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UNITED STATES GEOLOGICAL SURVEY

Reports - Open file

Geology of Southeastern Ventura Basin, Los Angeles County, California

by

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1956

OPEN FILE

This report is preliminary and has not been edited or reviewed for conformity with U. S. Geological Survey standards and nomenclature.

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I N T R O D U C T I O N

PURPOSE AND SCOPE OF WORK

The Ventura Basin (see index map, fig. 1) 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 the state and also several of those most recently discovered. Since 1937 several new fields have been discovered in the area and doubtless more oil remains to be found.

The first work of the U. S. Geological Survey in this region was reported by G. H. Eldridge and Ralph Arnold in Bulletin 309 (1907). The Survey's Bulletin 753 by W. S. W. 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 covers a small part of Kew's area on the larger scale of 1:12,000 (see index map, fig. 1). Attention is focused on the outcrop geology, particularly the stratigraphy. Subsurface data were collected where available, but they are incomplete.

FIELD WORK

Field work was begun in the summer of 1949, carried on a few days each month until the summer of 1950, and then continued on a nearly continuous basis until September 1952. D. L. Durham of the U. S. Geological Survey joined the project in the summer of 1951. The areas mapped by each are shown on an index map on Plate I. T. R. Fahy, also of the U. S. Geological Survey, assisted in the collection of foraminiferal samples on several occasions.

The geology was mapped on aerial photographs, [redacted]. A few of the photographs used were 1:24,000 contact prints but most were 1:10,000 enlargements. The data on the photographs were transferred by inspection to the topographic base map.

The stratigraphic sections of the Towsley formation (Plate VIII) were measured with plane table and alidade, and the stratigraphic sections of the Pico formation (Plate IX) were measured with tape and Brunton compass.

ACKNOWLEDGMENTS

Geologists on the staffs of oil companies operating in the region made available much subsurface information. Particular acknowledgment is due to E. J. Bartosh of the Bankline Oil Co., T. L. Macleod of the Bell Petroleum 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., Ltd., now with the Seaboard Oil Co. of Delaware, 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. of Delaware, 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 R. Menard of the Sunray Oil Corp., G. Y. Wheatley of the Superior Oil Co., F. D. Bode of the Texas Co., and 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 author in the field on several occasions, offered many valuable suggestions about stratigraphic problems and examined several foraminiferal faunas.

The micropaleontologic work for this report was begun by T. R. Fahy and was completed by Patsy Beckstead Smith of the U. S. Geological Survey. 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 E. J. Trumbull and J. G. Vedder. Woodring visited the field on several occasions to discuss stratigraphic problems and also prepared a special report on the <u>Calicantharus humerosus</u> group.

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

All field work for this report was done while the writer was employed by [redacted] the U. S. Geological Survey. To the officers of the Survey, and especially to A. O. Woodford, who exercised general supervision of the work and who made many valuable suggestions concerning this report, the writer is indebted for their continued interest and encouragement. To D. L. Durham is due the writer's gratitude not only for his contribution to the field mapping, and his drafting of most of the illustrations, but also for his contributions of ideas.

G E O G R A P H Y

INTRODUCTION

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

CLIMATE

The eastern part of the Santa Clara River Valley is semi-arid, having a mean annual rainfall of about 16 inches. The rain is seasonal, most of it falling 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 rock 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, this being especially heavy on north slopes. Big-cone spruce grow at higher altitudes in the vicinity of San Fernando Pass.

THE 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 above the water-stage recording station at the U. S. Highway 99 bridge about 4 miles west of Newhall is about 355 square miles. The largest tributaries enter the river from the north, west of U. S. Highway 99 and west of the mapped area. Tributaries include Piru, Sespe, and Santa Paula Creeks, whose combined drainage area and discharge is much greater than that of the main river upstream above the mouth of Piru Creek. With the exception of a short segment near Fillmore, the Santa Clara River bed is commonly dry in summer. All of its tributaries in the mapped area are intermittent streams.

The average annual discharge of the river for the 16-year period October 1929 to September 1945 as measured at the U. S. Highway 99 bridge water-stage recording station, was 19.7 second-feet. Maximum discharge measured there during that period was 24,000 second-feet on March 2, 1938, 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, 3747 feet, is in the Santa Susana Mountains. The western San Gabriel Mountains rise to an altitude of 3119 feet within the eastern part of the mapped area and to 4000 feet a short distance farther east. North of Santa Clara River Valley is a continuous belt of mountainous country. The Santa Clara

River descends from an altitude of 1385 feet to 805 feet in the mapped area.

HUMAN ACTIVITIES

San Fernando Pass is at the western 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. At the present time, U. S. Highways 99 and 6, connecting Los Angeles with the San Joaquin Valley and the Mojave Desert, respectively, as well as the Southern Pacific Railroad's main line from Los Angeles to the San Joaquin Valley, 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 complete the road network by means of which access may be gained to all parts of the area.

The towns of Newhall and Saugus, both on the Southern Pacific Railroad, are the chief centers of population within the mapped area. The Santa Clara River Valley, much of which is under irrigation, supports farms, orchards, and cattle ranches. Numerous oil fields add to the productivity of the region.

P H Y S I O G R A P H Y

INTRODUCTION

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 tributaries. The high surfaces extend to altitudes of more than 3,000 feet on the Santa Susana Mountains. The 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 belonging to 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 mountain and are tributary to the San Fernando Valley drainage.

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

STRUCTURAL AND LITHOLOGIC CONTROL OF DRAINAGE

Since 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 accumulation of 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 the structure and lithologic nature of the rocks. 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 course of a stream descending the mountain flank is commonly influenced by the differing resistance to erosion of the units which it crosses. This is especially well illustrated in Pico Canyon, where the stream follows weak shale units for long distances, then turns sharply to cross resistant sandstone units.

Location of the tributaries to the main canyons draining the mountains is largely determined by the positions of belts of soft rock. The more resistant units form strike ridges. Dip and anti-dip slopes are commonly about equally steep so that the tributaries are in narrow canyons. The major canyons are narrowest where they cut through the strike ridges. Towsley Canyon 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 enters the unit, makes a right-angle bend to follow the softer, intermediate beds along the strike for 400 feet, and 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 northwest part of the mapped area, San Martinez Chiquito Canyon follows closely the trend of the Holser fault for about two 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 two miles before crossing it to join the Santa Clara River.

RIVER TERRACES

Several river terrace levels and erosion surfaces are developed along the Santa Clara River and its tributaries. On the hills north of the river between Bouquet Canyon and the eastern border of the mapped area are remnants of seven distinct river terrace levels above the alluviated valley floor (fig. 2). The lowest terrace level is about 40 feet and the highest more than 400 feet above the present river bed. These terrace surfaces are generally nearly planar and slope gently toward the river, but some steepen near their termination against the hills. The highest terrace level extends back into the highlands up gently sloping valleys unrelated to the present drainage cycle. Surfaces reconstructed from the remnants of various terrace levels slope in approximately the same direction as the present river valley.

Because of their limited extent and distribution, and their possible deformation, a comparison of the gradient of the river that formed the terraces with the present river's gradient is difficult to make. The gradient of the two highest terrace levels, however, does appear to have been less than that of the present river in this area (see fig. 2).

Remnants of an old erosion surface are found above the river terraces. This surface is developed 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 the ones north of the river is apparent. Between Bouquet Canyon and Castaic Valley, no terraces are present along the north side of the Santa Clara River.

Remnants of several terrace and erosion surfaces are evident east of Saugus and Newhall in Placerita Canyon and Newhall Creek. The most extensive of these is found on the hills north and south of the lower part of Placerita Canyon. Its lowest altitude is about 150 feet higher than the altitude of the adjacent canyon bottom. This surface extends upward 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. The terrace surface is developed on a thick accumulation of river terrace material at its western end, 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 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 Santa Clara River several somewhat similar terrace levels can be distinguished below extensive higher terraces.

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

On the western flank of the San Gabriel Mountains in the vicinity of Elsmere Canyon, is a nearly undissected erosion surface cut on crystalline rocks. This is a resurrected surface exposed by the Recent removal of the Pliocene sedimentary rock cover (see fig. 6).

SANTA SUSANA EROSION SURFACE

The Santa Susana Mountains constitute a continuous northwest-trending ridge with steep, deeply dissected flanks and a relatively narrow top with rounded knolls and gentle slopes. Streams in the summit region have gentle gradients but steepen markedly where they begin to descend the mountain flank. At one time these streams must have flowed on a land surface with gentle gradients comparable to those now found along the uppermost parts of their courses. The crest of the Santa Susana Mountains consists of remnants of this old surface, which is here named the Santa Susana erosion surface.

At the head of Rice Canyon, near the eastern end of the mountains at an altitude of 2,750 feet, a number of boulders of granitic rock rest on Modelo shale. These 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 much of its flood plain.

Santa Clara River Valley in this area and the valleys 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, there is a river terrace surface about five feet above the present river bed that has been cut into the old alluvium. 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 northwest part of the area, steep slopes are developed on shales and siltstones of the Modelo and Pico formations. Soil creep, slumping and landsliding are prevalent in these areas. Many of the hills in the vicinity of the Del Valle and Ramona Oil Fields have dip slopes which 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.

DESCRIPTIVE GEOLOGY

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 effort was made to map these rocks during field work for this report and statements made about 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 rocks in the mapped area are assigned to the Placerita formation (Miller, 1934) and consist of schist, gneiss, quartzite, and marble. This formation of altered sedimentary rocks has been intruded by the Rubio diorite 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. Areas of such mixed rocks have been mapped by previous workers (Miller, 1934) as the San Gabriel formation. 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, especially in the Grapevine Canyon area, dark-colored mylonite is common.

Plutonic igneous rocks that are probably much younger than the

Placerita formation and the Rubio diorite are intrusive into the older formations. These younger rocks are medium- to coarse-grained and range from granite to quartz diorite in composition.

An important member of the group of pre-Cretaceous crystalline rocks, but not present in the mapped area, is a large body of anorthosite and norite containing irregular magnetite-ilmenite bodies, which is present on the northeast side of the San Gabriel fault. The anorthosite-norite occurrence is unique, for at no other place in California does a similar body occur, except perhaps 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 their presence in a conglomerate is presumptive evidence of a San Gabriel Mountains provenance, even though by a circuitous and interrupted route.

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 (1900, pp. 56-57) remarked on the resemblance of these rocks to sandstones of the Sespe district now assigned to the Domengine stage, but apparently found no fossils.

The rocks consist chiefly of light-gray to medium-gray well-indurated fine- to medium-grained sandstone that weathers grayish orange, interbedded with medium-gray to dark-gray siltstone that weathers light brown to moderate brown, and grayish-orange-weathering light-gray conglomeratic sandstone. 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 lower Pliocene rocks. Neither the base nor the top of the Eocene sequence is exposed. Numerous wells in the vicinity of Newhall have penetrated Eocene rocks. One well, Continental Oil Company's Phillips No. 1, drilled about 6,500 feet through Eocene rocks (see cross section AB, plate II) before reaching crystalline rocks. Dips were mainly between 20 and 60 degrees in this well, but the possibility that reverse faults repeat parts of the succession makes an estimate of the thickness of the sequence risky.

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

FOSSILS

Fossils collected at the outcrops in Elsmere Canyon and from cores of two wells, Union Oil Company's Needham No. 3 well in sec. 12, T. 3 N., R. 16 W., and North Star Mining and Development Co. Shepard No. 1 well in sec. 1. T. 3N., R. 16 W., were identified by Ralph Stewart and are listed in table 1.

AGE AND CORRELATION

According to Stewart,[1] "The fauna is comparable to that of the Santiago formation of the Santa Ana Mountains (Woodring, W. P., and Popenoe, W. P., (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 SERIES(?)

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 (see plates II and III). In wells that have drilled through this sequence, it is found that the variegated beds directly overlie Eocene rocks. The continental beds 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. So far as the writer was able to determine, no good evidence of any interfingering between the variegated beds and the marine upper Miocene beds has ever been discovered.

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[1] personal communication

The sequence ranges in thickness from nearly 2,000 feet at the British American Oil Co. Edwina No. 1 well in sec. 11, T. 3 N., R. 16 W., to the vanishing point between the Tunnel area and Elsmere Canyon (see plate II).

In the past, the variegated beds have been correlated with the Mint Canyon formation of middle(?) and late Miocene age, but at least two considerations are opposed to this correlation. First, the apparent lack of interfingering with upper Miocene beds 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 blue-green montmorillonitic clay, is not like the lithology of the Mint Canyon formation. In addition, the Mint Canyon formation is exposed only north of the San Gabriel fault. Crowell (1952a, pp. 2026-2035) has advanced several arguments in favor of a post-Mohnian right-lateral displacement of from 15 to 25 miles on the San Gabriel fault. Under this hypothesis the main area of deposition of the Mint Canyon formation would have been many miles to the northwest of Newhall during middle Miocene time.

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 (plate I), a thickness of about 900 feet, consisting of cream-colored, tan, and brown thick-bedded fine- to medium-grained sandstone with occasional thin lenses of pebble and cobble conglomerate, lies beneath middle Miocene shale. Locally the upper part of the formation contains an amygdaloidal basalt flow. The Standard Oil Company of California Ward No. 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., drilled through 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

Distribution

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

Nomenclature

Hershey (1902, pp. 356-358) named the beds which include the Mint Canyon formation the "Mellenia Series." Since the term "Mellenia" is not a place name, Kew (1924, p. 52) designated these beds the Mint Canyon formation in recognition of their excellent development in the Mint Canyon region. Jahns (1939, p. 819) demonstrated that two formations rather than one are represented in this section. He suggested that the lower part be called the Tick Canyon formation, that the term Mint Canyon formation be retained for the upper beds, and that the section as a whole be referred to as the Mint Canyon series. Jahns' usage is adopted in this report.

General lithology

The lithologic character of the Mint Canyon formation has been discussed in detail by Kew (1924, pp. 52-53) and Jahns (1940, pp. 154-163). Jahns (1940, 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. The 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. Fine-grained units may grade laterally into coarser-grained beds; this, 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 most of them are only three or four feet thick.

Thickness

Jahns (1940, p. 162) ascribes an aggregate thickness of about 4,000 feet to the Mint Canyon formation in the Bouquet Canyon region. Oakeshott (1950, p. 53) reports 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 recovery of vertebrate remains from the Mint Canyon formation came as a result of reconnaissance mapping by Kew in 1919. Following the recovery of additional material, Maxson compared the fauna with those of other regions and, considering the position of the Mint Canyon formation unconforably below marine strata regarded by Woodring (1930, p. 155) as the approximate equivalent of the Cierbo formation of northern California, he concluded that the Mint Canyon beds were deposited during approximately the middle portion of the late Miocene (Maxson, 1950).

In a critical review of Maxson's work, Stirton (1933, pp. 569-576) differed with him on the identification of the mammalian forms and advocated an early Pliocene age for the fauna. Subsequent papers by deCharden 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. The basic problem in the assignment of an age to the Mint Canyon fauna is the one recognized by Reed and Hollister (1936, pp. 40, 43), namely, 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: (1) the occurrence of Hipparion in the Mint Canyon fauna, and (2) the occurrence of marine beds unconformably overlying the formation. The presence of Hipparion means an early Pliocene age to many vertebrate paleontologists. Stirton (1933) preferred to adhere to this concept while Maxson (1930) favored the extension of the genus range to the Miocene, largely on the basis of stratigraphic relationships of the Mint Canyon formation to the younger marine rocks.

Although Kew (1924, p. 52) recorded a marked unconformity between the marine and Mint Canyon beds in Haskell Canyon, Stirton (1933, pp. 569-576) and later Clements (1937, p. 215) indicated that the relationship was an interfingering or gradational one. Jahns (1939, p. 822) was able to demonstrate a distinct, though in places slight, angular discordance between the marine beds 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.

The examination of additional collections of invertebrates from the marine beds by Grant (Maxson, 1938a, pp. 1716-1717) permitted a more refined 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 beds to the Delmontian stage and followed the concept of the contemporanity of the marine and Mint Canyon beds. Later, M. N. Bramlette (in Daviess, 1942) examined foraminiferal collections from the lower part of the marine beds and considered the faunas to be of Mohnian 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) considers the Mint Canyon formation to be of late Miocene age, a designation consistent with the stratigraphic position of the formation in the marine sequence. In addition, he points out that faunal gradation within the formation indicates that the deposition took place over a considerable time interval.

The Mint Canyon formation unconformably overlies the Tick Canyon and older formations. Jahns (1940, pp. 174-175) regards the Tick Canyon formation as late lower Miocene or possibly earliest middle Miocene.

The Mint Canyon and Tick Canyon formations overlie with pronounced unconformity beds called the Escondido series by Hershey (1902, pp. 349-372), referred to the Sespe(?) formation by Kew (1924, pp. 349-372) and named Vasquez series by Sharp (1935, p. 314) since Hershey's term is preoccupied. The Vasquez series is of continental origin, is unfossiliferous, and has been tentatively referred to the Oligocene by Jahns

(1940, p. 170-171). The Mint Canyon formation is also found unconformably overlying Eocene sedimentary rocks and the crystalline basement complex, considered to be pre-Cretaceous.

Stratigraphy and lithology in the mapped area

The Mint Canyon formation crops out in the northeastern part of the mapped area. It is a predominantly fine-grained section consisting of greenish gray siltstone units with interstratified sandstone, conglomerate, and thin tuff beds, (Fig. 3). The formation had been compressed into a series of comparatively tight, nearly east-west trending folds. Resistant sandstone and conglomerate beds form prominent hills and ridges; less resistant siltstone units form a more subdued topography, including the hummocky landscape typical of landslide areas.

Greenish-gray siltstone units include beds of mudstone and clay and thin beds of sandstone and tuff. The siltstones commonly have sharp contacts with interstratified sandstones and conglomerates, although at some places the contacts are gradational. Bedding in the siltstones is generally indistinct or contorted owing 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 siltstones. 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, white to gray, and break with a blocky or conchoidal fracture. The tuffs are commonly finely laminated, cross stratified, and ripple marked.

Figure 3. Mint Canyon formation, exposed in road cut on U. S. Highway 6, showing lenticular beds of conglomerate and sandstone interbedded with siltstone.

Most of the sandstone beds are light tan or yellowish brown but some are greenish gray. They are arkosic, 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 sandstone 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:

Type	% by no.
Gneiss	58.5
Volcanics	34.8
Anorthosite (and related rocks)	3.0
Quartzite	1.4
Schist	0.2
Miscellaneous	2.1
	100.0

The igneous and metamorphic rock types are like those found in the adjacent mountainous regions. The volcanics are similar to flows in the Vasquez series east and northeast of the area.

A thickness of about 1,500 feet of the Mint Canyon formation is exposed in the mapped area. The base is not exposed.

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" described by Kew (1924, p. 52) in the upper part of the formation does not occur in significant amounts in the mapped area.

Environment

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. Concurrently with the development of the alluvial fans, there were fresh-water lakes in the area at various places and at different times. Thick sections of siltstone with interstratified mudstone, tuff, sandstone, and conglomerate are lake deposits. The presence of fresh-water mollusks and a turtle possibly related to Clemmys (Maxson, 1930, p. 82, 87), provides evidence favoring a lacustrine environment for the deposition of part of the formation. Maxson regarded the presence of 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 semi-arid region. The grazing types of mammals occupied grass covered plains, while Parahippus, peccaries, and possibly oredonts and mastodons also found in the formation frequented wooded areas along streams and lakes. Axelrod (1940, pp. 577-585) made a study of fossil plants that occur in the 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, a desert scrub from the drier slopes of the lower basin, an oak savanna from the area surrounding the general basin and probably also from the borders of the 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 thunder-showers and winter rains, and that temperatures were similar to those now prevailing in the region, with the exception that the winters were slightly warmer.

The source of a large part of the Mint Canyon sediments was to the east where rocks similar to the types represented as clasts in Mint Canyon conglomerates occur in the San Gabriel Mountains. The presence of anorthosite and related rocks as clasts in the Mint Canyon conglomerates is especially indicative of an easterly derivation for the sediments, for the only known source of anorthosite that could have contributed appreciably is in the San Gabriel Mountains. The presence in some of the conglomerates of schist and sandstone clasts similar to the Pelona schist and Eocene sandstones found in the mountainous region north of the Santa Clara River Valley indicated a northerly source for part of the formation as well.

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

MODELO 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 (Plate I), the Modelo rests unconformably on the Topanga(?) formation a short distance south of the mapped area in the Aliso Canyon oil field (White, 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 through the towns of Newhall and Saugus.

The Modelo formation, as used in this report, includes the rocks that Kew (1924) termed the shale member of the Modelo in the Santa Susana Mountains, but does not include Kew's upper sandstone member, which is here referred to the Towsley formation. In the subsurface throughout most of the region the Modelo cannot consistently be differentiated from the overlying Towsley formation, because of the lenticular nature of all the sandstone and conglomerate lenses in both formations.

Some geologists have applied the term "Monterey formation" to the Modelo formation in this area, and indeed to virtually all middle and upper Miocene shaly rocks in California. It is not within the scope of this report to enter into this controversy, since the Modelo formation was mapped only in part, and only in the Santa Susana Mountains.

In the subsurface section 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 maximum thickness is not known.

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 is exposed. At the base of the formation in Aliso Canyon, overlying the Topanga(?) formation, is 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 is 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, which is overlain by about 800 feet of pale yellowish-orange hard platy thinly laminated to thin-bedded cherty shale, organic clay shale and porcelaneous shale. The upper part of the formation, about 1500 feet thick near Rice Canyon, consists chiefly of softer fine-grained rocks. The siltstone, claystone and mudstone are laminated to thick-bedded, light brownish-gray or grayish-orange when fresh, and 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 that commonly weathers pale yellowish-orange and that are probably of concretionary origin are interstratified in the shale. Ellipsoidal limy concretions, some of which are more than 6 feet long, are scattered through the shale (fig. 4). At most places concretions are more or less aligned 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 in thickness from laminae to beds several feet thick. The sandstone beds are generally graded from coarse at the bottom to fine 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.

Figure 4. Modelo formation, exposed in road cut in Towsley Canyon. Note the large ellipsoidal limy concretion at the right.

In the vicinity of Rice Canyon a thickness of about 1,000 feet of beds is exposed below the Towsley formation. The lithology is similar to 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 are valves of small mud pectens. 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 in Aliso Canyon contains a foraminiferal fauna representative of the Luisian stage of Kleinpell (White, R. T., 1952). Foraminiferal faunas from several localities in the upper part of the Modelo 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.

UPPER MIOCENE AND LOWER PLIOCENE SERIES

TOWSLEY FORMATION

Distribution

Along the north slopes of the Santa Susana Mountains the fine-grained, more or less organic sediments of the Modelo formation are overlain by and interfinger with a sequence of light-colored sandstone and conglomerate and brown-weathering mudstone. This sequence of beds is here named the Towsley formation because of its good exposures in the vicinity of Towsley Canyon.

The lithology and thickness of the formation change markedly from place to place but the section exposed along the north limb of the Pico anticline at Towsley Canyon is a representative one.

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. The basal part of the formation where it rests unconformably on older rocks 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 may be traced in the subsurface section by electric log correlations. The distinctiveness of the formation decreases as correlations are extended farther and farther from the belt of outcrops owing to the presence of numerous lenticular units of sandstone within 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 is drawn at the base of the first unit of thick-bedded coarse-grained sandstone that lies above the shales of the Modelo. This contact is not everywhere at the same stratigraphic level. The base of the Towsley is at a much lower stratigraphic level on the south limb of the Oat Mountain syncline than it is one or two miles farther north on the north limb of the Pico anticline. The interfingering between the Towsley and Modelo is particularly abrupt in the vicinity of the headwaters of Rice Canyon. The stratigraphic level of the base of the Towsley formation in the upper reaches of Rice Canyon is more than 1,500 feet below the horizon of the base of the Towsley on the north limb on the Pico anticline one and one-half miles farther north. Likewise, in the area between Little Moore and Pico Canyons, along the Pico anticline, the base of the Towsley formation shifts to lower and lower 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 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. A few of the uppermost beds of the Towsley were included by Kew in the overlying Pico formation. In the eastern part of the area, near Elsmere Canyon, Kew included most of the Towsley in the Pico formation, but assigned some of the higher beds to the Saugus formation.

Oakeshott (1950) assigned the beds of the Towsley formation in the eastern part of the area to the Repetto formation, and distinguished two members: the basal Elsmere member, which includes all the lower Pliocene beds 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 formation, and termed the lower parts of the sequence, corresponding to the Towsley formation, Repetto and Repetto equivalent.

Because the type locality of the Repetto formation is in Los Angeles Basin, which was not connected with Ventura Basin during Pliocene times, and because the Towsley formation does not resemble the type Repetto formation lithologically, the term "Repetto" is not adopted in this report. The tendency to use formational names in a time-stratigraphic sense leads more to confusion than to convenience.

In the Santa Susana Mountains, local geologists have used various names for the Towsley formation, including "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.

Stratigraphy and lithology

Santa Susana Mountains

Relation to Modelo--

The Towsley formation is exposed along a continuous belt of outcrops extending along the north slope of the Santa Susana Mountains to the western 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 formation at various places is shown in the columnar sections in Plate VIII. The dashed lines between the columns indicate correlations based on the tracing of mappable units in the field. Cross sections CD (Plate III), EF (Plate IV), and GH (Plate V) also show the stratigraphic relations of the Towsley in the Santa Susana Mountains area.

Fine-grained sediments--

The lenticular units of sandstone and conglomerate mapped in the Towsley formation alternate with units of brown-weathering mudstone, siltstone and shale. The mapped units in turn include many individual beds of different lithology, too thin or too local to show on the geologic map. 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 combine to 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 sparingly in the mudstone. The concretions are generally aligned along definite horizons rather than scattered at random. 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 four feet long.

Occasional beds of hard fine-grained gray limestone that weathers yellowish-gray are intercalated in the mudstone. The beds, some of which can be traced for several hundred yards, are as much as 18 inches thick but any one bed is generally variable in thickness. In some places the limestone beds contain foraminifers. Because of their similarity to the ellipsoidal concretions the 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% by weight, but this low percentage of clay may reflect incomplete dispersion of the samples rather than a real scarcity of material in this class. Fine-grained sand was present in all samples analyzed and many hand specimens contain angular, very coarse sand grains scattered in a muddy matrix. The lack of clear bedding and the poor sorting may be due to the activity of burrowing and mud-eating organisms.

Fossils are scarce in the mudstone. Foraminiferal faunas obtained were small, except for a few samples 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 indications of sulphurous bottom waters. However, the occurrence of benthonic foraminifers in some of the limy concretions indicates that living conditions were suitable at least some of the time. The fact that beds containing foraminifers within concretions are generally not only barren outside the concretions but closely similar in appearance with most other barren mudstone beds suggests that foraminifers 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. Fish bones and scales are abundant, and well preserved mud pectens (Delectopecten sp.) are common in these laminae.

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 units of sandstone and conglomerate contain large concretions such as those shown in figure 5. Bedding planes pass through the concretions without interruption.

Individual beds within these mappable units range in thickness from thin laminae to beds at least five 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 hundreds of 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 is represented by coarse-grained sandstone.

The clasts of pebble or larger size in the conglomerate consist of a great variety of rock types. At most places gneiss and leucocratic plutonic igneous rocks constitute about 80 per cent. Dark-colored volcanic rocks, chiefly andesite but representing a wide range in composition, generally make up about 15 per cent, and a host of other rock

Figure 5. Concretionary sandstone in the Towsley formation, exposed near the crest of the Santa Susana Mountains.

types including quartzite, vein quartz, chert, aplite, gabbro, norite, and anorthosite constitute the remainder.

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 eastermost outcrops of the Towsley formation. Gneiss and granitic rocks are exposed over extensive areas in both the San Gabriel Mountains and in the Transverse Ranges north of the eastern Ventura Basin. Flows and sills of andesite similar to the clasts in the conglomerates of the Towsley formation crop out in the Vasquez formation about 12 miles northeast of Newhall (Kew, 1924, p. 39). Many of the clasts in the Towsley 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, pp. 51-53).

Boulders larger than one foot in diameter are not common. Some lenses, for example the basal portion of the conglomeratic unit cropping out at the narrows in Towsley Canyon, do contain many boulders greater than one foot in diameter. On the divide between Rice and Towsley Canyons on the south limb of the Oat Mountain syncline a bed containing many three-foot boulders crops out near the base of the formation. Nearly all boulders consist of gneiss or light-colored plutonic igneous rock. Beds of cobble conglomerate occur throughout the extent of the Towsley formation in the Santa Susana Mountains, but occurrences of beds containing boulders are confined chiefly to the area between the Pico Canyon area and Wiley Canyon 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, suggesting 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 Towsley where it rests unconformably on older rocks in the vicinity of Elsmere Canyon, nearly all sandstone beds and most conglomerate beds are graded. Generally the grading is conspicuous. The contrast between average grain size at the base and at the top of most beds is marked. In some beds the grading is obscure. Some beds of sandstone have a nearly uniform grain-size distribution through more than 90 per cent of their thickness, but show distinct grading in the uppermost parts. Other beds that were thought to be ungraded when examined in the field were found to be graded when a sequence of samples from a single bed were analyzed for grain size distribution in the laboratory. There are sandstone beds that are not graded but these beds are generally thin and contain evidence that re-working may have destroyed any original grading.

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

The contact with the overlying bed is 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 for channeling of the claystone can be detected. In a few places 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 the 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.

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 one 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 Shepherd (1951, pp. 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 is given on pages 94-115.

San Fernando Pass and Elsmere Canyon area

Strata assigned to the Towsley formation in the region around San Fernando Pass and Elsmere Canyon, southeast of Newhall, include beds deposited in shallower depths than those that prevailed in the Santa Susana Mountains region. The formation thins eastward and northeastward, owing partly to 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 in the vicinity of 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 one or two feet. Viewed more broadly the contact is very even. The evenly sloping surface to the right of the canyon in figure 6 is capped by a thin veneer of strata near the steep wall of the canyon. Higher portions of the slope have been stripped of the thin sedimentary cover to reveal the pre-Towsley erosion surface.

At most places the basal bed of the Towsley 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 7 shows the basal part of the Towsley formation where it rests on quartz diorite basement on the divide between Elsmere and Whitney Canyons. The lowest part of the Towsley consists here 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 and as much as 10 feet thick. They 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) are particularly abundant in the lenses.

In Elsmere Canyon the lower conglomeratic beds are overlain by a sequence of fossiliferous beds of moderately-indurated poorly-bedded

Figure 6. Towsley formation in Elsmere Canyon.

Figure 7. Base of the Towsley formation between Elsmere and Whitney Canyons. Note the large angular blocks of quartz diorite and the rounded clasts between blocks.

sandstone, siltstone, mudstone, and occasional thin lenses of conglomerate. These beds are shown in figure 6. They occupy the interval from the bottom of the canyon to nearly the top of the first line of steep bluffs on the left (west) side of the canyon. The beds of sandstone commonly contain many concretions that are especially fossiliferous. The sequence is about 150 feet thick where it is exposed east of the Whitney Canyon fault in Elsmere Canyon. The beds are tar-stained in Elsmere Canyon and have been productive in wells in the Elsmere area, the Tunnel area, the Whitney Canyon area, and the Placerita field. In the Placerita field the beds are known as the lower Kraft zone. Oil issues from many seeps in this sequence of beds in Elsmere Canyon.

The tar-stained beds grade upward into moderate to dark yellowish brown massive sandy siltstone. The brushy gentle slope above the prominent line of bluffs in figure 6 is developed on this 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. Willis (1952, pp. 38, 39) correlates these beds with the so-called lower Kraft shale in the Placerita oil field. An unconformity at the base of the overlying Pico formation truncates these beds so that their true 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 in the Santa Susana Mountains. The beds are graded and exhibit such features as load casts. 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 of beds older than those resting on the crystalline rocks at the outcrops in Elsmere and Grapevine Canyons. The numerous faults in the vicinity of San Fernando Pass make correlations uncertain.

In the area where the axis of the Weldon syncline crosses U. S. Highway 6 the siltstones in the upper part of the Towsley grade northwestward in a very short distance into cross-stratified conglomerate and sandstone that is assigned to the Pico formation. The cross-stratification is very well developed in the vicinity of the San Fernando Pass (see fig. 8).

North of the San Gabriel fault

Beds assigned to the Towsley formation crop out north of the San Gabriel fault in sec. 20, T. 4 N., R. 15 W., and in sec. 32, T. 3 N. R. 15 W. The correlation of these beds with the Towsley south of the fault is based on lithologic similarity to the beds in Elsmere Canyon and on stratigraphic position. 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 sparsely fossiliferous light olive gray silty sandstone and sandy siltstone. Near the base of the formation are beds of light-colored fossiliferous pebbly sandstone.

In section 20 about 700 feet of Towsley strata are exposed, and a short distance beyond the eastern border of the geologic map in section 32 the formation is about 300 feet thick.

Subsurface development

The Towsley formation loses its identity as it is traced northward from the Santa Susana Mountains in the subsurface. Numerous lenses of sandstone and conglomerate occur in the Modelo formation as well as in the Towsley, so that the fine-grained rocks in the lower part of the Towsley are not distinguishable from the Modelo shale and the two formations cannot be separated on the basis of available information. Successful electric log correlations can be made in the areas where wells are fairly close together, but long-distance correlations are made by means of foraminifers. Owing to 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. Different species are used as index fossils for the same time-stratigraphic unit by different paleontologists. For example, the discrepancy between the position assigned to the top of the Miocene by different paleontologists is as much as 1,000 feet in some wells. The correlations shown in the structure sections (Plates II to VIII) are therefore subject to the errors inherent in adjusting conflicting views.

Fossils

Santa Susana Mountains

Foraminifers are relatively scarce in the Towsley formation in the Santa Susana Mountains. 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 ever found in the pelitic rocks of the Towsley 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. Material from only two localities has been identified. The species are listed on Table 3. Locality F 17 is outside the area shown on the geologic map, but is near the top of the Towsley along the line of the measured stratigraphic section between Tapo and Salt Canyons. The stratigraphic position of this collection is shown on Plate VIII.

The fossils at locality F 17 occur in several graded beds of pebbly sandstone interbedded with conglomerate.

"*Nassa*" *hamlini* Arnold, *Fulgoraria oregonensis* (Dall), *Glyptostoma* cf. *G. gabrielense* Pilsbry, *Nuculana*? cf. *N. hamata* (Carpenter), *Yoldia beringiana* (Dall), *Cyclocardia* aff *S. barbarensis* (Stearns), and *Calyptogena lasia* (Woodring) have not been reported previously from the Ventura Basin.

Elsmere Canyon region

The fauna of the Towsley from the vicinity of Elsmere Canyon has been described or listed by a number of workers, such as Gabb (1869, p. 49), Ashley (1896, p. 337), Watts (1900, p. 56), Eldridge and Arnold (1907, p. 25), English (1914, pp. 203-218), Kew (1924, pp. 77-80), and Grant and Gale (1931).

No attempt was made to collect new material from the area during the course of the field work for this report. Fossils are most abundant in the lowest part of the formation, especially in concretions. The preservation of the material in many places is excellent, owing to the tar that impregnates the rocks. Paired pelecypod valves are very common at most localities, suggesting that the shells 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, F 18 and F 19, in the Towsley formation in sec. 20, T. 4 N., R. 15 W. The species are listed on Table 4. *Norrisia norrisi* (Sowerby)?, "*Drillia*" cf. *D. graciosana* Arnold, and *Eucrassatella* aff. *E. fluctuata* (Carpenter) heretofore have not been recorded from the Ventura Basin.

Kew (1924, loc. 3591) gives a list of species collected from the Towsley in section 32, T. 4 N., R. 15 W., including *Chione fernandoensis* English, *Phacoides annulatus* Reeve [= *Lucinoma annulata* (Reeve), *Phacoides nutalli* Conrad (= *Lucinisca nuttali* (Conrad)], *Phacoides sanctaecrucis*

Arnold? (= ?*Miltha xantusi* Dall), *Tellina idae* Dall?, *Actaeon* (*Rectaxis*) cf. *A. punctocoelata* Carpenter, *Cancellaria elsmerensis* English, *Cancellaria fernandoensis* Arnold (=?"*Cancellaria*"*tritonidea* var. *fernandoensis* Arnold), *Cancellaria tritonidea* Gabb, *Columbella* (*Astyris*) cf. *C. tuberosa* Carpenter (= *Mitrella* cf. *M. tuberosa* (Carpenter)], *Mitra tristis* Swainson, *Nassa californiana* Conrad (=?"*Nassas*" *moraniana* Martin), *Natica recluziana* Petit (= *Neverita recluziana* (Deshayes)], *Terebra simplex* Cooper (=? *Strioterebrum pedroanum* Dall), *Trophosycon nodiferum* (Gabb) (=? *Trophosycon ocoyana* var. *ruginodosa* Grant and Gale), *Turris* (*Bathytonia*) *cooperi* Arnold, (*Megasurcula cooperi* (Arnold)], and *Turritella cooperi* Carpenter.

About one mile east of the eastern border of the area shown on the geologic map (Plate I), 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* var. Conrad from beds of similar lithology to those in section 32.

Environment suggested by the fossils

Attempts to define the environments that were occupied by fossil assemblages involve the assumption that the ecologic requirements of a species were nearly the same in the past as they are for living representatives of the same species today, or that living close relatives of extinct species have habitats similar to those of their dead cousins. 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 are not entirely valid is shown by many California late Tertiary assemblages in which there is 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 waters in northern regions are found only in deeper water in more southerly regions, owing, apparently, to the temperature requirements of the animals. The occurrence of shallow water fossils in coarse-grained rocks has led some workers to conclude, sometimes falsely, 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 allowed for, some fossil faunas still show a residue of anomalous associations of species. The only safe procedure is to base inferences about past environments on the community rather than on some selected individual species.

Depth of water

Santa Susana Mountains--

The fauna from locality F 17 contains a mixture of species whose modern representatives live in different depth zones. On Table 4 the bathymetric distribution of the Recent forms is shown. The data for both the bathymetric and geographic distribution were taken mainly from the minutes of the Southern California Conchological Club, edited by John Q. Burch, from Oldroyd (1924, 1927), from Woodring (1938; Woodring, Stewart, and Richards, 1940; Woodring, Bramlette, and Kew, 1946; Woodring and Bramlette, 1950), and from Grant and Gale (1931).

Deep water (more than 100 fathoms)
- Elaeocyma aff. E. empyrosia
- Yoldia aff. Y. beringiana
- Calyptogena lasia

Moderate depth (10-100 fathoms) but ranging into deep water
- Solariella off. S. peramabilis
- Cryptonatica aleutica
- Fusitriton oregonensis
- Barbarofusus aff. B. arnoldi
- Nuculana cf. N. hamata
- Cyclocardia aff. C. barbarensis

Moderate depth (10-100 fathoms)
- Turritella cooperi
- Kelletia cf. K. kelletii

Shallow depth (less than 10 fathoms) but ranging into moderate depth
- Tegula ligulata
- Crepidula cf. C. onyx
- Neverita reclusiana
- Aletes squamigerus
- Sacella taphria
- Aequipecten circularis
- Lucina excavata
- Lucinisca nuttallii
- Lucinoma cf. L. annulata
- Tellina idae
- Schizothaerus nuttallii
- Corbula luteola

<u>Shallow depth</u> (less than 10 fathoms)

Ostrea vespertina
Spisula hemphilli
Amiantis callosa

<u>Terrestrial</u>

Glyptostoma cf. G. gabrielense

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. Some other species, however, are also represented by a few incomplete or worn specimens.

The fauna is obviously a death assemblage; the occurrence 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 in excess of 100 fathoms.

The modern representatives of the assemblage at locality F 16 live in shallow water and in moderate depths.

Foraminiferal faunas from the Towsley formation of the Santa Susana Mountains contain such species as <u>Bulimina rostrata</u> and <u>Gyroidina rotundinargo</u>, suggesting water depths of perhaps 3,000 feet. Forms such as <u>Robulus cushmani</u> are known from Recent collections from depths as shallow as 100 feet, while <u>Bulimina rostrata</u> ranges downward to 11,000 feet. The depth of about 2,000 feet would seem to be near a middle point for the depth range of the part of the foraminiferal fauna having living close relatives.

<u>Elsmere Canyon</u>--

The modern representatives and relatives of the Towsley fauna in the vicinity of Elsmere Canyon live in shallow water or range from shallow water into 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 indeed 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 at Elsmere Canyon (locality F 36) is difficult to evaluate bathymetrically. Depth ranges of some of the species in that fauna having close allies 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 F 36 is little more than 150 feet above the base of the formation.

North of San Gabriel fault--

The fauna at locality F 18, near the base of the formation, consists of moderate-depth species such as *Terebratalia occidentalis*, *Calyptraea* cf. *C. fastigiata*, *Turritella cooperi*, *Chlamys islandicus* var. *hindsii*, and *Eucrassatella* aff. *E. fluctuata*; species that range from shallow water to moderate depths such as *Acmaea*? cf. *A. mitra*, *Olivella pedroana*, *Aequipecten circularis*, and *Trachycardium* cf. *T. quadragenarium*, and shallow-water species such as *Panope* cf. *P. generosa*.

At locality F 19, several hundred feet stratigraphically above locality F 18, no strictly shallow water species occur. Species that range from shallow water into moderate depths include Crucibulum cf. C. spinosum, Neverita reclusiana, Mitrella cf. M. tuberosa, Olivella pedroana, and Saccella taphria. Two species, Boreotrophon cf. B. stuarti and Compsomyax? cf. C. subdiaphana range from moderate depths into deep water. It is inferred that deposition was in slightly deeper water than at locality F 18.

Foraminiferal faunas from north of the San Gabriel fault (localities f 37 to f 40) close to locality F 18 are dominated by species whose Recent relatives can nearly all be found at depths of from 500 to 1,000 feet. Some species, e.g., Buliminella elegantissima range into quite shallow water, while several others range down to more than 3,000 feet.

Temperature of water

The geographic ranges of the Recent close relatives of the Towsley fossils provide a basis for inferences about Towsley environments. Table 5 shows the geographic affinities of Towsley fossils having living close relatives.

The southern affinities of the shallow-water species are further emphasized by the fact that the modern relatives of all Towsley species that are confined strictly to a very shallow-water habitat range at least as far south as Todos Santos Bay, Baja California. It is inferred that temperatures in shallow water during deposition of the Towsley were probably several degrees warmer than they are at Ventura. Mya truncata, which occurs in the shallow-water assemblage at Elsmere

Canyon, and also at a number of other shallow-water Pliocene localities in California, does not range south of Puget Sound today. Even though the modern species may range into moderate depths, the California Pliocene occurrences cannot be explained by southward migrations in deeper water. The anomalous occurrence of this circumboreal species in a "Southern" fauna may be similar to 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 be eliminated. The modern representatives of the species may occupy a narrow ecologic niche greatly different from those occupied by some of the fossil members.

PLIOCENE SERIES

PICO FORMATION

Throughout most of the eastern Ventura Basin the Towsley formation is overlain by the marine Pico formation. The Pico consists chiefly of light olive-gray and medium bluish-gray siltstone and fine-grained silty sandstone, containing small reddish-brown concretions, and generally 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 eastern part of the area the converse is true; there the formation consists largely of sandstone and conglomerate.

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

The Pico formation is entirely marine, but interfingers at the top with normal marine, brackish water, lagoonal, and non-marine beds belonging to the Sunshine Ranch member of the Saugus formation.

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 soft, generally poorly bedded, light olive-gray siltstone. The broad lowland containing the Newhall-Potrero oil field is developed on this soft siltstone.

The siltstone generally contains numerous more or less ellipsoidal concretions, commonly about 1 inch in diameter but ranging to 6 inches. 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 late Pliocene and early Pleistocene age, in the Ventura region. In well cores the concretions in the Santa Barbara formation contain ankerite (Bailey, T. L., 1935, p. 492). Weathered slopes developed on the Pico siltstones are commonly strewn with concretions.

The siltstone commonly contains foraminifers, 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_, _Macoma_, and _Spisula_ and other poorly preserved mollusks as well as echinoid spines and external molds of echinoids are scattered sparingly in the siltstone.

Interbedded with the siltstone are layers a few inches thick composed of pale-olive fine-grained silty sandstone that weathers to dark yellowish orange. In the lower part of the formation many of the sandstone beds are graded, and closely resemble the graded beds in the Towsley. In the upper part of the formation the beds of sandstone are commonly not perceptibly 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 moderate brown alternate with units of siltstone. The brown-weathering jarositic mudstone is indistinguishable from the mudstone in the upper portion of the Towsley formation (see p. 35) 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. The coarse-grained lenses tend to produce bold topographic forms. Some of the lenses 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 grade 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 shallow channels are cut into the underlying beds at many places. Sets of small-scale cross laminae, so common in the Towsley formation, occur only in the lower beds in the Pico.

Slump structures occur at a few places in the sandstone beds, but convolute bedding is not known. Beds containing small angular bits of charcoal-like material are common, especially in the lower part of the formation. Mollusks occur at many places in the sandstone and conglomerate beds, but the shells are generally concentrated in very local lenses and pods. Paired pelecypod valves do not occur at these localities and many of the shells are broken or worn.

Pebble counts made at several places in the Pico formation in this area showed that the Pico conglomerates very closely resemble the Towsley conglomerates with respect to kinds of clasts and to their relative abundance (see p. 38).

In the highest parts of the Pico the soft olive-gray 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*, *Pecten 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.

Area between Newhall-Potrero and East Canyon

Eastward from the southeastern part of the Newhall-Potrero oil field the siltstone in the upper part of the Pico formation grades laterally into marine sandstone and conglomerate which in turn grades into brackish water and non-marine beds of the Sunshine Ranch member of the Saugus formation. The contact between the two formations occurs at lower and lower stratigraphic levels as the beds are traced eastward. Near the southeastern end of the Newhall-Potrero oil field the Pico is about 5,300 feet thick; 4 miles farther southeast it is only about 2,000 feet thick. The decrease in the thickness results wholly from lateral gradation in the upper part of the formation.

Several persistent units of conglomerate and sandstone that occur in the middle of the Pico formation near the oil field can be traced eastward into the Sunshine Ranch member. The mapping of these persistent units shows that the thickness of the part of the formation below the key beds actually increases eastward.

The most abrupt lateral gradation from siltstone to conglomerate and sandstone 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 exposures are good enough in the transition zone so that the possibility of major faulting can be ruled out. Many of the sandstone and conglomerate beds in the transition zone are graded. Figure 8 shows thick beds of conglomerate and sandstone alternating with thinner beds of dark-colored siltstone and fine-grained sandstone exposed near the east edge of Newhall-Potrero oil field. Near the right edge of the figure a thick bed of conglomerate rests on an eroded surface; beds beneath the conglomerate are cut out to depths of at least 4 feet. 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. The sandstone beds in the center of the figure show marked changes of thickness, a very characteristic feature of the beds in this area. In the upper left part of the figure slump structures are well developed. As the conglomeratic beds in the transition zone are traced eastward, the graded bedding becomes more obscure and in a distance of about half a mile the beds show no

Figure ~~9~~ 8. Cross-stratified sandstone and conglomerate of the Pico formation in San Fernando Pass.

grading and are more conglomeratic. Scattered fragments of marine mollusks occur in the sandstone and conglomerate beds near the transition zone, but farther east fossils are lacking.

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

Area between mouth of East Canyon and San Fernando Pass

Beginning at a point near the mouth of East Canyon, numerous 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. As the formation is traced eastward the large-scale cross-stratification appears in units progressively lower in the formation. At San Fernando Pass even the lowest part of the formation consists of large-scale sets of cross-strata (see fig. 9).

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

Figure ~~8~~ 9. Graded beds and slump structures in the Pico formation at the southeast end of Newhall Potrero.

eastward 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 southeastern corner of the area shown on the geologic map (Plate I), the Pico formation is represented by nearly white, very thick-bedded conglomeratic sandstone and minor amounts of gray siltstone. Several 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.

Area between San Fernando Pass and San Gabriel fault

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

In 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 formation consists chiefly of lenses of brownish 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 Placerita Canyon east of Placerita oil field.

Area between the Santa Clara River and Del Valle fault

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

A thickness of about 6,000 feet of the Pico is exposed in the south-dipping homocline on the southern 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 consist of brown-weathering jarositic mudstone beds alternating with light-brown hard thick-bedded conglomeratic sandstone, thin-bedded light-brown and cream-colored 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 in the formation steadily decreases to the vanishing point and the proportion of olive-gray siltstone increases. 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 beds. 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. Throughout the formation the siltstone is foraminiferal and contains scattered, generally poorly preserved mollusks and echinoids. Paired pelecypod valves are very common in the siltstone.

The section exposed on the limbs of the Santa Clara syncline does not extend to the top of the Pico, although the conglomerate in the trough of the syncline near the county line is believed to be not far from the top of the formation.

Area between Del Valle and Holser faults

The base of the Pico is not exposed in the hanging wall block of the Holser fault, though the beds exposed immediately south of the trace of the 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. It is believed that these beds are within 1,000 feet of the base of the formation. In the area of the Ramona oil field the lower 2,000 feet of beds lying above the trace of the Holser fault consist chiefly of olive-gray siltstone with occasional lenticular units of sandstone and conglomeratic sandstone. Units of brown-weathering mudstone also occur in the lower half of this interval. Lying above the siltstone in the area near the county line is a sequence of nearly white very thick-bedded sandstone and minor lenses of conglomerate.

As the Pico formation is traced eastward from the county line, tongues of sandstone appear in it at progressively lower stratigraphic levels and thicken and coarsen eastward. Beginning at about the east line of sec. 17, T. 4 N., R. 17 W., mollusks occur in abundance in many of the silty intervals 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 into the Holser fault. An oyster reef cropping out about 200 feet east of the Texas Company's Malis No. 1 well in sec. 10, T. 4 N., R. 17 W., has yielded a few horse teeth (Locality V 84) that Chester Stock identified as Pliohippus.[2] East of San Martinez Chiquito Canyon the siltstone beds are greenish-gray rather than the typical olive gray of the Pico. Beds of reddish-brown sandy claystone are intercalated with the greenish siltstone beds and oyster reefs. Some of the sandstone beds contain numerous sand dollars. Although it is recognized that the red beds may represent non-marine deposits, and that the beds east of San Martinez Chiquito 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 all the beds below the uppermost echinoid-bearing beds in the Pico formation.

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[2] The teeth were collected by W. H. Corey of the Continental Oil Company, Los Angeles, California, who has a locality map with identifications of a number of vertebrate remains in the region in Stock's handwriting.

Area north of Holser fault

North of the Holser fault near the head of Holser Canyon the Pico formation consists of fine- to medium-grained light-tan sandstone and gray siltstone, with a minor amount of conglomerate. The sandstone is, for the most part, well-bedded with individual beds a few inches to several tens of feet thick. The siltstone contains thin hard limy beds and both siltstone and hard limy beds contain abundant marine fossils on the north side of Holser Canyon near its head. Fossils are also present, but not abundant, in the sandstone.

Fossils and environment suggested by the 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 IX shows four such sections in columnar form. The numbers beside the columns indicate the positions of the samples. The fauna from each sample is shown in the check lists on Plates X and XI. The locations of the sections are shown on the geologic map (Plate I). Numbers on the map at the ends of the various traverse legs correspond to the numbers on the columnar sections. 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 relatively fresh rock was not at or near the surface, holes were dug with a hand auger to obtain more or less unweathered material.

On Plates X and XI are checklists of 102 species from 343 localities. Nearly all of the Pico Canyon faunas were picked by Thomas Fahy. Identifications were made by Patsy Beckstead Smith, on both picked and unpicked material. The unpicked samples were examined and all specimens counted, without picking. Where foraminifers were especially abundant, samples were split by hand, all species counted, and the totals were multiplied by the number of splits. Fine distinctions between species were not attempted.

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 through nearly the entire section. Gyroidina rotundimargo is not present above sample 66. Nonion pompiliodes, not present in the lower part of the section, comes in at sample 59, and is present until sample 153. Cassidulina limbata has its lowest occurrence at sample 98 and continues to nearly the top of the section. Gaudryina arenaria comes in abundantly at about sample 97. Angulogerina angulosa begins its abundant occurrences at sample 120 and continues to the top. Cassidulina californica has its base at sample 139.

The succession in the Towsley Canyon section seems to be a rather compressed version of the Pico Canyon succession. Samples below no. 16 were nearly all barren. The base of the Pico formation is at about sample 14. 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 32, and Bolivina argentea ranges from samples 29 through 35. 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 16, contains a rather meager fauna, consisting chiefly of Epistominella pacifica, E. subperuviana, and Uvigerina peregrina. The fauna resembles that in the Gavin Canyon section.

The sequence of faunas in the Pico Canyon foraminiferal section presents a sketchy picture of gradual shallowing of the water during deposition of the Pico formation. However, this is not nearly as orderly a picture as that presented for the western part of the Ventura Basin (Natland, M. L., 1933, p. 225-230; Natland and Kuenen, Ph. H., 1951, p. 76-107; Bandy, O. L., 1953b, p. 200-203).

On Plate X is plotted the checklist for the Pico Canyon section. Assuming that the climate (and water temperature) during early Pliocene time was much the same as now (Axelrod: in Natland and Kuenen, 1951, p. 84), the attempt is made to reconstruct temperature and depth of deposition of the Pico by comparing species present with Recent forms of the same species off the coast of California.

This temperature and depth information for Recent species is compiled from Natland (1933), Crouch (1952), Butcher (1951), and Bandy (1953a). This information is given in column C on Plates X and XI. 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 between empty tests and live foraminifers from the various depth and temperature regions was made in any of the above studies. 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 optimum depth range for that species off San Diego. This range is confined to the top of the total depth range of tests collected.

The maximum and minimum ranges are plotted on diagrams D and E, Plates X and XI, 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 present ocean are reported to be 6,500 feet. In my Pliocene collections they occur abundantly from sample 59 to sample 147 of the Pico Canyon section, with 18 other species whose common depth is around 3,000 feet.

The association of these two deep-water forms with such forms as *Cassidulina limbata*, *Bulimina denudata*, *Gaudryina arenaria*, and *Cassidulina quadrata* is very puzzling. It is possible that the shallow-water forms are not indigenous, but were transported into deep water by sliding or turbidity currents. However, the rocks from which the faunas were collected are massive siltstones which give no evidence of any turbidity currents although the siltstone does interfinger eastward with coarse deposits believed to have been laid down by turbidity currents and submarine slides. Strengthening the view that at least part of the Pico Canyon section was deposited in shallow water is the fact that a few paired valves of *Schizothaerus*, a shallow- to moderate-depth pelecypod, were found in the upper part of the section, in geographic and stratigraphic positions close to the two "deep-water" species of foraminifers. It is unlikely that the deep-water forms are reworked, as the source of the Pico sediments lay generally to the east of the Pico Canyon section, and in that region there is no other evidence for erosion during the time of deposition of the Pico of deposits which would contain these two deep-water species. It seems more likely that *Nonion pompilioides* and *Pullenia bulloides* ranged into shallow water during the Pliocene.

Ignoring the few aberrant species a rather clear range of probable depth and temperature of deposition of the Pico Canyon section emerges. The water shallowed from a depth of 2,000-3,000 feet at the base of the section to a depth of 600-1, 600 feet at the top.

In the Towsley Canyon section the possible depth and temperature range is much greater than in the Pico Canyon section, although it is probable from its geographic position that the water was shallower.

In the Gavin Canyon section the water was probably never much deeper than 1,500 feet, and may have been considerably shallower. It, too, shows evidence of shallowing and of increasing temperatures toward the top of the Pico.

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

West and north of the previous four sections is the Holser-Del Valle section, which like the Towsley Canyon Section, shows ranges in depth and temperature that are wide and indefinite.

On Plate IX lines are drawn between the four columnar sections connecting the highest or lowest occurrences of certain species. Zones based on the dominance of several species can be correlated from one section to another; the boundaries of such zones are essentially parallel to the faunal lines shown on the chart. The columns are arranged with the highest occurrence of Cassidulina cushmani as a horizontal base line. Recent representatives of this species do not inhabit waters warmer than about $10^{\circ}C$. This corresponds to a depth of around 500 feet off the coast of southern California. The heavy dashed lines represent key conglomerate and sandstone beds that can be traced from one section to another. The crossing of faunal lines and key beds between the Towsley Canyon section and the Pico Canyon section 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. In view of the faunal evidence for a submarine slope, it is not surprising that most of the sandstone and conglomerate beds in the lower part of the Pico Canyon section and in areas farther west are graded. The primary requisite for the initiation of a turbidity current--an appreciable submarine slope-- is satisfied.

Megafossils

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

Several very rich faunas were collected from lenticular beds of sandstone and conglomerate in the lower part of the formation north of the Santa Clara River. These collections (localities F41-F48, F50, F51, F59, F60) come from graded beds, or beds intimately associated with graded beds; it is believed the faunas were transported to their place of final deposition by turbidity currents or submarine slides. The checklist (table 4) shows the species occurring 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, judging from the distribution of shell fragments along the stream, it is thought that the material comes from a horizon no lower than locality F 46.

The following species from these localities 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), Progabbia cf. P. cooperi (Gabb), Mangelia aff. M. variegata Carpenter, Melampus cf. M. olivaceus Carpenter, Nuculana cf. N. extenuata (Dall), Saccella cellulita (Dall), Pachydesma crassatelloides (Conrad), Macrocallista cf. M. squalida (Sowerby), and 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 the West Coast Tertiary.

The uppermost few hundred feet of the Pico are very fossiliferous at most places. Because of the interfingering relationships between the Pico and the Sunshine Ranch, member of the Saugus formation, this fossiliferous "zone," which Gale (Grant, U. S., and Gale, H. R., 1931) termed the middle Pliocene San Diego zone, is not of the same age everywhere. Collections were made from this "zone" near San Fernando Pass (locality F76) and near the mouth of Towsley Canyon (localities F77-f81).

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

Laevicardium cf. L. substriatum (Conrad), from locality F80, had not previously been reported from the Ventura Basin.

Some of the collections from the lower part of the Pico are from localities where there is field evidence to suggest deposition by turbidity currents and these collections contain a mixture of species indicative of various depth zones (shallow, less than 10 fathoms; moderate, 10 to 100 fathoms; deep, more than 100 fathoms). 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 various depth zones are:

Locality F42 - *Tegula gallina*? and *Ostrea* sp. indicate shallow water. *Cyclocardia* aff. *C. barbarensis* suggests moderate to deep water. The rest of the species live in moderate depths or range from shallow water into moderate depths.

Locality F43 - *Melampus olivaceous* lives above high tide line around shallow bays and mud flats; *Pachydesma crassatelloides*, the Pismo clam, lives in surf. Several species live in shallow water or range from shallow to moderate depths: *Tegula* cf. *T. ligulata*, *Crepidula* cf. *C. onyx*, *Olivella* cf. *O. pedroana*, *Conus californicus*, *Ostrea vespertina*, *Schizothaerus*? sp., *Dosinia* aff. *D. ponderosa*, *Amiantis* cf. *A. callosa*, *Protothaca* cf. *P. staminea*. Most species suggest moderate depths. Moderate depths to deep water are suggested by *Fusitriton* aff.

_F_. _oregonensis_, and deep water by _Yoldia_ aff. _Y_ _beringiana_ and _Nuculana_ cf. N. _leoniana_.

Locality F44 - _Glyptostoma_ sp. is a land snail. Shallow to moderate depths are suggested by _Crepidula_ _onyx_, _Mitrella_ _carinata_ _gausapata_, _Bulla_ cf. _B_. _punctulata_. _Ostrea_ _vespertina_, _Schizothaerus_? sp., _Protothaca_ _tenerrima_ and _Panope_ cf. _P_. _generosa_. Most of the other species suggest moderate depths. _Cyclocardia_ aff. _C_. _barbarensis_ and _Cardiomya_ cf. _C_. _planetica_ indicate moderate depths to deep water, and _Yoldia_ cf. _Y_. _beringiana_ suggests deep water.

Locality F45 - Shallow to moderate depths are suggested by _Tegula_ _ligulata_, _Crepidula_ cf. _C_. _onyx_, _Acanthina_ _spirata_, _Olivella_ _pedroana_?, _Bulla_ cf. _B_. _gouldiana_, _Aequipecten_ aff. _A_. _circularis_, _Ostrea_ _vespertina_, _Schizothaerus_? sp., _Dosinia_ _ponderosa_ subsp., _Amiantis_ cf. _A_. _callosa_, _Pseudochama_ _exogyra_?, and _Chama_ _pellucida_. The rest of the mollusks suggest moderate depths, except for _Cyclocardia_ aff. _C_. _barbarensis_, which ranges into deep water, and _Neptunia_ cf. _N_. _lyrata_, which suggests deep water. _Brissopsis_ _pacifica_ has been recorded from 20 to 780 fathoms.

Locality F48 - _Mitrella_ sp. and _Ostrea_ _vespertina_ indicate shallow water. Most of the other species suggest moderate depths. Nuculana cf. N. hamata suggests moderate depths to deep water. Deep water is suggested by Nuculana extenuata? and Yoldia cf. Y. beringiana. The only specimens of the living Nuculana extenuata in the U. S. National Museum collections were dredged at a depth of 1569 fathoms (Woodring, W. P., personal communication).

Locality F49 - Shallow to moderate depths are indicated by Mitrella carinata gausapata, Dosinia cf. D. ponderosa subsp.?, Protothaca tenerrina, and Gari edentula?. Most of the species indicate moderate depths. Cyclocardia cf. C. barbarensis suggests moderate depths to deep water.

Locality F50 - Shallow to moderate depths are indicated by all the species except Fusitriton? which suggests moderate depths to deep water.

Locality F51 - Shallow depths are indicated by Dendraster? sp., Ostrea vespertina, and Panope generosa. The rest of the species suggest shallow to moderate depths, except for Yoldia beringiana, which suggests deep water.

Localities at which there is no apparent mixing are:

Locality F41 - This very large fauna suggests a moderate depth environment. The cat bone seems no more anomalous here than the chunks of wood in adjacent beds.

Locality F46 - The meager fauna (3 species) hardly justifies an interpretation.

Locality F47 - All the specimens in this collection are incomplete, immature, or worn. Shallow to moderate depths are suggested.

Locality F59 - Shallow to moderate depths are suggested by all the species.

Locality F60 - Shallow to moderate depths are indicated by this assemblage.

With respect to the geographic distribution of the modern representatives or close relatives of the species at localities F41 to F51, the same conclusion is reached as for the fauna of the Towsley formation: that 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 suggests that surface water temperatures were slightly warmer than they are now at Ventura.

All the species that are extinct in the latitude of Ventura, but that are now living in areas north of Ventura, are moderate-depth or deep-water species. This 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 (personal communication) to represent a moderate depth facies of about 10 to 30 fathoms.

The collections from localities F77 to F81 consist of species that live in moderate depths and species that range from shallow tc moderate depths. Yoldia beringiana? from locality F80 indicates deeper water.

No collections were made from specific localities high in the Pico formation, but in several places, particularly around the northeast side of the Newhall-Potrero oil field, the upper Pico beds, higher than localities F77-F81, commonly yield a fauna consisting chiefly of Dendraster, pectens and oysters. This is interpreted to represent a gradual shoaling of the water during deposition of the upper part of the Pico.

UPPER PLIOCENE AND LOWER PLEISTOCENE SERIES

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 non-marine deposits which in turn grade upward and laterally into exclusively non-marine beds. In some areas it is practical to distinguish a lower member, termed the Sunshine Ranch member.

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, a term first used by Homer Hamlin, to all the post-Modelo, pre-terrace deposits in the Santa Clara Valley region. Kew (1924, p. 81) in raising the Fernando to group status, defined the Saugus as the upper part of the Fernando that rests unconformably on the Pico formation in most places. Kew assigned to the Saugus many beds which are referred to the Pico formation in the present report.

The term Sunshine Ranch was introduced as a formation name by J. C. Hazzard[3] for interfingering marine, brackish-water and non-marine beds lying above the Pico formation and below the Saugus formation in the vicinity of the San Fernando Reservoir, a few miles south of the area shown on the geologic map. At the type locality the Sunshine Ranch, which was mapped as Saugus by Kew, 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 formation. 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..." in the vicinity of the Placerita oil field and designated these beds as the uppermost member of the Pico formation. In this report the Sunshine Ranch is treated as a member of the Saugus formation and is shown on the geologic map in areas where greenish gray siltstone and fine-grained sandstone are present in sufficient amount to constitute a mappable unit.

[3] Private report for the Union Oil Company of California. Extensive quotation of portions of the report dealing with the Sunshine Ranch are given in Oakeshott (1950, p. 59).

Stratigraphy and lithology

San Fernando Valley

Near the mouth of San Fernando Pass the Sunshine Ranch member of the Saugus formation is represented by a thickness of about 800 feet of soft greenish-gray siltstone and fine-grained sandstone intercalated with light gray sandstone and conglomeratic sandstone. Figure 10 shows an exposure of these beds in a road cut on U. S. Highway 99.

Fossils are abundant at some horizons, 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.

The Sunshine Ranch member is separated by an unconformity from the upper part of the Saugus formation in the area east of U. S. Highway 99. The rocks above the unconformity consist 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 part of the Saugus, the younger beds consist chiefly of grayish-orange sandstone and light-gray conglomerate. Some beds are very firmly cemented by calcium carbonate, especially in areas near the Santa Susana fault zone.

Figure 10. Sunshine Ranch member of the Saugus formation, exposed in road cut on U. S. Highway 99 south of San Fernando Pass.

A thickness of only about 1,500 feet of the upper part of the Saugus is exposed on the north limb of a syncline near the mouth of San Fernando Pass. According to Oakeshott (1950, p. 62) the Saugus is at least 3,000 feet thick on the south limb of this syncline, the axial region of which is covered by alluvium. Oakeshott also reports the finding of a horse tooth about 800 feet stratigraphically above the base of the upper member of the Saugus formation in that area. The tooth was tentatively identified by Chester Stock as that of Pleistocene horse.

That the Saugus formation may be very thick in some places in this area is attested by evidence from Sunray Oil Corporation's Stetson-Sombrero well No. 1, drilled in sec. 21, T. 3 N., R. 15 W., about 100 yards east of the eastern boundary of the area shown on the geologic map (Plate I), and about 300 yards north of Foothill Boulevard. This well entered the Saugus formation below 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 degrees.

Area south of San Gabriel and Holser faults

In 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. Although in some areas, as near Elsmere Canyon and near the Del Valle oil field, a two-fold 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, over most of the area of outcrop the upward change in lithology is very gradual, and greenish beds occur even in the highest exposed parts of the formation.

The contact with the marine Pico formation is gradational and interfingering in many places, the chief distinction between the Pico and the Saugus 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 southeastern end of the Newhall-Potrero oil field the base of the Saugus is drawn for a short distance on an angular unconformity. This unconformity can be traced for only about twc miles as an angular discordance. In the vicinity of 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. Although mollusks occur very sporadically in the lower part of the Saugus formation the fauna consists chiefly of only three species: Ostrea vespertina var. sequens, Cryptomya californica and the slender form of Calicantharus humerosus.

The Saugus formation consists of lenticular units of light-colored loosely consolidated poorly bedded ill-sorted conglomerate, conglomeratic sandstone and sandstone alternating with intervals of greenish-gray siltstone and silty sandstone and light brown to moderate reddish-brown sandy siltstone and claystone (fig. 11). The proportion of greenish beds is greater in the lower part and the proportion of reddish beds is greater in the upper part of the formation.

At a few places between Towsley Canyon and Newhall the lower part

Figure 11. Saugus formation, exposed in road cut on U. S. Highway 6 between Whitney and Placerita Canyons, showing cross stratification and lenticularity.

of the formation includes beds especially rich in plant remains. These lignitic beds occur in units as much as six feet thick, but they are generally very lenticular and sandy.

The clasts in the Saugus conglomerates are nearly all rounded to well-rounded. Pebble counts made at several places in the Saugus show that the same rock types are represented in about the same abundance as in the Pico conglomerates. In fact, the variations with either formation are greater than the differences between the two formations. With respect to average clast size, there is a gradual decrease in average diameter of clasts from east to west. Near Newhall beds containing boulders are not uncommon; near Pico Canyon boulders are scarce, but cobbles are abundant; near the Del Valle oil field cobbles are less common and most of the conglomerates are merely pebbly.

Because the Saugus is the youngest formation to be involved in the principal deformation in the region, and because an unknown thickness of beds have been stripped away 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 the Saugus is about 7,000 feet thick.

Fossils

In the area south of the Holser and San Gabriel faults and in the San Fernando Valley, megafossils occur sparingly in the lower part of the formation. These consist mainly of the three species previously mentioned as well as fragments of unidentified naticids and fragments of Dendraster.

In the area north of the Santa Clara River and south of the Holser fault W. H. Corey collected horse teeth from the Saugus formation at several localities which are shown on the geologic map (localities V91, V92, V93). According to Corey, Chester Stock identified the teeth as probably belonging to Pliohippus.

Two samples (f89, f90), stratigraphically only a few feet apart, were collected from greenish-gray siltstone very near the base of the formation near the Newhall-Potrero oil field and examined for microfossils. The lower sample contained an abundance of Nonion scaphum along with Rotalia sp., Gaudryina sp., and ostracods. The higher sample contained only fresh-water gastropods, ostracods, a barnacle, and charaphytes. A sample (f88) collected higher in the formation, near the Castaic Junction oil field, contained fresh-water gastropods, ostracods and charaphytes.

Environment suggested by the fossils

The mollusks and foraminifers in the uppermost part of the Pico, which interfingers with the Saugus in many places, were 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 since living Ostrea vespertina and Cryptomya californica have a wide salinity tolerance. Dendraster would not be out of place in somewhat brackish water.

The microfauna at locality f89 indicates shallow-water marine conditions, while that at locality f90 only a few feet higher stratigraphically suggests a change to brackish-water conditions. The fauna from locality f88 suggests a lacustrine environment.

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

AGE OF THE TOWSLEY, PICO AND SAUGUS FORMATIONS

Because of the gradational and interfingering relationships between each successive pair of the four youngest formations in the area, the age assignment for each one of the last three of these formations is dependent on the ages assigned to the adjacent formations.

TOWSLEY FORMATION

The oldest beds in the Towsley, 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 formation about 50 feet stratigraphically below the base of the Towsley near Oat Mountain (locality f12, see table 2) is regarded as lower Mohnian. The base of the Towsley 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 within 100 feet below the base of the

Towsley from the Modelo formation (localities f10 and f11) indicate a Delmontian age for the basal Towsley beds. The lower part of the formation in the Pico Canyon area (localities f29, f30, f31, f32) yielded foraminifers assigned to the Delmontian stage.

The exact position of the Elsmere Canyon beds in the Towsley succession in the Santa Susana Mountains is not known owing to faulting near San Fernando Pass and to apparent thickenting of the Towsley formation as it is traced westward from near Elsmere Canyon. It is believed that the horizon represented by the base of the Towsley where the formation rests unconformably on older rocks near Elsmere and Grapevine Canyons corresponds roughly 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, then the fossils at locality F16, in the middle of the Towsley section, are at very nearly the same horizon. The base of the Towsley at Towsley Canyon would be about 1,500 feet stratigraphically below this horizon. The position of the horizon of locality F17, near East Canyon, with respect to the Elsmere Canyon beds is even more uncertain, but it is probably slightly higher.

The molluscan and echinoid fauna from the Towsley beds in the vicinity of Elsmere Canyon 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), and (Woodring, 1938, p. 20).

This age assignment is based on several sets of facts. First, the fauna contains a large number of species not known in other regions from beds older than Pliocene. Second, the fauna includes, in addition, 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 Jacalitos formation of the Coalinga region, and with the lower part of the San Diego formation. Both the Jacalitos and the lower part of the San Diego formation are regarded as lower Pliocene (Woodring, 1940, chart facing p. 112).

The Santa Susana Mountains localities both contain "Nassa" hamlini and locality F17 furnished Acila semirostrata. Both of these species occur only in lower Pliocene strata outside the Ventura Basin. "Nassa" hamlini has been reported from a locality near the base of the Towsley near East Canyon (O'Flynn, J. B., and Paschall, R. H., 1938, p. 18). The locality (U.C.L.A. locality 1089) is shown on the geologic map. It is about 500 feet stratigraphically below locality F16. Specimens of Turritella cooperi, a species reported (Merriam, 1941, p. 118) from only two localities elsewhere in beds older than Pliocene, were noted about 1,000 feet above the base of the formation near Towsley Canyon.

PICO FORMATION

There can be no doubt that the Pico formation in this area is entirely of Pliocene age in terms of the California division of the Cenozoic. What are believed to be the youngest beds in the formation, the beds along the northeast side of the Newhall-Potrero oil field, contain Patinopecten healeyi and Lyropecten cerrosensis, both of which occur in beds 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 and Acila semirostrata were collected, is regarded as lower

Pliocene although Acila semirostrata is reported elsewhere from only two localities in the Los Angeles Basin (Woodring, W. P., 1938, p. 28). At none of the localities where these two species occur is there evidence that the animals actually lived where their remains are found. In fact, at all eastern Ventura Basin localities there is evidence of transportation after death. The true depth facies of these two species is therefore not determined, although a moderate depth facies appears most likely.

The strongly plicate variety of Ostrea vespertina occurs at localities in the uppermost part of the Pico, and has not been found in association with either Acila semirostrata or "Nassa" hamlini. Although the presence of this variety 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 shows the stratigraphic distribution of varieties of Calicantharus humerosus in the Pliocene rocks of the area. The table is the result of a special study of this species by W. P. Woodring, using collections from the University of California at Los Angeles as well as those made for the U. S. Geological Survey. The typical variety, which is strongly inflated and has a strong angular shoulder, occurs in the Towsley formation at Elsmere Canyon. An intermediate form, which is moderately inflated and has a strong angular shoulder and which more or less intergrades with the typical form, occurs in the Pico formation. The slender form, which is round shouldered, occurs in the Pico formation and in the lower part of the Saugus formation. Except for one poorly described "U. C. L. A. locality" in the Towsley formation in Elsmere Canyon, where the typical and intermediate forms may possibly occur together, the three forms were not found together at the same locality. The typical form has about the same range as 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 of the other two forms.

If the three forms are not ecologic varieties adapted to different environments, then the typical-intermediate-slender lineage suggested by the stratigraphic distribution may be of chronologic value. The Towsley formation molluscan fauna at Elsmere Canyon, where the typical form occurs, is interpreted as indicating shallow water. The faunas at localities F76, F80 and F81, where the intermediate form occurs, suggest shallow to moderate depths. Where the slender form is found in an unmixed depth assemblage, the fauna suggests shallow water or even brackish water. At least a slight difference in habitat for the three forms is therefore possible.

At best, then, only a two-fold division of the Pliocene seems warranted in this region, with the lower Pliocene being characterized by Acila semirostrata, "Nassa" hamlini, and the typical form of Calicantharus humerosus and the upper Plicene being characterized by the strongly plicate form of Ostrea vespertina and the slender form of Calicantharus humerosus. More extensive colletions may make possible the recognition of a middle Pliocene subdivision characterized by the intermediate form of C. humerosus.

SAUGUS FORMATION

The Saugus formation interfingers with the upper Pliocene part of the Pico formation in the area south of the Holser fault. North of the fault, where the uppermost part of the Pico contains the typical form of Calicantharus humerosus, the Saugus may even extend into the lower Pliocene. The Pliohippus teeth which occur more than 1,000 feet above the base of the Saugus near the Del Valle field, where the base of the Saugus is relatively young with respect to the base farther north or east, indicate a Pliocene age for at least the lower half of the Saugus. The horse tooth collected by Oakeshott from the upper part of the Saugus in the San Fernando Valley indicates that the upper part of the formation extends into the Pleistocene. Near the village of Castaic, several miles north of the area shown on the geologic map, W. H. Corey collected a jaw-bone and teeth of a Bison from reddish sandy clay beds near a large fault. The beds containing the vertebrates dip about 30° and were tentatively regarded by Corey as Saugus (personal communication). Chester Stock examined the material and told Corey that the Bison was a very modern one, possibly even Recent. It may be that the dipping beds are not Saugus but are upper Pleistocene stream terrace deposits that were deformed during movements along the nearby fault. If, on the contrary, the beds containing the Bison are within the Saugus, then the age range of that formation must be extended at least into the late Pleistocene.

LATE PLEISTOCENE SERIES

TERRACE DEPOSITS

Deposits on stream terraces are widely distributed in the region but are most extensively developed near the town of Saugus and in the immediate vicinity of the Santa Clara River (see figures 12 and 13). The deposits consist of crudely stratified, poorly consolidated, reddish 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, owing to the similarity of the terrace gravels and the loosely consolidated conglomerate beds in the Saugus formation.

The extensive terrace deposits east of Saugus are as much as 200 feet thick. Farther west, in the vicinity of 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 large as two feet in diameter are scattered on ridge tops developed on shale of the Modelo formation.

The thick terrace deposits exposed in the vicinity of Saugus, the deposits near the Castaic Junction and Del Valle oil fields and near the mouth of the stream draining Newhall-Potrero are apparently remnants of a once-continuous cover of alluvium. The altitude above the present Santa Clara River Valley of the base of this series of terrace deposits is about 150 feet near the Del Valle oil field, but near Saugus the base

Figure 12. Stream terrace deposits, exposed in road cut near Castaic Junction oil field, showing unconformable contact with underlying Saugus formation.

Figure 13. Stream terrace deposits at Del Valle oil field. The base of the terrace deposits is at the top of the white cliffs.

is lower than the river bed. An erosion surface developed 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 believed to be due to broad warping after the formation of the terrace deposits.

The assignment of the terrace deposits to the upper Pleistocene is based on the fact that 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 there is a suggestion that the large terrace near the east end of the Del Valle field and the large terrace just southwest of the Castaic Junction field have been slightly folded. Aside from these minor exceptions, the terrace deposits are almost undeformed. In the western part of the Ventura Basin the oldest undeformed rocks are assigned on faunal grounds to the upper Pleistocene.

The only direct faunal evidence for the age of the terrace deposits in the southeastern Ventura Basin is of very doubtful nature. A tooth of a Bison was collected by W. H. Corey at an outcrop of the Saugus formation near the junction of Castaic Creek and the Santa Clara River (locality V94). At this place terrace gravels lie unconformably on the Saugus. The tooth was collected at the surface of the Saugus outcrop and Corey reported (personal communication) that he could not be certain whether the tooth came from the Saugus or was washed from the overlying terrace gravel. Chester Stock identified the tooth as belonging to a very late Pleistocene or even Recent Bison.

TURBIDITY CURRENT EFFECTS IN THE TERTIARY ROCKS

GRADED BEDS

Although 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, the possible origin and significance of this prevalent sedimentary structure has not been dealt with directly. Mention has been made in connection with the anomalous associations represented in depth of molluscan faunas from the Towsley and Pico formations that turbidity currents might 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 deep water, perhaps 3,000 feet deep, and certainly more than 600 feet. Yet interstratified with the siltstone beds carrying the deep-water foraminifers are beds of sandstone and even of coarse conglomerate. Unless we are to deny that the foraminifers have any depth significance we must admit of some mechanism that will transport large volumes of material into 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, then to lower it again to depths at which the foraminifers can live. Significantly, the sandstone and conglomerate beds in the midst of the deep-water-deposited siltstones contain sedimentary structures that show their probable agent of transportation to be turbidity currents. Chief among these structures are graded beds.

Several lines of evidence lead to the conclusion that most marine graded beds represent deposits of turbidity currents. A turbidity current, as the term is used in this report, is a current that contains suspended sediment and that flows in a body of standing clear water 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). The 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, Arizona and Nevada, during late spring and early summer when, owing to their lower salinity, the incoming Colorado River waters are lighter than the surface waters of the lake (Gould, 1951, pp. 38, 39). Turbidity currents that flow at some intermediate level in a body of standing water, termed interflows, can be produced easily in the laboratory in 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 the 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, pp. 38, 39). Turbidity currents flowing along the bottom have not been 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, 1940; Kuenen, 1950, p. 367) in Recent deep sea sediments. Faunas consisting of shallow water or mixed shallow and deep water species of foraminifers recovered in cores of Recent deep sea sands have been ascribed to transportation by turbidity currents (Phleger, 1951).

Turbidity currents acting in conjunction with submarine slumping and sliding have been invoked as possible agents in the erosion of submarine canyons (Daly, 1936; Kuenen, 1950, pp. 485-526; Woodford, 1951; Crowell, 1952b); and deep sea channels (Dietz, 1953; Ewing, Heezen, Ericson, Northrop, and Dorman, 1953).

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 progressively more dilute and slower moving. A pronounced vertical gradient in both density and velocity was observed in many 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, thus providing a clear picture of the formation of graded beds by turbidity currents. Deposition is rapid enough so that a mixture of particles of all sizes at the base of the flow is deposited and buried before the current can winnow out the finer-sized 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 Coloradc 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 feet per second near the Colorado River mouth to less than 0.25 feet per second farther down the lake. Measurements indicate the flows are only a few feet thick and have a vertical density gradient. Effective densities measured in one flow ranged from 0.001 at the top to 0.200 at the bottom.

Evidence of the existence or importance of marine turbidity currents is indirect but 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 is improbable. Some of the sand layers are well sorted, and others graded. Remains of shallow-water organisms, especially of foraminifers, are present in some layers of sand. The sand layers are interbedded with deep-water sediments in some areas hundreds of miles from the nearest land or even from the nearest 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 meters thick. Some of the cores were as much as nine meters long and contained as many as 20 layers of sand. Many of the layers are graded from coarse at the bottom to fine at the top, with abyssal red clay at the top of some layers. A core taken 90 miles from the edge of the continental shelf at a depth of 1,900 fathoms contains a thickness of nearly 3 meters of gravel in the lower part of the core. The gravel contains pebbles as much as 2 centimeters in diameter as well as shells and shell fragments of Recent and Pleistocene mollusks. The mollusks are chiefly shallow-water species but a few deep-water forms are also present. In the North Atlantic the deep-water sands are in depressions in the ocean floor. Sediments blanketing slopes and the divides between submarine canyons do not contain sand layers.

In the San Diego trough, off the coast of southern California, Ludwick (1950) showed that the sand layers, although present in many parts of the trough, are most abundant near the outer portion of La Jolla Submarine Canyon. Near the mouth of La Jolla Canyon are wide shallow channels with a gentle gradient extending partly across the floor of San Diego trough. A fathogram (Menard & Ludwick, 1951, fig. 1) along a line of echo sounding across a channel shows levees on both sides of the channel.

Marine turbidity currents provide an explanation for the presence of layers of coarse 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, but not on appreciable 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, transportation by wind, and transportation 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 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. It is difficult to see how this mechanism can produce well sorted or graded beds. The distribution of the rafted sediments should bear no relation to the topography of the sea bottom. Wind blown sands should likewise be distributed without relation to submarine topography.

Lowering sea level sufficiently to bring the sand layers within the range of shallow water currents, even if the mechanism responsible for such a lowering could be found, fails to account for the layers of fine-grained sediment containing remains of deep water foraminifers interstratified with the sand.

An additional line of 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 south of Newfoundland, were broken in an orderly succession in the period following the quake. The farthest cable was more than 300 miles from the epicenter, and the average slope of the sea floor below the epicentral area is $1^{\circ}50'$; 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. As the material moved down the slope it was converted into a turbidity current which broke the lower cables in succession. The velocity of such a flow was calculated to be about 50 knots on the upper part of the slope where the slope is about 0.5 per cent, and about 12 knots near the last cable, where the slope is only 0.05 per cent. Because about a 200-mile length of the last cable was destroyed and deeply buried it is reasonable to assume that the flow travelled even farther into the ocean basin. Heezen and Ewing (1952, pp. 865, 866) state that the deposits of the flow are graded.

Although earthquakes may initiate submarine slides or slumps that later are transformed into turbidity currents, the flow might be triggered by other means. Shepard (1951, pp. 58-59) reported that frequent surveys of the nearshore end of Scripps submarine canyon, which is a branch of 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 every year. The immediate cause of the slides is not known, although heavy storm waves appear to be a likely trigger. 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 all the characteristics that would appear to be required for marine turbidity current deposits. The evenly graded beds are similar to those produced by Kuenen in tank experiments in which a batch of material is introduced suddenly into the standing water. The beds that are nearly homogeneous throughout most of their thickness and show grading only in their uppermost parts are similar to those produced by Kuenen (Kuenen, Ph.H., and Menard, W. H., 1952, pp. 83-96) in the laboratory by introducing the coarse material, not in one sudden slide, but in a continuous stream. In a 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 farther upstream. When a supply of sediment is fed continuously into the current, no such horizontal grain-size gradient can be established and the current deposits an ungraded bed until the supply is cut off, at which time a horizontal gradient in the flow is established and vertical grading in the deposit begins. In nature a continuous feeding might result from a large slide originating over a broad area measured up and down a submarine slope (Kuenen, Ph. H., and Menard, H. W., 1952, p. 94). Slumping of sediment that has accumulated for some distance along the headward portions of a submarine canyon appears to be a plausible mechanism for maintaining a continuous feeding. Most of the beds of sandstone in the Towsley formation that are graded only in their uppermost parts are thicker than average, indicating that they are deposited by currents of large volume.

A very well sorted supply might lead to the near absence of grading also, but the sorting of the nearly homogeneous beds in the Towsley formation is commonly not so good as to make this explanation the most likely. In many beds grading is uniform up into material of fine- or very fine-grained sand size. Resting abruptly on this material with a very smooth contact is claystone. The portion of the bed that is normally represented by very fine-grained sandstone and siltstone is missing.

The sediments that would have formed the absent layers were probably carried farther by currents in the tail of the turbidity current. Beds with these layers missing generally contain sets of cross-laminae near their tops, indicating reworking by currents.

The missing layers could have been eroded by the next succeeding flow, or the next succeeding flow may have followed so closely behind the first one that the rapidly moving head of the second current overtook the dilute slow-moving tail of the first current, and began depositing its load before the first bed was completed. A succession of vertical grading in the deposit begins. In nature a continuous feeding might result from a large slide originating over a broad area measured up and down a submarine slope (Kuenen, Ph. H., and Menard, H. W., 1952, p. 94). Slumping of sediment that has accumulated for some distance along the headward portions of a submarine canyon appears to be a plausible mechanism for maintaining a continuous feeding. Most of the beds of sandstone in the Towsley formation that are graded only in their uppermost parts are thicker than average, indicating that they are deposited by currents of large volume.

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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.

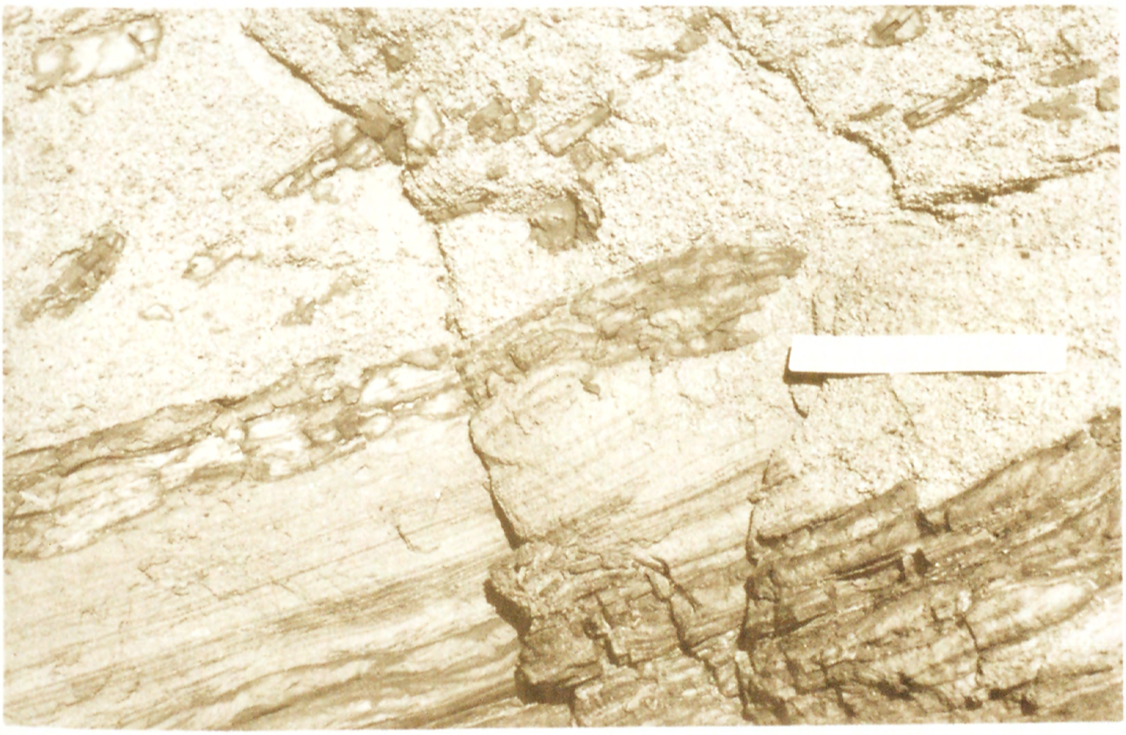
INTERRUPTED GRADATIONS

Although most beds grade upward into siltstone or even claystone, many beds end in sandstone. The base of the next overlying sandstone bed generally is not conspicuous because there is not a striking grain-size or color contrast across the contact. The degree of induration is commonly the same in both beds and the contact is commonly not a surface of fissility as is the surface where fine-grained rock separates the coarser beds. What may appear at a distance to be a single thick bed of sandstone may prove to comprise several beds when examined closely (see fig. 14).

Within many graded beds the median grain size does not decrease upward in a uniform fashion. Thin dark-colored streaks and wisps of micaceous silt such as those in the channeled bed to the left of the 6-inch rule in figure 15 produce interruptions in the otherwise orderly sequence. The lower portions of graded beds are free of the fine laminae. The laminae may be deposited because 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 are deposited by a current moving its load at least partly by

Figure 14. Graded beds in the Towsley formation. The 0.2-foot ruler is near the top of a graded bed of sandstone about 0.4 feet thick.

Figure 15. Cut-and-fill structure in the Towsley formation. See text for discussion.



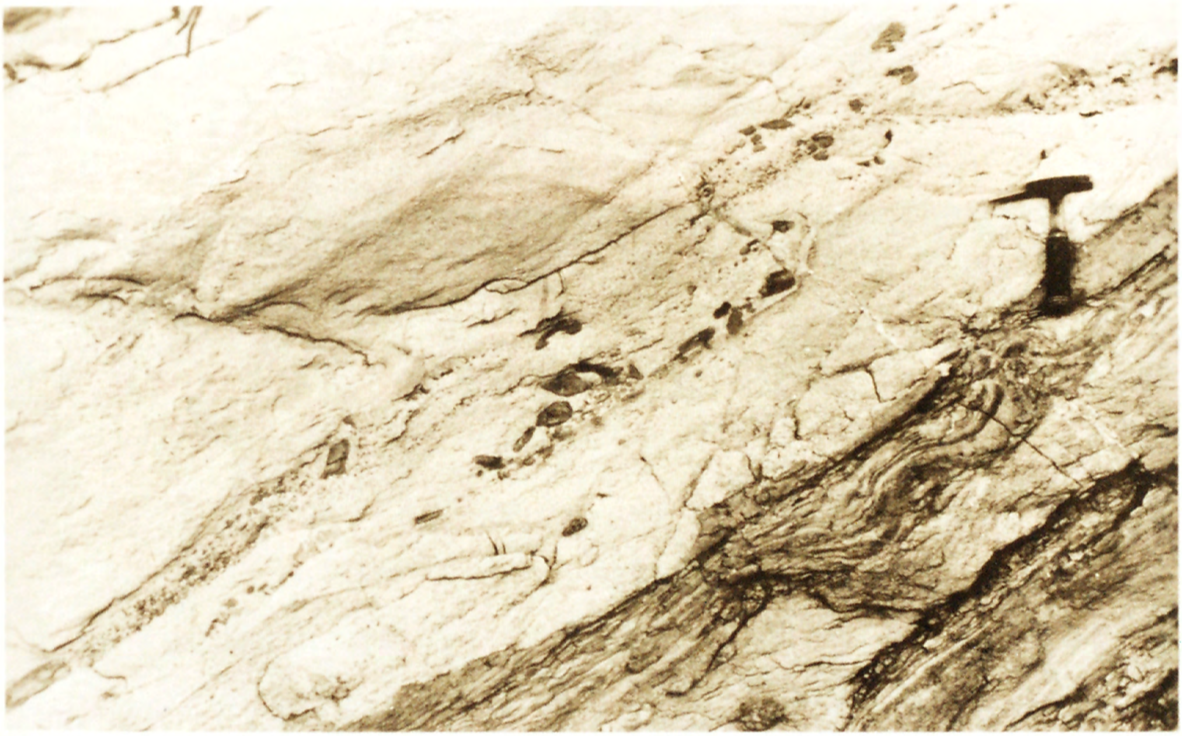
traction, rather than wholly by suspension.

ANGULAR FRAGMENTS IN SANDSTONE

A notable exception to the uniform grading is the position of the mudstone fragments that are so commonly incorporated in the sandstone beds. These fragments are generally well up in a graded bed rather than at its base. In some places they are scattered at various levels as in figure 16, in other places they are chiefly at one level. Their low density and their commonly slabby habit probably combined to give the fragments a slow settling velocity. A block of laminated siltstone and fine-grained sandstone that was several inches above the base of a graded bed of medium- to coarse-grained sandstone had an apparent specific gravity of $2.201 \pm .003$ at 26° C. according to an determination by J. E. Schoellhamer. The sandstone matrix had an apparent specific gravity of $2.158 \pm .003$ at 26° C.

The alignment of fragments along fairly definite planes within a graded bed suggests that a layer of mudstone was being eroded from the sea floor a very short distance upslope and that the erosion proceeded concurrently with the passage of a turbid flow. The fragments thus might not even be available for transport until the lower part of the graded bed had been deposited downslope. Intermittent erosion during passage of the current could produce trains of fragments which would be deposited in distinct layers a short distance downslope.

Figure 16. Angular fragments of mudstone in the Towsley formation. The fragments occur in several distinct layers, all of which are included in one graded bed of sandstone.



IRREGULAR CONTACTS

Commonly the contact between two graded beds, although abrupt, is 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 in figure 15, are not rare.

Irregularities in the shape of the surface of contact are very commonly 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 17 shows several varieties of deformation of the interface due to unequal loading. These features have been called load casts (Kuenen, Ph. H., 1953, p. 1048). The load casts are pockets of coarse-grained material projecting down into the 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 pockets is generally markedly coarser than the material at the base of the overlying bed outside of 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 like that at A in figure 17, but some are much deeper and have a narrow connection with the overlying bed, as at B. In some places the pocket is isolated within the lower bed, as at C. The asymmetric load cast at D owes its form to slumping, perhaps due to the drag of the passing turbidity current, in addition to unequal loading.

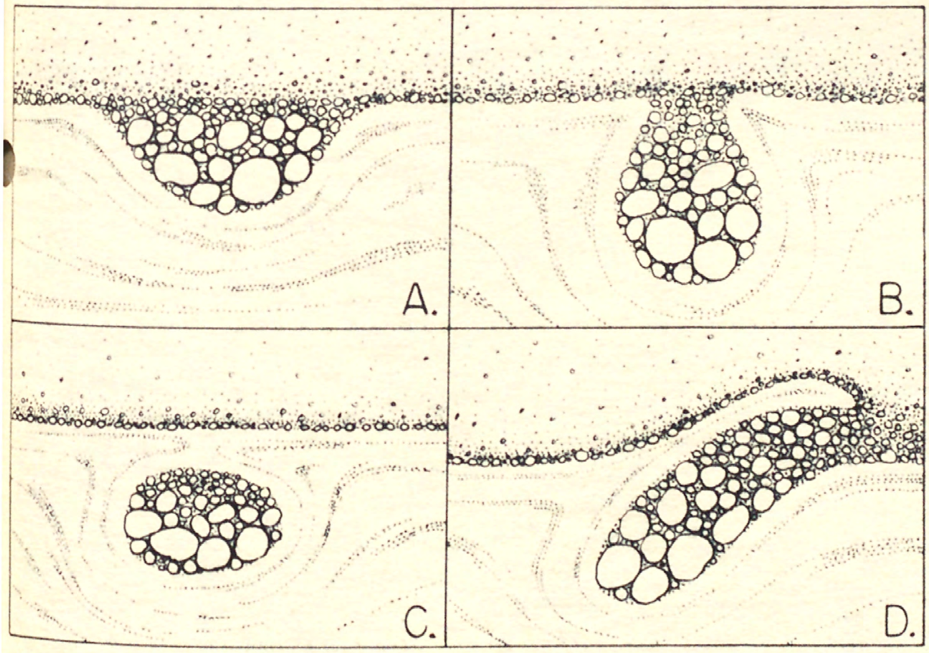


Fig. 17

Load casts in various stages of development

Figure 18 shows asymmetric load casts at the base of a bed of pebbly sandstone. A small block of siltstone near the right side of figure 19 has apparently been completely detached from the parent bed below. The very 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 20 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 mean that the depression would be filled and a more equal load distribution developed before the pocket sank very deep.

INTRAFORMATIONAL BRECCIAS

Intraformational breccias are abundant throughout the Towsley formation. Figure 21 shows a breccia consisting of dark-colored chips,

Figure 18. Asymmetric load casts in the Towsley formation.

Figure 19. Load casts in the Towsley formation.

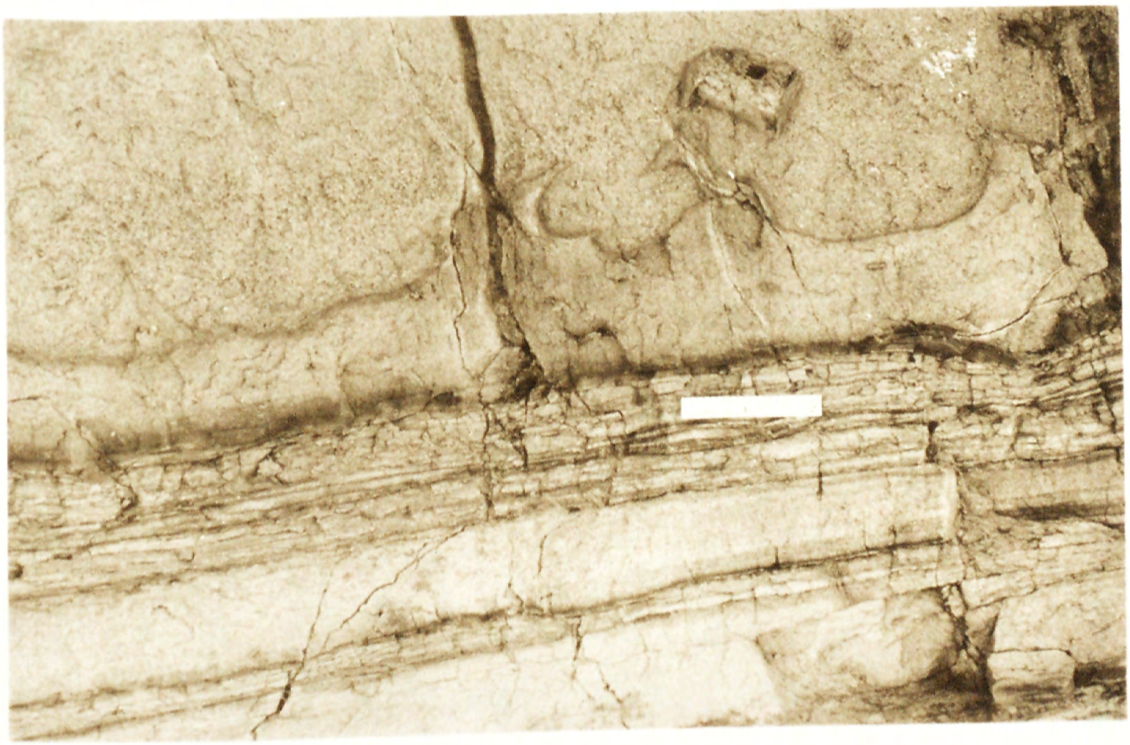


Figure 20. Load casts in the Towsley formation, viewed from underneath.

slabs and blocks of sandy mudstone in a matrix of light-colored coarse-grained sandstone. The important stages in the development of such breccias are preserved in the rocks. Figure 22 shows chips "peeling" away from a siltstone bed that underlies a bed of coarse-grained sandstone. The curved shape of the chips indicates the siltstone was plastic when eroded. Deformed chips and slabs are common in the intraformational breccias. Figure 15 shows a bed of coarse-grained sandstone containing mudstone fragments. In the center of the picture, the two-inch layer of mudstone that underlies the sandstone has been eroded and the sandstone bed rests on a lower mudstone layer. The fragments in the sandstone bed are lithologically identical with the mudstone in the eroded interval. The channeling sandstone bed actually underlies the mudstone layer for a distance of about 2 inches to the left of the broken end of the mudstone layer. The numerous dark laminae below the mudstone layer in the left hand part of the figure terminate against the sandstone filling the channel. The overhanging bed is bent downward slightly and was apparently next in line for erosion. Fragments in the sandstone were probably derived chiefly from a part of the mudstone layer that lies beyond the plane of the photograph.

Figure 23 shows another intraformational breccia. The 6-inch rule rests above shale blocks scattered to the left of the parent layer and whose thickness and lithology match that of the parent layer.

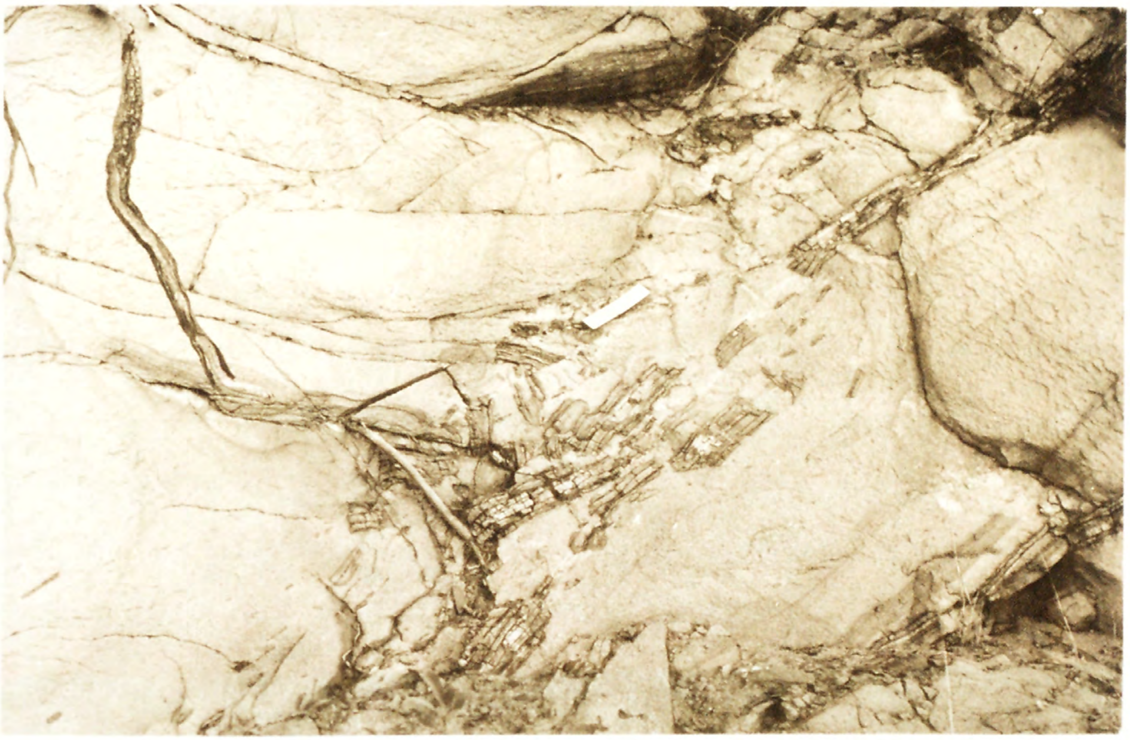
In one place the sandstone contains a very large angular block of shale more than 10 feet long in its largest exposed dimension (fig. 24).

Figure 21. Intraformational breccia in the Towsley formation.

Figure 22. Mudstone layer that has "peeled away" from the substratum and is incorporated in the overlying graded bed of sandstone. Ruler is about 6 inches long.

Figure 23. Intraformational breccia in the Towsley formation. Angular mudstone blocks are derived from mudstone layer in upper right. Scale is about 6 inches long.

Figure 24. Large shale block in the Towsley formation.



The block is exposed in the cut made for the Standard Oil Co. of California Brady Estates No. 1 well, in sec. 13, T. 3 N., R. 17 W. The base of the block lies within, but not at the base of, a sandstone bed. Several beds of sandstone and mudstone buttress against higher portions of the shale block. Beds adjacent to the block show no sign of deformation, indicating that the upper portions of block projected above the sea floor and sediment filled in around it after the block arrived at its final resting place. The shale in the block is phosphatic, but no phosphatic shale crops out in this part of the Towsley formation nearby. The block therefore is not like those in the intraformational breccias described above. A unit of very similar phosphatic shale in the Modelo formation, a few hundred feet stratigraphically below the shale block, crops out a few hundred feet to the south. The sandstone beds containing the block interfinger to the north with phosphatic shale of the Modelo formation exposed near the axis of the Pico anticline about 2 miles away. Evidence from sedimentary structures (pp.109 ff.) indicates that the direction of transport of the sediments of the Towsley formation in this area was from the east or northeast. The nearest land in those directions was no closer than 5 miles.

In any event the block must have travelled a considerable distance from the place where it was eroded to 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 much more firm and 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 as to prevent the block from being smashed to pieces as it moved along. If the results of laboratory experiments by Kuenen can be extrapolated a large swift turbidity current of moderately high density could effect the transport of 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 thick enough sequence of compacted beds to produce a block of the correct dimensions. It is notable, however, that no other shale blocks of comparable dimensions were observed near this one, nor indeed anywhere in the formation. Other large blocks might be expected if sliding produced this block. A single block could, however, be broken off the steep wall of a submarine gully.

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. Current bedding is shown in figure 25. The bed on which the 3-inch rule rests shows a typical succession involving current bedding. The base of the bed is its coarsest part and the basal contact is irregular but very distinct. The middle parts of the bed are banded by discontinuous streaks and wisps of dark-colored silt and clay. Near the top of the bed, left of the scale, are several small-scale lenticular trough sets of concave high-angle thin cross

Figure 25. Current bedding in the Towsley formation.

laminae (McKee, E. D., and Weir, G. W., 1953, pp. 381-390). Resting with an abrupt contact on the sets of cross laminae is a band of dark-colored 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. Sets of cross laminae are either thin or missing under the wave troughs. In the sandstone bed that lies on the siltstone land the coarsest material lies in the wave troughs. The grain size distribution along the base of the bed on which the ruler rests is similar.

The cross laminae dip to the left not only in the bed on which the ruler rests but also in all other beds in the figure. The direction of inclination of the cross laminae is an indication of the direction of flow of the current that produced them. When determining the direction of inclination care must be taken to observe the true dip and not an apparent dip. Naturally the dip of the enclosing strata must be allowed for. Beds containing cross laminae are slumped in some places. Contorted cross laminae can be seen in figure 29.

Observations at numerous places in all parts of the Towsley formation 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.

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 in wildcat oil wells. It would be a relatively simple task 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. Doubtless the direction of inclination, and hence the direction of currents, will be different in various parts of the eastern Ventura Basin, but it should not be too difficult to establish a pattern of variation. The writer has seen cross strata in well cores taken from both the Towsley and Modelo formations. Core descriptions made available by oil companies very commonly include references to "small scale cross-bedding" in the upper Miocene and lower Pliocene rocks of the region.

Recovering well-oriented cores of measuring the direction of dip with electrical devices is sometimes expensive and time-consuming. Attention to cross stratification in cores might prove to be rewarding.

The wavy form of the upper surfaces of the sets of cross strata plus the facts that the overlying siltstone bed is thin over the wave crests and thick in the troughs and that the coarsest material in the next succeeding graded bed of sandstone is in the wave troughs, indicates that the wavy form is a primary feature and is a cross section of a series of ripple marks. The average wave length of the ripples in the Towsley formation is about 10 inches. In only one place, in a road cut in the Pico Canyon Oil Field, was a bedding plane seen that had been stripped over a large enough area to show the pattern of the ripple marks. Figure 26 shows this bedding surface. The ripple marks are tongue-shaped in the lower left part of the exposure. In the upper right the ripples consist of short subparallel curved ridges

Figure 26. Ripple-marked sandstone bed in the Towsley formation. The current flowed from lower left toward upper right.

aligned diagonally from upper left to lower right. The current that produced the ripples flowed from the northeast.

The ripples and cross stratification indicate a current moving material by traction. The occurrence of 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 stable pattern of currents required to explain the persistence 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 pattern of currents is generally subject to rapid shifting.

In a basin deep enough to prevent normal fluctuating wind, wave, and tidal currents from stirring the sediments on the bottom, turbidity currents having their place of origin along a submarine slope on one side of the basin could not only transport coarse-grained material into the basin, but also produce a rather uniform orientation of ripple marks.

Subsurface data from wells show that both the Modelo and Towsley formations thin very markedly eastward between the intersection of U. S. Highway 99 with Pico Canyon and the vicinity of Newhall and Saugus. Structure section AB (Plate II) 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 sediments thinned existed in that area or a very unequal rate of subsidence prevailed in two areas of equal depth on either side of the zone of thinning. The former possibility is consistent with the direction to the source of turbidity currents indicated by the inclination of the cross laminae.

That the same general source direction may have been dominant during deposition of the Pico is evidenced by the lateral change in foraminiferal faunas from deep-water types at the longitude of the Newhall-Potrero oil field to much shall-water types at the longitude of Towsley Canyon. Single mappable units of conglomerate and sandstone may be traced continuously from the shallow to the deep area. At the shallow end the beds are apparently not graded; at the deep end graded beds are prevalent.

Well preserved current lineations were seen at only one place in the Towsley formation. Current lineations are not easily preserved because the sandstones of the Towsley are generally friable. Figure 27 shows lineations on the base of a bed of sandstone. The block in the photograph was not in place, but had fallen from an overhanging ledge of sandstone that overlies a layer of siltstone. The lower surface of the bed is marked by a number of nearly parallel narrow low ridges. Individual ridges do not extend for more than a few inches. The base of the sandstone bed where it is in place 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 siltstone layer. Because the orientation of the lineations corresponds to the direction of current flow indicated by cross laminae in adjacent beds, the lineations are believed to have been produced by a current. Sand grains rolling and sliding along the silty or clayey bottom of

present-day shallow streams can cut short narrow and shallow grooves on the stream bottom. The process was observed in several streams in the area. Flow markings similar to those shown in figure 20 have been described by Rich (1950, pp. 717-741; 1951, pp. 1-20) and Kuenen (1953).

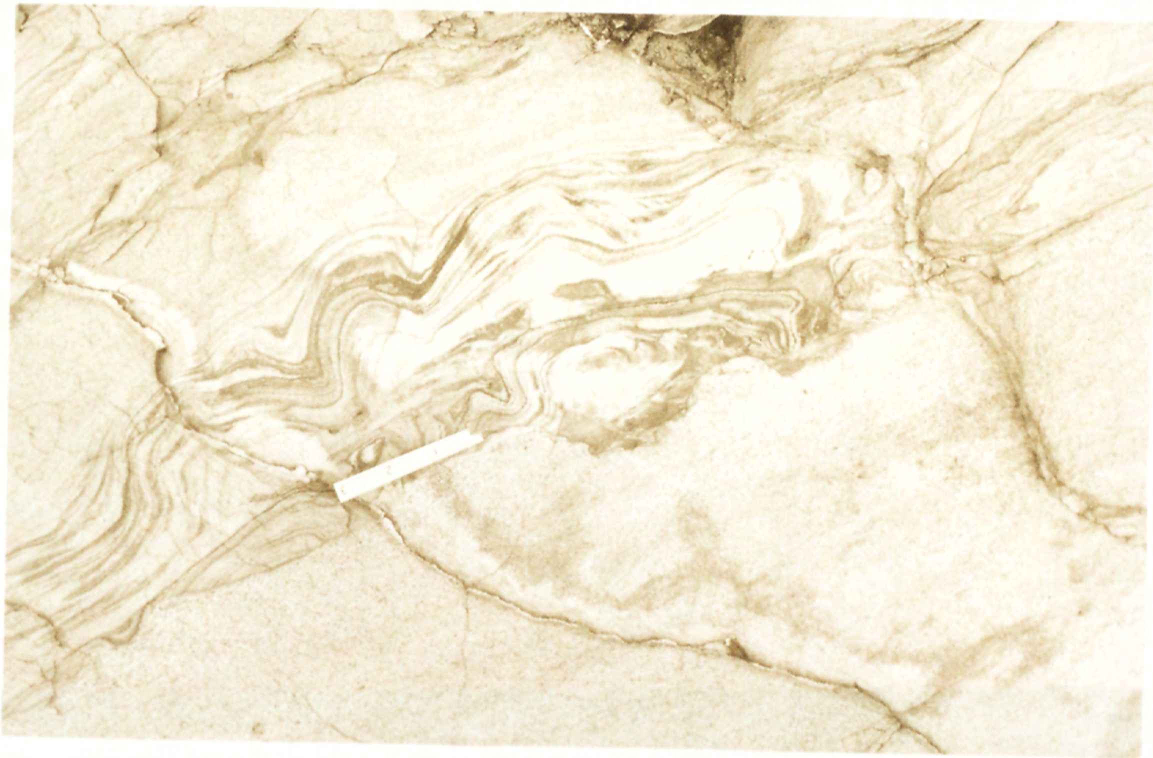
SLUMP STRUCTURES AND CONVOLUTE BEDDING

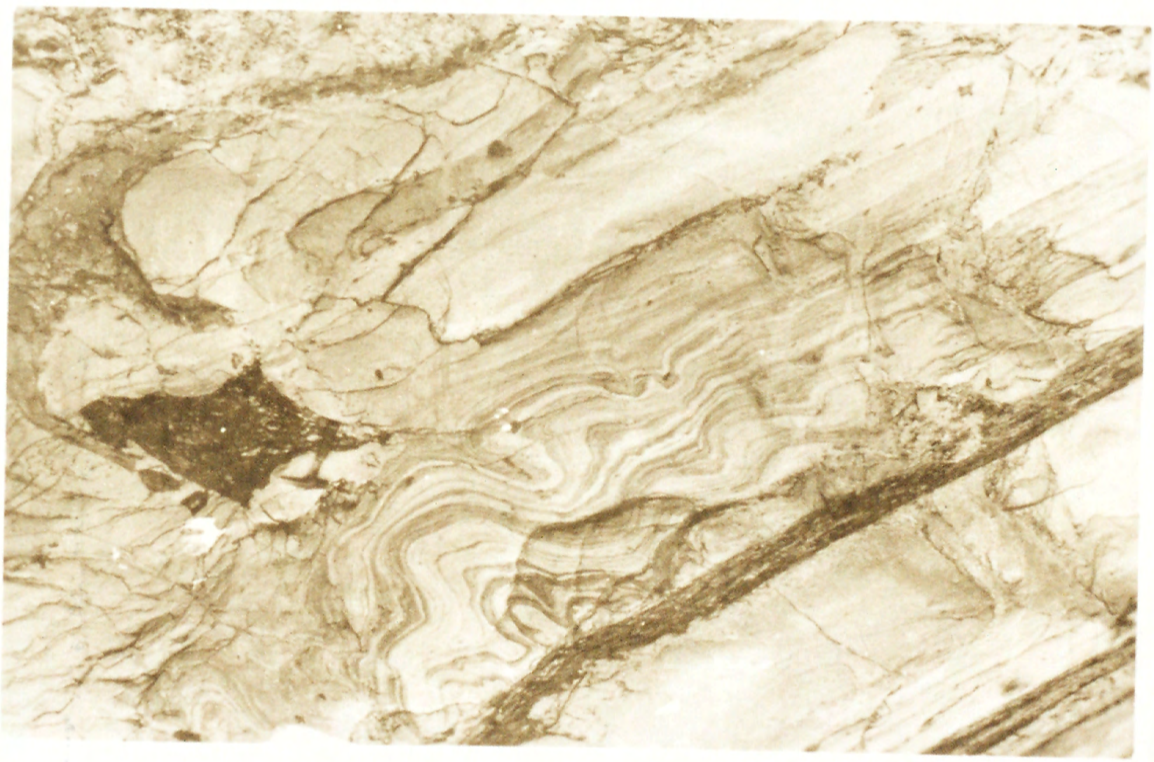
Slump structures are common in the Towsley formation. Figure 28 shows a slump structure that involves a sequence of beds about 8 feet thick. The lowest bed, at the extreme right edge of the figure, is mudstone. This bed probably provided the slipping base on which the slumping began. The light-colored banded rock is sandstone. The darker bands within the sandstone are discontinuous wisps of micaceous silt such as those shown in figure 29. The dark colored layer of siltstone in the upper left part of the figure truncates the contorted beds below. Two large prongs project up into the sandstone from the lower mudstone layer. The dark-colored diamond-shaped block of mudstone near the hammer was probably also derived from the mudstone layer.

A type of deformed bedding, termed convolute bedding (Kuenen, P. H., 1952, p. 31), that is commonly very difficult to distinguish from a slump structure is shown in figure 29. The folds in the laminated bed die out downward (toward the lower right) and the folding is confined to one bed. Ideally the folding dies out upward also. Laminae are commonly attenuated on the crests of the folds and thickened in the troughs, as in slump structures, but the sets of cross laminae ordinarily associated with the laminae near the top of a bed are generally more prevalent and thick in the troughs than on the crests. A true

Figure 28. Slump structure in the Towsley formation.

Figure 29. Convolute bedding in the Towsley formation.





slump structure is post-depositional in origin and generally involves more than one bed. Cross-stratification, where present, is equally well developed over troughs and crests of folds. Individual beds having only then middle parts crumpled are rare in the Towsley. Folds truncated by the next overlying bed as in figure 29 are more common. Convoluted bedding characteristically extends for considerable distances along a bed. One convoluted bed about 5 inches thick that was traced for about 50 yards shows no appreciable change in thickness and retains a distinctive pattern of crumpling. Not only does the thickness of bed remain constant, but also the steepness and asymmetry of folds, the distance between crests, and the relative width of the troughs and crests. Many other beds exhibit a particular pattern of crumpling that remains nearly the same for many yards along the exposure.

Where the crumpling is confined to the center of the bed it is clear that the movements began and ceased during, not after, the deposition of the bed. Where the top part of the crumpled bed is missing owing to erosion, the dating of the movement is more uncertain.

Crumpling of the beds during deposition may be due to frictional drag of the current, but the currents producing the sets of cross-laminae associated with the convoluted 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 may be helpful in promoting the creep.

S T R U C T U R E

REGIONAL RELATIONS

The geologic map (Plate I) shows a portion of the southeastern Ventura Basin. This basin is a narrow, east-west trough filled with a thick prism of Upper Cenozoic sedimentary rocks. The axis of the basin 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 since the beginning of the Tertiary period, the narrow trough-like 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 bordering the Ventura Basin on the south, from Oxnard through the Simi Hills to the north side of San Fernando Valley. Upper Cenozoic strata thin toward this persistent high and are developed dissimilarly on its north and south sides.

The axis of the Late Cenozoic trough north of the Oakridge high extends westward from the vicinity of Sunland (Index map, fig. 1) 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 high-standing, pre-Cretaceous rocks of the San Gabriel Mountains. Near Newhall the trough increases in width and its margin of crystalline rocks trends northwestward, following the trace of the San Gabriel fault. Farther west, the northern 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 trough margin must have been only a short distance north of the Oak Canyon oil field area during Pliocene times, and quite possibly only 7 or 8 miles north of there during Miocene times. In the Ventura Basin the Miocene seas were, in general, more widespread than the Pliocene seas.

Near the southern 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 thrust faulting extends northeastward, obliquely across the axis of the depositional trough near San Fernando Pass. The zone continues as a series of steeply north-dipping faults along which the pre-Cretaceous rocks of the San Gabriel Mountains are thrust southward over the northern margin of the basin.

The southeast-trending San Gabriel fault zone transects the northeast part of the Ventura Basin. This fault can be traced from the Frazier Mountain area, some thirty miles northwest of Saugus, to the eastern part of the San Gabriel Mountains, a total distance of about 90 miles. Dissimilar facies in the pre-Pliocene rocks on opposite sides of the fault indicate a long history of continued movement. Evidence for 15-25 miles of right-lateral displacement along the fault in post-late Miocene time has been presented by Crowell (1952a).

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

STRUCTURAL HISTORY

PRE-LATE CRETACEOUS

Since no attempt was made in connection with the field work for this report to distinguish rock units within the crystalline complex of the San Gabriel Mountains, no inferences are attempted regarding the structural history of that older terrane.

LATE CRETACEOUS AND EARLY TERTIARY

Cretaceous rocks are unknown in the area north of the Santa Susana fault, but their thickness (5500 ± feet) in the nearby Simi Hills and their presence in wells immediately south of the fault suggest that Cretaceous seas may have covered at least part of the region north of the fault. Paleocene rocks likewise crop out in the Simi Hills and are reported from the Aliso Canyon oil field, just south of the Santa Susana fault. In addition, a sliver of Paleocene rocks crops out between branches of the San Gabriel fault about 10 miles southeast of Newhall (Hill, M. L. 1930, pl. 15) and in a large area about 5 miles north of Castaic in the vicinity of Elizabeth Lake Canyon. Even if allowance is made for large lateral displacements along the San Gabriel fault, the possibility that the southeastern Ventura Basin was a depositional site during Paleocene times is strong.

Eocene rocks exposed in Elsmere Canyon are at least in part equivalent in age to the Llajas formation of the Simi Valley. The Llajas formation rests with slight unconformity on older beds in the Simi Valley area. The counterpart of this unconformity in the region north of the Santa Susana fault may be the contact between crystalline rocks and Eocene rocks in Continental Oil Company's Phillips No. 1 well.

The Sespe formation is reported to rest conformably on the Llajas formation in the Simi Valley (Stipp, T. F., 1943, p. 422), and there is no evidence that the relationship between the Sespe (?) formation and marine Eocene rocks in the Newhall area is different.

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. 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, points toward the separation of the Oak Ridge-Simi area as a positive element.

LATE MIOCENE

Subsidence in the trough continued during the late Miocene and the change from dominantly organic and fine-grained clastic material in the Modelo formation to dominantly sandstone and conglomerate in the Towsley formation suggests the uplift of adjacent land areas to a higher altitude. The distribution of coarse anorthosite-bearing conglomerates in rocks of Mohnian age northwest of Castaic was interpreted by Crowell (1952a) as suggestive of their derivation from a nearby area across (northeast of) the San Gabriel fault. Coarse late Miocene gneiss-bearing breccias on the northeast side of the fault are interpreted as having accumulated farther north at the base of a fault scarp. The change from the finer rocks of the Modelo formation to the coarser rocks of the Towsley, especially in light of the eastern derivation of the materials, may well be correlated with the start of important activity along the San Gabriel fault.

The angular unconformity at the base of the late Miocene Castaic formation north of the San Gabriel fault records post-Mint Canyon late Miocene local, but intense, deformation. The Whitney Canyon fault may have been active during the late Miocene also, but it cannot now be dated more precisely than post-Eocene and pre-Pliocene.

PLIOCENE AND EARLY PLEISTOCENE (?)

Lower Pliocene strata overlap older formations in the area, but no unconformity separates Miocene and Pliocene rocks in the central part of the trough. 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 record increasing activity. That these disturbances also affected areas at some distance from the edges of the basin is evidenced 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

At sometime following the deposition of the Saugus formation, which may include beds as young as early Pleistocene, the entire region was intensely deformed and the present structural features of the region were developed. Accurate dating of this deformation is not possible in this area, but it is presumed to be the same as that which affected the Ventura region, where vertebrate fossil evidence points to mid-Pleistocene age (Bailey, T. L., 1935, p. 491).

LATE PLEISTOCENE MOVEMENTS

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 which lies across the axis of the Del Valle anticline seemingly has a very straight profile, suggesting that the fold is still in the process of being formed. Similarly, the profile of a terrace surface which lies across the axis of the syncline southwest of Castaic Junction oil field appears to be very 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 portion of the Santa Susana Mountains shown on the geologic map (Plate I) lies on the north or upthrown side of the Santa Susana fault. This fault has a very sinuous trace, with an average trend of about N. 60° W. on the southern slopes of the mountains. Only in the southeastern part of the area was the mapping extended far enough south to include the surface trace of the fault.

The Santa Susana fault dips gently northward near the surface at most places, but at a few localities the fault surface is flat or even south-dipping. The fault dips steeply to the north at depth (Structure sections CD, EF, GH). It is not known whether it continues to dip steeply at greater depth, or if it flattens out again. Dissimilar stratigraphic sections on either side of the fault indicate a northward flattening as well as considerable movement along it. Leach (1948) suggests 5 miles and Hazzard (1944) a minimum of one and one-half miles of movement. Near Bee Canyon, the fault trace curves toward the northeast, suggesting that this segment may be a tear 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 pre-Cretaceous and Pliocene rocks into contact. The outlier of crystalline rocks east of Grapevine Canyon is believed to be 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 developed 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 (Structure section IJ), a reverse fault which dips steeply toward the northeast, truncates the Pico anticline on the west. 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 the Newhall Potrero it is postulated that it terminates against an east-trending fault in the Potrero.

Folds

From Salt Canyon eastward, the general northerly dip of the strata above the Santa Susana fault is disrupted by the Pico anticline and the paralleling Oat Mountain syncline (Structure sections CD, EF, GH). The Pico anticline is even-crested along most of its extent. Its axial plane is nearly vertical in exposures in the canyon bottoms, but south-dipping 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 field (Structure section IJ) is represented at the surface only by a broad structural terrace in the central part of the field changing toward the northwest to a northwest-plunging nose. No unconformity is known by which the marked difference in surface and subsurface structure can be explained. The steep south limb of the structure may be caused by a fault in the subsurface. Although steep dips on the divide between Pico Canyon and Newhall Potrero 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.

AREA NORTH OF SANTA CLARA RIVER AND SOUTH OF SAN GABRIEL FAULT

Faults

The Del Valle and Holser faults are two of the most important structural features in the area north of the Santa Clara River. 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 east-trending part of the fault trace is a south-dipping, reverse fault (Structure section KL); the south-trending part of the fault trace is interpreted to be a tear fault.

On the geologic map (Plate I) these two parts 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 prominent south-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 (Structure sections EF, GH, IJ). The Holser fault is inferred to intersect the San Gabriel fault each of Saugus. Subsurface data in the Del Valle and Ramona fields demonstrate that the Holser fault is a south-dipping, rather sharply folded reverse fault (Structure section KL). It is offset by cross-faulting in at least one place near the east boundary of section 9, T. 4 N., R. 17 W.

Folds

Folds in the vicinity of the Ramona and Del Valle oil fields (Structure sections AB, KL) trend eastward, plunge gently eastward, and have essentially vertical axial planes. The easterly trend of the folds changes to a southeasterly trend where they cross the Santa Clara River.

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

Pliocene rocks in the vicinity of Newhall and San Fernando Pass have a regional dip to the west. South-dipping thrust and reverse faults have deformed these strata into gentle, west-plunging folds. Legion fault and Beacon fault are local names commonly used by geologists for two of these faults. The Legion fault is named for its exposure behind the American Legion Hall east of Newhall, and the Beacon fault for its exposure near an airway beacon in San Fernando Pass.

The Legion fault, which is the northermost of these reverse faults (Structure section CD), is exposed about one mile east of Newhall. Most of the extent of the fault is 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 a thrust fault that dips about 30° southward at the surface along the eastern part of its trace (Structure section CD), but apparently steepens to the west. At its eastern 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 changes its strike from west-northwest to nearly north. Both the Weldon and Beacon faults are believed to steepen at depth. The pre-Pliocene stratigraphy in the subsurface on either side of the Weldon fault is very dissimilar (Structure section CD). Wells drilled south of the fault found a thick section of the Modelo formation, while north of the fault the Modelo formation is practically absent. This contrast in the thickness of the Modelo formation could be explained by the presence of a strike slip fault along which there has been a large displacement, most probably in a left-lateral sense. Although many small west-northwest-trending faults are exposed in Weldon and Gavin Canyons (some of which have horizontal slickensides), none of these appears to have a displacement large enough to account for the marked differences in the stratigraphy in this area. It is possible, however, that different pre-Pliocene stratigraphic sections may have been brought together along a strike-slip fault whose movement was chiefly pre-Pliocene.

The nature and age of movements along the Whitney Canyon fault are not definitely known. No Eocene rocks are present east of this fault. However, the Continental Oil Co. Phillips No. 1 well drilled only 1,600 feet west of the surface trace of the fault, penetrated a very thick section of Eocene rocks at a depth of 7,911 feet (Structure section AB). The difference in depth to crystalline rocks on either side of the fault indicates a vertical displacement along it of about 6,000 feet. The base of the Pliocene section, however, has a vertical displacement of only about 400 feet across the fault, and in the opposite sense from the displacement of the top of the crystalline rocks. From this evidence it seems probable that the Whitney Canyon fault had at least two periods of activity; post-Pliocene movement, mainly dip-slip as evidenced by the similarity in thickness and facies of the Pliocene rocks on opposite sides of the fault, and pre-Pliocene movement, which may have been either dip-slip or strike-slip.

SAN GABRIEL FAULT AND AREA NORTH OF IT

The San Gabriel fault is a major right-lateral, strike-slip fault which trends in a northwesterly direction across the northeastern part of the area. The pre-Pliocene stratigraphic sections on opposite sides of the fault are quite different (Structure sections CD, EF). The Miocene rocks south of the fault are marine, but those north of it are chiefly non-marine. The Pliocene rocks, however, particularly the Saugus formation, are similar on both sides of the fault. Although the post-late Miocene movement along the San Gabriel fault may have been quite large (Crowell, J. C. 1952a), the major movement occurred before the deposition of the Saugus formation. The trace of the fault through the Saugus formation is simply a zone of abnormally steep dips and minor faults and fractures.

South of the Santa Clara River, the Mint Canyon formation is compressed into a number of tight folds (Structure section CD). 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 northeast-trending fault may be present beneath the valley. This would be a pre-Saugus fault, since no evidence of it was found in exposures of the Saugus formation.

The Saugus formation north of the San Gabriel fault is warped into a number of broad folds (Structure section EF). The trend of some of these is at variance with the regional trend of folds.

G E O L O G I C   H I S T O R Y

Fundamental to an understanding of the geologic history of very nearly 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 depositional province northeast of the fault appears to have followed a course of development more or less independent of the province southwest of the fault until late Tertiary times, when movements along the fault began to unite the two provinces into one.

The earliest event in the region for which there is a record in the rocks was the deposition of the Placerita formation, which was later intruded by the Rubio diorite. Both of these formations were metamorphosed and then intruded at some later time, but before Late Cretaceous time, by granitic rocks.

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 may have extended across the mapped area also. Middle or late Eocene seas did definitely cover the area south of the San Gabriel fault, and in those seas were deposited several thousands of feet of sandstone, siltstone and conglomerate. Graded beds suggest that turbidity currents may have been operative in transporting and depositing sediment.

In Ventura basin deposition of non-marine variegated strata of the Sespe (?) formation followed withdrawal of the Eocene seas. Whether a period of erosion may have intervened between the marine and non-marine periods of deposition is not clear, nor is it known for how long non-marine deposition continued. Beds of montmorillonitic clay in the non-marine strata suggest volcanic activity accompanied by ash falls.

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

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

Deformation northeast of the San Gabriel fault during the time between the close of Vasquez deposition and the early part of the Miocene epoch is recorded by the angular unconformity at the base of the Tick Canyon formation. The deformation in the Simi Hills area and in the area of Vasquez deposition 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 the Tick Canyon and the Topanga (?) formations reduce this correlation of tectonic activity in the two regions to speculation.

Non-marine conditions of deposition prevailed in the area northeast of the San Gabriel fault during deposition of the Tick Canyon formation. The region southwest of the fault was at least in part in a marine environment because lower Miocene marine deposits of the Vaqueros formation are present near the fault a few miles northwest of Castaic. Early Miocene seas probably did not, however, cover much of the mapped area.

The generally coarse texture of the Topanga (?) formation suggests nearby land masses as source areas, but the local paleogeography of middle Miocene times is obscure. The sea probably covered the Simi Hills area, but deposition there was very slow relative to the Santa Monica Mountains area to the south and Ventura basin to the north. Middle Miocene seas extended eastward through the San Fernando Pass area to the Sunland area, but how far northward the sea spread is not known. Fine-grained marine strata assigned to the Rincon formation, a part of which is equivalent in age to the Topanga (?) outcrops in the Santa Susana Mountains. The Topanga (?) may grade laterally into these finer-grained beds in the subsurface. Minor eruptions of basalt accompanied Topanga (?) deposition in the Aliso Canyon area.

Topanga (?) deposition was followed by tilting and erosion, at least in the Aliso Canyon area, perhaps reflecting renewed uplift in the Simi Hills area. Deposition may have been continuous in areas farther north in 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 marks the near-shore deposits in this sea. Either the Luisian seas were quite widespread and the Santa Susana Mountains area was far from land, or else possible nearby lands 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 main elements in the geography of the region at that time are thought to be these (see figure 30): 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 Ventura, through the Fillmore and Piru areas into the Santa Susana Mountains area. South of this trough was the Simi Hills-Oak Ridge high, which even if not actually emergent was not an area receiving important amounts of sediment. North of the trough, perhaps 10 miles north of the Del Valle oil field, was a land area that was probably contributing detitus to the northern part of the basin. A fairly steep submarine slope bordered the basin from the Newhall area northward through Saugus, where the trend of the slope may have swung northwestward to become parallel to the present San

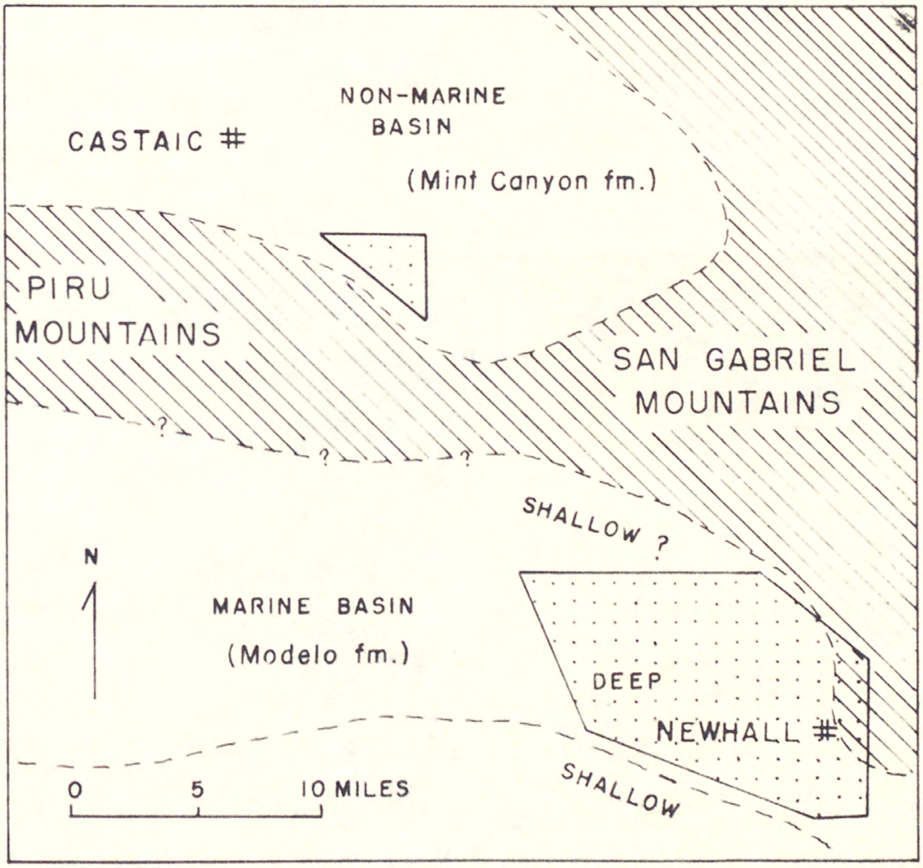


FIGURE 30. Paleogeography of beginning of late Miocene time, eastern Ventura Basin. Ruled area, land; stippled areas shown on geologic map, Plate I.

Gabriel fault.

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

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

Movements along the San Gabriel fault apparently began at least as long ago as the early late Miocene (Mohnian) and exerted a strong influence on sedimentation during much of the later Tertiary period. During late Miocene time, after deposition of the Mint Canyon formation, the sea spread northeastward across the former barrier between the Ventura basin and the basin of Mint Canyon deposition (see figure 31). In the shallow basin northeast of the fault was deposited sand and silt that now constitute the Castaic formation. Near the active fault northwest of Castaic very coarse gneissic breccias accumulated, possibly as talus slides at the base of steep scarps. On the opposite side of the fault, and many miles farther southeast, coarse gravel accumulated near the submarine slope leading from the shoreline near the fault down into the deeper waters of the Ventura basin. Occasionally sand and gravel were carried far out into the basin by undersea slides and turbidity currents. All through the remainder of the Miocene epoch and

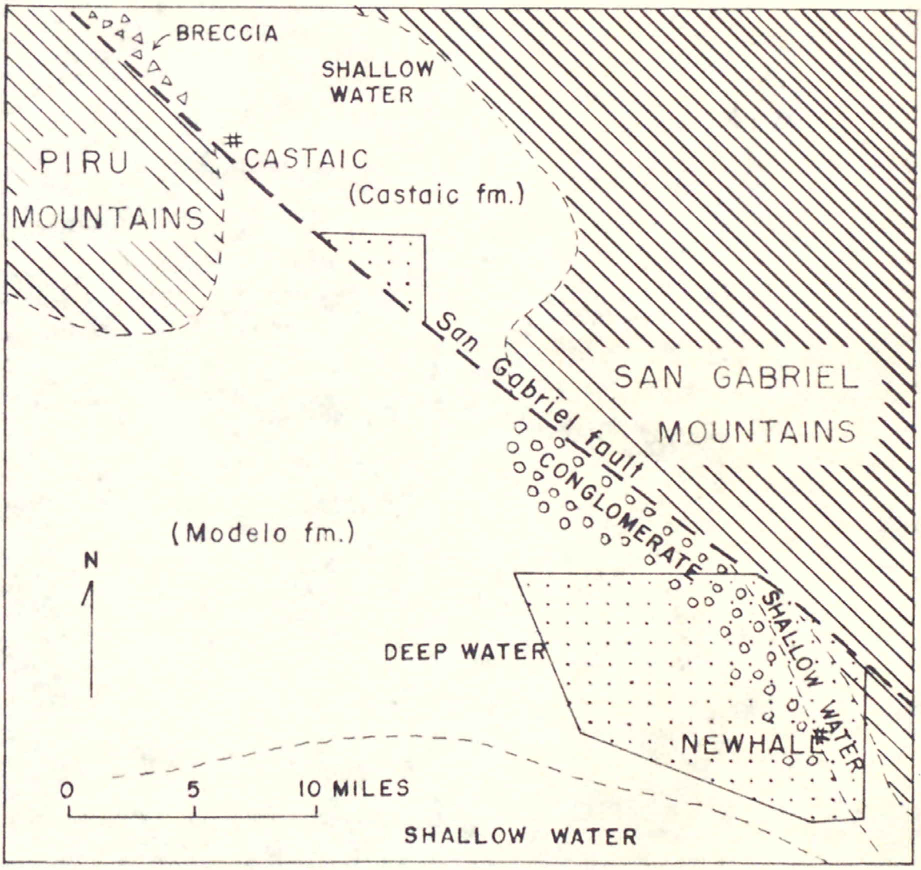


FIGURE 31. Paleogeography of part of late Miocene (late Mohnian) time, eastern Ventura Basin. Ruled areas, land; stippled areas shown on geologic map, Plate I.

probably through most of the Pliocene lateral movement along the fault continued. Vertical movements along this or other nearby faults kept the land areas high enough so that coarse material was nearly always being brought to the sea by streams. Near the close of the Miocene the area close to the fault was probably uplifted and the Castaic formation was partly eroded, 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 seas extended not only into the region northeast of the 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 were laid down 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 so that the basin gradually became more shallow. Near the margins of the basin shallow-water marine environments were gradually replaced by lagoonal and estuarine environments and then by fluviatile conditions. The shore line was pushed farther and farther westward until finally fluviatile deposition prevailed over the entire area. Subsidence and deposition continued through the Pliocene and perhaps into the early Pleistocene epoch.

At about the middle of the Pleistocene epoch the entire Ventura basin -- in fact almost the whole 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 even today.

Following the orogenic episode the region began to be uplifted slowly. Erosion surfaces were carved during the uplift and locally stream terrace gravels were deposited on these surfaces.

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For Release NOVEMBER 13, 1956

REPORT ON IMPORTANT CALIFORNIA OIL-PRODUCING AREA RELEASED

Exploration for oil in the region near Newhall, Los Angeles County, Calif., will be aided by a new geologic report placed on file for public inspection by the Geological Survey of the Department of the Interior.

It was explained today that the report discusses an area of approximately 125 square miles lying on the north flank of the Santa Susana Mountains, the west flank of the San Gabriel Mountains, and in part of the Santa Clara River Valley in the vicinity of Newhall. The accompanying geologic map, on a scale of 1:12,000 (about 5 inches equal 1 mile), is compiled on a topographic base. The oldest rocks in the area are pre-Cretaceous igneous and metamorphic rocks. These are exposed in the western San Gabriel Mountains. Six sedimentary formations that range in age from Eocene to Pleistocene are shown on the geologic map. These units, together with two additional subsurface formations, also are shown on six accompanying structure sections.

Particular emphasis is given to two formations containing beds of conglomerate and sandstone with microfossils and sedimentary structures that indicate deposition by submarine turbidity currents in water more than 1,000 feet deep. Such coarse-grained sediments are commonly thought to be deposited only in shallow water. Several productive oil pools occur in the coarser grained parts of these deep-water formations.

The report, titled "Geology of southeastern Ventura Basin, Los Angeles County, California," by E. L. Winterer, is available for public inspection at the following Geological Survey offices: Library, Room 1033, General Services Administration Building, Washington, D. C.; 1031 Bartlett Building, Los Angeles, Calif.; and 724 Appraisers Building, San Francisco, Calif.

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