feet at the west end of the field and lenses out in an easterly direction. As of Dec. 31, 1951, a total of 56 wells had been drilled on leases of the Sunray Oil Corp., which produced oil from the combined first, second, and third zones. The cumulative production of these wells to that time was 19,451,000 barrels of oil averaging 35° API gravity. About two-thirds of this oil came from the third zone.

The fifth zone, in rocks of the lowermost part of Kleinpell's Delmontian stage or the uppermost part of his Mohnian stage, is at depths of from 8,000 to 10,300 feet. It was discovered in 1946 in Barnsdall Oil well R.S.F. 53-5 (Sunray Oil R.S.F. 53-5), which had an initial production of 533 barrels per day. The zone is more than 500 feet thick in the southeast-central part of the field. By the end of 1951, 31 wells had been completed in the fifth zone on Sunray Oil Corp. leases with a cumulative production of 3,413,000 barrels of 25° to 40° API gravity oil. The gravity of the oil generally decreased down the flanks of the structure.

The sixth zone, which is about 400 feet below the base of the fifth zone, is in rocks assigned to the upper part of Kleinpell's Mohnian stage. It was discovered in 1945 in Barnsdall Oil well R.S.F. 44 (Sunray Oil R.S.F. 44), which reached a total depth of 11,229 feet and had an initial production of 530 barrels of oil and 590M cu ft gas per day. Cumulative production from the sixth zone as of December 31, 1951, was 1,594,000 barrels of oil.

The seventh zone, which is about 400 feet below the sixth zone, is believed to be in rocks of the lower part of Kleinpell's Mohnian stage (Loofbourow, 1952). The only completed well in this zone at the end of 1951 was the discovery well, Barnsdall Oil R.S.F. 65-6 (Sunray Oil 65-6), which was completed in 1948 with a rated initial production of 431 barrels a day. Before the well was shut down, it produced 113,000 barrels of 30.5° API gravity oil.

The ninth zone is the deepest producing zone in the field and is in rocks assigned to the lower part of Kleinpell's Mohnian stage. The only well to produce from this zone, as of the end of 1951, was Barnsdall Oil R.S.F. 66 (Sunray Oil R.S.F. 66), completed late in 1948. The well penetrated 2,700 feet of rocks assigned to the ninth zone, of which 432 feet, between the depths of 13,936 and 14,501 feet, was open to production. It had produced 26,000 barrels of 24° to 28° API gravity oil by the end of 1951.

The subsurface structure of the field is a long narrow northwestward-plunging asymmetrical anticline whose axis strikes N. 55° W. (pl. 45). At the surface, the structure is either not present or is obscured owing to the lack of exposures in siltstone of the Pico formation. There are numerous reverse crossfaults in the subsurface section with displacements ranging from 50 to 300 feet, but these appear to have had little effect on the accumulation of oil.

DEL VALLE

The Del Valle oil field is north of the Santa Clara River, 8 miles northwest of Newhall, in secs. 16, 17, 20, and 21, T. 4 N., R. 17 W. The field was discovered in September 1940, when the R. E. Havenstrite Lincoln 1 (Union Oil Lincoln 1), was completed in the interval between 6,690 and 6,885 feet. The well had an initial production of 400 barrels of 58° API gravity oil with 1 percent water, and 11,000M cu ft of gas per day. It was recompleted in October to lower the gas-oil ratio and gave a rate of 875 barrels of 33° API gravity oil and 280M cu ft of gas per day.

TABLE 9.—*Oil- and gas-producing zones of Del Valle field*

[Modified from Nelson (1952)]

Zone	Discovery well	Date	Initial production		API gravity (degree)	Depth to zone (feet)	Age
			Oil (bbls. per day)	Gas (M cu ft per day)			
Sepulveda 20	Standard Oil of California Sepulveda 20	1951		1,259		2870–3620	Early Pliocene.
Kinler	Trigood Oil Kinler 1	1950	140		22.3	7128–7393	Delmontian.
Sepulveda	Standard Oil of California Sepulveda 3	1942	707		35.5	5040–5120	Do.
Vasquez 13	Ohio Oil Vasquez 13	1945	400	264	36	5550–5645	Do.
Vasquez	Ohio Oil Vasquez 1	1941	1,512		31.4	5840–6193	Do.
Videgain	R. E. Havenstrite (Union Oil) Lincoln 2	1940	3,000	3,000	36	6037–6082	Do.
Intermediate	Standard Oil of California Sepulveda 12	1950	196		34.8	[1] 5751–7091	Do.
Del Valle	R. E. Havenstrite (Union Oil) Lincoln 1	1940	400	11,000	58	6690–6885	Do.
Anderson	R. E. Havenstrite (Union Oil) Lincoln 15?	1947	310		43	7540–8150	Late Mohnian.
Bering	R. E. Havenstrite (Union Oil) Barnes 2	1943	972	580	44	7900–8065	Do.
Lincoln	R. E. Havenstrite (Union Oil) Lincoln 15	1947	75		32	10,110–10,480	Early Mohnian.

[1] Intermediate included in Vasquez 13 interval.

The 11 oil and gas producing zones recognized in the field are tabulated in table 9.

The field is on the Del Valle anticline, whose position in the subsurface closely corresponds to its surface location (pl. 45). The anticline, which trends in an easterly direction, plunges to the east except in sec. 17, where 100 feet of closure is obtained. The structure is sharply terminated at the west against the Ramona anticline, probably by faulting. The oil accumulation is due to folding combined with faulting and to lenticularity of reservoir beds. The structure is also complicated by thrust faulting below the top of the Intermediate zone. The strata of Kleinpell's Delmontian stage between the Videgain and Del Valle zones appear to merge into one almost continuous sand body east and southeast of the center of the field.

RAMONA

Although the Ramona field is immediately adjacent to the western part of the Del Valle field, it is on a different structural feature and is considered a separate field. It is in sec. 18, T. 4 N., R. 17 W. and sec. 13, T. 4 N., R. 18 W. Part of the field is in Ventura County, west of the area covered in this report. The topography in the vicinity of the field is very rugged, so that many of the wells have been whipstocked to the proper subsurface position in order to avoid landslides and the roughest terrain.

The field was discovered by the Texas Co. with its Kern 1, which was completed in 1945 in the Kern zone at 2,810 to 3,004 feet and which produced 196 barrels per day of 29.3° API gravity oil with 0.4 percent water, and 70M cu ft of gas per day. Shale and oil sand from 3,004 to 3,114 feet was plugged off but was left open in subsequent producing wells.

The Black zone is in sandstone and conglomerate about 150 feet below the top of strata assigned to Kleinpell's Delmontian stage and is 660 feet (well thickness) above the top of the Kern zone. It was discovered in 1946 by Bankline Oil Co. in Black 102 at a depth between 2,190 and 2,332 feet. This well had an initial production of 180 barrels per day of 26° API gravity oil. The zone usually is from 90 to 180 feet thick and is at depths of 2,220 to 2,680 feet. Wells producing form this zone have initial productions of from 120 to 180 barrels per day of 24° to 28° API gravity oil.

The Kern zone, the first productive zone found in the field, varies in well thickness from 100 to 300 feet and is at depths of 2,000 to 4,000 feet. The first wells producing from this zone pumped from 25 to 200 barrels a day of 20° to 30° API gravity oil. After the Del Valle zone was discovered, however, dual Kern and Del Valle zone completions gave a better and more sustained production. These wells usually had initial productions of 50 to 400 barrels a day of 17° to 25° API gravity oil. In the easternmost part of the field, the Del Valle zone is cut out by the Holser fault and production is from sand of the Kern zone only.

The Del Valle zone was discovered by Superior Oil Co. and British American Oil Producing Co. with their Black 1. The Del Valle zone has from 300 to 1,400 feet of oil-producing sandstone and conglomerate at depths of 3,000 to 6,000 feet.

Superior Oil-British American Oil Producing Black 14, a deep test well that was completed in 1951, had an initial production of about 150 barrels per day of 20° API gravity oil from a sand of latest Miocene age that is duplicated below the Holser fault at depths from 7,680 to 7,800 feet. This well produced the first oil from below the Holser fault in the field. It also had favorable production tests in the Bering zone above the Holser fault at 6,245 to 6,690 feet.

The oil in the Ramona field has accumulated on the Ramona anticline, which is a drag fold developed on the upthrown block of the Holser fault. The anticline trends and plunges in a northeasterly direction. The north flank is narrow and locally steep, but the south flank, where most of the oil has accumulated, dips regularly at 45° to 50°. The structure is closed to the north by the Holser fault and the northeasterly plunge of the anticline. The closure to the west is stratigraphic, for the producing zones lens out in that direction. To the east the structure terminates against the Del Valle anticline, probably by faulting.

CASTAIC JUNCTION

The Castiac Junction field is 5 miles northwest of Newhall in secs. 23 and 24, T. 4 N., R. 17 W., and sec. 19, T. 4 N., R. 16 W. It was discovered early in 1950 with the completion of Humble Oil and Refining Newhall Land and Farming 1. The well was completed in the interval 11,792 to 11,841 feet with a rated initial production of 161 barrels per day of 34.2° API gravity oil. This producing zone, Reservoir 21, is in rocks assigned to Kleinpell's Mohnian stage.

Late in 1950, Humble Oil and Refining N. L. & F. 3 reached a new producing zone, Reservoir 10, at a depth of 9,745 to 9,880 feet, down structure from the first well. Reservoir 10 is in sand and conglomerate near the contact between Kleinpell's Mohnian and Delmontian stages. Its thickness ranges from 95 feet in well N. L. & F. 3 to 221 feet in N. L. & F. 4. There is an apparent natural stratification of the gravity of oil in Reservoir 10, for structurally low wells produce 18.5° gravity oil whereas structurally higher wells produce oil of gravity as high as 21.3°.

A third zone, Reservoir 15, in the upper part of Kleinpell's Mohnian stage, was discovered by Humble Oil and Refining Co. in well N. L. & F. 6 in 1951. This zone was found at depths of 10,722 to 10,923 feet and produces 27° to 29° gravity oil.

Early in 1952 a fourth zone was penetrated by Humble Oil and Refining N. L. & F. 8. This well had an initial production of 581 barrels per day from a depth of 11,080 feet.

The field is developed on an anticlinal structure, the Del Valle nose, which plunges to the southeast (pl. 45). The axis of the structure has a pronounced shift to the north in the subsurface. Accumulation of oil is due either to pronounced cross faulting or to stratigraphic traps caused by the lenticular nature of the sands on the structure.

WILDCAT WELLS

Many wildcat wells have been drilled in the area. Table 10 lists 236 of these wells and such pertinent information concerning each well as was available to the authors. Many of the early wildcat wells in the region were drilled by small companies and little if any information on them is available. All the later wildcat wells in the area on which drilling was completed before June 1, 1953, are included in the table.

POTENTIAL PETROLEUM RESOURCES

Rocks of Eocene age are present at depth over much of the area and are considered by many geologists to be a source of at least part of the oil that has accumulated in younger formations in the region. Some of the oil in the Whitney Canyon area, and possibly also in the Elsmere area, is from rocks of Eocene age. High-gravity oil obtained from schist of the basement complex in Placerita Canyon, east of the mapped area, is considered by Brown and Kew (1932) to have migrated from rocks of Eocene age. Several wildcat wells have been drilled to Eocene rocks in the mapped area, but as yet no production of importance has been obtained from them. Most of the sandstones of Eocene age which have been tested have shown both low porosity and low permeability. These characteristics, together with the great depth to possible reservoir rocks of Eocene age throughout most of the area, discourage exploration and may prevent Eocene rocks from becoming important oil producers in the near future.

In view of nearby production from sandstone assigned to Kleinpell's Luisian stage, rocks deposited during this stage should be considered as promising for future development. In the Aliso Canyon field, just south of the mapped area in the southeastern part of the Santa Susana Mountains, the Sesnon zone of Luisian age is one of the major petroleum-producing zones. In the Oakridge field, which is immediately southwest of the mapped area, sands of this age also have been productive. Wells in fields in the area covered in this report have yet to be drilled to depths great enough to test the oil possibilities of rocks of the Luisian stage.

Wildcat wells have been drilled in nearly every section in the area. All of the conspicuous potentially productive structural features have been tested. In some cases wildcat wells did not provide an adequate test of their site because they were not drilled deep enough. One notable part of the mapped area which has not been productive is north of the San Gabriel fault. Most of the wildcat wells drilled there were started in continental beds of the Saugus formation and were drilled to and bottomed in continental beds of the Mint Canyon formation. Marine rocks of late Miocene and early Pliocene age are found north of the fault but do not appear to be either source beds or reservoir rocks for petroleum.

TABLE 10.—*Wildcat wells, including all known prospect wells outside productive oil fields*

[Information presented in this table is the best available to the authors, but is not of uniform accuracy or quality. Elevation: gr, ground; df, derrick floor; kb, kelly bushing]

Number (pl. 44)	Operator	Well	Location			Year drilled	Elevation (feet)	Total depth (feet)	Geologic information (depths in feet)	Oil and gas shows (depths in feet)	Remarks (depths in feet)
			Sec.	T. N.	R. W.						
1	Abbe, Robert E	Montie 1	8	4	17	1951	1,750 gr	4,268	------	Formation test: 3,200–3,833, recovered mud and water.	Formerly: Brinkman Oil Operations Montie 1; A. and P. Devel. Montie 1.
2	Aidlin, Joseph W., and Bering, R. E.	Atwood 1	[1]10	3	16	1952	1,438 gr	6,134	Top of the Mint Canyon formation 5,714. Bottomed in Mint Canyon formation Dip 10°–18° at 2,120–2,129.	Possible oil shows at 2,100–2,500 in original hole.	Whipstock set at 1,965 and redrilled to 2,600.
3	Airline Oil Co. and and Herwick, C.C.	Needham 4	[1]13	3	16	1930	1,796	3,504	Pico formation and Sespe(?) formation contact, 1,780; Sespe(?) formation and Eocene contact, 2747±.	No indication of commercial oil below 2,150.	Formerly Southern California Drilling Needham 4.
4	Algord Oil Co.	Shepard 5	[1]1	3	16	1949	1,407	1,225	------	Swabbed water with trace of oil.	Formerly M.G.N. Oil Shepard 5.
[2]5	Alliance Oil Co.	------	13	3	16	1901	------	700±	------	Penetrated some tar sands.	
[2]6	Anderson, P. B.	2	1	3	16	1929	1,253	1,248	------	Some oil sand reported.	
7	Anderson, W. O. and J. I., and Palmet, Inc.	Anderson-Palmet Tomato Can 1.	[1]11	3	16	1944	1,530	4,736	Top of the Sespe(?) formation, 4,270; top of the Delmontian stage of Kleinpell, 3,800±.	------	
8	Apex Petroleum Corp.	Weldon 1	24	3	16	1951	2,025 gr	4,518	In Pliocene at 3,110; in rocks of the Delmontian stage of Kleinpell at 3,315. Good 45° dips at 3,315–3,331; 35°–45° dips at 4,176–4,184.	Formation tests: 4,190–4,376, open 20 min, recovered 1,100 ft gassy, muddy water; 3,310–3,417, recovered 520 ft gas-cut mud.	See pl. 45, section *D–D′*.
9	Ball, W. T.	1	[1]34	4	16	1932	1,250	3,629	------	Few oil and gas shows reported.	
[2]10	B. and L. Drilling Co.	1	14	3	16	1931	------	1,309	------	No oil or gas shows reported.	
11	Bankline Oil Co.	The Newhall Corp. 1.	[1]31	4	16	1947–48	1,623 kb	9,906	Top of the Miocene, 7,760; top of the Mohnian stage of Kleinpell 9,110. Poor 52°–55° dips at 8,190–8,192; 36° dip at 9,374–9,376.	------	See pl. 45, section *D–D′*.
12	Barmore, Ned.	Hays 1	[1]36	4	16	------	1,335	2,384	------		
13	Barnsdall Oil Co., Bandini Petroleum Co., and Ambassador Oil Co.	Limbocker 1	17	3	16	1941–42	1,680± gr	7,071	Bottomed in lower Mohnian stage of Kleinpell.	Oil sands at 1,488–2,230, 4,040–4,136, and 6,652–6,713.	See pl. 45, section *C–C′*.
14	Barnsdall Oil Co.	T.I. & T. 1	[1]30	3	15	1942	1,318 gr	8,035	------	------	
15	Beal, Carlton	Betsy Linda 1	[1]1	3	16	1949	1,378 gr	2,830	Pliocene and Eocene contact at 1,913.	Swabbed and flowed fresh water with some heavy oil.	
16	do	Betsy Linda 2	[1]1	3	16	1950	1,397	1,262	------	Pumped 8 bbls per day, 11.3° gravity, oil, 1 percent cut.	
17	Bettymac Oil Co.	Warren 1	[1]1	3	16	1949	1,481	2,650?	Pliocene and Eocene contact at 2,591.	------	
18	do	Braille 2	[1]1	3	16	------	------	------	------	------	
19	Bevo Drilling Co.	Carter-Earl 4	5	3	15	1949	1,506	1,248	------	------	
[2]20	Big 4 Oil Co.	Brona 1	[1]32	4	16	1932–33	1,500	2,170?	------	------	
21	Brazell, James, Trustee.	Perkins 1	[1]11	3	16	1941	1,600 gr	4,473	Top of the Sespe(?) formation, 4,380; in lower Delmontian, stage of Kleinpell, 4,000.	------	
22	British-American Oil Producing Co.	Edwina 1	[1]11	3	16	1940	1,655±	6,196	In lower Pliocene, 3,500; top of the Miocene, 3,600±; top Sespe(?) formation, 4,103; top of the Eocene, 5,955.	Shows of tarry oil, 4,200–5,962.	
23	do	Kinler-So. Cal. 1.	16	4	17	1947–48	1,280 kb	6,857	Top of the Miocene, 5,500; Holser fault, 6,200.	Formation tests: 5,870–5,905, open 30 min, recovered 246 ft gas-cut mud.	Redrilled to 4,385. See pl. 45, section *F–F′*.
[2]24	Buick Oil Co.	1	18	3	15	1918	------	1,126	------	Some tar and oil shows reported; excessive water.	
[2]25	do	2	18	3	15	1918–19	------	1,485	------	------	Hole junked with lost tools.
26	Bush, W. W.	Perkins 1	[1]11	3	16	1949–50	1,550 gr	5,122	Top of the Delmontian stage of Kleinpell, 4330±.	Pumped very small amount of 40° gravity oil, some gas.	
[2]27	California Oil Co.	1	18	3	15	1900	------	1,200	Drilling started in metamorphic rocks.	------	
[2]28	do	------	15	3	16	------	------	400	------	------	
29	California Newhall Oil Co.	1	8	3	15	1920–22	1,350±	1,865	------	Some shows light oil below 1,765.	
30	Carter, W. J	Carter-Earl 2	5	3	15	1948	------	653	In granitic rock at bottom	------	
31	do	Carter-Earl 3	5	3	15	------	------	1,038	In granitic rock at bottom	------	

See footnotes at end of table.

TABLE 10.—*Wildcat wells, including all known prospect wells outside productive oil fields*—Continued

Number (pl. 44)	Operator	Well	Location			Year drilled	Elevation (feet)	Total depth (feet)	Geologic information (depths in feet)	Oil and gas shows (depths in feet)	Remarks (depths in feet)
			Sec.	T. N.	R. W.						
32	Chanselor-Canfield Midway Oil Co.	Sanborn 1	6	3	16	1941	1,524	8,038?	Top of the Mohnian stage of Kleinpell, 7130; in rocks of the Mohnian stage of Kleinpell, 7,388–8,038.	------	
[1]33	Chamberlain, Chauncy W.	Poco 2	6	3	15	1951	1,430 df	1,053+	Top of the upper Kraft zone, 760; top of the lower Kraft zone, 895.	------	
34	Clark, W. J	Conroy 2	[1]11	4	16	------	------	3,985	In Mint Canyon formation, 1,270–3,985.	------	
35	C. M. S. Oil and Drilling Co.	Cook 1	[1]12	3	16	1949	1,400	1,540	------	Swabbed water	
[1]36	Community Oil Producers of Calif.	1	[1]23	4	16	1920	1,214	227	------	------	Water flowed over casing; made into water well.
[1]37	do	2	[1]23	4	16	1920	1,214	255±	------	------	
38	Continental Oil Co	Braille 1	[1]1	3	16	1951–52	1,324 kb	3,273	Top of the marine Miocene, 3,151; cored Eocene.	Pumped 57 barrels in 18 hrs., 18.3° gravity oil, 7 percent cut, 2–13–52; 16 bbls per day, 17.6° gravity oil, 15 percent cut, 2–20–52.	
39	do	Braille 2	[1]1	3	16	1951	1,308	3,648	In upper Pliocene, 3,079–3,425; top of the lower Pliocene, 3,320; top of the Braille sand, 3,420; top of the Miocene (Eocene?), 3,520; bottomed in Sespe(?) formation or Eocene.	Pumped 30–40 bbls per day rate, 60 percent cut.	
40	do	Braille 3	[1]1	3	16	1951–52	1,308 kb	3,835	Top of the Braille sand, 3,345; in Eocene between 3,405–3,476.	Formation test: 3,386–3,480, open 2 hrs, strong blow 4 min, diminishing to dead, recovered 549 ft gassy, oily mud.	
41	do	Newhall 1	[1]20	4	17	1938	1,591	2,616	In lower Pliocene, 1,790; in rocks of the Delmontian stage of Kleinpell 1,870–2,260.	------	
42	do	Phillips 1	6	3	15	1951–52	1,650 gr	8,253	Pliocene and Eocene contact, 1,300; top of the pre-Cretaceous crystalline rocks, 7,911.	Plug, 1415; pumped water with trace of oil; tar shows at 400–600 and oil shows on ditch 600–1,434.	See pl. 45, section *A–A′*.
43	do	Phillips 2	6	3	15	1952	1,562 gr	1,814	------	------	
[1]44	do	Phillips 2A	6	3	15	1952	1,550±	1,060	------	Tested Kraft zone; completed producing 70 bbls per day gross in 7 hrs; 152 bbls per day 76 percent water, 2 days later. Abandoned.	
45	Corinth Petroleum Co.	Karen 1	36	4	16	1949	1,400?	2,005	Pliocene and Eocene contact, 2,600±.	------	
[1]46	do	Thompson 1W.	36	4	16	1949	1,673 kb	3,967	------	------	
47	Corwin, W. T., McBeath, T. W., and Donley, Fred.	Wegner 1	[1]36	4	16	------	------	------	------	------	
48	Crawford and Hiles	Placerita 1	32	4	15	1949	1,925 gr	3,307	------	------	
49	Denison, Geo. A	1	[1]2	3	16	1924	1,400±	240	------	------	
[1]50	Dexter, George	Wegner 2	[1]36	4	16	1951–52	1,215 gr	1,684	------	------	
51	Dividend Oil Co	1	10	3	16	------	------	700	------	------	
52	Doc Oil Co	Doc 2	31	4	15	------	------	------	------	------	
53	Downey Oil Corp	Burt 1	[1]31	4	16	1938	------	3,100	Bottomed in Towsley formation. Below 2,500 dips average 15°–20°.	------	
54	Eagle Oil and Refining Co.	Eagle Oil 1	[1]34	4	16	1949	1,285	6,236	Base of the Pliocene, 5,285; top of the Sespe(?) formation, 6,210. 28° dips, 6,090–6,116; 18° dips, 6,116–6,184.	------	
[1]55	Edwards and Cole	1	23	3	16	------	------	------	------	------	
[1]56	Electrological Petroleum Corp.	Overman 1	6	3	16	1931	1,400±	1,070	------	------	
57	Ellis, F. E	Lowe 1	[1]36	4	16	1950	1,330 gr	3,445	Pico formation, 3,360 to bottom.	Few stringers of oil sand at 2,586.	
58	Enterprise Oil Co	1	13	3	16	1900	------	1,050±	------	------	
[1]59	do	2	13	3	16	1900	------	700	------	No oil or gas encountered.	Junked with tools and abandoned.
60	Fairfield, F. E	Reed-Ulrich 1	[1]34	4	16	1949	------	3,646	------	------	
[1]61	Federal Oil Co	Oakgrove 1	[1]36	4	16	1949	1,417 gr	1,716	------	------	
62	Fletcher, D. S	Betsy Linda 3	[1]1	3	16	1951	1,374 kb	777	------	------	

See footnotes at end of table.

TABLE 10.—*Wildcat wells, including all known prospect wells outside productive oil fields*—Continued

Number (pl. 44)	Operator	Well	Location			Year drilled	Elevation (feet)	Total depth (feet)	Geologic information (depths in feet)	Oil and gas shows (depths in feet)	Remarks (depths in feet)
			Sec.	T. N.	R. W.						
63	Frasier, M. E.	Eagle Oil-Bishop 2	[1] 24	3	16	1948–49	1,260	5,985	Top of the Miocene, 5,012; top of the Sespe(?) formation, 5,896.	All sands very tight. Formation test: 5,856–5,906, steady blow, 2 hrs, gas to surface in 55 min, blew 5 min and died. No oil.	
[2] 64	Frasier, N.M.	Gerard 1	[1] 31	4	16						
[2] 65	Garliepp and Associates.	1	14	3	16	1933	2,300±	1,220		No oil or gas reported.	
66	General Exploration Co. of Calif.	N.L. & F. 1	[1] 29	4	16	1951	1,415 gr	12,478	Pico formation lithology at 7,526; top of the Delmontian stage of Kleinpell, 9,540±; top of the Mohnian stage of Kleinpell, 11,060; bottomed in lower Mohnian stage of Kleinpell. Dips at 11,700–11,800, 5°–10° to SW.		See pl. 45, sections *A-A′* and *D-D′*.
[2] 67	General Exploration Co. of Calif.	N.L. & F. 2	[1] 28	4	16	1953	1,365 gr	11,503	Top of the Miocene, 8,480–8,520; top of the Mohnian stage of Kleinpell, 9,480.	Plug 10,703; formation tests: 10,423–10,570, recovered salt water; formation tests: 11,433–11,503, recovered salt water.	
68	General Petroleum Corp.	Bermite 1	[1] 25	4	16	1950	1,483 mat	5,043	Base of nonmarine section, 3,500; top of the basement complex, 4,951.	Formation test: 4,968–5,043; open 2 hrs, recovered 140 ft drilling fluid.	
69	do.	Circle J-1	[1] 26	4	16	1949	1,300	6,560	Top of the Miocene, 5,540; top of the Eocene, 5,929.	Swabbed salt water with scum of oil.	
70	do.	Circle J-2	[1] 26	4	16	1949–50	1,336 kb	6,112	In Saugus formation, 4,100–4,260; in upper Pliocene, 4,270–5,140; in Pliocene or Miocene, 5,163–5,476; basement complex at 5,570?.	Formation test: 3,751–3,796 (redrill); open 7¼ hrs., recovered 157 ft gassy mud with trace of tarry oil.	Whipstock at 3,430; redrilled to 3,796.
71	do.	H. & M. 1	[1] 27	4	16	1949	1,199 kb	7,485	In Pliocene, 5,020–5,976; top of the Delmontian stage of Kleinpell, 6,410±; top of the Mohnian stage of Kleinpell, 7,200±; top of the basement complex (green schist), 7,420.		See pl. 45, section *C-C′*.
72	do.	Mendota 1	22	3	16	1943	1,825 gr	6,834	Bottomed in lower Mohnian stage of Kleinpell.		
[2] 73	do.	N.L. & F. 3	[1] 20	4	17	1953	925	11,497	Top of the Delmontian stage of Kleinpell, 5,680; fault between 6,480–7,380; Delmontian above fault; top of the Mohnian stage of Kleinpell, 8,580; fault at 8,900, Delmontian below fault; sand of the Delmontian stage of Kleinpell, 11,115–11,143.		
74	do.	Stabler 3	31	4	15	1919–20	1,450	2,640		Few oil and gas shows reported, 1,800–2,100.	
75	do.	Stabler 4	30	4	15	1919–20	1,605	3,514	Bottomed in Mint Canyon formation.	Small oil and gas shows in shale, 700–3,500.	See pl. 45, section *B-B′*.
76	Gerard, P. M.	Fisher-Wosk 1.	6	3	16	1943	1,438	7,852	Top of the Delmontian stage of Kleinpell, 6,010.		
77	Grapevine Cañon Oil Co.	1	22	3	16	1901		1,300?		No oil shows.	
78	Guiberson Oil Corp.	Bailey 1	1	3	16	1949	1,640 gr	3,750	Pliocene and Eocene contact, 2,030.		
[2] 79	Halfmoon Oil Co.	1	6	3	16	1921	1,450				
80	Havenstrite Oil Co.	Vasquez 1	21	4	17	1941	1,102	7,102			
81	Hicks, H. C.	Lillie 1	8	3	15	1930	1,000±				
82	Holbrock Petroleum Corp.	Broughton 1	[1] 28	4	16	1936	1,400	6,284	Base of nonmarine rocks, 6,055.	No oil or gas shows.	
[2] 83	Howard Petroleum Co.	1	[1] 11	3	16	1921–22	1,000?	665		No oil or gas shows reported.	
84	Humble Oil and Refining Co.	N.L. & F. Co. B-1.	[1] 12	4	17	1950–51	1,007 kb	12,744	Top of the Delmontian stage of Kleinpell, 9,200; top of the upper Mohnian stage of Kleinpell, 11,280.	Formation test: 740–905, open 3¾ hrs., good decreasing blow 15 min. Swabbed mud and fresh water.	Plug, 3,900; redrilled to 4,452. See pl. 45, section *E-E′*.
85	do.	N.L. & F. Co. D-3.	[1] 9	4	16	1951	1,156 gr	1,389			

See footnotes at end of table.

TABLE 10.—*Wildcat wells, including all known prospect wells outside productive oil fields*—Continued

Number (pl. 44)	Operator	Well	Location			Year drilled	Elevation (feet)	Total depth (feet)	Geologic information (depths in feet)	Oil and gas shows (depths in feet)	Remarks (depths in feet)
			Sec.	T. N.	R. W.						
86	Humble Oil and Refining Co.	N.L. & F. Co. E-1.	[1]33	4	16	1952	1,278	12,450	Top of the Delmontian stage of Kleinpell, 6,780; top of the upper Mohnian stage of Kleinpell, 9,250; top of the lower Mohnian stage of Kleinpell, 9,570.	Formation test: 8,220–8,311, strong steady blow, recovered water with slight scum of oil.	See pl. 45, sections *A–A'* and *C–C'*.
87	Hurley and Mandelbaum.	1	8	4	17	1952	1,625 gr	3,251			
88	do.	Exploration 1	8	4	17	1952	1,625 gr				
89	Kavenaugh, C., and Wilhite, L. R.	Ramona Hills 1.	8	4	17	1946	2,006	2,026			
90	Keck Inv. Co.	Pena 1	18	4	17	1927	2,085	5,128	In lower Pliocene to bottom. Del Valle fault, 2,205–2,270.		
[2]91	Keystone Oil and Development Co.	Hammon 3	8	3	16	1952		1,575			
92	L. & J. Oil Co.	Clarella 1	31	4	15	1950	958 gr				
93	Larson, Ivar	Larson 10	31	4	15	1949	1,700 gr				
94	Lee, W. Y.	Heil 1	32	4	15	1949	1,680	1,435			
95	do.	Lee 1	32	4	15	1949	1,650 gr				
96	Lockhart, L. M.	Miller 1	[1]2	3	16	1948–49	1,250?	5,423	In Miocene, 4,785; top of first zone, 4,842.	Formation test: 5,199–5,218, open 20 min., medium to steady blow, no gas, recovered 2,790 ft thin, watery mud.	
97	Los Nietos Co.	Odeen 1	12	3	17	1951–52	2,800 gr	9,215	Bottomed in lower Mohnian stage of Kleinpell.		See pl. 45 section *D–D'*.
98	Lytle Exploration Co.	N.L. & F. 1	[1]22	4	16	1949–50	1,175	9,735	Top of the Pico formation, 6,380; top of the Delmontian stage of Kleinpell, 7,800; top of the upper Mohnian stage of Kleinpell. 8,880.		
99	McAdoo, Wm. G., Jr.	1	6	3	15	1925	1,497	895±		Oil sands reported at 710–895.	Could not shut off water.
100	McFann Drilling Co.	Lottie B. McFann 2.	[1]1	3	16	1949	1,385				
101	Meyers & Wilhite	M. & W. 1	31	4	15	1949	1,575	652		Bailed water with spots of oil.	
102	Milham Exploration Co.	Conroy 1	[1]11	4	16	1925		2,148	Base of the Saugus formation, 930±.		
103	Morgan Petroleum Corp.	Dunlap 1	31	4	15	1923–25	1,550	1,300		Few small oil and gas shows, 600–970.	
104	Morrow, Tevis F.	G.P.M. 17	31	4	15						
[2]105	do.	G.P.M. 26	31	4	15	1951	1,451	4,111	Bottom in Eocene		
106	do.	WF 38	31	4	15		1,560±	2,507	Pliocene and Eocene contact, 2,352.		See pl. 45, section *B–B'*.
[2]107	Murphy, Dan	1	14	3	16						
108	Mutual Development Corp.	Sanborn 1	6	3	16	1947	1,542	6,415			
[2]109	do.	Sanborn 2	6	3	16	1948	1,516	6,301		Formation test: 6,215–6,301, recovered mud.	
110	Nelson-Phillips Oil Co.	Swall-Ferrier 1.	31	4	15						
111	do.	Swall-Ferrier 3.	31	4	15						
112	Newhall Land and Farming Co.	County Line 1.	[1]32	4	17	1951–52	1,052 kb	10,798	Spud in Pliocene; top of the Miocene 2,150±; 2,500±, fault; Pliocene below fault; top of the Miocene, 3,800± top of the Mohnian stage of Kleinpell 6,900±; top of the lower Mohnian stage of Kleinpell, 9,500±.	Two formation tests at 9,700 failed.	See pl. 45, section *F–F'*.
113	Newhall Mt. Oil Co.	1	21	3	16			1,800		No oil shows reported.	
114	Newhall Refining Co.	Clampitt Community 1.	13	3	16	1952	1,377 gr	1,958			Formerly Morton and Dolley Clampitt Community 1.
115	North Star Mining and Development Co.	Shepard 1	[1]1	3	16	1930–31	1,360	2,291	Pliocene and Eocene contact, 1,930±.	Oil sands reported between 850–1,880.	Formerly National Securities Oil 1.
116	Oakes, R. F., Coombs, E. E., and others.	Lufge 1	[1]2	3	16	1949	1,288 gr	4,812			
117	Occidental Petroleum Corp.	1	22	3	16	1922		876		Good show 18° Bé gravity oil reported at bottom original hole. Second hole produced 350–500 bbls per day water with maximum of 2 bbls per day oil.	Originally drilled by Bradshaw & Beville in 1899? Deepened from 650 to 876 in 1922 by Occidental Petroleum Corp.
118	do.	1	31	4	15	1922	1,375	605			

See footnotes at end of table.

TABLE 10.—*Wildcat wells, including all known prospect wells outside productive oil fields*—Continued

Number (pl. 44)	Operator	Well	Location			Year drilled	Elevation (feet)	Total depth (feet)	Geologic information (depths in feet)	Oil and gas shows (depths in feet)	Remarks (depths in feet)
			Sec.	T. N.	R. W.						
119	Ohio Oil Co	Mable S. Henderson 1.	10	4	17	1950	1,180 gr	5,875	Bottomed in Miocene		Redrilled from 3,476 to 5,875.
[2]120	Ora Negro Development Corp.	1	14	3	16	1932	1,800	700			
[2]121	Padua Oil Co		24	3	16	1900		1,200		A little oil near surface.	
[2]122	Parton Transportation and Associates.	Brown 1	18	3	15	1950		755			
123	Pico Dome Oil Co	1	14	3	16	1929	1,600±	918		No oil or gas reported.	
[2]124	Pioneer Petroleum Co., Ltd.	1	14	3	16	1930	1,550	2,840		No oil or gas reported.	
[2]125	Portland Oil Co		31	4	15	1902		800			
126	Provost, R. A., and Associates.	Protrana 1	[1]25	4	16	1950	1,540 gr	1,120			
127	do	Protrana 2	[1]25	4	16	1950	1,571 gr	3,652		Gas shows, 3,260–3,280; sands wet from 3,280 to bottom.	
128	Provost, Wm. H., Jr.	P.D.S. 1	1	3	16	1953	1,399 gr	1,180			Could not shut off water. Formerly P.D.S. Oil P.D.S. 1.
129	Range Oil Co. and Ault, Lee A.	Dorothy 1	32	4	15	1949	1,575 gr	1,649			
130	Republic Petroleum Co.	Amet 1	[1]12	3	16	1921	1,494	215			
131	do	Banner 2	6	3	15	1919–20	1,756	1,692			Formerly Tunnel Petroleum 3.
132	do	Fink 4	12	3	16	1921	1,480±	1,383			
133	do	Price 4	6	3	15	1930–33	1,476	2,842	Pliocene and Eocene contact, 1,174.	Initial production, 2 bbls per day 20° gravity (API), from Eocene rocks.	Formerly Southern Production 1.
134	do	Price 5	6	3	15	1934–35	1,475	1,812		Oil shows reported between 650–1,100.	
135	do	Yankee Doodle 1.	6	3	15	1900		705		Some oil reported.	Formerly Yankee Doodle Oil 1.
136	Richfield Oil Corp	Brady Estate 1.	13	3	17	1949	3,388 kb	2,748			
137	do	Shepard 1	[1]1	3	16	1921–23	1,525	1,600		Oil shows reported at 800 and 1,400.	
138	do	T.I. & T. 1	[1]19	3	15	1943–44	1,321	8,207	Continental sedimentary rocks to bottom?.		
139	do	Watson 1	13	3	16	1949	1,702 gr	4,000	In Pliocene, 0–3,400; in rocks of the Delmontian stage of Kleinpell, 3,692–4,000.	Oil sand cored 3,656–3,641.	See pl. 45, section *B–B′*.
140	Rocco, Robert S	D. & C. 1	[1]36	4	16	1949–50	1,342	4,015	Pliocene and Eocene contact, 3,722.	Flowed 35 bbls per day water with trace of oil.	
141	Rothschild, Harry S.	Barbour 1	16	4	17	1952–53	1,197 kb	5,753		Formation test: 5,530–5,642, open 40 min gas in 5 min, strong decreasing blow, recovered 370 ft gas-cut mud, no oil.	
142	Rothschild Oil Co	Phillips 2	7	3	15	1950	1,465	3,000	Pliocene and Eocene contact, 972.	Poor oil sand in core, 925–927.	
143	do	Pleasant Community 1.	31	4	15						
144	do	Ramona Community 1.	8	4	17	1952	1,710 df	4,078			
145	do	Wickham-Ferrier 1.	32	4	15	1951	1,800 gr	1,652			
[2]146	Safe Oil Co	1	[1]12	3	16	1901		1,000±		Small amount of heavy tar.	
[2]147	San Fernando Oil & Gas Co.	1	13	3	16	1919–20	1,400±	1,245		Oil sand reported at 1,240.	Could not exclude water.
148	San Gabriel Oil Co	San Gabriel 1	32	4	15						
149	Schroeder Oil Syn	Daugherty 1	4	3	16	1922–23	1,321	2,785		No oil or gas reported.	
150	Seaboard Oil Co	Daugherty 1	9	4	17	1952	1,241 kb	6,017	In rocks of the Delmontian stage of Kleinpell, 5,057–5,140; in Pliocene, 5,157–6,017.	No oil shows	
151	do	Evans 1	23	3	16	1945	1,783 gr	992			
152	do	Evans 1-A	23	3	16	1945–46	1,783 gr	8,209	Top of the Mohnian stage of Kleinpell, 1,150±; top of the lower Mohnian stage of Kleinpell, 2,500; top breccia, 5,310.		See pl. 45, section *B–B′*.
153	do	Mission Land 8-1.	[1]25	3	16	1946	1,430 gr	9,528	Top of the Mohnian stage of Kleinpell, 1,450; lower Pliocene, 2,900–3,045.		Do.

See footnotes at end of table.

TABLE 10.—*Wildcat wells, including all known prospect wells outside productive oil fields*—Continued

Number (pl. 44)	Operator	Well	Location			Year drilled	Elevation (feet)	Total depth (feet)	Geologic information (depths in feet)	Oil and gas shows (depths in feet)	Remarks (depths in feet)
			Sec.	T. N.	R. W.						
154	Seaboard Oil Co.	Mission Land 8-2.	[1] 25	3	16	1947	1,410	4,202			
155	Section 31 Petroleum Corp.	1	31	4	15	1930	1,475±	2,008	Pliocene and Eocene contact, 1,000±; bottomed in granitic rocks.	No oil or gas reported.	
156	Seigenberg, Horton and Rodgers.	Warren 1	[1] 1	3	16	1930		1,448			Also called Shalimar Oil Warren 1.
157	Serago Oil Co	Yeager Community 1.	30	4	15						
158	Shaffer Tool Works	Shaffer 6	[1] 36	4	16						
159	Shallow Field Oil Co.	1	[1] 12	3	16	1921	1,400±	1,140		Oil shows reported, 1,115–1,120.	
[1]160	Shell Oil Co.	1	14	3	16						
161	do.	Daugherty 1	9	4	17	1938	1,342 gr	2,220			See pl. 45, section *F–F′*.
162	do.	Mission 2-1	[1] 25	3	16	1941–42	1,505	6,978	Top of the lower Mohnian stage of Kleinpell, 2,090; top of the Luisian stage of Kleinpell, 6,400; top of the Topanga formation, 6,590.		See pl. 45, section *B–B′*.
163	Sherman, R. W.	Newhall Community 1-1.	[1] 2	3	16	1949	1,335 gr	5,891			
164	do.	Newhall Community 2-1.	[1] 2	3	16	1949	1,335	961			
165	do.	Newhall Community 3-1.	[1] 2	3	16	1949–50	1,280	5,846		2-11-49, 300 bbls per day gross, 90 percent cut; 2-12-49, flowed average 520 bbls per day net oil, 30–50 percent cut; 3-19-49, flowed estimated, 47 bbls per day net, 40° gravity, 85 percent cut.	Redrilled to 5,687. See pl. 45, section *A–A′*.
166	Signal Oil and Gas Co.	Signal-Needham 1.	[1] 13	3	16	1945	1,604	4,997	Top of the Delmontian stage of Kleinpell, 2,400; top of the Sespe(?) formation, 2,733; top of the Eocene, 4,425.		
167	Skinner, L. V., Corwin, Tom, and Beck, Fred.	L. V. Skinner's Ann 1	6	3	15						
168	Southern California Petroleum Corp.	Handy 1	18	4	17	1942	1,590	5,973			
169	do.	Kinler 16-1	16	4	17	1951	1,226 kb	8,590	In rocks of the Delmontian stage of Kleinpell between top of Miocene and stratigraphic level of Intermediate zone, 6990–7,013; in Delmontian between stratigraphic levels of Intermediate zone and Del Valle zone, 7,650–8,410.	Formation test: 6,565–6,720, failed.	See pl. 45, section *F–F′*.
170	do.	Lassalle 44-1	[1] 2	3	16	1943	1,350	6,073	Base Pliocene, 5165		
171	do.	N.L. & F. 2	[1] 20	4	17	1951	1,052 df	10,719	Top of the Miocene, 3,474?; top of the Mohnian stage of Kleinpell 6,840?; below fault—in rocks of the Delmontian stage of Kleinpell, 7,010–9,160, top of the upper Mohnian stage of Kleinpell, 9,300; top of the lower Mohnian stage of Kleinpell, 9,830.		
172	do.	Vazquez B-2	17	4	17						
173	Standard Oil Co. of Calif.	Bobier 1	15	4	17						
174	do.	Brady 2-1	13	3	17	1944	3,429 df	9,576			See pl. 45, section *D–D′*. Contacts in well projected from western Gulf Brady Estates 1 (well 233, this table).
175	do.	Brady 2-1A	13	3	17						
176	do.	Elsmere 1	7	3	15	1889	1,465	1,376		Numerous small shows of black oil down to 940; show of green oil at 1,020; small amount of gas, 1,020–1,200.	Drilled by Pacific Coast Oil Co. Abandoned while drilling.
177	do.	Elsmere 3	7	3	15	1891	1,457	555		Few shows of oil and tar.	Drilled by Pacific Coast Oil Co. Could not shut off water at 384.

See footnotes at end of table.

TABLE 10.—*Wildcat wells, including all known prospect wells outside productive oil fields*—Continued

Number (pl. 44)	Operator	Well	Location			Year drilled	Elevation (feet)	Total depth (feet)	Geologic information (depth in feet)	Oil and gas shows (depths in feet)	Remarks (depths in feet)
			Sec.	T. N.	R. W.						
178	Standard Oil Co. of Calif.	Elsmere 4	7	3	15	1891–92	1,625	705	----	Few small shows of oil.	Drilled by Pacific Coast Oil Co.
179	do	Elsmere 8	7	3	15	1899	1,555	500	----	----	Drilled by Pacific Coast Oil Co. Could not shut off water.
180	do	Elsmere 11	7	3	15	1899–1900	1,514	700	----	----	Do.
181	do	Elsmere 12	7	3	15	1900	1,604	1,225	----	Little oil show	Drilled by Pacific Coast Oil Co. Abandoned because of water and loose gravel.
182	do	Elsmere 14	7	3	15	1900	1,589	490	----	Produced very little oil.	Drilled by Pacific Coast Oil Co.
183	do	Elsmere 19	7	3	15	1900–01	1,596	848	----	----	Drilled by Pacific Coast Oil Co. Could not shut off water.
[2] 184	do	Newhall 1	19	3	15	1899–1900	----	700	----	----	Drilled by Pacific Coast Oil Co.
185	do	N.L. & F. Co. 3–2.	[1] 19	4	17	1944–45	1,665 df	6,084	----	----	
186	do	N.L. & F. Co. 3–3.	[1] 20	4	17	1945	1,547 df	6,224	----	----	
187	do	N.L. & F. Co. 5–1.	[1] 34	4	16	1947–48	1,232 df	9,296	Top of the Pico formation, 5,000±; top of the Delmontian stage of Kleinpell, 6,190±; top of the upper Mohnian stage of Kleinpell, 7,750±.	----	
188	do	N.L. & F. Co. 5–2.	[1] 34	4	16	1949	1,264 df	1,000	----	----	
189	do	N.L. & F. Co. 5–3.	[1] 34	4	16	1949	1,252	7,792	Base of the Pliocene, 5,440	----	See pl. 45, section *A–A′*.
190	do	N.L. & F. Co. 6–52–19.	[1] 19	4	16	1951–52	1,264 df	13,255	----	Formation test: 12,595–12,800, no good.	
191	do	N.L. & F. Co. 7–1.	[1] 35	4	17	1952–53	1,519	9,327	----	----	
192	do	P.C.O. 42	1	3	17	1942	2,293 df	8,258	----	----	
193	do	Ward 3–1	[1] 27	3	16	1944–45	2,759 df	10,363	Top of the lower Mohnian, 1,500; top of the Sesnon zone, 9,730.	----	
194	St. Anthony Oil Corp.	(LaSalle) 1	10	3	16	1941	1,480	5,416	Top of the Delmontian stage of Kleinpell, 3,158; top of the upper Mohnian stage of Kleinpell, 4,293.	----	
195	St. Bernard Oil Co.	1	18	3	16	1903	----	2,100	----	----	
196	St. Helens Petroleum Corp.	Ladd 1	7	4	17	1949	1,452	4,501	----	----	
197	Stine, Sabasta and Ackland.	Bailey 2	1	3	16	1952	1,440±	----	----	----	
198	do	Henderson 1	1	3	16	----	----	----	----	----	
199	Sunray Oil Corp	NCW 1	[1] 26	4	17	1945	1,269	9,046+	First zone, 6,700; 2nd zone, 6,925; 3rd zone, 7,225.	----	
200	do	R.S.F. 103	[1] 34	4	17	1952	1,183 kb	9,483	In Pliocene, 1,640–6,040; in Delmontian stage of Kleinpell, 6,280–7,972; in upper Mohnian stage of Kleinpell, 8,000–9,480; base 3rd zone equivalent, 7,607.	Two tests with slight gas.	See pl. 45, section *E–E′*.
201	Superba Petroleum Corp.	1	11	3	16	1932	1,800±	----	----	----	
202	Superior Oil Co.	Bonelli 14–23	[1] 23	4	16	1951	1,254	8,969	Top of the Miocene, 6,750; upper Mohnian stage of Kleinpell, 7,922; gneiss and schist at 8,515 (8002 in redrill).	No oil shows	Whipstock set, 5281; redrilled to 8070. See pl. 45, section *C–C′*.
203	do	L.A. Homes 1	[1] 36	4	16	1949–50	1,348 gr	5,399	Base of the Saugus formation, 3,325; in Pico formation 4,250–4,430; top of the Eocene, 4,687.	----	
204	do	N.L.&F. 37–8	[1] 8	4	16	1951	1,060 gr	13,303	Top of the Delmontian stage, 10,100; top of the upper Mohnian stage of Kleinpell, 11,355; top of the lower Mohian stage of Klenpell, 12,250.	----	See pl. 45, section *D–D′*.
205	do	N.L.&F. 48–21	[1] 21	4	16	1952	1,175 kb	13,553	Top of the Delmontian stage of Kleinpell, 8,333; in Mohnian(?) stage of Kleinpell, 10,300-10,310; in good Mohnian stage of Kleinpell at 10,550.	----	
[2] 206	Talisman Oil Co.	Morrison 1	[1] 1	3	16	1952	1,450 df	161	----	----	Suspended at 161.
207	Terminal Drilling Co.	Independent-Chiggia 1.	[1] 24	4	16	1949	1,381 gr	1,922	Saugus formation and Mint Canyon formation contact, 1,282.	----	

See footnotes at end of table.

TABLE 10.—*Wildcat wells, including all known prospect wells outside productive oil fields*—Continued

Number (pl. 44)	Operator	Well	Location			Year drilled	Elevation (feet)	Total depth (feet)	Geologic information (depth in feet)	Oil and gas shows (depths in feet)	Remarks (depths in feet)
			Sec.	T. N.	R. W.						
208	Terminal Drilling Co.	Phillips 1	12	3	16	1950	1,397 kb	1,350	Top of the upper Kraft zone, 850; top of the lower Kraft zone, 1,100; top of the Eocene(?), 1,320.	Oil and tar shows in cores at 410–430, 639–665, and 1,334–1,350; formation test: 560–652, recovered 440 ft mud, gas, and water.	
209	do	Thompson 1	[1]36	4	16	1949	1,664	3,990			
210	The Texas Co	Bonelli 1	[1]13	4	16	1952	1,265 gr	1,502			
211	do	Deaton 1	7	4	17	1945	1,300	4,803	Top of the Miocene, 1,995; top of the Mohnian stage of Kleinpell 4,782; Kern sand, 2,597–2,805; top of the Del Valle sand, 3,320.	Initial production, 41 bbls per day, 36.0 percent cut.	Abandoned.
212	do	Malis 1	10	4	17	1947–48	1,259	8,408			
213	do	Newhall A-1	[1]9	4	16	1952		5,312			
214	do	Newhall B-1	[1]11	4	16	1953	1,136 kb	8,079			
215	do	N.L.F. 2	[1]21	4	17	1945	870(?) gr	8,467			
216	do	Whitnah 1	14	3	16	1941	1,928 gr	4,999	In Pliocene, 2,700–3,800; in rocks of the Delmontian stage of Kleinpell 3,900–4,400; top of the upper Mohnian stage of Kleinpell, 4,400; top of the Sespe(?) formation, 4,452.	Shows of tarry oil in Sespe(?) formation.	
[2]217	Trigood Oil Co	Southern Calif. Petroleum Kinler 2.	16	4	17	1950	1,160 gr	8,359			Redrilled from 5750–7589.
218	Tunnel Oil Co	(Needham) 1	[1]13	3	16		1,650 df	1,548			
219	T.W.A. Oil Co	Newhall 1	[1]15	4	17	1925	963			No oil sands encountered.	
220	Union Oil Co. of Calif.	Needham 1	13	3	16	1951	1,775 gr	4,008	Pliocene and Delmontian contact, 1,700; probably in Sespe(?) formation, 2,010–2,525; top of the Eocene, 3,850±.		
221	do	Needham 2	[1]12	3	16	1951–52	1,560 gr	1,805		Produced 17 bbls per day, 31.3° gravity oil, 12.0 percent cut on 1–9–52. Shut in.	
222	do	Needham 3	[1]12	3	16	1952	1,500±	4,031	Base of the Pliocene, 1,805; Sespe(?) formation and Eocene contact, 1,880±; bottom in Eocene.		See pl. 45, section *B–B′*.
223	do	Newhall Land & Farming 1.	[1]20	4	17	1942	946	7,004			
224	do	Newhall-Saugus 1.	[1]15	4	16	1925–26	1,199	5,893	In Mint Canyon formation, 2,625–5,893.		
225	do	Union-Ferguson 1.	[1]31	4	16	1951–52	1,530 gr	11,549			
226	Universal Consolidated Oil Co.	Phillips 1	[1]2	3	16	1949	1,260	5,264	Bottomed in Sespe(?) formation.	Formation test: 5,196–5,264, recovered two stands gassy drilling fluid.	
227	Von Glahn Oil Co	Lassale 1	10	3	16		1,500 df		Top of the Miocene, 4,800±; top of the Sespe(?) formation, 7,980.		Also called Mutual Development Lassale 1.
228	Watkins, Jack	Braille 1	[1]2	3	16						
229	do	Legion 1	1	3	16	1952–53	1,338 kb	3,231	Base of the Pliocene, 2,890±; top of the Sespe(?) formation, 2,990; probably some rocks of Delmontian stage of Kleinpell between.		
[2]230	do	Needham 2-2	[1]12	3	16	1953	1,661 kb	1,848		Completed on pump 2–27–53; 40 bbls per day, 21.6° gravity oil, 8.8 percent cut.	
231	Watkins, Jack	Thompson 1	12	3	16	1952–53	1,568 kb	2,163	Bottomed in Sespe(?) formation.	Plug at 2,137; 15 barrels per day, 16° gravity oil, 19 percent cut on 1–4–53; sanded up, abandoned.	
232	West Coast Development Co.	Broughton 2	[1]27	4	16						

See footnotes at end of table.

TABLE 10.—*Wildcat wells, including all known prospect wells outside productive oil fields*—Continued

Number (pl. 44)	Operator	Well	Location			Year drilled	Elevation (feet)	Total depth (feet)	Geologic information (depth in feet)	Oil and gas shows (depths in feet)	Remarks (depths in feet)
			Sec.	T. N.	R. W.						
233	Western Gulf Oil Co.	Brady Estate 1.	13	3	17	1943	3,460 df	9,807	Spud in lower Mohnian stage of Kleinpell; top of the Luisian stage of Kleinpell, 1,770; top of the Topanga(?) formation, 2,230; Santa Susana fault, 2,505; lower Mohnian stage of Kleinpell, 2,505–2,650; small fault, 2,650; rocks of the Delmontian stage of Kleinpell below fault; Brady fault, 5,100; Pliocene, 5,100–7,300; top of the Delmontian stage of Kleinpell, 7,300; top of the lower Mohnian stage of Kleinpell, 8,510; top of the Luisian stage of Kleinpell, 8,690.	--------	
234	Willard, R. D.	Phillips 3.	12	3	16	1950	1,406 kb	931	--------	Oil sand at 810; pumped water with trace of oil.	
[2] 235	Young Napoleon Oil Co.	(?)	5	3	16	--------	--------	--------	--------	--------	
236	Young, Roy W., Inc.	Walker 1	[1] 11	4	16	1941?	1,250±	9,981	Saugus formation and Mint Canyon formation contact, 2,937; bottom in Mint Canyon formation.	--------	See pl. 45, section *C–C'*.

[1] Projected section (within boundaries of land grants).

[2] Well not shown on geologic map, plate 44.

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TABLE 11.—*Fossil localities*

[Number, this report: F, megafossil locality; f, Foraminifera locality; V, vertebrate locality. Altitude from topographic base of geologic map, pl. 44]

Number			Altitude (feet)	Collector	Date	Description
This report	USGS	Field				
EOCENE SERIES						
F1 [1]		Kew loc. 4		Kew		Elsmere Canyon.
F2	18294a			Winterer, Durham, Fahy	1952	Core from Union Oil Needham 3, NE. cor. sec. 12, T. 3 N., R. 16 W. (projected), at well depth 2269–2289 ft.
F3	18294c			do	1952	Core from Union Oil Needham 3, NE. cor. sec. 12, T. 3 N., R. 16 W. (projected), at well depth 2742–2753 ft.
F4				Kew, Driver	1931?	Core from North Star Mining and Development Shepard 1, sec. 1, T. 3 N., R. 16 W. (projected), at well depth 2105 ft.
F5				do	1931?	Core from North Star Mining and Development Shepard 1, sec. 1, T. 3 N., R. 16 W. (projected), at well depth 2237 ft.
UPPER MIOCENE **Modelo formation**						
f6			2165	Winterer, Durham, Bramlette	1952	East Canyon, 11.310 ft S. and 3,000 ft W. of lat 34°22′, long 118°32′.
f7		Rice Canyon 8	2190	do	1952	East Canyon, 11,490 ft S. and 3,060 ft W. of lat 34°22′, long 118°32′.
f8		Rice Canyon 7	2210	do	1952	East Canyon, 11,570 ft S. and 3,070 ft W. of lat 34°22′, long 118°32′.
f9		Rice Canyon 6	2320	do	1952	East Canyon, 11,830 ft S. and 2,960 ft W. of lat 34°22′, long 118°32′.
f10		Rice Canyon 5	2350	do	1952	East Canyon, 11,830 ft S. and 3,090 ft W. of lat 34°22′, long 118°32′.
f11		Rice Canyon 1A	2470	Winterer, Durham	1951	East Canyon, 11,800 ft S. and 3,380 ft W. of lat 34°22′, long 118°32′.
f12			3475	Winterer, Durham, Bramlette	1951	SW. of Towsley Canyon, 530 ft S. and 10.040 ft W. of lat 34°20′, long 118°34′.
UPPER MIOCENE AND LOWER PLIOCENE **Towsley formation**						
f15			1600	Winterer	1953	Towsley Canyon, 4,600 ft S. and 3,450 ft W. of lat 34°22′, long 118°34′.
F16	16842	JCH 343	2085	Hazzard		East Canyon, 10,150 ft S. and 690 ft W. of lat 34 22′, long 118°32′.
F17 [2]	18208	M 200	850	Winterer, Woodring	1950	South side of Santa Clara Valley, Ventura County, on north-south ridge midway between Tapo Canyon and Los Angeles-Ventura County line, about 1.75 miles S. 4° W. from intersection of county line and State Route 126, and 0.57 mile S. 58° E. from top of Hill 1988, Santa Susana quadrangle (1: 62,500).
F18	18436	M 500	1525	Durham	1951	SE. of Honby, 8,550 ft S. and 3,090 ft W. of lat 34°26′, long 118°28′.
F19	18437	M 501	1400	do	1951	SE. of Honby, 7,880 ft S. and 2,800 ft W. of lat 34°26′, long 118°28′.
F20		SOC–F3	2300	Hariss	1944	S. of Gavin Canyon, 10,850 ft S. and 9,620 ft W. of lat 34°22′, long 118°30′.
F21 [1]		USGS 4401				Elsmere Canyon.
F22		Kew loc. 7	1575	Kew		Elsmere Canyon, 2,700 ft S. and 9,870 ft W. of lat 34°22′, long 118°28′.
F23		CIT 1539	1575			Do.
F24		UCLA L 2056	1575			Do.
F25		UCLA L 242	1575	Crickmay(?)	1928	Do.
F26 [1]		UCLA 3319				North side of Elsmere Canyon, probably near Standard Oil of California Elsmere 1.
F27 [1]		UCLA 3322				North side of Elsmere Canyon, probably near Standard Oil of California Elsmere 1.
f28		F 219B	1975	Winterer, Bramlette	1951	Pico Canyon, 9,560 ft S. and 8,100 ft W. of lat 34°24′, long 118°36′.
f29		F 222	1915	do	1951	Pico Canyon, 10,810 ft S. and 8,650 ft W. of lat 34°24′, long 118°36′.
f30		F 223	1960	do	1951	Pico Canyon, 10,820 ft S. and 8,400 ft W. of lat 34°24′, long 118°36′.
f31		F 224	2110	do	1951	Pico Canyon, 10,520 ft S. and 7,760 ft W. of lat 34°24′, long 118°36′.
f32		F 224A	2125	do	1951	Pico Canyon, 10,400 ft S. and 7,630 ft W. of lat 34°24′, long 118°36′.
f33		F 140	2460	Winterer	1950	SW. of Salt Canyon, 11,700 ft S. and 1,930 ft W. of lat 34°24′, long 118°40′.
f34		F 147	2190	do	1950	SW. of Salt Canyon, 10,440 ft S. and 2,110 ft W. of lat 34°24′, long 118°40′.
f35		F 148	2225	do	1950	SW. of Salt Canyon, 10,340 ft S. and 2,110 ft W. of lat 34°22′, long 118°40′.
f36		SEPM	1570	Bramlette		Elsmere Canyon, 4,310 ft S. and 8,800 ft W. of lat 34°22′, long 118°28′.
f37		RR 2	1400	Winterer, Durham	1953	SE. of Honby, 7,880 ft S. and 2,640 ft W. of lat 34°26′, long 118°28′.
f38		RR 3	1400	do	1953	SE. of Honby, 7,810 ft S. and 2,690 ft W. of lat 34°26′, long 118°28′.
f39		RR 4	1400	do	1953	SE. of Honby, 7,760 ft S. and 2,710 ft W. of lat 34°26′, long 118°28′.
f40		RR 5	1400	do	1953	SE. of Honby, 4,440 ft S. and 2,770 ft W. of lat 34°26′, long 118°28′.

See footnotes at end of table.

TABLE 11.—*Fossil localities*—Continued

Number			Altitude (feet)	Collector	Date	Description
This report	USGS	Field				
PLIOCENE **Pico formation**						
F41	18097	M 205	2000	Winterer	1950	S. of San Martinez Grande Canyon, 2,590 ft S. and 10,040 ft W. of lat 34°26′, long 118°40′.
F42	18435	M 304	2125	do	1951	S. of San Martinez Grande Canyon, 2,640 ft S. and 9,510 ft W. of lat 34°26′, long 118°40′.
F43 [2]	18283	M 300		Winterer, Durham	1951	North side Santa Clara River valley, Ventura County, 5,550 ft northwestward along Los Angeles-Ventura County line from intersection of county line and State Route 126, thence 780 ft southwestward at right angle, Santa Susana quadrangle (1:62,500). On W. slope of small hill bordering large eastwest closed basin.
F44 [2]	18432	M 301		do	1951	North side of Santa Clara River valley, Ventura County, 5,460 ft northwestward along Los Angeles-Ventura County line from the intersection of the line and State Route 126, thence 640 ft southwestward at right angle. On same low hill and about 150 ft east-southeast of loc. F43.
F45	18433	M 302	1650	do	1951	W. of San Martinez Grande Canyon, 5,000 ft S. and 9,680 ft W. of lat 34°26′, long 118°40′.
F46	18421	M 207	1510	Winterer	1951	W. of San Martinez Grande Canyon, 6,340 ft S. and 7,840 ft W. of lat 34°26′, long 118°40′.
F47	18425	M 211	1180	do	1951	W. of San Martinez Grande Canyon, 6,850 ft S. and 4,440 ft W. of lat 34°26′, long 118°40′.
F48	18424	M 210	1080	do	1951	W. of San Martinez Grande Canyon, 7,400 ft S. and 5,420 ft W. of lat 34°26′, long 118°40′.
F49	18419	M 198A	1000	Winterer, Woodring	1950	W. of San Martinez Grande Canyon, 7,230 ft S. and 8,750 ft . W. of lat 34°26′, long 118°40′. Float.
F50 [2]	18418	M 198		do	1950	North side Santa Clara River valley, Ventura County, 2,925 feet northwestward along Los Angeles-Ventura County line from intersection of county line and State Route 126, thence 200 ft southwestward at right angles along ridge top.
F51	18422	M 208	1285	Winterer	1951	W. of San Martinez Grande Canyon, 7,380 ft S. and 7,800 ft W. of lat 34°26′, long 118°40′.
F52 [2]		MNLF 180	1200	Durham, Fahy	1951	North side Santa Clara River valley, Ventura County, 5,000 ft N. 52° W. of intersection of Los Angeles-Ventura County line and State Route 126; from sandstone at sharp bend in bottom of south-draining canyon.
F53 [2]		NLF 177		do	1951	294 ft S. and 32 ft W. of loc. F52.
F54 [2]		NLF 179		do	1951	196 ft S. and 38 ft E. of loc. F52.
F55 [2]		NLF 180		do	1951	In siltstone immediately above sandstone of loc. F52.
F56 [2]		NLF 181		do	1951	36 ft N. and 44 ft E. of loc. F52.
F57 [2]		NLF 182		do	1951	93 ft N. and 46 ft E. of loc. F52.
F58 [2]		NLF 185		do	1951	232 ft N. and 96 ft E. of loc. F52.
F59	18423	M 209	965	Winterer	1951	W. of San Martinez Grande Canyon, 7,940 ft S. and 5,500 ft W. of lat 34°26′, long 118° 40′.
F60	18426	M 212	1075	do	1950	San Martinez Grande Canyon, 6,490 ft S. and 1,720 ft W. of lat 34°26′, long 118°40′.
F61	18209	M 203	1400	do	1950	W. of San Martinez Chiquito Canyon, 3,750 ft S. and 9,710 ft W. of lat 34°26′, long 118°38′.
F62		M 504	1775	Durham, Winterer	1952	Holser Canyon, 4,220 ft N. and 8,880 ft W. of lat 34°26′, long 118°40′.
F63		SL 10	2075	Stiles	1952	Holser Canyon, 4,880 ft N. and 8,880 ft W. of lat 34°26′, long 118°40′.
F64 [2]		SL 7		do	1952	In tributary to upper part of San Martinez Chiquito Canyon, 1,150 ft S. and 75 ft E. of NW. corner sec. 8, T. 4 N., R. 17 W. Castaic quadrangle.
F65		SL 3	1375	do	1952	S. of San Martinez Chiquito Canyon, 3,700 ft N. and 9,860 ft W. of lat 34°26′, long 118°38′.
F66		SL 5	1525	do	1952	W. of San Martinez Chiquito Canyon, 3,560 ft N. and 9,100 ft W. of lat 34°26′, long 118°38′.
F67		CKL 7	2200	Cooper, Kelley	1938	Holser Canyon, 5,400 ft N. and 8,690 ft W. of lat 34°26′, long 118°40′.
F68		UCLA 8118	885			W. of San Martinez Grande Canyon, 9,000 ft S. and 3,190 ft W. of lat 34°26′, long 118°40′.
F69		UCLA L349	1535	Brown		W. of San Martinez Chiquito Canyon, 1,890 ft N. and 9,780 ft W. of lat 34°26′, long 118°38′.
F70		UCLA L355	1550	do		E. of San Martinez Chiquito Canyon, 1,820 ft N. and 5,700 ft W. of lat 34°26′, long 118°38′.
F71		UCLA L351	1510	do		N. of San Martinez Grande Canyon, 780 ft N. and 888 ft W. of lat 34°26′, long 118°40′.
F72		CKL 22	1750	Cooper, Kelley	1938	W. of San Martinez Chiquito Canyon, 2,000 ft N. and 9,600 ft W. of lat 34°26′, long 118°38′.
F73		UCLA L347	1250	Brown		San Martinez Chiquito Canyon, 190 ft S. and 9,370 ft W. of lat 34°26′, long 118°38′.
F74	18417	M 197	1290	Woodring, Winterer	1950	San Martinez Chiquito Canyon, 3,570 ft N. and 5,900 ft W. of lat 34°26′, long 118°38′.
F75		UCLA L358	1450	Brown		E. of San Martinez Chiquito Canyon, 3,740 ft N. and 3,820 ft W. of lat 34°26′, long 118°38′.
F76	18434	M 303	1850	Winterer	1951	San Fernando Pass, 9,840 ft S. and 2,980 ft W. of lat 34°22′, long 118°30′.
F77	18427	M 240	1525	do	1951	Towsley Canyon, 2,400 ft S. and 8,000 ft W. of lat 34° 22′, long 118° 32′.
F78	18428	M 241	1530	do	1951	Towsley Canyon, 2,220 ft S. and 8,150 ft W. of lat 34° 22′, long 118° 32′.
F79	18429	M 242	1535	do	1951	Towsley Canyon, 2,080 ft S. and 8,190 ft W. of lat 34° 22′, long 118° 32′.
F80	18431	M 244	1530	do	1951	Towsley Canyon, 1,850 ft S. and 8,910 ft W. of lat 34° 22′, long 118° 32′.
F81	18430	M 243	1560	do	1951	Towsley Canyon, 1,800 ft S. and 8,620 ft W. of lat 34° 22′, long 118° 32′.
F82		M 505	1600	Winterer, Durham	1952	Pico Canyon, 6,500 ft S. and 1,540 ft W. of lat 34° 24′. long 118° 36′.

See footnotes at end of table.

TABLE 11.—*Fossil localities*—Continued

Number			Altitude (feet)	Collector	Date	Description
This report	USGS	Field				
				PLIOCENE—Continued **Pico formation—Continued**		
F83		UCLA L1085	1510	O'Flynn, Paschall	1938	Towsley Canyon, 2,090 ft S. and 9,070 ft W. of lat 34° 22′, long 118° 32′.
V84		V 2	1450	Corey		E. of San Martinez Chiquito Canyon, 3,900 ft N. and 4,300 ft W. of lat 34° 26′, long 118° 38′.
F95		M 600	1300	Vedder, Durham	1954	North edge of Newhall-Potrero oil field, 11,700 ft S. and 8,500 ft W. of lat 34° 26′, long 118° 36′.
				UPPER PLIOCENE AND LOWER PLEISTOCENE **Saugus formation**		
F85		M 507	1470	Winterer, Durham, Cloud, Woodring, Bramlette.	1953	Grapevine Canyon, 2,100 ft S. and 6,890 ft W. of lat 34° 20′, long 118° 28′.
F86		UCLA L364	1625	Kew		N. of Towsley Canyon, 9,710 ft S. and 2,370 ft W. of lat 34° 24′, long 118° 34′.
F87		UCLA L1088	1425	O'Flynn, Paschall	1938	N. of Towsley Canyon, 10,680 ft S. and 860 ft W. of lat 34° 24′, long 118° 34′.
f88		F 180	925	Winterer	1950	E. of Del Valle, 5,500 ft S. and 690 ft W. of lat 34° 26′, long 118° 38′.
f89		F 181A	1250	Winterer, Bramlette	1950	Potrero Canyon, 11,740 ft S. and 7,880 ft W. of lat 34° 26′, long 118° 36′.
f90		F 181B	1250	do	1950	Potrero Canyon, 11,740 ft S. and 7,880 ft W. of lat 34° 26′, long 118° 36′.
V91		V 1	1025	Corey		NE. of Del Valle, 1,400 ft S. and 4,050 ft W. of lat 34° 26′, long 118° 38′.
V92		V 3	1200	do		NE. of Del Valle, 850 ft S. and 2,280 ft W. of lat 34° 26′, long 118° 38′.
V93		V 4	1200	do		W. of Castaic Station, 4,030 ft N. and 560 ft W. of lat 34° 26′, long 118° 38′.
				UPPER PLEISTOCENE		
V94		V 12	985	Corey		SW. of Castaic Station, 1,510 ft S. and 8,700 ft W. of lat 34° 26′, long 118° 36′.

[1] Locality in area but not shown on geologic map (pl. 44) because location is uncertain.
[2] Locality outside of map area.

INDEX

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Upper Pleistoc

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Terrace deposits

Clay, silt, sand, and gravel, unconsolidated or poorly consolidated; gray, light-brown, or reddish-brown

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