Ground-water Geology of the Coastal Zone Long Beach-Santa Ana Area, California

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1109

Prepared in cooperation with the Orange County Flood Control District, the Orange County Water District, the Los Angeles County Flood Control District, and the Board of Water Commissioners of the city of Long Beach, all of California

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By J. F. POLAND, A. M. PIPER, *and others*

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CONTENTS

ILLUSTRATIONS

[All plates in pocket]

CHART

TABLES

GROUND-WATER GEOLOGY OF THE COASTAL ZONE, LONG BEACH-SANTA ANA AREA, CALIFORNIA

By J. F. Poland, A. M. Piper, and others

ABSTRACT

This paper is the first chapter of a comprehensive report on the ground-water features in the southern part of the coastal plain in Los Angeles and Orange Counties, Calif., with special reference to the effectiveness of the so-called coastal barrier—the Newport-Inglewood structural zone—in restraining landward movement of saline water.

The coastal plain in Los Angeles and Orange Counties, which covers some 775 square miles, sustains a large urban and rural population, diverse industries, and intensive agricultural developments. The aggregate ground-water withdrawal in 1945 was about 400,000 acre-feet a year, an average of about 360 million gallons a day.

The dominant land-form elements are a central lowland plain with tongues extending to the coast, bordering highlands and foothills, and a succession of low hills and mesas alined northwestward along the coastal edge of the central lowland plain. These low hills and mesas are the land-surface expression of geologic structure in the Newport-Inglewood zone.

The highland areas that border the inland edge of the coastal plain are of moderate altitude and relief; most of the ridge crests range from 1,400 to 2,500 feet in altitude, but Santiago Peak in the Santa Ana Mountains attains a height of 5,680 feet above sea level. From these highlands the land surface descends across foothills and aggraded alluvial aprons to the central lowland, Downey Plain, here defined as the surface formed by alluvial aggradation during the post-Pleistocene time of rising base level.

The Newport-Inglewood belt of hills and plains (mesas) has a maximum relief of some 500 feet but is widely underlain at a depth of about 30 feet by a surface of marine planation. As initially formed in late Pleistocene time that surface was largely a featureless plain. Thus the present land-surface forms within the Newport-Inglewood belt measure the earth deformation that has occurred there since late Pleistocene time and so are pertinent with respect to structural features that influence the watertightness of the so-called coastal barrier.

The hills and mesas of the Newport-Inglewood belt are cut by six gaps through which tongues of the central lowland extend to the coast. The gaps are trenched in the deformed late Pleistocene surface and are floored with alluvium that is highly permeable in its lower part. The Long Beach-Santa Ana area, with which this report is concerned, encompasses the central and eastern segments of the coastal plain, and includes five of the gaps in succession from northwest to southeast: Dominguez, Alamitos, Sunset, Bolsa, and Santa Ana Gaps.

In the Long Beach-Santa Ana area a thick sequence of Quaternary and Tertiary sedimentary rocks has been deposited on a basement of metamorphic and crystalline rocks of pre-Tertiary age. In the broad syncline underlying the central part of Downey Plain these sediments probably exceed 20,000 feet in thickness. This report pertains chiefly to the geology and water-bearing character of the rocks that underlie the coastal zone of the Long Beach-Santa Ana area. This

area extends some 27 miles from Dominguez Hill on the northwest to Newport Beach on the southeast, has an average width of about 6 miles, includes some 180 square miles, and borders the Pacific Ocean.

Of the Quaternary deposits the youngest are of Recent age and comprise silt, sand, gravel, and clay, chiefly of fluvial origin; they are the latest contributions to the alluvial cones of the Los Angeles, San Gabriel, and Santa Ana Rivers; their thickness is as much as 175 feet. The upper division of the Recent deposits, largely fine sand and silt of low permeability, commonly furnishes water only to a few wells of small yield; the lower division is coarse sand and gravel deposited chiefly in two tongues extending respectively, from Whittier Narrows through Dominguez Gap and from Santa Ana Canyon through Santa Ana Gap. These tongues, designated in this report the Gaspur and Talbert water-bearing zones, range from 40 to 100 feet in thickness and from 1 to 6 miles in width; they yield water freely to numerous wells with individual yields from a few hundred to more than 1,000 gallons a minute. It is estimated that the aggregate withdrawals for all uses from the Gaspur and Talbert zones in 1945 was about 25,000 acre-feet a year each.

The Pleistocene deposits which underlie nearly all the Long Beach-Santa Ana area consist of interfingered beds of sand, gravel, silt, and clay. In downward succession they include a capping terrace deposit, the Palos Verdes sand, certain unnamed late Pleistocene deposits, and the San Pedro formation of early Pleistocene age. They range in thickness from about 200 to 1,000 feet along the coast, and 20 to 900 feet under the hills and gaps of the Newport-Inglewood zone and attain maximum thickness of about 3,000 feet beneath the central part of Downey Plain. In general, the San Pedro formation occupies from 75 to 90 percent of the Pleistocene section. The deposits of late Pleistocene age, which cap the hills and mesas of the Newport-Inglewood belt of hills and underlie Downey Plain at depths of as little as 100 feet, comprise silt, clay, sand, and some gravel, chiefly of fluvial but in part of lagoonal and marine origin. They range in thickness from a thin edge to about 700 (?) feet. The beds of gravel and sand hold confined water and supply many small domestic and stock wells and a few larger irrigation wells. The San Pedro formation, which embraces all strata of early Pleistocene age, underlies the deposits of late Pleistocene age and, locally at least, is unconformable with them and with the underlying sediments of late Pliocene age. It is essentially correlative with the type San Pedro sand, Timms Point silt, and Lomita marl, but is much thicker and more heterogeneous. In this report the Timms Point silt and Lomita marl are discussed as the two basal members of the formation; they occur locally on the east flank of the Palos Verdes Hills and northeast of Signal Hill where they are as much as several hundred feet thick.

The San Pedro formation is of diverse physical character within the extent of the coastal zone. In Los Angeles County west of the San Gabriel River it is composed largely of sand and gravel of marine and littoral origin, especially in the lower two-thirds of the formation; the remaining upper part is silt, clay, and fine sand. Here the sand-and-gravel member within the San Pedro formation is so extensive and so productive to wells that it is designated in this report the Silverado water-bearing zone. In the Long Beach area the Silverado zone underlies some 68 square miles, or 43,000 acres, and has a thickness of 300 to 500 feet in nearly all that area. It supplies many industrial and municipal wells with individual yields of 1,000 to as much as 4,000 gallons a minute. In 1941 the withdrawal from the Silverado zone in the Long Beach area was 30,000 to 35,000 acre-feet a year. Along the inland edge of the coastal zone in Los Angeles County the Silverado zone fingers out northward into lagoonal sediments that are predominantly silt and clay. In Orange County the deposits of Pleistocene age are chiefly of the San Pedro formation. They are heterogeneous, composed of about equal proportions of permeable sand and gravel and impermeable silt and clay. The thickness of these deposits in Orange County ranges from about 20 feet at the south edge of Newport Mesa to as much as 900 feet beneath Sunset Gap. The most persistent and prolific water-bearing zone within the Pleistocene deposits of Orange County underlies most of the central and northern part of Newport Mesa where it is 200 to 500 feet thick and yields as much as 2,000 gallons a minute to single wells. An analogous zone underlies Huntington Beach Mesa. Elsewhere the aquifers commonly are dispersed among beds of low permeability and are less than 100 feet thick; nevertheless, they supply many irrigation and some municipal wells whose yield ranges from a few hundred to 1,500 gallons a minute. From all the Pleistocene deposits of the coastal zone in Orange County the withdrawal in 1941 is estimated at about 15,000 acre-feet a year.

Consolidated rocks of Pliocene and Miocene age underlie the Quaternary deposits in nearly all the Long Beach-Santa Ana area. The Pliocene comprises the Pico formation above and the Repetto formation below. The Pico formation has been subdivided into upper, middle, and lower divisions. The upper division, comprising semiconsolidated sand, silt, and clay members of marine origin, is about 1,800 feet thick and contains essentially fresh water. In most of the coastal zone the upper few hundred feet are not water bearing, but the lower 600 to 1,000 feet include several members of sand. The productivity of these sand layers is not known but might be several hundred gallons of water a minute to a single well. Hence the upper division of the Pico formation affords a large reserve supply of essentially fresh water now virtually untapped.

The middle and lower divisions of the Pico formation, the Repetto formation, and the rocks of Miocene age, which are at least several thousand feet thick under all the Long Beach-Santa Ana area, are largely siltstone and shale of low permeability. Their sand members contain only saline waters ranging from about half to the full salinity of ocean water. In nearly all the area these rocks are far below the depths penetrated by water wells.

The thick succession of sedimentary rocks underlying the coastal plain has been deposited in a broad synclinal depression that includes several local structural features whose axes are roughly parallel and trend northwest. The most extensive of these is the Newport-Inglewood structural zone, a composite belt of anticlinal folds and echelon faults. In effect it divides the coastal plain into two synclinal troughs: to the northeast a broad syncline that underlies Downey Plain and extends from Hollywood to and beyond Santa Ana, to the southwest a narrow syncline that extends from Santa Monica to Long Beach. Within the Newport-Inglewood zone and the flanking troughs all rocks older than the alluvial deposits of Recent age have been warped and locally ruptured by deformation developed successively since at least late Miocene time. Much of this deformation occurred in Pleistocene time—largely in mid-Pleistocene, but also in late-Pleistocene (post-Palos Verdes) or Recent time—to form the present topographic relief along the structural zone.

The recurrent structural activity along the Newport-Inglewood zone has produced both folds and faults which are critical with respect to inland movement of ocean water. The folds determine the depths to impermeable rocks of upper Pliocene age in the core of the zone; ocean water must pass above this lip in order to reach the productive water-bearing zones farther inland. From Dominguez Hill southeast to San Gabriel River the estimated depth of this lip is 400 to 700 feet below sea level, except at Signal Hill where it is as much as 200 feet above sea level; southeastward in Orange County it increases to 900 feet below sea level in Sunset Gap and then rises gradually to sea level beneath Newport Mesa. Within the coastal zone a nearly continuous set of faults is alined along the crest of the Newport-Inglewood zone. These faults displace the permeable deposits of Pleistocene age and so produce structural traps. In many places they have been cemented, largely by calcium carbonate. The structural traps and zones of cementation, together with lithologic discontinuities, have developed a substantial barrier which along much of the reach from Dominguez Gap to Santa Ana Gap greatly impedes but does not wholly prevent movement of water across the Newport-Inglewood zone in the permeable rocks of Pleistocene age. Little barrier effect, if any, has been developed in the tongues of Recent age that lie athwart the structural zone.

In general at least three distinct bodies of ground water exist in the Long Beach-Santa Ana area; in downward succession they are a semiperched body of water which occurs at shallow depth, commonly less than 50 feet below land surface; the principal body of naturally fresh ground water, which occupies the coarser water-bearing zones of Recent age, the deposits of Pleistocene age, and the upper division of the underlying Pico formation; and a body of saline connate water which occurs in rocks of Tertiary age beneath the whole area.

The semiperched body is essentially unconfined, is generally inferior in quality, and supplies relatively few water wells of small capacity.

The principal body of fresh ground water has its base 800 to 2,600 feet below sea level along the crest of the Newport-Inglewood zone but extends to depths as great as 8,000 feet beneath the central part of Downey Plain. It is tapped by several thousand wells ranging in depth from less than 50 to about 1,700 feet; about two-thirds of their aggregate yield is for irrigation and the remainder for domestic and industrial use. The waters of this body, as tapped by wells, commonly contain less than 25 parts per million of chloride. The sediments containing the body of fresh ground water are largely of marine origin, however, and so initially were saturated with ocean water. This saline water was displaced by fresh water, chiefly before or during mid-Pleistocene time, or before the barrier features had been developed in the Pleistocene deposits along the Newport-Inglewood zone. The fresh-water body is effectively confined between impermeable layers of silt and clay, except in permeable reaches of San Gabriel River and Rio Hondo downstream from Whittier Narrows, and of Santa Ana River downstream from Santa Ana Canyon. Here most of the replenishment occurs by infiltration from the river channels, but some is derived from underflow and by deep penetration of irrigation water and rain. Circulation was wholly oceanward under natural conditions but was restrained sufficiently by confining strata and by the barrier of the Newport-Inglewood zone to produce an area of flowing wells for as much as 12 miles inland from the structural zone. Heavy withdrawals and declining water levels have dissipated the head and at times have developed a landward gradient over a substantial part of the coastal plain. As a result saline encroachment has moved a few miles landward in the permeable aquifers of Recent age in Dominguez and Santa Ana Gaps.

The extent, character, and source of this contamination, and the hydrologic evidence relating to the barrier features of the Newport-Inglewood zone, are discussed in succeeding chapters of the comprehensive report.

INTRODUCTION

SCOPE OF THE INVESTIGATION

This interpretative paper is essentially the first chapter of a comprehensive report on an investigation of a part of the coastal plain in Los Angeles and Orange Counties, Calif. This investigation has been carried out by the Federal Geological Survey in cooperation with four local agencies: the Los Angeles County Flood Control District, the Orange County Flood Control District, the Orange County Water District, and the Board of Water Commissioners of the city of Long Beach.

The specific objective of the investigation is the determination of conditions that have given rise to four critical questions: (1) to what degree is the so-called coastal barrier effective in restraining deterioration of the quality of the ground-water supply by incursion of ocean water; (2) is the known deterioration in ground-water quality locally along the coast being aggravated progressively owing to the incursion of ocean water, connate waters or oil-well brines, industrial wastes, or other waters of high concentration; (3) can withdrawals of ground water for the many requirements of the area be continued freely and indefinitely without the present areas of salt-water contamination extending substantially; (4) to what degree are remedial or preventive measures feasible.

These questions are critical because developments in and adjacent to the area—a great metropolitan district of some 2,000,000 people, diversified industries, and extensive agricultural districts—are dependent to a very great degree on water withdrawn from wells. In 1945 water so derived satisfied fully three-fourths of the requirements for all purposes in the whole coastal-plain area, except in the city of Los Angeles whose supply is imported principally from Owens Valley. The aggregate withdrawal of ground water within the coastal plain is approximately 400,000 acre-feet a year, an average of about 360,000,000 gallons a day.

The objective of the investigation has been approached by an intensive study of all pertinent features in a coastal zone that extends from Dominguez Hill on the northwest to Newport Mesa on the southeast, spans the areas of most pressing deterioration in water quality, and covers some 180 square miles; and by a general study of certain selected features in the coastal-plain area that extends inland to the bordering mountains or foothills and covers some 380 square miles. Facts from the intensive and general studies have been largely released to the public. (*See* Piper, Poland, and others, 1942, 1943; Poland and others, 1942; Garrett and others, 1943; Meinzer, Wenzel, and others, 1944, p. 77–169; Poland, Sinnott, and others, 1945.)

The whole area of both coastal and inland zones, which together cover some 560 square miles, is here designated the "Long Beach-Santa Ana" area. Its location is shown in figure 1, and some of its general features are shown on figure 2.

The cooperative investigation is concerned primarily with a problem of water quality but in one aspect fundamentally with the water-tightness of the longshore barrier. Hence it is concerned with features of stratigraphy and geologic structure that determine the extent and continuity of water-bearing materials in and adjacent to the barrier and with the land forms of the area in which certain of the stratigraphic and structural features are expressed. These pertinent geologic features are discussed in this report, which deals largely with the coastal zone of the Long Beach-Santa Ana area but of necessity is extended to cover certain broad features of the inland zone of that area and of the contiguous region.

Particular study of the geologic features of the area was begun in July 1940 and was essentially completed in June 1943. Owing in part to conditions of the war it has been carried on successively by

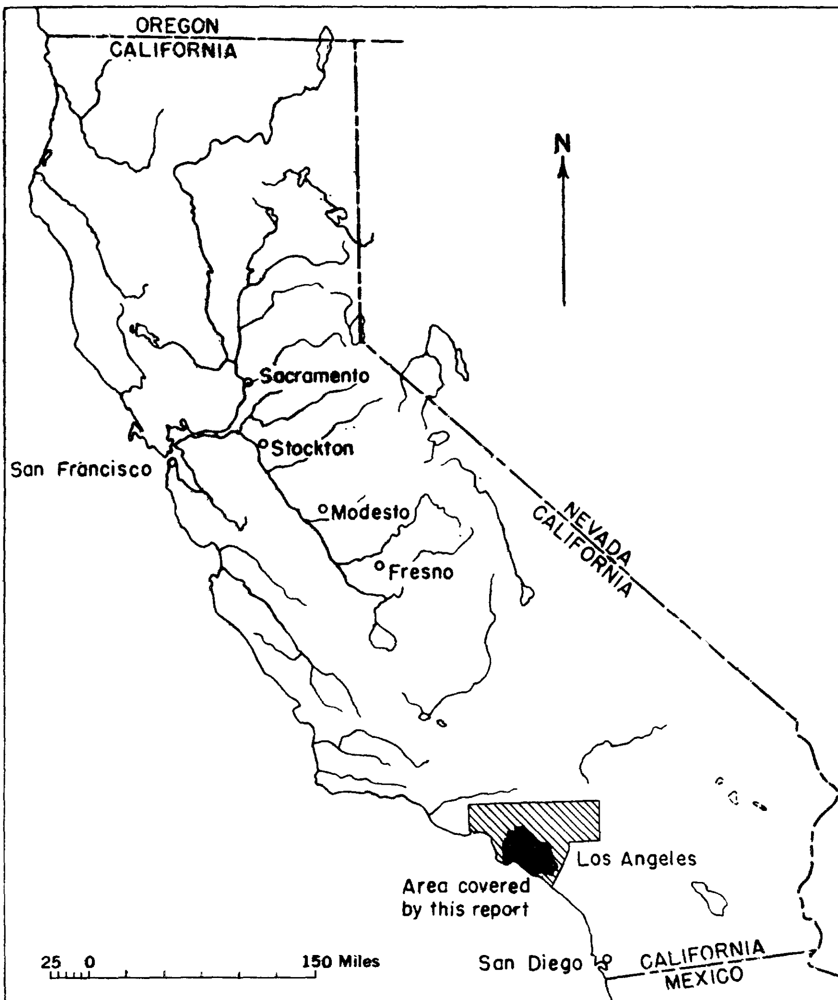

FIGURE 1.—Map of California showing area covered by this report and that covered by figure 2.

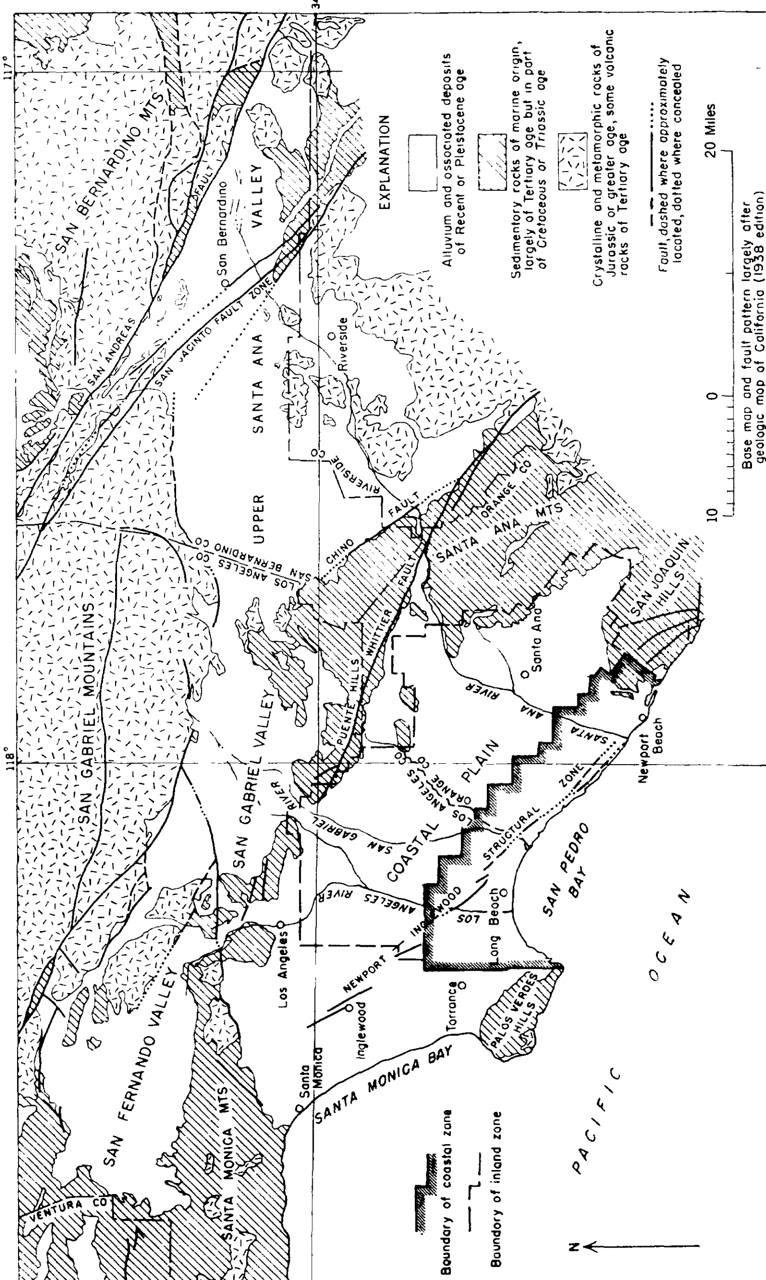

FIGURE 2.—Generalized geologic map of the coastal plain and contiguous areas in Los Angeles and Orange Counties, Calif.

J. F. Poland, R. C. Newcomb, and W. W. Paulsen. Newcomb and Paulsen each prepared a draft of a report prior to his detachment for military service, but neither of these drafts covered the full scope of the geologic studies. To the report in its present form substantial contributions have been made by J. F. Poland, A. M. Piper, and Allen Sinnott.

This report was written in 1944 and was first released to the public in 1945, in duplicated form. Publication has been delayed, first by conditions resulting from World War II and later by the decision to wait until the revised topographic sheets of the area became available for the base map. The last of these was supplied in December 1952.

ACKNOWLEDGMENTS

In the investigation of the geologic features of the relatively small area covered by this report considerable assistance has been drawn from numerous and diverse sources. Broad features of the area and its vicinity are covered in the published reports by Mendenhall (1905a, 1905b, 1905c, 1908) on work in 1903 and 1904 and by Eckis (1934) in 1930–34. Critical discussions of specific features by numerous geologists have been published and these are cited where pertinent. Substantial contributions of critical information have been made by several oil companies through certain geologists and paleontologists: by the Associated Oil Co. through A. S. Diven; by the Bankline Oil Co. through E. V. Bartosh; by the Continental Oil Co. through R. M. Barnes, Glenn Bowes, and W. D. Rankin; by the General Petroleum Corp. through E. C. Edwards and P. H. Gardett; by the Hilldon Oil Co. through C. G. Willis and Robin Willis; by the Hogan Petroleum Co. through Dana Hogan; by the Ohio Oil Co. through G. P. Gariepy; by the Richfield Oil Corp. through H. W. Hoots, M. L. Natland, and P. H. Dudley; by the Shell Oil Co., Inc., through Alex Clark, Frank W. Bell, G. C. Kuffel, and A. W. Gentry; by the Signal Oil and Gas Co. through Harry Godde and L. H. Metzner; by the Standard Oil Co. of California through W. S. W. Kew, R. G. Reese, and H. L. Driver; by the Texas Co. through Hampton Smith and A. I. Gregersen; by the Union Oil Co. through S. G. Wissler and K. M. Bravinder; and by the Western Gulf Oil Co. through R. W. Clark. Special acknowledgment is due S. G. Wissler and M. L. Natland, who have assisted greatly through discussions of stratigraphic problems and who have kindly undertaken the microfaunal examination of critical suites of samples from water wells.

Certain of the stratigraphic problems were discussed with W. W. Woodring, who also furnished paleontologic data from a critical outcrop.

Other geologists, paleontologists, and engineers who have furnished information are C. R. Browning, R. H. Garrison, P. P. Goudkoff, U. S. Grant 4th, R. H. Moran, F. S. Parker, E. R. Stanley, H. P. Stolz, Read Winterburn, and H. P. Vail.

Some of the information so received is cited in the body of this report as pertinent; much more was made available in confidence, but by arrangement it is not specifically cited although it affords the fundamental basis for certain interpretations of data otherwise obtained.

Drillers' records for many water wells were compiled and made available by the California Division of Water Resources. Some 300 additional logs have been made available by many individuals and organizations, chiefly by the Orange County Flood Control District, the San Gabriel Valley Protective Association, the Water Department of the city of Long Beach, the Southern California Edison Co., Inc., the Western Gulf Oil Co., the city of Signal Hill, and the Corps of Engineers, U. S. Army.

Electric logs for oil wells in the Wilmington area were supplied by the Board of Harbor Commissioners of the city of Long Beach through F. J. Hardesty and by the Los Angeles County Flood Control District through Paul Baumann.

The geologic features of the structural zone and of the entire coastal zone of the Long Beach-Santa Ana area have been studied partly in three-dimensional perspective by a peg model of all water wells for which logs were available, and of certain oil wells for which electric logs were made available through the courtesy of oil companies. These electric logs afford much of the basis for correlation of the deeper fresh-water-bearing beds and a material basis for fairly explicit interpretation of the structure of these beds within the area. They also furnish specific information on the depth to the zone of saline connate water that underlies the fresh-water zone throughout the area. This peg-model study proved to be highly effective in amplifying the usual field methods of geologic mapping.

NUMBERS APPLIED TO WELLS BY THE GEOLOGICAL SURVEY

In its cooperative program in Los Angeles and Orange Counties the Geological Survey has designated wells by numbers that indicate the respective locations according to rectangular land surveys. For example, for well 5/10–13B7, the first part of the Geological Survey number indicates the township and range—T. 5 S., R. 10 W., San Bernardino baseline and meridian—the digits following the hyphen indicate the section, as sec. 13, and the letter indicates the 40-acre subdivision of the section shown on the accompanying diagram.

Within each 40-acre tract the wells are numbered serially as indicated by the final digit or digits of the number. Thus, well 5/10–13B7 is in the NW¼NE¼ sec. 13, and is the seventh well listed in that tract.

D	C	B	A
E	F	G	H
M	L	K	J
N	P	Q	R

The California Division of Water Resources and several local agencies have assigned serial and location numbers to water wells in an extensive district that includes the Long Beach-Santa Ana area. These two systems of numbers are explained, and cross references to corresponding Geological Survey numbers are given in an informal report heretofore released to the public (Piper, Poland, and others, 1942, p. 219–298).

The system of Geological Survey numbers is applied to all parts of the coastal plain. In the small parts of the area that once were public land the official Federal land survey is followed. In nearly all the remainder of the area, except the extensive Irvine Tract, the land is subdivided according to extensions of the Federal survey, so that the system applies readily. For a few small areas land lines are projected because no rectangular survey has ever been made. In some other areas, as within the city of Long Beach, the projected lines are shifted slightly to coincide with main roads.

The extensive Irvine Tract, the easternmost part of the area, is subdivided into blocks numbered serially 1 to 185; nearly all these blocks are rectangular and a mile square. For well I–123R1 in this part of the area the initial letter indicates the Irvine Tract, the digits following the hyphen indicate the block (No. 123), and the remainder of the number indicates the location of the well with respect to projected 40-acre subdivisions of the block corresponding to the 40-acre tracts in the standard section of land.

This system of numbers is also used as a convenient means of locating a feature described in the text. Thus, an area or feature within the NW¼NW¼ sec. 7, T. 5 S., R. 11 W., projected land lines, may be identified as 5/11–7D.

LAND FORMS OF THE COASTAL-PLAIN AREA

GENERAL FEATURES

The coastal plain in Los Angeles and Orange Counties, although small among the coastal plains of the world, is uncommon in the diversity of its land forms. Its elements are quite unlike in mode of development and complex in their genetic relation to one another. None the less these diverse forms express rather faithfully certain features of the stratigraphy and geologic structure by which the movement of ground water is determined; hence a general discussion of them is pertinent. The discussion is extended to all the coastal-plain area in the two counties because only in this way can the fundamental pattern of the forms be developed.

The dominant land-form elements are a central lowland plain with tongues extending to the coast, bordering highlands and their foothills, and a succession of low hills and mesas in alinement along the coastal edge of the main lowland plain. These alined hills and mesas are the land-surface expression of the Newport-Inglewood structural zone, the so-called coastal barrier with whose watertightness the Geological Survey is fundamentally concerned in the investigation here reported in part. All the land-form elements so far discriminated in the coastal-plain area are listed below according to a tentative genetic classification. The location and extent of each are shown on plate 1 in somewhat generalized fashion; details of their form are shown on the Geological Survey topographic maps of the region.

Tentative classification of land-form elements in the coastal-plain area of Los Angeles and Orange Counties

Bordering highlands—substantially of structural origin in mid-Pleistocene(?) time, moderate to bold in relief, and generally of mature form:
- Santa Monica Mountains.
- Puente Hills.
- Santa Ana Mountains.
- San Joaquin Hills.
- Palos Verdes Hills.

Inland foothills—of moderate relief, initiated about in mid-Pleistocene(?) time by uplift; substantially degraded in general in late Pleistocene time, locally planed and veneered with alluvium, then moderately deformed; some further dissection in Recent time:
- Elysian Hills.
- Repetto and La Merced Hills.
- Coyote Hills uplift and La Habra Basin.

Alluvial aprons adjacent to highlands and foothills—surfaces of aggradation considerably older than the central lowland plain, of late Pleistocene(?) and Recent age:
- Santa Monica Plain.
- La Brea Plain.
- Tustin Plain.
- Minor aprons, unnamed.

Newport-Inglewood belt of hills and plains—features formed chiefly by marine and adjacent continental planation, sedimentation, and deformation; all in latest Pleistocene and Recent(?) time:
- Pronounced uplifts along the axis:
  - Baldwin and Beverly Hills.
  - Rosecrans Hills.
  - Dominguez Hill.
  - Signal Hill uplift.
  - Landing Hill.
- Mesas and related plains:
  - Ocean Park Plain.
  - Torrance Plain.
  - Long Beach Plain.
  - Huntington Beach Mesa.
  - Bolsa Chica and Newport Mesas.

El Segundo sandhills—of late Pleistocene(?) and Recent age, in large part of eolian origin.

Downey Plain—the central lowland, of aggradational origin and Recent age.

BORDERING HIGHLANDS

The highland areas that form a discontinuous border along the inland edge of the coastal plain and the isolated Palos Verdes Hills at the coast are alike in that their land-surface profiles are largely smooth sweeping curves of moderate gradient with rounded crests and valleys. These features have been interpreted as elements of an old erosion surface (Eldridge and Arnold, 1907, p. 103), subsequently elevated and undoubtedly deformed by recurrent earth movements. Commonly these highlands terminate in slopes that pass into the adjacent plains without abrupt change of gradient, but at some places they terminate in or are transected by scarps of which some are known to be faultline scarps. The higher parts of the composite terranes are intricately gullied, and the lower parts sharply incised by the present drains. Nearly all parts have been considerably smoothed by slope wash and other materials that constitute a continental terrace cover.

In altitude the highlands range considerably. In the Santa Monica Mountains the main ridge crests are from 1,400 to 2,150 feet above sea level and in general are lower toward the east. (Hoots, 1931, pl. 16.) In the Puente and Palos Verdes Hills the greatest altitudes are about 1,780 and 1,480 feet, respectively. The Santa Ana Mountains include the highest summit along all the coastal-plain border, Santiago Peak, whose crest is about 5,680 feet above sea level.

On the two highland areas along the coast—the Palos Verdes Hills and the San Joaquin Hills—successive wave-cut terraces cover a wide range in altitude on the leeward slopes and to some extent on the windward slopes. On the Palos Verdes Hills (Woodring, Bramlette, and Kew, 1946) is an interrupted series of 13 such terraces, ranging from about 50 to 1,300 feet above present sea level. The lowest of these terraces is strikingly deformed; from about 50 feet above sea level in the vicinity of San Pedro it rises gradually around the eastern and northern flanks of the hills to about 400 feet opposite the western edge of Torrance Plain, from which it is separated by a scarplike feature 200 to 300 feet high and of structural origin. The succession of terraces and the relatively young but strongly deformed lowest terrace on the Palos Verdes Hills exemplify a characteristic feature in the progressive development of the highland areas, which have been uplifted recurrently into late geologic time and, although somewhat deformed within, commonly have been intensely deformed along their margins.

On the San Joaquin Hills, wave-cut terraces exist at 100, 200, 300, 600, and 900 feet above present sea level. The higher terraces have been almost completely destroyed by intricate gullying; the lowest or 100-foot terrace extends northward to pass beneath the edge of Downey Plain.

Composed very largely of nonpermeable rocks of sedimentary or metamorphic origin, except for slope wash and the relatively thin and discontinuous continental terrace cover, the highlands quickly shed much of the rain that falls on them. Essentially they are not functional intake areas and no substantial quantity of ground water is derived from them to sustain the withdrawals from the coastal-plain lowlands.

INLAND FOOTHILLS

The Elysian (Woodring, 1932, pl. 2), Repetto, and La Merced Hills are formed largely on rocks of Tertiary age, substantially degraded in the triangular area between the Santa Monica Mountains on the west, the Puente Hills on the east, and the San Rafael Hills on the north between Glendale and Pasadena, beyond the area shown on plate 1. Once probably continuous, an old land surface so formed has been transected by antecedent streams, two of whose channels now constitute major passes to the inland basins (see fig. 2); one of these passes is now occupied by the Los Angeles River, the other jointly by the Rio Hondo and the San Gabriel River. The surface has been further and intricately dissected by numerous minor streams, all of which are now ephemeral.

In these hills the principal crests occur in the northern part of the respective areas outlined on plate 1 and range between 600 and 800 feet above sea level. From these crests the land surface descends rather steeply southward and between 250 and 325 feet above sea level passes into a somewhat discontinuous alluvial apron.

Like the adjacent highlands the higher parts of the Elysian, Repetto, and La Merced Hills are formed on rocks that are substantially impermeable and quickly shed much of the rain falling on them. The frontal apron to the south doubtless is fairly permeable and in part probably constitutes an intake area from which some water is transmitted to the productive water-bearing zones beneath Downey Plain.

In its major form the remaining foothill unit, Coyote Hills and La Habra Basin, shown on plate 1 combines a canoe-shaped ridge, whose crest is somewhat nonlinear and convex southward, and a complementary elongate basin to the north. This general outer form is largely of structural origin and comprises an anticline, Coyote Hills uplift, and a syncline, La Habra Basin (Eckis, 1934, p. 217–223); it is, however, of composite origin. Its highest point on the crest of the Coyote Hills is some 600 feet above sea level. Northward it descends gradually to the axis of La Habra Basin, which is 275 to 300 feet above sea level, and then rises smoothly to the flank of the Puente Hills. Southward it descends fairly smoothly to a low bordering scarp whose altitude along the margin of Downey Plain is 120 to 325 feet above sea level.

The general outer form of the Coyote Hills is of composite origin. Recent work by Dudley (1943, p. 352) indicates that the area was sharply folded in mid-Pleistocene time; that lower Pleistocene rocks were stripped off in considerable thickness, at least 2,500 feet locally; and that a land surface of degradational origin was so formed by fairly late Pleistocene time. This degradational surface forms many of the higher elements of the present terrane. Locally, especially in the western part of the hills, the end product of degradation was a continental platform veneered by alluvium of late-Pleistocene age. Subsequently this late-Pleistocene surface apparently was warped into the present general form and transected by Coyote Creek and several other antecedent streams. All along their southern flank the hills are now intricately dissected by subsequent streams, all ephemeral. In at least the eastern half of La Habra Basin the surface has been only slightly modified by some gullying and by superposition of a few small alluvial fans; in the western half the deformed surface appears to plunge so gently beneath alluvium of Recent age that its extent in that direction is not determined precisely and can be shown only approximately on plate 1.

ALLUVIAL APRONS ADJACENT TO HIGHLANDS AND FOOTHILLS

Along the inland edge of the central lowland adjacent to the highlands and foothills are several surfaces of alluvial aggradation whose age and relation to other land-form elements are known only roughly. Distinctive among these are the Santa Monica and La Brea Plains along the flank of the Santa Monica Mountains westward from the Elysian Hills. The mountain's lower slope is a plexus of alluvial fans whose apexes range from about 450 to 600 feet above sea level along the flank of the Santa Monica Mountains to as low as 275 feet above sea level along the flank of the Elysian Hills. At its southern edge the slope is 75 to 200 feet above sea level. The alluvial forms of this area apparently were graded in at least two cycles. The earlier cycle is tentatively assigned to the late Pleistocene, partly on the basis of the well-known fauna from the Rancho La Brea tar pits (Merriam, 1911, p. 197–213; Stock, 1930) on its surface of aggradation. The later cycle is doubtless of the Recent epoch, as is shown by the mapping of Hoots (1931, pl. 16) and by the apparent overlap of its deposits onto the central lowland along the northern flank of the Ballona Gap (see pl. 1).

All the lower slope along the south flank of the Santa Monica Mountains has been designated by Hoots (1931, p. 130) the Santa Monica Plain. In this report, however, that name is restricted to the older of the two alluvial surfaces in the area westward from Beverly Hills, and the segment of the older surface between Beverly and Elysian Hills is designated La Brea Plain.

At the opposite extreme of the area, in the alcove between the Santa Ana Mountains and the San Joaquin Hills, the Tustin Plain discloses features largely analogous to those of La Brea Plain. Its northern lobe is the slightly gullied alluvial cone of Santiago Creek, which emerges from the Santa Ana Mountains nearly east of Anaheim. From its apex some 400 feet above sea level the surface of the cone descends at gradients ranging between 25 and 100 feet to the mile, and beyond Santa Ana it emerges with the central lowland at an altitude of 50 to 200 feet above sea level. The southeastern lobe of Tustin Plain is a complex of small alluvial fans that head along the flank of the Santa Ana Mountains at altitudes between 350 and 500 feet above sea level and coalesce into a slightly gullied plain that declines westward between 35 and 100 feet in a mile. At its western margin this plain of aggradation merges into the central lowland. To the southeast near the head of the alcove it passes into an intricately gullied terrain on rocks of Pleistocene age.

Although the surface of Tustin Plain doubtless is of Recent age it seems likely that most of the materials of which it is aggraded were placed during late-Pleistocene time and that the materials of Recent age constitute only a relatively thin mantle. In this respect it is believed essentially analogous to La Brea Plain. Tustin Plain does not appear to have been aggraded substantially by materials transported from the San Joaquin Hills which border it on the southwest.

Between La Brea and Tustin Plains along the inland border of the coastal plain are two moderately extensive aggraded areas inferred genetically distinct from the central lowland and from adjacent foothills. They lie, respectively, at the foot of Repetto and La Merced Hills, in the angle between the Los Angeles River and the Rio Hondo, and in a triangular alcove that transects the Coyote Hills due northeast of Anaheim. Both aggraded surfaces descend southward into the central lowland with only a faint change in profile, but rise northward to pass into land-form features distinctly older than the lowland. The easterly of the two surfaces is scarred by a few headward-cutting gullies.

Although having some features in common and discussed under a common topic heading these surfaces should not be construed as strictly contemporaneous and alike in origin. In their features as now known, La Brea and Tustin Plains appear to have been formed in much the same way and to be younger than the adjacent highlands. Each may have been tilted to approximately its present mass by earth movement concurrently with or following aggradation. La Brea Plain is definitely younger than the Elysian and Repetto Hills. Tustin Plain, however, has many features in common with the unnamed surface northeast of Anaheim, which as a land form is definitely younger than the Coyote Hills uplift and La Habra Basin; but the deformed Pleistocene surface of the basin has features resembling those of the aggraded surface adjacent to the Repetto and La Merced Hills. Also, certain similarities in form suggest that La Brea and Tustin Plains may be closely related in origin to the common land surface of the Newport-Inglewood belt. From the evidence here reviewed it is concluded tentatively that the four surfaces described under this topic heading are considerably older than Downey Plain and plunge beneath it even though their lower borders are not sharply distinguishable; also that they were aggraded to about their present form in late-Pleistocene time. Strict correlation of these surfaces with one another and with the deformed surface or surfaces of the Coyote Hills and the Newport-Inglewood belt appears to be a refinement not attainable by ordinary methods of physiographic mapping alone.

With respect to the source and movement of ground water these foothill surfaces of aggradation are inferred to be substantially alike in being formed of, or at relatively shallow depth underlain by, materials in some slight hydraulic continuity with certain zones from which water is withdrawn by wells on the central lowland. All or part of these surfaces may be functional intake areas from which probably a very minor part of the withdrawals is sustained.

NEWPORT-INGLEWOOD BELT OF HILLS AND PLAINS

COMMON GENETIC FEATURES

It is inferred tentatively that the several land-form elements of the Newport-Inglewood belt have certain features in common with one another and with the lowest deformed terrace of the Palos Verdes Hills (see p. 12). This inference probably is correct for all the coastal zone of the Long Beach-Santa Ana area that was investigated critically by Newcomb and Paulsen for the purposes of this report, but its soundness has not been tested by critical field studies farther northwest. These common features in upward succession are as follows:

1. A genetically common underlying platform was cut across previously deformed rocks of early-Pleistocene age (San Pedro formation) along much of the present coast but passed onto rocks of Tertiary age in Newport Mesa, along the flanks of the Palos Verdes Hills, and along the flank of the Santa Monica Mountains. Somewhat inland from the coast, at least in the vicinity of Wilmington in the western part of the area, the platform is believed to have passed onto rocks of late Pleistocene age (p. 56). It is overlain at many places by deposits of marine origin affording material evidence that from the coast well into the present Newport-Inglewood zone this platform was cut by marine planation in late-Pleistocene time. Farther inland the platform may have passed into a surface of continental degradation, but within the area of the present Downey Plain it is inferred possibly to have passed into a surface of continental aggradation. No prolongation of this composite surface is recognized in the foothill land forms. Over much of the Newport-Inglewood belt this common platform appears to be no more than about 30 feet beneath the present land surface; nowhere within the belt is its depth known to be more than 50 feet.

2. In the coastal zone of the Long Beach-Santa Ana area and somewhat extensively to the northwest is a deposit of unoxidized sand, largely medium- or coarse-grained and only slightly coherent, that at several widely separated places contains abundant marine fossils (see p. 53). Locally this deposit includes a basal gravel-and-cobble layer. On the lowest terrace of the Palos Verdes Hills this basal deposit of marine sand is that which Woodring (Woodring, Bramlette, and Kew, 1946) has designated Palos Verdes sand and has assigned to the upper Pleistocene (see p. 53). Near the northern and southern extremities of the Newport-Inglewood belt corresponding deposits of sand have been described and have been assigned to the upper Pleistocene by Hoots (1931, p. 121, 130) and by Willett (1937, p. 379–406; also, a personal communication on the late Pleistocene fauna from Newport Mesa). All such deposits on the platform of marine planation in the belt are tentatively accepted as essentially contemporaneous. In measured thickness this marine deposit ranges from a thin edge to 35 feet in and near the Palos Verdes Hills, according to Woodring (Woodring, Bramlette, and Kew, 1946, p. 56), and is as much as 15 feet between Dominguez Hill and Newport Mesa, both inclusive, where identified by one of the writers. At the sea cliff east of Long Beach it is at least 23 feet thick, according to Arnold. Beneath the Santa Monica Plain it appears to be as much as 25 feet thick, according to Hoots (1931, p. 121).

3. Overlying the marine sand, or at some places apparently resting directly on the platform of marine planation, is a deposit that forms the present land surface. So far as observed in the field or reported in the literature this capping deposit is nonfossiliferous and accordingly has been described as nonmarine or continental. The soil that constitutes its uppermost part is characteristically deep reddish brown and sandy. At some exposures the capping deposit is nearly all sand of a grain size indistinguishable from that of known marine sand below, and there is no clear physical evidence of discontinuous sedimentation at any horizon between fossiliferous marine sand and the present land surface. The subsoil is brown, owing to an iron oxide coating on the sand particles, and this coloration fingers out irregularly several feet below the land surface. Under such conditions no indubitable evidence that the capping deposit is of nonmarine origin appears, and this may be the reason why "marine terrace deposits" are mapped by Eckis (1934, pl. B) over nearly all the Newport-Inglewood belt. Elsewhere, however, the capping deposit is distinctly silty and in that respect it contrasts strongly with underlying fossiliferous sand. In thickness the capping deposit of the Newport-Inglewood belt ranges between 5 and 20 feet.

These three features common to nearly all the land-form elements of the Newport-Inglewood belt lead to a critical generalization. The present land surface within the belt, even though it has a relief of some 500 feet, is extensively underlain at shallow and practically uniform depth by a surface of marine planation which, as initially formed in late-Pleistocene time, evidently was a featureless plain of very flat grade, at least in large part. The present land surface is scarred by only minor gullies and by a few transecting trenches or gaps. It follows that the present land-surface forms within the Newport-Inglewood belt, with few and inconsequential restorations, measure with fair strictness the earth deformation that has there taken place since late-Pleistocene (Palos Verdes) time. Hence, the land forms within the belt have considerable weight with respect to structural features that influence the watertightness of the so-called coastal barrier.

This generalization is opposed to the conclusion by Vickery (1927, p. 419) that two hills on the crest of the Signal Hill uplift, delineated on plate 702, rise above the "Dominguez surface," which in the type area of Dominguez Hill is strictly equivalent to the deformed surface described in this report. But it is in accord with the conclusion by Woodring (Woodring, Bramlette, and Kew, 1946, p. 105) that "on physiographic, stratigraphic, and faunal grounds the strata at [which mantle] Signal Hill and the Palos Verdes sand are essential equivalents." (See also DeLong, 1941, p. 229–252.) It is also in strict accord with the conclusion by Arnold (1903, p. 30) who wrote with respect to Signal (Los Cerritos) Hill, as follows:

W. S. T. Smith thinks that perhaps this hill is wave built, but a careful examination shows that it is the result of an orogenic movement which has taken place since the lower San Pedro beds [San Pedro formation] were deposited there. This is shown by the contortion of the lower formation [San Pedro], and by the steep dips of the uppermost layers [Palos Verdes sand and terrace cover], which conform almost exactly with the slope of the hill. This orogenic movement has taken place since the upper San Pedro series [Palos Verdes sand] was deposited * * *.

PRONOUNCED UPLIFTS ALONG THE AXIS

The dominant feature of the Newport-Inglewood belt is an alinement of discontinuous low hills that extend from the Santa Monica Mountains southeastward into the coastal zone of the Long Beach-Santa Ana area. These hills are uplifts having a common initial surface (see p. 17), now deformed but virtually unmodified by erosion or alluviation. In succession from the northwest they include Beverly, Baldwin, Rosecrans, Dominguez, Signal, and Landing Hills.

Baldwin and Beverly Hills.—Among these uplifts the Baldwin Hills (Tieje, 1926, p. 502–503) north of Inglewood are the boldest; the highest point is some 410 feet higher than the central lowland to the north and 513 feet above sea level. (See pl. 2, sections *A–A′*, *B–B′*.) Roughly linear scarps constitute the outer faces on the west, north, and east, and these are pierced by numerous valleys sharply incised and reaching headward to the very center of the hill mass, with flat-topped ridges intervening. On the south, however, the hills descend ramplike to the adjacent lower terrane where the surface is also incised and the flat ridge tops and southward-sloping ramps are parts of a land surface initially continuous, gently arched from east to west, and plunging to the south. This is a segment of the late-Pleistocene land surface, uplifted, tilted southward, and warped by earth movements. Bisecting the segment and apparently interrupting the Pleistocene surface is a linear westward-facing scarp 75 to 150 feet high that trends N. 20° W.; this feature is tentatively interpreted as a fault scarp modified only by small gullies.

North of the Baldwin Hills and across the trench of Ballona Creek the Beverly Hills disclose features analogous to those of the Baldwin Hills, but with less relief. The principal summit in this northern terrane is about 200 feet lower than the crest of the Baldwin Hills and about 300 feet above sea level. The name Beverly Hills is restricted in this report to a segment of hilly terrane wholly south of Santa Monica Boulevard, whose land surface is essentially composed of late-Pleistocene (Palos Verdes) marine deposits.

Rosecrans Hills.—Beginning just north of Inglewood at the south flank of the Baldwin Hills and extending southeastward about 8 miles to the flank of Dominguez Hill is a low swell herein designated the Rosecrans Hills. (See pl. 2, sections *A–A′*, *C–C′*.) This swell is about 3 miles wide. Its crest declines southeastward from an altitude of 240 feet above sea level just east of Inglewood to about 100 feet above sea level as it passes into Dominguez Hill. Its transverse profiles are all somewhat asymmetric, with flatter eastern slopes that grade imperceptibly into the central lowland and with steeper western slopes that pass into Torrance Plain. Superposed on this general form are modifying features of three types: a few headward-eroding gullies and small streams; local bulges, not of erosional origin; and at least two westward-facing fault escarpments. The more prominent of the two escarpments, some 60 feet high and 2½ miles long, trends N. 25° W., and opposite Inglewood it passes about half a mile west of the crest of the hills. To the south it appears to die out in the relatively steep western flank of the hills; to the north its alinement is prolonged in an eastward-facing escarpment that bounds the most southerly promontory of the Baldwin Hills. The less prominent of the two escarpments begins at the northern flank of Dominguez Hill, trends about N. 25° W. for a length of 1½ miles, and is half a mile west of the crest of the hills; it is about 25 feet high to the south and dies out northward. These two escarpments are not in common alinement; the one to the south is offset about 2 miles to the east of the prolongation of the one farther north. Ignoring its gullies and few small creek valleys the surface of Rosecrans Hills is deformational in origin; it is another segment of the late-Pleistocene (Palos Verdes) surface, upwarped and faulted.

Dominguez Hill.—Among the pronounced uplifts of the Newport-Inglewood belt Dominguez Hill is unique in the simplicity of its form. It is essentially an elliptical dome whose major dimension trends N. 60° W., acutely across the general trend of the belt, and whose transverse profile is asymmetric. (See pl. 2, sections *A–A′*, *D–D′*.) Dominguez Hill is approximately 3 miles long, 2 miles wide, and rises 170 feet above the adjacent central lowland. The summit is about 195 feet above sea level. Its northeastern flank has the gentler slope, approximately half that of the opposite flank. The origin of the hill by doming of the surface of late-Pleistocene age is substantiated by the occurrence on its west slope of marine sand (Palos Verdes ? sand) beneath a thin terrace cover. (See table 6, log for well 3/13–32F6.)

The general and fundamentally simple form of Dominguez Hill is not substantially modified by features of detail. The surface of the hill is only slightly dissected by gullies none of which is yet graded throughout. The eastern toe of the hill has been cut back somewhat by steam erosion and now terminates in a meander scar about 100 feet high facing the channel of the Los Angeles River. On the western slope of the hill the uniformity of its gradient is broken by a low linear terrace and bench trending N. 25° E. for 0.7 mile. This feature has been interprteted as a "shore-line groove" by Ferguson and Willis (1924, p. 581). However, the terrace is notably linear and is alined with a relatively large gully to the north and with a prominent rill to the south; this common alinement, in conjunction with the abundance of known fault scarps elsewhere along the Newport-Inglewood belt, suggests that the "groove" may be of fault origin, but evidence is inconclusive. Bravinder (1942, p. 392) has discriminated certain faults at depth in the Dominguez oil field—of which one seems to be alined approximately with the groove—but he concludes that none of these extends to the land surface.

Signal Hill uplift.—Across the Los Angeles River from Dominguez Hill the Newport-Inglewood belt contains its most widely known topographic feature, Signal Hill, the central and dominating feature of an uplift that spans three distinct elements: a central segment of relatively strong relief culminating in the two summits of Signal Hill and Reservoir Hill; a northern segment that includes Los Cerritos (little hills) and their physiographic equivalents to the east; and an eastern segment that includes Alamitos Heights and the extension of that district eastward nearly to the San Gabriel River. (See pl. 2, sections *A–A′*, *E–E′*, *F–F′*.)

The central segment of this composite uplift is 3½ miles long by 1½ miles wide and rises some 340 feet above the adjacent plains on either side. It is a plexus of discontinuous warped ramps that rise at various gradients from the plains and are separated by or merge into bold linear scarps. This plexus is cut by subsequent gullies of inconsequential size and by one antecedent trench, somewhat tortuous, that transects the northern tip of the segment, trends S. 60° W., and passes just north of the intersection of Orange Avenue and Spring Street in Long Beach. From this confusion of detail the general form of the central segment emerges, if the scarps are visually suppressed and the gullies and trench disregarded; the warped ramps merge into a fairly smooth ellipsoidal surface elongated N. 55° W. and somewhat asymmetric in transverse profile. This reconstruction of general form is based on substantial evidence that these particular ramps are segments of the late-Pleistocene (Palos Verdes) land surface and that the scarps are of fault origin.

The most extensive fault escarpment of this central segment cuts the southwestern flank of the uplift. About 3½ miles long, it begins near the intersection of Junipero Avenue and State Street in Long Beach, trends N. 45° W., passes beyond the central segment at the intersection of American Avenue and 32d Street, and continues to the far edge of the northern or Los Cerritos segment. This scarp is the land-surface trace of the Cherry-Hill fault (see pl. 3 and 1, p. 98); along the scarp the land surfaces are lower to the southwest; the land-surface offset ranges from 40 to 250 feet, diminishing northwestward. Parallel to this most extensive scarp, in echelon with it and with one another, are two scarps each about a mile long, which cut the northeastern flank of the uplift, and along which the land surfaces are lower to the northeast than to the southwest. These scarps mark the traces of the Reservoir Hill and northeast flank faults. Along each the land-surface offset increases northwestward from 30 to 125 feet along the Reservoir Hill scarp and from 30 to 250 feet along the northeast flank scarp. The echelon is closed on the northwest by a single transverse scarp, the trace of the Pickler fault; it faces northwest and is some 180 feet high.

Signal Hill, the dominant summit of the central segment, is a sharply uptilted slice in the overlap between these longitudinal scarps. It is about 0.5 mile wide and 0.8 mile long. Only its southeast face is an element of the late Pleistocene surface; that ramplike face begins in a small saddle on the crest of the uplift at 125 feet above sea level, rises at a uniform grade of 7 percent, and attains a summit altitude of 365 feet above sea level. The opposite face of the hill is the transverse scarp cited.

Reservoir Hill, a secondary summit 1 mile southeast of Signal Hill and about 205 feet above sea level, is a sharply upwarped bulge offset eastward from the base of the Signal Hill ramp. Its southern and southwestern faces are ellipsoidal; its bold northeastern face is a part of the most easterly of the longitudinal scarps. This hill may have been appreciably disfigured by erosion.

The northern segment of the composite Signal Hill uplift consists primarily of a rude dome, Los Cerritos, which is nearly circular and about a mile across and has a flattish summit about 115 feet above sea level and 80 feet above the lowland plain to the west. On the southwest a small sector of this domed surface is offset downward about 35 feet along the extension of the Cherry-Hill scarp. On the northwest its flank has been cut back in a sinuous bluff some 15 to 60 feet high, facing the channel of the Los Angeles River. Its flattish summit is gently undulating and suggests very slight degrading by a meandering stream. On the east Los Cerritos is physiographically continuous with a slightly undulating plain that declines radially eastward on a gradient between 20 and 40 feet a mile and merges imperceptibly with the central lowland. The southeastern flank of this plain is traversed by a faint valley trending southwestward to the head of the transverse trench cited. This valley is now very slightly arched in longitudinal profile; presumably it was formed by a stream since deflected from the rising uplift to a more advantageous course but possibly maintained sufficiently long to have degraded slightly a substantial part of the Los Cerritos segment.

The eastern or Alamitos Heights segment of the composite Signal Hill uplift is a low swell about 2 miles long by 1 mile wide, whose greater dimension trends about N. 60° W.; its crest is 60 to 80 feet above sea level. In outer form this segment is half an ellipsoid pointed northwestward into the southeastern flank of Reservoir Hill. It is terminated on the southeast by a dissected escarpment 75 feet high that faces the San Gabriel River. From the base of this escarpment a gentle low swell about 15 feet high extends southeastward 0.4 mile into Alamitos Gap. Although covered in part by a peat bed of Recent age this low swell is interpreted as a stream-cut bench formed during the erosion of Alamitos Gap and gently warped by subsequent folding of the anticlinal structure, thus indicating growth of the anticline during or since transection of the gap.

Barnes and Bowes (1930, p. 10–11) have described the Alamitos Heights segment as the terminal northwestern part of a topographic dome rather extensively disfigured on its southwestern flank by subsequent minor streams. They also have interpreted a subdued discontinuity in land slopes high on the southwest flank of the dome in Recreation Park as a modified fault scarp prolonging the Reservoir Hill scarp to the southeast.

Landing Hill.—The most southeasterly of the pronounced uplifts along the Newport-Inglewood belt is Landing Hill, 2 miles beyond the Alamitos Heights segment and just beyond the San Gabriel River. In outer form this small hill, its summit slightly less than 70 feet above sea level, appears to be the terminal segment of an ellipsoid pointed southeastward and little modified by erosion except on the northwest where it ends in an erosional escarpment 60 feet high facing the San Gabriel River. Landing Hill is bisected by a low escarpment that trends northwestward, across which the domed surface is offset about 15 feet downward to the northeast.

Barnes and Bowes (1930, p. 10) have interpreted Landing Hill as the terminal southeastern part of an elongate breached dome of which Alamitos Heights across the lowland of San Gabriel River is the terminal northwestern segment; also they have interpreted the small scarp that bisects Landing Hill as of fault origin, a definite prolongation of the alined fault scarps on Alamitos Heights and Reservoir Hill.

MESAS AND RELATED PLAINS

Corresponding to each of these uplifts and alined on their coastal sides is a succession of plains that have many features in common and are inferred both on physiographic and stratigraphic grounds to be essentially contemporaneous, segments of the late-Pleistocene (Palos

Verdes) surface and hence genetically related to one another and to the uplifts. In sequence from the northwest these are Ocean Park Plain, corresponding to but separated from Beverly Hills; Torrance Plain, contiguous with Rosecrans Hills to the northeast; Long Beach Plain, contiguous with the central segment of the Signal Hill uplift; and an unnamed plain of small extent at the western foot of Landing Hill. Analogs of these plains intervening discontinuously to the terminus of the Newport-Inglewood belt include Bolsa Chica, Huntington Beach, and Newport mesa and, also remnants of an unnamed deformed terrace on the flank of the San Joaquin Hills. These in turn all appear to be genetically related to and essentially contemporaneous with the deformed lower terrace of the Palos Verdes Hills (see p. 53).

Ocean Park Plain.—The Ocean Park Plain is defined in this report as that part of the Santa Monica Plain, described by Hoots (1931, p. 130), which lies mostly in the southwest angle of Pico Boulevard and Bundy Drive, extends inland from the coast about 3 miles, and is between 1 mile and 2 miles wide; its surface is composed largely of marine deposits of late-Pleistocene (Palos Verdes) age. It includes three physiographic subdivisions: on the east an isolated small bench 200 to 180 feet above sea level, sloping gently northward to northeastward; a central and relatively extensive segment, undulating, but sloping generally from an altitude of 175 feet above sea level on the north to 125 feet on the south; and on the west a ridge-and-trench element alined parallel to the coast, which Hoots (1931, p. 121) concludes combines "sand bars and shore-line bluffs that were developed when the ocean stood at a higher level with relation to the land." He describes the materials of this plain as largely "fine brown thin-bedded sand that has been washed free of all clay material." In most features Ocean Park Plain is unique among the coastal mesas and plains of the Newport-Inglewood belt. Its origin is not fully understood at this time.

Torrance Plain.—In this report Torrance Plain is defined as that part of the coastal lowland which lies west of the Rosecrans and Dominguez Hills and is composed of marine or alluvial deposits of late-Pleistocene (Palos Verdes) age. Thus defined Torrance Plain is genetically a part of the Newport-Inglewood belt and is distinct from the remaining and western part of the coastal lowland, which is composed of inactive dunes and is here designated El Segundo sandhills (see p. 33). As here restricted, Torrance Plain and El Segundo sandhills together constitute El Segundo Plain, described by Reed and Hollister (1936, p. 115) and by Wissler (1941, p. 211).

Torrance Plain declines 5 to 10 feet per mile eastward or southeastward to its inland margin and there passes upward into the flank of the Rosecrans Hills, its altitude ranging 25 to 125 feet above sea level.

Along its western and generally higher margin it is inferred to pass beneath the eolian deposits of El Segundo sandhills. (See pl. 2, section *C–C′*.) At its southern margin it terminates against the escarpment, as much as 225 feet high, that cuts off the deformed lower terrace on the north flank of the Palos Verdes Hills. It is somewhat warped throughout, especially along its inland margin. Just north of Gardena this warping has formed a moderately extensive shallow depression that lacks natural external drainage and is floored with playa deposits of Recent age and of local origin. This post-Pleistocene playa surface is not discriminated on plate 1. A more pronounced downwarp of the same sort occurs at the southwestern flank of Dominguez Hill; the central part of this downwarp involves a plain of post-Pleistocene age, outlined on plate 1 by the pronounced northwestward extension of Downey Plain into Torrance Plain. To the west the marginal part of Torrance Plain is warped upward against the flank of the Palos Verdes Hills. (See pl. 2, section *D–D′*.)

Under natural conditions Torrance Plain was very imperfectly drained. From its east-central part drainage passed to the downwarp north of Gardena by way of several small depressions, and from its central part to the downwarp southwest of Dominguez Hill by way of Laguna Dominguez and an unnamed creek that trends eastward from the vicinity of Torrance. A small district north and west of Wilmington, on the southernmost part of the plain, drained internally to Bixby Slough. Only the extreme southeastern part of the plain drained externally—to San Pedro Bay through the outlet from Watson Lakes (Mendenhall, 1905b, pl. 4). Much of this discontinuous natural drainage has been integrated artificially by the so-called Dominguez Channel, which discharges to the Cerritos Channel of Los Angeles Harbor.

Long Beach Plain.—This plain is similar to Torrance Plain in that it slopes generally inland and is warped within itself; it is dissimilar in that its southern edge is a sea cliff, its western and eastern edges are stream-cut bluffs, and it is undrained except by the municipal storm sewers of Long Beach. Typical profiles are shown on plate 2, sections *E–E′* and *F–F′*. Along the sea cliff the plain is between 25 and 65 feet above sea level and is higher toward the east. In its western part it sags radially inland to an undrained depression directly below the crest of Signal Hill where it is 20 feet above sea level; this sag probably is an eastern segment of a downwarped area correlative with a western and more extensive segment at the southwest flank of Dominguez Hill. In its eastern part the plain rises in a gentle swell to a crest of 65 feet above sea level.

Corresponding to Long Beach Plain is a small plain on the coastal side of Landing Hill; it is about 20 feet above sea level at its marginal sea cliff and, like Long Beach Plain, dips gently inland.

Huntington Beach Mesa.—Among the three coastal mesas that constitute the southeastern and lower part of the Newport-Inglewood belt, Huntington Beach Mesa discloses diverse features that in the main are inferred deformational in origin. (See pl. 2, section *H–H'*.) As is shown on the topographic maps of the Seal Beach and Newport Beach quadrangles, this land-form element is roughly rectangular, 2½ miles wide along the coast and extending inland nearly 4 miles. Its southwestern face is a sea cliff 30 to 40 feet high; its northwestern and southeastern faces are stream-cut bluffs respectively 70 and 45 feet high, declining in height away from the coast. Its surface is disposed in three inland-dipping segments of distinctive altitudes, and at the northeastern margin of the mesa plunges beneath Downey Plain.

The coastal segment of Huntington Beach Mesa extends inland about half a mile and there terminates in a succession of small undrained depressions alined parallel to the coast. Its surface is very nearly horizontal and between 30 and 40 feet above sea level; it is believed not to be a wave-cut platform because, to the northwest, a corresponding feature of Bolsa Chica Mesa is considerably deformed.

A mile to a mile and a quarter inland from the coast the inland and highest segment of the mesa rises in a rudely linear escarpment or ramp, which trends S. 60° E., to three small hills, the highest about 130 feet above sea level. Beyond the hills the characteristic mesa plain declines northeastward from an altitude of 75 feet above sea level to about 25 feet as it plunges beneath the central lowland 2½ miles away. This inland segment of the mesa is sharply trenched by several gullies, the most extensive fully 2 miles long.

The intervening or central segment of Huntington Beach Mesa is half a mile to a mile wide and is a plexus of several forms. On the west it includes a ramp that rises between 35 and 40 feet from the inland edge of the coastal segment, trends S. 30° E. for about a mile, then swerves sharply due east for three-quarters of a mile. In the angle between its two trends the ramp is capped by an inland-plunging bench 75 to 87 feet above sea level. This ramp-and-bench feature abuts against the bordering escarpment of the inland segment and at either end merges into it. Beyond this feature and alined southeastward from it two small hills, 65 and 45 feet above sea level, define the shoreward edge of the central segment and pass inland into a somewhat undulating plain 30 to 35 feet above sea level. In this central segment the land forms are somewhat rounded as though smoothed by streams, but if their configuration was caused primarily by erosion they are notably anomalous with relation to practically all other land forms of the Newport-Inglewood belt.

Huntington Beach Mesa spans a zone of probable faulting and shearing in the underlying rocks, and its central segment may be bounded by fault traces along either side. It is inferred tentatively that the mesa is essentially of deformational origin, not greatly disfigured by subsequent erosion. In conformity with the origin of forms elsewhere in the Newport-Inglewood belt the linear ramps would be essentially fault scarps, and the several small hills would be warped slices and upsheared blocks between or adjacent to principal fractures.

Bolsa Chica and Newport Mesas.—Northwest and southeast of Huntington Beach Mesa, respectively, the Bolsa Chica and Newport Mesas are fundamentally of simpler configuration. (See pl. 2, sections *G–G′* and *I–I′*.) Bolsa Chica Mesa consists of two parts separated by a linear ocean-facing fault scarp. Its principal or inland part has the form of a sector from an inland-plunging ellipsoid, its crest is some 65 feet above sea level, and its southeastern face is a stream-cut bluff 50 feet high. Shoreward the mesa is extended by a bench about a third of a mile wide, 25 feet above sea level on its highest part and plunging northwestward; it is essentially a slice from the ellipsoidal surface of the inland part of the mesa, depressed 20 to 40 feet with respect to that part. Its shoreward face is a low sea cliff, now shielded by a barrier beach and a small lagoon.

Newport Mesa is even simpler in form and its upper surface is very slightly warped, if at all. From a crest near the coast where it is 85 to 105 feet above sea level this surface dips northeastward about 20 feet in a mile and at its inland edge passes beneath Downey Plain at an altitude of about 30 feet. To the south the mesa terminates in a gullied sea cliff 65 to 100 feet high, facing the barrier beach and lagoons of Newport Bay. To the west and east it terminates in gullied stream-cut bluffs about 100 feet high, facing respectively toward the Santa Ana River and the trench that contains the inland arm of Newport Bay.

Along the western part of the south-facing sea cliff, and 25 to 35 feet below the upper surface of the mesa, a narrow bench nearly a mile long terminates landward in a ramp roughly alined with the ramp and low hills along the inland side of the coastal segment of Huntington Beach Mesa. It is conceivable that this bench is of deformational origin, but geologic features of the vicinity are too poorly exposed to indicate this conclusively.

Eastward across the inland arm of Newport Bay and its lowland the surface of Newport Mesa appears to be correlative with a terrace along the flank of the San Joaquin Hills. This terrace, the terminal feature of the Newport-Inglewood belt on the southeast, is 0.6 mile wide and extends discontinuously inland some 6 miles. Genetically it appears to be a strict analog of the lowest terrace on the Palos Verdes Hills (see p. 54), although it is less deformed. From its

100-foot sea cliff in the Corona del Mar district the terrace arches gently to a crest about 3 miles inland and 115 feet above sea level, then declines gradually until it finally passes under or merges into the edge of Tustin Plain at an altitude of about 75 feet.

Much of this lowest terrace on the San Joaquin Hills, virtually all of Newport Mesa, the inland segment of Huntington Beach Mesa, and the larger segment of Bolsa Chica Mesa, jointly define a single and formerly continuous surface. That common surface, an element of the deformed late-Pleistocene (Palos Verdes) surface, is tilted uniformly somewhat east of north and is warped only locally and slightly at its western edge in Bolsa Chica Mesa; it is substantially disfigured only by the gaps which intervene between the several mesas.

GAPS

The hills and mesas of the Newport-Inglewood belt are interrupted by six gaps through which tongues of the central lowland, Downey Plain, extend to the coast. These gaps are critical in relation to the occurrence and chemical character of ground-water bodies in the coastal-plain area because each is floored by alluvial materials, permeable in part, through which ocean water might move inland if the fresh-water bodies were drawn down excessively. Beginning at the northwest the six gaps are: Ballona Gap between the Beverly Hills and the Baldwin Hills, 1.2 miles across at its narrowest part; Dominguez Gap of the Los Angeles River between Dominguez Hill and the Signal Hill uplift, 1.6 miles; Alamitos Gap of the San Gabriel River, 1.5 miles; Sunset Gap between Landing Hill and Bolsa Chica Mesa, 2.2 miles; Bolsa Gap northeast of Huntington Beach Mesa, 1.6 miles; and Santa Ana Gap between Huntington Beach and Newport Mesas, 2.4 miles. Only three of these six gaps are now occupied perennially by streams. The aggregate width of all six gaps is 10.5 miles, or nearly one fourth of the 45-mile length of the Newport-Inglewood belt. The Long Beach-Santa Ana area includes five of the six gaps in a 27-mile segment of the belt; the five gaps have an aggregate width of 9.3 miles, nearly 35 percent of the 27-mile segment.

To the southeast beyond the six gaps the so-called Newport Canyon separates Newport Mesa from the lowest terrace on the San Joaquin Hills. Newport Canyon is a sinuous trench that extends inland about 6 miles across the full width of the mesa, is 0.2 to 0.8 mile wide, about 115 feet deep near the coast but shallows inland to 20 feet at its head, and is flanked on either side by gullied stream-cut bluffs. Its southwestern part is occupied by the inland arm of Newport Bay. Farther inland it has an aggraded floor composed of deposits of Recent age; this floor does not merge inland with the central lowland (Downey Plain) but terminates at the base of a low ramp that rises some 20 feet to that lowland and tentatively is inferred to be deformational in origin. This canyon does not naturally drain any part of the plains inland from Newport Mesa, but its origin is largely analogous to the wider gaps to the northwest.

Concerning the origin of the several gaps the following 8 features are critically diagnostic:

1. All except Sunset Gap are flanked on either side by stream-cut bluffs that trend across the Newport-Inglewood belt, and range in height from 60 feet at the northwest face of Landing Hill to 400 feet at the north face of the Baldwin Hills.

2. All are trenched into the deformed late-Pleistocene (Palos Verdes) surface, which was initially a plain very little above the sea level of that time (see p. 17).

3. The Dominguez and Santa Ana Gaps are floored by deposits of Recent age about 150 feet thick, as shown by the logs of numerous water wells. In both gaps the late-Pleistocene surface was initially trenched to a depth of about 250 feet at the axis of greatest deformation of the late Pleistocene surface and to a depth of about 150 feet below present sea level at the coast. In the Dominguez Gap the longitudinal profile of that trench, now buried, appears to have been deformed downward not more than about 25 feet at the axis of the downwarp adjacent to and southwest of Dominguez Hill. In the Santa Ana Gap the profile of the buried trench is not deformed substantially, if at all.

4. These two trenches in the late-Pleistocene surface extended inland across the full width of the coastal plain; profiles of their floors are very nearly parallel to the present land surface. (See p. 44 and pl. 7.) Clearly the pre-Recent trenches of the Dominguez and Santa Ana Gaps were adjusted to a regional base level not less than 150 feet lower than that of the undeformed late-Pleistocene surface and about 150 feet lower than at present. Then as now base level was doubtless fixed by the ocean.

5. Along the coast of all the area shown on plate 1, and far beyond, there is an extensive though somewhat discontinuous submerged shelf whose inshore and offshore margins are, respectively, about 20 and 40 fathoms (120 and 240 feet) below sea level (U. S. Department of Commerce, Coast and Geodetic Survey, 1939, chart 5101). Presumably this shelf is a feature of a former shore; it may be fortuitous that it is approximately on the prolonged profiles of the pre-Recent trenches of the Dominguez and Santa Ana Gaps. However, the uniformity of its depth indicates little or no subsequent tilting of the region in a northwesterly direction.

6. In the Dominguez and Santa Ana Gaps the Recent epoch of aggradation began with the deposition of gravel and coarse sand to a

depth of 40 to 70 feet. Equally thick deposits of coarse material do not exist in the intervening gaps.

7. Bolsa Gap is floored by deposits of Recent age about 80 feet thick that include a basal gravel member 5 to 20 feet thick. (See p. 45.) Here the late Pleistocene surface was trenched to a depth of about 210 feet below the crest of Huntington Beach Mesa, and about 70 feet below present sea level at the coast. Inland from the coast this trench extends northeastward about 6 miles; near Westminster it is cut off by the western flank of the deeper trench of Santa Ana Gap. Beneath Bolsa Gap the trench floor is almost horizontal; if stream-cut, its initial seaward grade has been flattened by inland tilting. (See p. 46.)

8. Everywhere southeast of Ballona Gap the inland margin of the Newport-Inglewood belt is the overlapping edge of a single deposit of Recent age, tongues of which extend through the several gaps to the coast. There appear to be no other deposits superposed on the deformed late-Pleistocene surface.

These features are interpreted to indicate that: (1) The gaps of the Newport-Inglewood belt were cut by major streams which existed on the late-Pleistocene surface prior to its deformation and which had sufficient eroding power to maintain graded courses as the uplifts rose athwart them. (2) During the pre-Recent epoch of trenching, the regional base level of erosion declined progressively though intermittently, inferentially owing to withdrawal of the ocean from a regionally stable land area. The aggregate decline was not less than 150 feet, with at least one temporary halt after a decline of about 70 feet. (3) Deformation in the Newport-Inglewood belt was substantially completed within the pre-Recent epoch of trenching, and largely before the temporary stand with base level lowered about 70 feet; however, the downwarp southwest of Dominguez Hill and Signal Hill has been somewhat deepened subsequently. (4) In the Long Beach-Santa Ana area, only the Dominguez and Santa Ana Gaps were occupied by streams in the late part of the pre-Recent epoch and were then trenched in full adjustment to the lowest base level. (5) During the Recent epoch the antecedent trenched surface has been aggraded about 150 feet concurrently with a regional rise of base level. There is substantial evidence that this rise was caused by advance of the ocean upon a regionally stable land area.

Major transecting streams could have entered the coastal plain through the inland foothills and highlands only at the three passes: Los Angeles Narrows, Whittier Narrows, and Santa Ana Canyon. On the deforming late-Pleistocene surface such streams probably became established across the Newport-Inglewood belt, and once trenched to substantial depth were not easily diverted thereafter. At the northwestern end of the belt the Ballona Gap probably was cut and trenched largely by a stream that coursed westward from the Los Angeles Narrows. There is also substantial evidence that at the time of deepest trenching the stream or streams from Whittier Narrows passed to the Dominguez Gap (p. 44 and pl. 7).

Farther east only the Santa Ana Canyon afforded a major stream discharging onto the late-Pleistocene surface, but the opposing reach of the Newport-Inglewood belt, the reach southeast from the Signal Hill uplift, includes four of the six gaps as well as Newport Canyon. Among these, Sunset Gap lacks stream-cut flanks and includes two hillocks inferred to be parts of the late-Pleistocene surface, too small to be shown on plate 1. This particular gap could have been formed wholly by flood-wash aggradation of a structural saddle on the deformed late-Pleistocene surface and need never have been occupied by a major stream. The remaining three gaps and the canyon across this reach are all stream cut; all were incised below the level of the present central lowland and may have been so incised by an ancestral Santa Ana River. For this seeming multiple transection of the deforming late-Pleistocene surface by a common stream a full explanation is not now possible, although certain features are clear. Within this reach of the Newport-Inglewood belt the deformed late-Pleistocene surface is not overlain by aggradational deposits other than the single overlapping alluvium of Recent age; hence a single stream was not superposed at one gap after another in succession, but each gap must have been incised from an antecedent channel.

In an initial stage of the transection all these stream-cut gaps must have been incised at least down to the level of the present central lowland; at no time in this stage could one have been incised substantially below another, else the remainder would now have floors higher than the lowland. All or several may have been occupied simultaneously by streams at one time or another. The gradients of the streams must have been low, and somewhat inland from the present Newport-Inglewood belt they may have been developed by aggradation of the late-Pleistocene surface. This initial incision of the several gaps must have been completed before the late-Pleistocene surface had been trenched far inland, while base level was relatively high.

In an intermediate stage of the transection at least two of the gaps, Bolsa and Santa Ana, were incised to adjustment with a common base level about 70 feet below present sea level. Both were then aggraded somewhat, owing perhaps to a slight oscillation of sea level. This interpretation is deduced largely from features of Bolsa Gap (see p. 30). During this intermediate stage neither Sunset Gap nor Alamitos Gap is known to have been occupied by a stream.

A final stage of transection was induced by further deformation, locally if not generally, in the Newport-Inglewood belt and by withdrawal of the sea to its lowest known stage of late-Pleistocene time. By the deformation the trenches of the intermediate stage were reduced to substantially horizontal grade—at least the trench of Bolsa Gap was so reduced. The further downcutting appears to have been relatively rapid, so that the gap which afforded the most advantageous grade inevitably beheaded any others that had been graded to the intermediate stage. Of the several gaps east of the Signal Hill uplift only the Santa Ana Gap appears to have been degraded in pace with falling base level during the final stage.

These features of origin become critical in relation to the possibility of ocean water being drawn inland. Because in this area of investigation only two gaps—Dominguez and Santa Ana— appear to have been trenched to the lowest pre-Recent base level, only in those two were deposited the thick tongues of very permeable gravel and coarse sand that form most of the basal part of the Recent alluvium. Subsequently, after the central lowland was aggraded to the level of the intervening beheaded gaps, the Recent deposits were largely silt with only inextensive thin stringers of highly permeable material; hence by far the greater part of the aggregate cross-sectional area of permeable materials of Recent age occurs in the Dominguez and Santa Ana Gaps. In the intervening gaps the materials of Recent age have much less capacity to transmit water. (See p. 120.)

A few additional land-form features in the western part of the Long Beach-Santa Ana area are related to the epoch of gap cutting and warrant brief treatment here. At the southwest flank of Dominguez Hill is a depression that lacks external drainage, into which runoff from Torrance Plain is discharged by Laguna Dominguez and an unnamed creek near Torrance. These creeks have flood channels 300 to 800 feet wide sharply incised into Torrance Plain but drowned by alluvium in their lowest reaches for distances of 3 and 2½ miles, respectively. These features are shown strikingly on the topographic maps of the Compton and Wilmington quadrangles. During the epoch of gap cutting the two creeks evidently were occupied by small streams eroding headward from Dominguez Gap. During the Recent epoch of alluviation the streams for a time probably adjusted grades by backfilling their channels, but finally external drainage was terminated by the more rapid aggradation in Dominguez Gap or by downwarping at the flank of Dominguez Hill, or by both. The slightly deformed profile of the late-Pleistocene floor in Dominguez Gap (see p. 29) suggests that downwarping did take place in Recent time.

Northeast of Wilmington the Watson Lakes, now largely drained, formerly occupied ramifying trenches incised across a low swell on Torrance Plain (Mendenhall, 1905b, pl. 4). Certain of their aspects suggest that these trenches were cut initially by antecedent streams that were able to maintain their grades across the rising swell. Like the lower reach of the Laguna Dominguez these channels are in part now backfilled with post-Pleistocene deposits.

West of Wilmington is Bixby Slough, a small land-locked water body in the lowest part of a trench incised in the upwarped southern margin of Torrance Plain. Southward the trench leads to a windgap, the so-called Gaffey Street trough, which has been cut into the east-ward-tilted lower terrace of the Palos Verdes Hills and which leads in turn to the West Basin area of Los Angeles Harbor. The floor of this trough is now arched in longitudinal profile. Clearly the Gaffey Street trough and the Bixby Slough trench were cut by an antecedent stream which for a time was able to maintain a graded course across an upwarping segment of the late-Pleistocene surface at the present southern margin of Torrance Plain. This upwarping segment appears to complement the downwarping segment that adjoins Dominguez Hill to the northeast. On Torrance Plain during the epoch immediately prior to this warping the stream that discharged through the Gaffey Street trough may have drained an area considerably more extensive than at present.

EL SEGUNDO SANDHILLS

From Ballona Gap southward to the Palos Verdes Hills, a distance of about 11½ miles, Torrance Plain is flanked on the west by a belt of dunes and sandhills which extend to the coast. This belt is here designated the El Segundo sandhills. It has two distinct parts, one of which extends alongshore southward nearly to Redondo Beach, is a third of a mile to half a mile wide, and is composed largely of dunes with crests from 85 to 185 feet above sea level. These dunes are inferred to be of Recent age although some appear to be stable in form. The main part of the belt lies inland and is 2¼ to 5 miles wide, the highest crest 245 feet above sea level. The dunes and sandhills appear to be thoroughly stabilized in form; in part they may be as old as latest Pleistocene. In the inland part of the belt not all the land forms are dunes; many of the sandhills are distinctly elongate with major dimensions parallel to the shore, and others are alined in ranks parallel to the shore. As concluded by Eckis (1934, p. 25) these features suggest strongly that the sandhills are derived in part from offshore bars that have been disfigured by the action of wind and streams since their emergence from the ocean.

The El Segundo sandhills afford a land surface that is moderately extensive, virtually undrained, and highly permeable. A considerable part of the rain that falls on them doubtless penetrates below the land surface and enters ground-water storage, and thus to the extent that they are in hydraulic continuity with underlying permeable materials these sandhills may be a source of substantial ground-water replenishment.

DOWNEY PLAIN

The extensive central lowland of the coastal plain in Los Angeles and Orange Counties was initially named "Downey Valley Plain" by R. T. Hill (1928, p. 94) and has been called "Downey Plain" by other writers (Reed and Hollister, 1936, p. 113, 115; Wissler, 1943, p. 211). These writers define the feature only in general terms. For purposes of this report the name Downey Plain is restricted to the surface formed by alluvial aggradation during the post-Pleistocene time of rising base level and considerably adjusted in grade to the major streams that enter the coastal plain at the several passes through the bordering highlands and foothills. Thus defined, Downey Plain includes a main part, 32 miles long and 4½ to 8½ miles wide, with tongues that extend inland to the several passes and to the ocean through the several gaps of the Newport-Inglewood belt.

Essentially Downey Plain comprises the alluvial fans of the Los Angeles, San Gabriel, and Santa Ana Rivers; the apexes of these fans lie respectively in the Los Angeles Narrows at an altitude of 275 feet above sea level, in the Whittier Narrows at 200 feet, and in the Santa Ana Canyon at 275 feet. From these narrows the fans descend in gradients between 10 and 20 feet to the mile and coalesce into a common plain that extends to and merges with the coastal tidelands; two profiles across this plain are embodied in plate 7.

On slopes so gentle the three trunk streams have dispersed their coarse sediments across the full scope of their several fans by substantial and continual migration, such as has been observed in historic time. These streams are intermittent; they carry large flows only with flash runoff from heavy winter rains. At present their channels are bordered by artificial levees across the coastal plain, and thus the runoff is constrained except during high floods. Under the natural regimen, however, the streams meandered rather widely in shallow braided channels. These former conditions are well shown on the topographic maps of the Downey, Las Bolsas, Anaheim, and Santa Ana quadrangles, surveyed in 1893–94 by the Geological Survey.

For example, at that time the Santa Ana River maintained a shallow flood channel from a quarter to half a mile wide. During periods of low flow, streams only a few feet wide were braided back and forth across this channel. With storm runoff of ordinary magnitude the channel filled from bank to bank, and the stream carried fine sand, silt, and clay to the ocean. With abnormally large runoff the river overtopped its channel and spread widely over its alluvial fan, eroding new channels here and there. With recession of the flood the river either withdrew to its former channel or remained in some new channel of more favorable gradient. Silt and sand were spread widely over the alluvial cone, thinly on the higher land, and more thickly in depressions. In channels, coarse sand and gravel in transit during floods were dropped after the time of maximum bed scour, then covered by finer gravel and sand during the waning-flood stage. The coarsest alluvial materials commonly were deposited as lenses or stringers that can be seen only in excavations or where exposed by later erosion.

Frequently floods have been sufficiently great to overtop the banks along one or more of the three major streams, as published reports amply testify. Troxell (1942, p. 385–394) gives an excellent historical summary of major floods since 1770. More detailed descriptions are to be found in diaries of the Spanish Mission Fathers, in transcripts of court hearings, and in the so-called Reagan report (Reagan, 1914–15). This historical record of some two centuries shows that extensive floods have occurred 10 to 20 times within each century on one or more of the major streams. It also testifies to certain major changes in the location of the three main streams, as follows:

Before 1825 the Los Angeles River flowed westward from Los Angeles to Ballona Gap and entered the ocean just north of Playa del Rey; in the flood of 1825 it was diverted south to join the San Gabriel River and to flow into San Pedro Bay by way of Dominguez Gap. Before the flood of 1867–68 the San Gabriel River flowed into San Pedro Bay; during that flood it cut a new course south from Whittier Narrows along an irrigation ditch and discharged into Alamitos Bay through a channel known to many early residents as New River. The flood of 1825 also changed the course of the Santa Ana River; prior to that year the river entered the ocean "several miles to the northwest of its present channel." It is inferred that for a time prior to that date the Santa Ana discharged through Bolsa Gap. The topographic maps of Anaheim and Downey quadrangles (surveyed in 1894) show clearly that a former channel of the Santa Ana River passed to the north of Anaheim and continued westerly nearly to Los Alamitos. Floods passing down this channel would have discharged to the ocean through Alamitos and Sunset Gaps.

During major floods virtually the whole Downey Plain becomes a tremendous flood plain. Harmon (1941, p. 345) states that at the height of the flood of 1867–68 the waters of Los Angeles, San Gabriel, and Santa Ana Rivers covered the coastal plain in a continuous sheet from Dominguez Hill to the mountains east of Santa Ana. During the flood of 1916 the flood waters of the Santa Ana River inundated more than three-fourths of the part of Downey Plain that lies in Orange County (Elliott, Etcheverry, and Means, 1931, pl. 1). The report by Troxell (1942, pls. 1, 2, 4, 5, 21, 24, 25, and 26) includes many excellent airplane photographs that show the extent of off-channel flooding over the central and eastern parts of the coastal plain during the floods of March 1938. At that time the Santa Ana River broke through levees on both its banks and deposited a blanket of sand several feet thick on the adjacent low lands in Santa Ana Gap. This deposit of a single flood shows clearly the capacity of the major streams to have aggraded the extensive Downey Plain.

Certain segments of Downey Plain adjacent to the passes from the inland basins are highly permeable; they constitute the principal intake areas for the water-bearing zones from which very large withdrawals are made from many widely dispersed wells. Along the coast the several tongues of the plain that pass through the principal gaps of the Newport-Inglewood belt are the most probable zones of potential inland movement of salt water from the ocean. In short, Downey Plain is the area of greatest ground-water withdrawals and of the most complex problems of ground-water utilization.

STRATIGRAPHY AND GENERAL WATER-BEARING CHARACTERISTICS OF THE ROCKS

SEQUENCE AND GENERAL FEATURES

In the Long Beach-Santa Ana area a thick sequence of Tertiary and Quaternary sedimentary rocks has been deposited on a basement of metamorphic and crystalline rocks of pre-Tertiary age.

The Tertiary strata range in age from Oligocene(?) to Pliocene and include sandstone, siltstone, shale, and mudstone; they are almost exclusively of marine origin. These rocks underlie all the Long Beach-Santa Ana area, but in the coastal zone they crop out only locally on the Palos Verdes Hills and along the escarpment of Newport Mesa. Several of the Tertiary formations are not exposed in the area and are known locally only from the records of drilled wells.

The deposits of Quaternary age were laid down chiefly during the Pleistocene epoch; those of the Recent epoch are much less extensive or voluminous. These Quaternary deposits comprise coarse clastic gravel and sand and fine-grained silt, sandy clay, and clay; the coarse-grained and fine-grained materials are about equal in aggregate thickness. In the coastal zone of the Long Beach-Santa Ana area these deposits are largely of marine, littoral, or lagoonal origin; farther inland, however, continental detritus becomes predominant.

In the Newport-Inglewood structural zone these rocks, except those of Recent age, are deformed in a succession of anticlines or domes with intervening structural saddles, and by nearly vertical normal faults and thrust faults that are discontinuous and arranged in echelon. From the axis of this structural zone the rocks dip generally downward both oceanward and landward; they attain greatest thickness in the broad syncline underlying the Downey Plain approximately along a line through Huntington Park and Santa Ana. Here the combined thickness of Tertiary and Quaternary rocks probably exceeds 20,000 feet. Southwest of the Newport-Inglewood zone the rocks of Pleistocene age are upturned to crop out on the outlying flanks of the Palos Verdes Hills; some units of the older underlying Tertiary rocks are flexed upward and exposed farther up the hills (Woodring, Bramlette, and Kleinpell, 1936, p. 125–149).

In any area the availability and chemical quality of the ground water are determined by the character, extent, thickness, and hydraulic continuity of the water-bearing members. In the Long Beach-Santa Ana area the bodies of fresh ground water extensively used occur in the unconsolidated and semiconsolidated deposits of Quaternary and latest Tertiary age, but the rocks between the fresh-water-bearing zone and the underlying basement of crystalline and metamorphic rocks contain saline ground waters and are a potential source of contamination. The stratigraphic treatment in this report extends to all these deposits and rocks pertinent to the water problems discussed. Plate 3 shows the surface distribution of the stratigraphic units that crop out in the coastal zone of the Long Beach-Santa Ana area, and the table on page 38 summarizes their sequence, general character, and water-bearing properties. Several geologic sections (see pls. 4 and 5) show general stratigraphic relations and structural features. In this report the rocks are described in order from youngest to oldest in succession downward as encountered by the drill, and pertinent details are discussed in succeeding pages.

Much of the descriptive information relating to the character and thickness of the deposits of earliest Quaternary and Tertiary or pre-Tertiary age is based on reports by Wissler (1943, p. 210–234) and Woodring (Woodring, Bramlette, and Kew, 1946), adapted to the restrictions of this report.

Plate 6 presents eight representative columnar sections in the coastal zone of the Long Beach-Santa Ana area. The profile trends approximately northward from Palos Verdes Hills to Dominguez Hill and thence southeastward along the Newport-Inglewood zone to Newport Mesa. The Tertiary rocks approach the land surface and crop out at either end of this profile.

Stratigraphy of the coastal zone in the Long Beach-Santa Ana area, California

Geologic age		Formation and symbol on plate 3	Thickness (feet)	Physical character	Ground-water conditions
Quaternary	Recent	Alluvial and coastal deposits (Qal)	0–175	Beneath Downey Plain are unconsolidated silt, gravel, and sand of fluvial origin; the coarser materials more plentiful in the lower half of the deposit. Beneath the coastal tidelands are silt and clay of lagoonal and fluvial origin overlying and enclosing tongues of fluvial sand and gravel. Locally along the coast are accretional beach deposits and dune sand.	Beds of gravel and coarse sand in the lower part of the deposit contain confined water and yield water freely to numerous wells, especially in tongues extending from the Whittier Narrows through the Dominguez Gap and from the Santa Ana Canyon through the Santa Ana Gap. This water is of good chemical quality inland, but moderately to highly saline from the coast inland about 7 miles in the Dominguez Gap and about 1½ miles in the Santa Ana Gap. Near the coast, tongues and beds of fine sand, and some of fine gravel, in the upper part of the deposit, contain unconfined semiperched water that is moderately to highly saline.
		-Unconformity-			
	Pleistocene	Terrace cover and Palos Verdes sand (Qpu)	0–50	Reddish-brown sand, silt, and soil, chiefly nonmarine in origin; underlain locally by a deposit of fossiliferous sand and gravel of marine origin, the Palos Verdes sand; together these mantle the hills and mesas of the Newport-Inglewood structural zone.	Above the water table and therefore unsaturated; sufficiently permeable to transmit some rainfall to underlying materials.
		Unnamed upper Pleistocene deposits (Qpu)	0–700 (?)	Silt, clay, sand, and some gravel, chiefly of fluvial origin; gravel members more numerous beneath Downey Plain than nearer the coast.	Beds of gravel and sand hold confined water and supply many small domestic and stock wells and some larger irrigation wells. This water is of good quality inland from the Newport-Inglewood zone, except locally at very shallow depth; it is also of good quality in part of Wilmington area.
		-Local unconformity-			
		San Pedro formation, including Timms Point silt and Lomita marl members (Qsp)	0–1, 350	West of San Gabriel River: unconsolidated to semiconsolidated gravel, sand, silt, and clay; chiefly marine, beach, and lagoonal deposits, but probably of fluvial origin in part; the coarser materials more plentiful in the lower two-thirds of the deposit. At some places silt and clay predominate. East of San Gabriel River: silt, clay, sand, and gravel; in part, marine and littoral deposits but largely of fluvial and lagoonal origin. Locally under Newport Mesa: contains thick beds of gravel and sand, chiefly of marine origin.	Beds of gravel and coarse sand, most commonly in lower two-thirds of deposit, hold confined water and yield copiously to numerous wells. This water is of good chemical quality almost everywhere inland from the Newport-Inglewood structural zone, also on coastal side of zone in area west of Long Beach (except near shore in Wilmington).

			-Local unconformity-			
Tertiary	Pliocene	Pico formation	Upper division	0-1,800	Semiconsolidated sand, silt, clay, and some gravel, chiefly of marine origin. Tongues of fluvial (?) sand and gravel locally; the gravel beds northerly from the Newport-Inglewood structural zone and in the upper fourth of the deposit, the sand layers commonly in the lower two-thirds of the deposit.	Beds of gravel in the upper part of the deposit contain confined water and yield freely to a few wells. This water is exceptionally soft, with low total solids. Beds of sand in the lower part of the deposit are permeable but have not been tapped by water wells. This water is essentially fresh although total solids may be too high for domestic use and for irrigation.
			-Local unconformity-			
			Middle division	0-1,100	Olive- to dark-brown massive claystone and siltstone, fine to coarse gray sand,[1] all of marine origin.	
			-Local unconformity-			
			Lower division	0-330	Fine to coarse gray sand, occasionally pebbly, brown sandy siltstone and claystone,[1], all of marine origin.	
		Repetto formation		0-2,800		
			Local unconformity			
	Miocene	Monterey shale, at least in part (Puente formation of Wissler and others)	Division A of Wissler	430-1,140	Alternating dark- to olive-brown sandy micaceous siltstone and shale; fine to coarse gray sand.[1]	Largely impervious; the sandy members, if water bearing, contain connate waters ranging from about half to the full salinity of ocean water.
			Division B of Wissler	550-1,370	Fine to medium gray sandstone and dark-brown, platy to semiplaty shale.[1]	
			Division C of Wissler (in part equivalent to the Malaga mudstone member).	550-1,400	Bluish-gray and dark-brown platy shale; dark-brown massive sandy claystone; fine to medium sand.[1]	
			Division D of Wissler (in part equivalent to the Valmonte diatomite member.)	(?)-1,600	Bluish-gray and dark-brown hard platy shale; semiplaty massive shale; fine to medium silty sand.[1]	
			-Local unconformity-			
			Division E of Wissler (in part equivalent to the Altamira shale member).	(?)-60	Black and tan phosphatic shale; sand and schist-bearing conglomerate.[1]	
			-Local unconformity-			
			Division F of Wissler	0-130	Dark grayish brown silty shale and medium to coarse pebbly sandstone.[1]	
			-Unconformity-			
Jurassic (?)		Franciscan (?) formation			Greenish, grayish, or bluish serpentine, talc, or schist.[1]	Impervious, non-water-bearing.

[1] After Wissler, 1943, p. 210.

QUATERNARY SYSTEM

RECENT SERIES

DEFINITION

The deposits of Recent age include all the materials laid down during the present cycle of alluviation by streams, in lagoons, and along the coast. These deposits are chiefly continental and comprise the latest contributions to the alluvial cones of the Los Angeles, San Gabriel, and Santa Ana Rivers. Their top is the Downey Plain, which by definition (p. 34) has been restricted to the land-surface element formed by alluvial aggradation during the post-Pleistocene time of rising base level. Their base is the former land surface that had been produced by deformation and trenching of the coastal plain of late Pleistocene time (see p. 29). That former land surface comprised at least three types of terrain: two major trenches, which coursed to the ocean from Whittier Narrows and Santa Ana Canyon by way of Dominguez Gap and Santa Ana Gap, respectively (see pl. 1), and whose floors are 90 to 175 feet below the present Downey Plain; several minor trenches of less extent and less depth below Downey Plain; and intervening and outlying elements whose form is not known in any detail but which presumably are substantially higher than the floors of the major trenches.

PHYSICAL CHARACTER AND MODE OF ORIGIN

GENERAL FEATURES

The alluvial deposits of Recent age consist chiefly of sand, gravel, silt, and some clay. The lenses or layers of coarse sand and gravel are largely the channel deposits of major streams; the fine sand, silt, and clay are chiefly flood-plain deposits carried to the interstream areas during flood stages. Within the term of the Recent epoch the courses of the aggrading streams doubtless shifted widely (see p. 34); thus their relatively coarse channel deposits form tongues and pipes dispersed irregularly in an enclosing mass of the finer flood-plain materials.

In general physical character, but more especially in their water-bearing characteristics, the alluvial deposits of Recent age can be divided into upper and lower parts. In the upper division fine sand and silt predominate; coarse sand and gravel are not abundant, except locally. The lower division is composed very largely of coarse materials that range from coarse sand to cobble gravel. The two divisions are discriminated locally by their textural character, but probably both span about the same stratigraphic range over all the Long Beach-Santa Ana area.

UPPER DIVISION, INLAND FROM THE COASTAL HILLS AND MESAS

The heterogeneity of the Recent alluvial deposits that form Downey Plain is well illustrated on the soil maps of the Los Angeles and Anaheim areas (Nelson and others, 1919; Eckmann, 1919). The soil map of the Anaheim area shows bands of silty clay, silt, sandy loam, and sandy and coarse gravelly soils fingering and interlacing southwestward across the alluvial plain of the Santa Ana River. In spite of this heterogeneity, fine sand is the predominant sediment. On the two soil maps the Hanford sandy loam is shown as the most widely distributed of the alluvial soils. Table 1 shows typical size analyses of soil and subsoil of the Hanford fine sandy loam within the coastal plain.

TABLE 1.—*Size analyses of the Hanford fine sandy loam in the Long Beach-Santa Ana area*

Soil fraction and size range (millimeters) [1]		Quantities, in percent of dry weight, in—			
		Soil		Subsoil	
		A [2]	B [3]	A [2]	B [3]
Fine gravel	2.0 to 1.0	0.0	1.2	0.0	1.8
Coarse sand	1.0 to 0.5	.1	3.4	.2	6.4
Medium sand	0.5 to 0.25	.1	3.2	.2	4.3
Fine sand	0.25 to 0.125	17.7	16.6	20.6	21.7
Very fine sand	0.125 to 0.05	41.6	25.4	36.8	23.0
Silt	0.05 to 0.005	34.9	43.6	36.2	35.4
Clay	<0.005	5.6	6.6	6.1	7.4

[1] The soil classification used here is that of the U. S. Department of Agriculture, Soil Conservation Service; it is not used by the Geological Survey.
[2] After Nelson and others, 1919, p. 55.
[3] After Eckmann and others, 1919, p. 53.

The present channels of the Los Angeles, San Gabriel, and Santa Ana Rivers are bottomed with sand throughout most of their coastal-plain reaches. Near the inland hills, where river gradients range from 12 to 20 feet per mile, the coarsest materials have been deposited and lenses of gravel are interspersed in the sand. Near the coast, where river gradients range from 5 to 7 feet per mile and where flood waters are ponded behind barrier beaches, the finest materials have been laid down and layers of silt and sand interfinger. The process of accumulation within these channels has involved alternate scour during rising flood stages and fill during falling stages. Because the average depth of scour has been exceeded by the average thickness of fill the net result is aggradation of the channel bed.

The available logs of wells suggest that in the Long Beach-Santa Ana area the upper division of the alluvial deposits of Recent age is composed largely of materials such as these. Fine materials similar to the soils of Downey Plain predominate and enclose discontinuous but locally interconnected tongues and lenses of coarser materials similar to the channel deposits of the present rivers.

MARSH DEPOSITS AND PEAT BEDS

Near the coast and within the lower reaches of the several gaps across the Newport-Inglewood zone, tidal marshes extend inland for

1 to 3 miles. These marshes include small lagoons and tidal sloughs connected with the ocean through channels that breach the barrier beaches fronting each of the five gaps. Salt-water grasses and other plants grow in these marshes, and where drainage channels supply fresher water rank thickets of tules and cattails flourish. Thin layers of black muck rich in organic matter accumulate in the tidal sloughs; some sand blown inland from the beaches and fringing dunes mixes with this finer sediment. Certain of these tidal marshes receive considerable marine debris at times when high tides and ocean storms combine to overtop the barrier beaches, but the main sedimentary contribution to all is the muck—silt, fine sand, and clay—laid down from the intermittent floods of the streams.

The physical character of these uppermost Recent deposits in the tidal marshes and on the lower reaches of the flood plains is best illustrated by the logs of shallow wells given in table 4; these logs are for wells bored with post-hole augers by the Geological Survey during this cooperative investigation.

Beds of peat have been developed locally in protected areas or in areas that are bypassed by the floods because a stand of rank vegetation has raised them slightly above the surrounding plain. Such a peat deposit occurs in the upper end of Newport Canyon in the northwesterly half of blocks I–58 and I–59. This deposit lies a few feet below the land surface and is 10 to 15 feet thick. Obviously it must have been protected from scour or deposition by inland flood waters for several hundred years, as the accumulation of a foot of peat has been estimated conservatively to require about 75 years.

Another bed of peat ranging in thickness from a few inches to many feet lies a few feet beneath the floor of Santa Ana Gap in much of the area between Atlanta and Talbert Avenues. Locally this bed is reported to be 50 feet thick (see table 6, log of well 5/10–31R3 and p. 9).

Other extensive deposits of peat occur along either flank of Bolsa Gap, 1 to 3 miles inland from the coast. A narrow band of peat crops out on the flanks of Landing Hill inland from the Newport-Inglewood zone, and a rather extensive bed is exposed in the westerly part of Alamitos Gap about 2 miles inland from the shore, in and adjacent to the NW¼ sec. 2, T. 5 S., R. 12 W.

These near-shore bodies of peat could have accumulated only in areas where water was of relatively low salinity; otherwise the necessary rank growth of vegetation could not have flourished. For the bodies along the flanks of the gaps, water of low salinity doubtless has been supplied in part by gravity springs issuing from Pleistocene beds of gravel and sand that underlie the adjacent mesas and have been truncated in the cutting of the gaps. Other bodies of peat, as in Santa Ana Gap, have developed in areas apparently fed by water rising from the unconfined portions of underlying sand and gravel layers. The 50-foot bed of peat in well 5/10–31R3 suggests that such a condition favorable to rank vegetal growth has been maintained continuously for the past several thousand years.

BEACH DEPOSITS

Recent beach deposits occur as narrow strips fringing the sea cliffs cut by the waves in the soft Pleistocene sediments of the coastal mesas and plains. These fringing beaches commonly lie almost entirely within the tidal span, but the coarse clastic deposits of which they constitute the visible segment extend seaward for many hundreds, and in places thousands, of feet. They are connected across each of the several gaps by barrier beaches. Together the beach deposits form an arcuate strip of sand and gravel that extends almost continuously from Newport Mesa to Palos Verdes Hills, breached only by the outlets from the several gaps; these outlets are maintained by the intermittent flood runoff from the coastal plain and by tidal scour.

EXTENT AND THICKNESS OF THE UPPER DIVISION

The upper division of the deposits of Recent age extends beneath all of Downey Plain, and the upper surface of this division constitutes that plain. In thickness the division ranges from a thin edge along the margins of the plain to about 100 feet locally; it probably is thickest along the inland edge of the area shown on plate 3.

Within the central reach of the coastal plain, from the Signal Hill uplift to Bolsa Chica Mesa and inland to the Coyote Hill uplift, the available logs of wells indicate that the Recent deposits are chiefly silt and fine sand, contain no extensive continuous masses of sand or gravel at their base, and are not more than about 100 feet thick. In this particular district almost all these deposits of Recent age probably belong to the upper division. To the east and west the fine-textured upper division is underlain by the several gravel tongues that constitute the lower division of the Recent deposits.

In the several gaps through the coastal hills and mesas the thickness of the upper division of the Recent deposits ranges considerably. In the Dominguez and Santa Ana Gaps—the western and eastern ends of the area—the upper division is 60 to 75 feet and 60 to 90 feet thick, respectively, and is underlain by a thick gravel tongue of the lower division. In the intervening three gaps, in succession from the northwest, the Recent deposits probably are no more than 100 feet thick in Alamitos Gap and belong chiefly if not wholly to the upper division; in Sunset Gap the Recent deposits seem to be only a few tens of feet thick at most; extensively they may be no more than 20 feet thick and are definitely ascribed to the upper division. In

Bolsa Gap the upper division is 60 to 90 feet thick, as in Santa Ana Gap, and probably is underlain by a thin gravel tongue of the lower division.

LOWER DIVISION, TALBERT AND GASPUR WATER-BEARING ZONES

The lower division of the alluvial deposits of Recent age is known only from the logs of wells and from samples taken during drilling; both sources indicate that the lower division is composed almost wholly of well-assorted coarse sand and gravel contrasting strongly in physical character with the finer materials of the upper division. The lower division appears to exist largely or exclusively within the valleys trenched into the deformed coastal plain of late Pleistocene age (see p. 29); well logs suggest that it was not deposited extensively, if at all, over much of the central part of the area, hence it does not underlie the entire Downey Plain but is divided into several distinct tongues.

The two principal segments or tongues of the lower division trend entirely across the coastal plain near the eastern and western margins, respectively, of the Long Beach-Santa Ana area, from Santa Ana Canyon to the ocean by way of Santa Ana Gap, and from Whittier Narrows to the ocean by way of Dominguez Gap. (See pl. 7.) In this report these two segments are designated the Talbert and Gaspur water-bearing zones, respectively. Each is essentially a distinct basal unit in the deposits of Recent age.

The Talbert water-bearing zone, laid down by an ancestral Santa Ana River, is 20 miles long within the Long Beach-Santa Ana area; it ranges in width from 1.1 miles in the lower part of Santa Ana Canyon to about 6 miles between Anaheim and Garden Grove—averaging about 2.1 miles in Santa Ana Gap—and in thickness along its axis between 40 and 100 feet. The type section of the Talbert zone is that penetrated by well 5/10–30Q1 near the village of Talbert at the inland end of the Santa Ana Gap (see drillers log in table 6, p. 147). Locally the upper part of the zone is sand, but commonly the entire thickness is largely gravel; cobbles up to 5 inches in diameter were encountered in well 6/10–18C1. The base of the Talbert zone is 75 feet above sea level, 140 feet below the land surface, at the mouth of the Santa Ana Canyon, and 150 feet below sea level at the coast; its average gradient is some 14 feet to the mile, approximately equal to that of the Gaspur zone farther west. The Talbert zone doubtless extends inland beyond the Long Beach-Santa Ana area and offshore as well.

The Gaspur water-bearing zone is the deposit of an ancestral San Gabriel River. Within the Long Beach-Santa Ana area it is 21 miles long; it ranges in width from 1 mile in Dominguez Gap to about 4 miles near Downey, and it ranges in thickness along its axis from 50 to 100 feet. The type section of the Gaspur zone is that penetrated by well 4/13–35M3 at Gaspur Station at the coastal end of Dominguez Gap (see drillers log in table 6, p. 146). In general it comprises an upper part of medium- to coarse-textured sand 20 to 60 feet thick, and a lower part of coarse clean gravel 25 to 60 feet thick containing cobbles up to 4 inches in diameter. Within the area the base of the zone has an average gradient of 12 feet to the mile, from about 100 feet below the land surface and 90 feet above sea level in Whittier Narrows to 150 feet below sea level at the coast. The Gaspur zone doubtless extends northeastward beyond Whittier Narrows into the San Gabriel Valley and southward beneath part of San Pedro Bay.

The coarseness and uniformity in texture of the materials across the full width and length of the Talbert and Gaspur zones show that they were deposited by streams with much greater transporting power than the rivers of today. This could have been due either to steeper gradient or to perennially large flow; but because the average gradients were but little steeper than those today, which are about 10 to 12 feet in a mile, it is concluded that greater flow transported such coarse materials into Dominguez and Santa Ana Gaps. The ancestral streams must have deposited the coarse detritus chiefly by continuous lateral migration across their entrenched valleys. Although fine sediments doubtless were left intermittently as a flood-plain cover they must have been removed during the height of later floods, so that gravel and coarse sand were the final deposits blanketing the bottoms of these valleys in a continuous strip from bank to bank.

LOWER DIVISION, MINOR WATER-BEARING ZONES

Two minor zones or tongues in the lower division of the alluvial deposits of Recent age are noteworthy. These are in physical continuity with the Talbert and Gaspur zones, respectively.

Like the Talbert zone with which it is in continuity the more easterly of these two minor tongues is probably the deposit of an ancestral Santa Ana River, although the two probably were not deposited simultaneously. The minor tongue diverges from the Talbert in the vicinity of Westminster and Midway City, thence extends southwestward about 6 miles into and probably through Bolsa Gap. As shown by many well logs, over much of this area it is a bed of fairly uniform gravel; its top is 60 to 90 feet below the land surface, its thickness is 5 to about 20 feet, and its width is 1.2 to 2.2 miles. Locally it is known as the "80-foot gravel" (see pls. 5, 7). So far as known to the writers, only one well more than 20 feet deep has been drilled in Bolsa Gap within a mile of the ocean; this well, 5/11–29P1, encountered gravel from 60 to 70 feet and from 75 to 88 feet below the land surface. Doubtless the upper gravel stratum, and possibly the lower one, represent extension of this 80-foot gravel to the coast.

Structurally this minor zone differs from the Talbert zone because it does not have a similar seaward gradient. Its base is uniformly about 70 feet below sea level from the coast inland for about 4 miles and is about 80 feet below sea level near Westminster. As initially deposited it doubtless had a seaward gradient, but that apparently has been offset by subsequent inland tilting. As the profile on the base of the Talbert zone is not similarly modified it is suggested that the 80-foot gravel was deposited during an intermediate stage of the post-Pleistocene erosion cycle and that deposition was engendered by a temporary rise of ocean level with respect to the land after Bolsa Gap had been eroded to a depth of about 80 feet below present sea level. At that time Santa Ana Gap probably had been excavated to the same temporary base level (see p. 31) and may have received a correlative of the 80-foot gravel. Throughout the subsequent further lowering of the sea and the concurrent erosion the ancestral Santa Ana River must have flowed only in Santa Ana Gap, so that the 80-foot gravel was stripped from much of that area but was preserved in Bolsa Gap.

The base of the 80-foot gravel could have been flattened during this second stage of downcutting in Santa Ana Gap, concurrently with the latest inland tilting of the Pleistocene deposits and the mesa surfaces which they underlie. This tentative explanation for the horizontal position of the 80-foot gravel does not disagree with any known facts; if accepted, it dates the latest substantial crustal deformation in the vicinity of Huntington Beach and Bolsa Chica Mesa as subsequent to the deposition of the 80-foot gravel, but antecedent to the cutting of Santa Ana Gap to its depth of about 150 feet below present land surface. Deposition of the Talbert zone occurred still later as sea level recovered toward its present height. Thus the 80-foot gravel would be somewhat older than the Talbert zone; it is the oldest known deposit of the area ascribed to the alluvial deposits of Recent age.

To the east of the Talbert zone as delimited on plate 7, and inland somewhat beyond Newport Mesa, certain wells encounter a thin water-bearing zone that may be correlative with the 80-foot gravel of Bolsa Gap. In well 5/10–9P3 the Talbert zone is 71 feet thick, but well 5/10–16C1 a third of a mile to the southeast found only an 18-foot bed of gravel. About 1½ miles nearly east, well 5/10–15J1 encountered a possible extension of this 18-foot water-bearing zone. To the south in sec. 21 and the N½ sec. 22, T. 5 S., R. 10 W., numerous wells tap a thin bed of water-bearing gravel 130 feet below land surface and 80 feet below sea level. These thin water-bearing zones that underlie the Santa Ana River are correlated tentatively with the 80-foot gravel. Doubtless they are in hydraulic continuity with the Talbert zone to the west.

Along the eastern flank of Santa Ana Gap the Talbert zone (see pl. 7) locally includes water-bearing deposits whose base is somewhat shallower than that of the main body of the Talbert zone to the west and that possibly are correlative with the 80-foot gravel. For example, about half a mile west of Newport Mesa certain wells in 6/10–18J (see pl. 7, section *H–H′*, wells 6/10–18J2 and 6/10–18J6) tap a gravel bed whose base is about 100 feet below sea level, or about 30 feet above the base of the Talbert zone as encountered in well 6/10–18C1. Thus it is inferred that locally at least the gap was trenched to full depth only in the central span of 1.6 miles width, and that a terrace about 0.8 mile wide was preserved on the eastern flank of the gap. The water-bearing beds now superposed on these ancient terraces may have been deposited in part as a correlative of the 80-foot gravel, and in part as the latest deposits at the top of the Talbert zone. Because these thinner extensions are definitely in hydraulic continuity with the Talbert zone, and because logs of wells are not available to indicate the western edge of the buried marginal terrace, these extensions have been included in the Talbert zone shown on plate 7.

To the west the minor tongue in continuity with the Gaspur zone apparently is the deposit of an ancestral Los Angeles River. It trends nearly south from the Los Angeles Narrows and merges into the Gaspur zone about a mile northeast of Compton; in the central part of this reach southward as far as Lynwood its axis is about coincident with Alameda Street. Its width ranges between 1 and 2 miles, its thickness between 40 and 80 feet. The average southward gradient of its base, 24 feet to the mile, is about double that of the Gaspur zone; at the junction of the two near Compton their bases have a common altitude of about 70 feet below sea level, or 140 feet below the land surface. These features of the minor tongue suggest that during a part of the gap-cutting cycle of the late Pleistocene or post-Pleistocene time (see p. 29) the ancestral Los Angeles River flowed southward and eroded a valley in the Pleistocene deposits graded to a confluence with the ancestral San Gabriel River near Compton.

So far as known the existence of this minor tongue and water-bearing zone was first publicly noted in the so-called Reagan report (Reagan, 1917, unnumbered plate following p. 35). A geologic section in that report indicates a water-bearing zone continuously from San Pedro Bay to the Los Angeles River Narrows. Thus it combines a 10-mile segment of the Gaspur zone from Compton south with the minor tongue just described.

Reference has been made to the relatively steep gradient of this westerly minor tongue, about 24 feet to the mile. That gradient appears inordinately large with respect to the relatively uniform thickness of the minor tongue, 40 to 80 feet, and to the relatively uniform texture of its material. Possibly the gradient is normal for a weak ancestral Los Angeles River tributary to a strong ancestral San Gabriel River.

On the other hand, it is possible that since deposition the gradient has been steepened by crustal deformation complementary to the inland tilting of the minor tongue to the east. This minor tongue is on the coastal flank of the structural basin that underlies Downey Plain, whereas the westerly minor tongue is on the inland flank. Deepening the structural basin during the late Pleistocene or post-Pleistocene time of trenching, which seems definitely established, would tend to flatten stream gradients across the coastal flank and to steepen them across the inland flank. If such deformation occurred, and if both flanks of the basin were tilted 12 feet per mile, then the initial seaward gradients of the two minor tongues were about equal to one another and to those of the two major tongues—which appear not to have been deformed substantially—all at the rate of 10 to 14 feet per mile. Because the western minor tongue lies beyond the coastal zone of the Long Beach-Santa Ana area, all its features have not been studied in detail; its general features neither confirm nor invalidate the suggestion that it may have been steepened by crustal deformation.

GENERAL WATER-BEARING FEATURES

Although of relatively fine texture over much of the area the upper division of the alluvial deposits of Recent age presents a land surface, Downey Plain, which over extensive districts is moderately permeable. Large volumes of water penetrate below the plain by infiltration of rain, by percolation from streams, and from deep penetration of irrigation water; water so derived constitutes virtually all the ground-water replenishment in the area, but only a part of that water reaches permeable zones from which substantial withdrawals are feasible.

Except locally along the inland flank of Downey Plain where it contains considerable gravel the upper division contains tongues and sheets of permeable sand and some of gravel, but generally these are neither thick nor extensive and have only imperfect hydraulic continuity. As a whole, the division is of low average permeability and does not yield water copiously to wells, but the several gravel tongues that constitute the lower division are each comparatively extensive, highly permeable throughout, and yield copiously to many wells. The relative water productivity of the lower and upper divisions of the Recent deposits is brought out in table 2, which shows the depth distribution for all wells of known depths within three mile-wide strips across Downey Plain in the western, central, and eastern parts of the area. In the central strip which is underlain by only the upper division of the Recent deposits, nearly 90 percent of the wells are more than 200 feet deep; to secure an adequate source of water they were drilled entirely through the upper division and into the underlying Pleistocene deposits. In the western and eastern strips, however, nearly 90 percent of the wells are less than 200 feet deep; an adequate source of water was encountered in the Gaspur and Talbert zones of the lower division, by which these two strips are respectively underlain.

TABLE 2.—*Percentage distribution of wells by depth ranges in three mile-wide strips across Downey Plain*

Depth range (feet)	Terminal Island to Whittier Narrows; underlain by Gaspur water-bearing zone		Seal Beach to Coyote Hills; underlain by only the upper division of the Recent deposits		Santa Ana Gap to Anaheim; underlain by Talbert water-bearing zone	
	Number of wells	Percent	Number of wells	Percent	Number of wells	Percent
50–200	165	83	9	12	109	89
201–500	16	8	39	52	13	11
501–1,000	13	6	24	32		
>1,000	6	3	3	4		
Total	200	100	75	100	122	100

From Whittier Narrows downstream about 4 miles and from the mouth of Santa Ana Canyon downstream to about Anaheim and Orange the upper division of the Recent deposits contains much medium- to coarse-textured sand and gravel, is moderately to highly permeable, and rests directly on the highly permeable gravel tongues of the lower division. Within these two intake areas the ground water is unconfined, there is hydraulic continuity between the upper and lower divisions of the Recent deposits and water that penetrates below the land surface can recharge the gravel tongues of the lower division. Beyond these intake areas to the coast, however, the upper division of the Recent deposits is sufficiently impermeable that its contained water is hydraulically discontinuous from the water in the lower division. In that outlying area, which extends over most of Downey Plain, the water in the upper division of the Recent deposits is essentially unconfined in large part, and that in the lower division is effectively confined.

Under natural conditions the water table in the intake areas was sufficiently high that the gravel tongues of the lower division were completely saturated. The two main tongues, the Gaspur and Talbert zones, functioned as regional ground-water arteries conveying fresh water from their respective intake areas, beneath Downey Plain, through the Dominguez and Santa Ana Gaps, and probably to offshore submarine springs. They also conveyed water to permeable zones of older formations with which they were in hydraulic continuity. The westerly of the two minor tongues is in hydraulic continuity with the Gaspur zone and presumably functioned as a secondary ground-water artery tributary to that zone. The easterly minor tongue apparently is in hydraulic continuity with the Talbert zone and presumably functioned as a distributary ground-water artery conveying water into and possibly through Bolsa Gap. From these several ground-water arteries there was substantial leakage at "ciénagas" or spring zones on low ground along the inland flank of the Newport-Inglewood zone.

With respect to the inferred discharge from these ground-water arteries at submarine springs, the water-level contours drawn by Mendenhall (1905b, pl. 4) in 1904 suggest discharge from the Gaspur zone into San Pedro Bay not more than 2 miles from Terminal Island. In 1915 George Bouton (in Reagan, 1914–15, p. 54) reported:

> It has been the practice of the fishermen at San Pedro when they arrived at about a mile outside the beach, and about midway between Long Beach and San Pedro, to lower a jug weighted so it would sink and corked up so that when it reached a certain depth the pressure would push the cork in, and the jug would fill with pure, fresh water.

These two independent pieces of evidence agree in placing submarine springs within 2 miles offshore and about halfway between Long Beach and San Pedro. Presumably these were sustained by discharge from the Gaspur zone. Although specific evidence is lacking it is inferred that corresponding discharge from the Talbert zone caused submarine springs off Santa Ana Gap.

In the early stages of ground-water development in the Long Beach-Santa Ana area the confined water in the Gaspur zone of the lower division was under sufficient head so that flowing wells were obtained throughout its extent from the intake area southward to Dominguez Gap (Mendenhall, 1905b, pl. 4) a distance of some 11 miles. From the gap to the coast the water of the Gaspur zone was also confined but not under sufficient head to yield flowing wells; evidently there was considerable loss of head within Dominguez Gap, presumably by leakage. In the area of the Talbert zone to the east numerous flowing wells were sustained within an area beginning about 2 miles north of Garden Grove and extending to the coast (Mendenhall, 1905a, pls. 6, 7). With increasing use of water, however, the initial head was dissipated in considerable part and withdrawals were sustained and even increased greatly by pumping. At the stage of greatest development several hundred wells had been drilled into the Gaspur and Talbert zones for irrigation, municipal, domestic, and industrial supplies. On the Gaspur zone these were dispersed from Whittier Narrows to Terminal Island; on the Talbert zone, from Santa Ana Canyon to within a few hundred feet of the coast at Santa Ana Gap. Even though numerous wells near the coast have been abandoned, the aggregate withdrawals for all uses from the Gaspur and Talbert zones currently are each about 25,000 acre-feet a year.

Owing to the very large and constantly increasing withdrawals of water from the two zones during the past several decades the natural ground-water conditions have been profoundly modified. In the western part of the area the Gaspur zone has remained almost fully saturated, possibly in part owing to artificial replenishment from the off-channel spreading basins maintained since 1938 by the Los Angeles County Flood Control District. In the eastern part of the area the Talbert zone has remained saturated over most of the initial area of flowing wells; but inland, beyond a line connecting Anaheim and Orange, that zone has been unwatered almost constantly since 1930. In the Gaspur and Talbert zones the head has been so greatly dissipated that currently the static levels of their waters are at sea level, or somewhat below, for substantial distances inland from the coast. Concurrently with dissipation of head, and beginning in the late twenties, salt water has invaded each of the zones near the coast, and in those areas the chemical quality of the water yielded by wells has deteriorated progressively. Owing to this deterioration, withdrawal from the Gaspur zone has virtually ceased from the coast inland about 4½ miles into Dominguez Gap. Withdrawal from the Talbert zone also has nearly ceased from the coast inland to Atlanta Avenue, a distance of about 1½ miles; in that coastal area only about 10 wells currently are withdrawing appreciable amounts of water from the Talbert zone.

This condition poses the fundamental problem with which this report is concerned, the adequacy of the so-called coastal barrier to restrain further deterioration in ground-water quality by incursion of ocean water within the Long Beach-Santa Ana area. In this problem the lower division of the Recent deposits plays a critical role; under the artificial ground-water conditions of today its several gravel tongues afford the principal conduits through which ocean water might be drawn inland through the gaps in the barrier—the Newport-Inglewood zone—to the main inland segment of Downey Plain. Those conduits exist where thick or extensive tongues of the lower division extend to the coast; principally through the Dominguez and Santa Ana Gaps, to a lesser degree through Bolsa Gap, possibly but probably not extensively at Alamitos Gap, and probably not in Sunset Gap. In aggregate width these channels of potential salt-water invasion in the Dominguez, Bolsa, and Santa Ana Gaps constitute 22 percent of the coastal length of the Long Beach-Santa Ana area.

With respect to general ground-water features the beach deposits (see p. 43) are somewhat anomalous. They are highly permeable, may be several tens of feet thick locally, and doubtless are in contact with lenses of permeable sand and fine gravel that extend inland. Under such conditions they will transmit fresh water oceanward or salt water landward, depending on their thickness below sea level, and the height of the local water table. They doubtless contain some small bodies of unconfined fresh water, whereas the shallow ground water in other materials near the coast is commonly inferior in quality. Obviously, however, they are not in hydraulic continuity with the main water-bearing zones in the lower division of the Recent deposits.

PLEISTOCENE SERIES

GENERAL FEATURES

Unconsolidated or slightly consolidated deposits of Pleistocene age cap all the low hills and coastal mesas along the Newport-Inglewood structural zone, underlie the Recent deposits, and overlie Pliocene and older rocks. These Pleistocene deposits consist of interfingered beds of sand, gravel, silt, and clay. In downward succession they include a capping terrace deposit, the Palos Verdes sand, certain unnamed upper Pleistocene deposits, and the San Pedro formation of lower Pleistocene age. In the area shown on plate 3, the San Pedro formation is by far the thickest of the Pleistocene deposits.

These Pleistocene sediments range in thickness from about 200 to 1,000 feet along the coast, and from about 20 to 900 feet under the hills, mesas, and gaps of the Newport-Inglewood zone. Inland beyond that zone they attain a maximum thickness of 3,000 feet beneath the central Downey Plain, about on a line through Huntington Park and Santa Ana; still farther northward they thin along the inland hills where they have been displaced by faulting, warped upward on anticlinal uplifts, and partly removed by erosion.

TERRACE COVER AND PALOS VERDES SAND

The hills, mesas, and plains of the Newport-Inglewood belt are capped almost everywhere by nonfossiliferous sand and silty sand ranging in thickness from a few feet to about 20 feet. This terrace cover is characteristically red, especially in the upper part of the soil zone, owing to a coating of iron oxide over its particles. At exposures along the Signal Hill uplift the terrace cover is a uniform sand of fine to medium texture, with considerable content of silt-sized particles in the top few feet where it is 5 to 15 feet thick.

In the Palos Verdes Hills to the west of the area shown on plate 3 this terrace cover locally is more than 100 feet thick; Woodring (Woodring, Bramlette, and Kew, 1946) states that this thick facies represents cliff talus, stream-fan and channel material, rill wash, and slope wash; remains of land mammals have been reported at several localities. Similar deposits elsewhere along the southern California coast have been described by Davis (1933, p. 1055–1061). Such deposits are definitely continental in origin.

For the thinner terrace cover in this area, however, continental origin is not clearly established (see p. 18). Probably at some places the terrace cover may represent a flood-plain deposit laid down on the late Pleistocene marine platform immediately after its emergence from the ocean, but elsewhere the terrace cover probably is sand of marine origin modified by soil-forming processes.

Extensive accumulations of marine shells, chiefly pelecypods, occur in the top few feet of this terrace cover at many places on the several mesas along the Newport-Inglewood zone. These occurrences of shells are almost invariably associated with a black soil that commonly leaves a greasy residue on the hands. These particular accumulations of shells doubtless are of kitchen-midden origin, although the shell-mound materials probably have been scattered by cultivation of the land.

At several places along and near the Newport-Inglewood structural zone this terrace cover is immediately underlain by a thin layer of fossiliferous gray sand and gravel. The type exposure of this marine sand at San Pedro was originally described by the Arnolds (Arnold and Arnold, 1902, p. 120, 126–128; Arnold, 1903, p. 12, 23–30) under the designation "upper San Pedro series." In a manuscript report on the geology of the Palos Verdes Hills, Kew proposed the name "Palos Verdes formation," but that name first appeared in print in 1926 (Tieje, 1926, p. 502–503). In a recent detailed report on this area Woodring (Woodring, Bramlette, and Kew, 1946, p. 56) defines this stratigraphic unit as the Palos Verdes sand and describes its typical characteristics as follows:

> The Palos Verdes sand, like the older marine terrace deposits, consists of a thin veneer on the terrace platform, which bevels formations ranging in age from lower Pleistocene to Miocene. Also like the older marine terrace deposits, the strata consist generally of coarse-grained sand and gravel but include silty sand and silt. Limestone cobbles are the prevailing constituent of the gravel, but granitic and schist pebbles are locally abundant. The Palos Verdes generally ranges in thickness from a few inches to 15 feet and is usually less than 10 feet. At places it consists of thin lenses and at other places it is absent.

From its marine fauna Woodring ascribes the Palos Verdes sand to the upper Pleistocene. The antecedent terrace platform on which it rests in the type area, and presumably over extensive parts of the area shown on plate 3, is a surface of marine planation also of upper Pleistocene age. The lowest and youngest of 13 such features formed on the flank of the Palos Verdes Hills after early Pleistocene time, the

Palos Verdes sand and its platform evidently are products of the latest part of the Pleistocene epoch.

Within the Long Beach-Santa Ana area the Palos Verdes sand or its essential equivalent has been identified specifically at four localities as follows:

1. About 6 miles west of Long Beach and 200 feet south of the intersection of Sepulveda Boulevard and Vermont Avenue a thin lens of gray sand containing marine shells is exposed beneath red soil. This sand has been identified by Woodring (personal communication, Nov. 23, 1943) as the essential equivalent of the Palos Verdes sand.

2. At several places on Signal Hill are exposures described in some detail in a recent paper by DeLong (1941, p. 229–252). Certain of these exposures were initially described by Arnold (1903, p. 30–32) who listed a fauna of 160 species of megafossils and correlated the exposed deposits with his upper San Pedro series. DeLong has confirmed the conclusion that these deposits are essentially equivalent to the Palos Verdes sand of the type locality, and has listed 119 species from the outcrops.

As exposed on the west flank of Signal Hill, in the east cut bank of Cherry Avenue about 800 feet north of Hill Street, the Palos Verdes sand unconformably overlies steeply dipping sand of lower Pleistocene age. Here it attains a thickness of about 14 feet. The basal 2 feet is reddish fossiliferous gravel containing cobbles up to 6 inches in diameter. This gravel is overlain by 12 feet of fine- to medium-grained gray sand, richly fossiliferous in the basal 2 feet but barren of fossils above. This gray sand merges irregularly into reddish-brown sandy soil 8 feet thick.

3. At the sea cliff in Long Beach is one exposure of sand 41 feet thick with a fossil horizon near its base, described by Arnold (1903, p. 32) who also noted a second exposure about 50 feet thick with a fossil bed at its base. He reported on the fauna from these exposures and concluded that the outcrops represented a continuation of his upper San Pedro series (Palos Verdes sand). These fossil localities at the sea cliff are no longer exposed.

4. Extensive exposures along the south face of Newport Mesa and along the stream-cut bluffs flanking Newport Canyon reveal a reddish soil underlain in turn by loose gray sand and a layer of fossiliferous gravel and sand. According to Arnold (1903, p. 56) a faunal list by J. C. Merriam indicates that this horizon is equivalent to his upper San Pedro series (Palos Verdes sand). Willett (personal communication, Jan. 17, 1944) has made a recent study of the fauna from two of these exposures on Newport Mesa and concludes that they are essentially the same age as upper Pleistocene beds (Palos Verdes sand) near Playa del Rey.

Other outcrops of fossiliferous gray sand in the Long Beach-Santa Ana area are lithologically and structurally similar to the four identified specifically as Palos Verdes sand. Also, a shell bed has been encountered at shallow depth in numerous wells and borings in the Wilmington district and on the Signal Hill uplift. Probably most of these occurrences, if not all, are the Palos Verdes sand initially deposited extensively along the Newport-Inglewood zone within the Long Beach-Santa Ana area at least. However, it should be recorded here that no shallow shell horizon of probable Palos Verdes age is known to occur in the central reach of that zone—Landing Hill, Bolsa Chica Mesa, or Huntington Beach Mesa.

The terrace cover and Palos Verdes sand are shown as a single cartographic unit on plate 3, because nowhere in the area does their aggregate thickness appear to be more than about 50 feet, they are conformable if not gradational one into the other, and they could not be mapped separately except on a large scale and by very intensive paleontologic search. The composite unit is moderately deformed; initially it must have constituted a featureless coastal plain, but subsequently it has been warped and faulted into the land forms of the Newport-Inglewood zone (see p. 17). Inland from that zone, correlatives of the terrace cover and Palos Verdes sand may be extensive beneath parts of Downey Plain, below the deposits of Recent age; but data by which they can be discriminated in the logs of wells in that part of the area are not available.

The terrace cover and the underlying Palos Verdes sand contain very little water within the Newport-Inglewood zone, as together they are not more than about 50 feet thick and occur almost exclusively in the zone of aeration above the water table. Thus, although the Palos Verdes sand is permeable it is not saturated and hence cannot supply water to wells. Where these deposits form the land surface they are sufficiently permeable to absorb some rainfall and to transmit water to underlying strata; but those underlying strata are commonly not highly permeable, and the contribution to the major ground-water bodies from this source doubtless is inconsequential.

UNNAMED UPPER PLEISTOCENE DEPOSITS

CHARACTER, THICKNESS, AND EXTENT IN THE COASTAL ZONE OF THE LONG BEACH-SANTA ANA AREA

In this report certain strata that are encountered in wells between definite or probable correlatives of the Palos Verdes sand above and the San Pedro formation below are designated as unnamed upper Pleistocene deposits. Subsequent paragraphs describe characteristics of these deposits at three localities typical for the westernmost part of the Long Beach-Santa Ana area.

High on the northwest flank of Dominguez Hill, near the intersection of Victoria Street and Central Avenue, wells are reported by Wissler (1943, p. 212; also from his unpublished data) to pass successively through four deposits: (1) nonmarine yellow and brown sand, sandy clay, and gravel to 175 feet below the land surface; (2) lagoonal deposits 40 feet thick; (3) a thin deposit of lignite containing abundant carbonized fragments; (4) and about 300 feet of marine sand and gravel including a megafossil zone of San Pedro age from 215 to 250 feet below the land surface. He assigns the top 175 feet of nonmarine sediments to his Palos Verdes formation but correlates the lagoonal deposits and the marine sand and gravel with the San Pedro formation. Wissler here uses the name "Palos Verdes formation" to include all deposits of upper Pleistocene age. The writers believe that the entire 175-foot section of nonmarine sediments cannot be equivalent to Palos Verdes sand as defined by Woodring, although it probably represents the thickness of upper Pleistocene deposits on Dominguez Hill. About a mile to the west, low on the flank of Dominguez Hill, drilling of water well 3/13-32F6 is reported to have encountered two zones of marine shells—one in sand 20 to 30 feet below the land surface, the other 238 to 260 feet. The upper shells probably represent the Palos Verdes sand; the lower shells doubtless represent Wissler's megafossil zone of San Pedro age.

At these two places all wells begin at a common stratigraphic horizon on the terrace cover. It is thought that on Dominguez Hill the basal 145 to 150 feet of Wissler's nonmarine upper Pleistocene, about 30 to 175 feet below the land surface, probably conforms to the antecedent definition of the unnamed upper Pleistocene deposits.

For the vicinity of Wilmington it is reported by Bartosh (1938, p. 1053) that abundant marine shells have been encountered to a depth of 200 feet below the land surface in many oil wells. Marine shells have been reported also for many water wells in the same district; for wells near the crest of the Wilmington anticline marine shells have been reported commonly within the depth intervals 10 to 35 feet and 140 to 200 feet below the land surface. It is inferred that the upper of these two megafossil zones is the Palos Verdes sand or its essential equivalent and that the lower zone probably represents the upper part of the San Pedro formation; the strata between the two zones are ascribed, in this report, to the unnamed upper Pleistocene deposits.

About midway between Wilmington and Dominguez Hill, and half a mile north of the intersection of Alameda Street and Sepulveda Boulevard, the materials penetrated by well 4/13-22D1 were sampled during drilling. The samples were examined by Natland (personal communication, 1943), of the Richfield Oil Corp., who reported that those collected in the top 164 feet contained no fossils but those from below this depth contained fossils. From this information it is inferred that the upper 164-foot interval is nonmarine and probably of upper Pleistocene age. Here the Palos Verdes sand and some other materials of uppermost Pleistocene age have been stripped off, and alluvial deposits of Recent age about 30 feet thick have been deposited. The nonmarine deposits underlying those of Recent age, about 30 to 164 feet below the land surface, are ascribed in this report to the unnamed upper Pleistocene deposits.

About a mile to the northeast near the intersection of Carson and Alameda Streets and near the axis of a minor syncline (see pl. 4, section *B–B′*) the Pleistocene deposits attain their greatest known thickness on the coastal side of the Newport-Inglewood zone; the base of the Pleistocene is about 1,200 feet below the land surface, and the base of the unnamed upper Pleistocene deposits may be 320 feet below the land surface.

Correlatives of the unnamed upper Pleistocene deposits do not occur in Signal Hill nor under much of the Los Cerritos district (see p. 64) where the fossiliferous San Pedro deposits have been identified by DeLong (1941, p. 234, fig. 3) in a cut bank about 40 feet below the general land surface of that area. Also, they probably are absent in the Seal Beach area in the central part of Huntington Beach Mesa where sand and gravel of San Pedro age probably crop out (see pl. 3), and in the southern part of Newport Mesa where the Palos Verdes sand rests directly on beveled rocks of Pliocene and Miocene age. However, they probably are present under part of the Long Beach Plain, where they are not more than 100 feet thick; beneath Sunset Gap, where their thickness is unknown; beneath the southern or ocean-front segment of Huntington Beach Mesa; and beneath the northern part of Newport Mesa, where the materials of Pleistocene age thicken rapidly northward (see pl. 4, section *D–D′*). None of these areas affords outcrops at which the stratigraphic boundaries or the lithologic character of the unnamed upper Pleistocene deposits are clearly disclosed. From well logs it is inferred that the deposits are chiefly fine sand and silt with coarse sand and gravel interspersed at some places.

On plate 4, sections *C–C′*, *D–D′*, and part of *A–A′* (see Dominguez Hill) the deposits of upper Pleistocene age are discriminated tentatively from the underlying San Pedro formation on the basis of the change in lithology from fine-grained deposits above to coarse-grained deposits below. It should be noted that faunal evidence beyond that already cited is not now available to substantiate this tentative discrimination. The lithologic change at some places is not apparent from evidence at hand, and for these no differentiation is attempted (pl. 4, section *A–A′*, central part).

Inland from the Newport-Inglewood zone and beyond the area shown on plate 3 these unnamed upper Pleistocene deposits doubtless thicken progressively and are several hundred feet thick under the central part of Downey Plain. There they consist largely of silt and clay with some beds of sand and gravel interspersed. Toward the inland edge of the plain and beneath the upper reaches of the major alluvial fans materials presumably correlative with the unnamed upper Pleistocene deposits are composed dominantly of sand and gravel. The very coarsest materials of upper Pleistocene age lie near the apexes of the Santa Ana and San Gabriel alluvial fans.

In their yield of ground water the unnamed upper Pleistocene deposits are not highly productive in that part of the area of plate 3 which lies west of the San Gabriel River in Los Angeles County. These deposits are predominantly fine sand, silt, and clay; they are tapped by relatively few water wells and where tapped commonly supply only small domestic wells.

In that part of the area (see pl. 3) which lies east of the San Gabriel River in Orange County the unnamed upper Pleistocene deposits are also predominantly fine sand, silt, and clay, but they contain a number of limited sand and gravel layers 20 to 30 feet thick. These coarser layers are tapped by a large number of water wells and yield both irrigation and domestic supplies, but the irrigation wells tapping only these shallower deposits commonly do not produce more than 200 to 400 gallons a minute.

STRATIGRAPHIC RELATIONS

Except with regard to sequence of deposition, the stratigraphic relations of the unnamed upper Pleistocene deposits to the overlying Palos Verdes sand and to the underlying San Pedro formation are not clearly disclosed by available data. This obscurity results in part because substantial crustal deformation and erosion occurred locally as these deposits were accumulating.

The unnamed upper Pleistocene deposits probably were laid down over most of the Long Beach-Santa Ana area, but they are missing from the stratigraphic sequence at several places near the coast (p. 57). At Signal Hill they are absent, and at least 200 feet of deformed San Pedro deposits were removed (see pl. 4, section *C–C′*) before the Palos Verdes sand was deposited unconformably on the San Pedro. About 14 miles to the southeast on the south part of Newport Mesa and for 2 miles inland along Newport Canyon the Palos Verdes sand was deposited directly on beveled rocks of Miocene and Pliocene age. Obviously, if the unnamed upper Pleistocene deposits had been present at either of these two localities they were stripped off before the Palos Verdes sand was laid down. Probably the southeastern part of Newport Mesa was undergoing erosion during all of pre-Palos Verdes upper Pleistocene time.

If the unconformities of these coastal localities were of regional extent it would follow that the contact of the unnamed upper Pleistocene deposits with the underlying San Pedro formation was everywhere an unconformity, but it is doubtful that such unconformity extends throughout the Long Beach-Santa Ana area; none can be recognized in the available logs of water wells or oil wells. Also, for only a few wells is there faunal evidence for differentiating the two deposits tentatively, as has been suggested. It seems altogether possible or even probable that inland from the Newport-Inglewood zone, perhaps within part of the area shown on plate 3, sedimentation went on continuously from lower into upper Pleistocene time, and that there the unnamed upper Pleistocene deposits are conformable with the underlying San Pedro formation.

Nowhere in the area has the contact between the unnamed upper Pleistocene deposits and the overlying Palos Verdes sand been discriminated in outcrop. Presumably the contact would be unconformable locally, at least along and near the Newport-Inglewood zone. Inland beyond that zone, however, it is altogether possible that the contact is conformable.

CORRELATION WITH AREAS BEYOND THE COASTAL ZONE

On the Palos Verdes Hills are 13 marine terraces ranging in altitude from 100 to 1,300 feet above sea level. The Palos Verdes sand was deposited on the latest and lowest of these terraces. The 12 older terraces were cut between successive episodes of uplift during the interval between the deposition of the San Pedro sediments and the deposition of the Palos Verdes sand. The unnamed upper Pleistocene deposits of the Long Beach-Santa Ana area were laid down during the same interval and thus, at least in part, appear to be correlative with the deposits on the 12 older terraces of the Palos Verdes Hills. Of these terrace deposits Woodring (Woodring, Bramlette, and Kew, 1946, p. 53–54) reports as follows:

> Deposits lying on the terraces embrace material of two classes—marine sand and gravel and nonmarine debris designated the nonmarine cover. The marine deposits consist generally of cleanly washed, poorly sorted stratified coarse-grained sand and gravel, but include silty sand and rubble. They form a thin veneer on the terrace platform. They are generally only a few feet thick but toward the seaward edge of a terrace they may be as much as 10 to 15 feet thick. At places they are represented by only a single layer of pebbles and interstitial sand. Owing to inequalities on the platform, to submarine scouring, or to subaerial erosion prior to deposition of the nonmarine cover, marine deposits are at places absent.

The elevation of the Palos Verdes Hills and the cutting of the older 12 terraces doubtless occupied a considerable period of time, obviously a time of structural activity locally if not regionally.

Inland across the coastal plain from the Palos Verdes Hills, the stratigraphic conditions have been summarized by Wissler (1943, p. 212); the following statement is based largely on his findings, which are quoted directly in part. In the Repetto and La Merced Hills west of Whittier Narrows, lower Pleistocene (San Pedro) and upper Pliocene deposits are overlain unconformably by buff to reddish-brown sand, silt, and conglomerate; these are chiefly of nonmarine origin.

These upper Pleistocene sediments range in thickness from 0 to nearly 500 feet along the southern flank of the Montebello oil field and attain a maximum thickness of 1,700 feet in the Repetto Hills east of Garfield Avenue. A similar unfossiliferous buff silt and reddish-brown gravel series is exposed over the major portion of the East and West Coyote oil fields where it ranges in thickness from 0 to 500 feet, and along the southern flank of the Puente Hills where it attains a thickness of 1,350 feet near the Whittier field. This conglomerate series, known locally as the La Habra conglomerate, has been referred to the lower Pleistocene by Eckis (1934, p. 49).

Wissler states that because these sediments, known locally as the La Habra conglomerate, unconformably overlap fossiliferous strata of lower Pleistocene as well as upper Pliocene age, he considers them to be upper Pleistocene, and so correlative with the upper Pleistocene deposits of the Newport-Inglewood zone and of the Wilmington area.

In a recent paper on the East Coyote Hills, Dudley (1943, p. 349–354) assigns to the upper Pleistocene a body of alluvium 200 feet thick and cites field evidence that this alluvium is separated by an unconformity from underlying nonmarine(?) sand, conglomerate, sandy clay, and silt which in the aggregate are about 2,350 feet thick. Dudley identifies these underlying beds as the series known locally as the La Habra conglomerate and assigns them to the lower Pleistocene in accord with the earlier assignment by Eckis.

Thus with respect to the Pleistocene deposits along the inland border of Downey Plain the geologists and paleontologists most familiar with that area are not yet in agreement as to the stratigraphic horizon for the boundary between upper Pleistocene and lower Pleistocene deposits. So long as such disagreement continues regarding an area where the strata are fairly well exposed, it is obviously premature to attempt a correlation of the unnamed upper Pleistocene deposits of the area shown on plate 3 with the Pleistocene section exposed along the inland edge of Downey Plain.

SAN PEDRO FORMATION

DEFINITION

The designation of San Pedro formation is applied in this report to a stratigraphic unit that in the full stratigraphic sequence underlies the unnamed upper Pleistocene deposits and overlies the Pico formation of Pliocene age; is discriminated in part from outcrops but largely by data from hundreds of water wells and oil wells—drillers' logs, electric logs, formational samples, and faunal lists; is essentially correlative with but thicker and more heterogeneous than the type San Pedro sand, Timms Point silt, and Lomita marl, as defined by Woodring (Woodring, Bramlette, and Kleinpell, 1936, p 125–149) and others (Clark, 1931, p. 25–42; Galloway and Wissler, 1927, p. 35–87); but doubtless includes some strata that are younger and may include some that are older than any exposed in the type section cited. Owing to the heterogeneity of the materials constituting this unit the nonlithologic designation of San Pedro formation is preferred to "San Pedro sand." The Timms Point silt and the Lomita marl are discussed as the two basal members of the formation.

Essentially, the San Pedro formation embraces all strata of lower Pleistocene age. In most of the Long Beach-Santa Ana area the full stratigraphic sequence prevails and the San Pedro formation intervenes between the unnamed upper Pleistocene deposits above and the Pico formation below. However, in the northwestern and southeastern parts of the area shown on plate 3, major unconformities occur both at its top and its bottom so that locally it underlies the Palos Verdes sand of late Pleistocene age and rests on rocks as old as upper Miocene.

For the stratigraphic units with which the San Pedro formation is correlative—San Pedro sand, Timms Point silt, and Lomita marl of Woodring and others—the type exposures occur low on the east flank of the Palos Verdes Hills in and near San Pedro. The eastern part of this type district extends into the area shown on plate 3.

In the type area the San Pedro sand is made up largely of stratified and cross-bedded sand but includes some beds of fine gravel, silty sand, and silt. Its component particles are derived chiefly from some distant area of granitic rocks; however, according to Woodring, some of the gravel beds contain pebbles of limestone, siliceous shale, and schist, which are assumed to have been derived locally from the Palos Verdes Hills. In the same area two local stratigraphic units in the lower Pleistocene, underlying the San Pedro sand, have been discriminated by several stratigraphers; in downward succession these are the Timms Point silt and the Lomita marl. The Timms Point silt of the type area is made up of brownish to yellowish sandy silt and silty sand. Its type outcrop at Timms Point has been ably described by Clark (1931, p. 25–42).

The underlying Lomita marl consists chiefly of marl and calcareous sand. According to Woodring (personal communication) the Lomita marl wherever found is at the base of the lower Pleistocene deposits, and he now ranks the Timms Point and Lomita units as formations. Before this assignment of higher rank was known to them the writers had followed the earlier assignment of these units to the rank of members in and at the base of the San Pedro.

Woodring (Woodring, Bramlette, and Kew, 1946, p. 43) reports that in the San Pedro area the greatest exposed thickness of the San Pedro sand is about 175 feet, that of the Timms Point silt about 80 feet, and that of the Lomita marl about 70 feet. Where they are concealed in the same area he estimates these three lower Pleistocene units to have a maximum thickness of about 600 feet.

One of the clearest exposures of the lower Pleistocene section in San Pedro is along Second Street where the Lomita marl, Timms Point silt, and basal beds of the San Pedro sand crop out successively from Pacific Avenue eastward to Mesa Street, and higher beds of the San Pedro sand are exposed in the low bluff that extends to Beacon Street. In these exposures the beds dip eastward and gradually flatten from a dip of about 28° at Pacific Avenue to about 3° along Beacon Street.

REPRESENTATIVE EXPOSED SECTIONS

Beyond the type area the San Pedro formation crops out at only a few places along the Newport-Inglewood structural zone. None of these outcrops spans a full section of the formation. They are discussed in order from northwest to southeast.

At Signal Hill, in discontinuous but moderately extensive exposures, the Palos Verdes sand is unconformably underlain by the San Pedro formation. (See pl. 3.) The exposed section comprises sand, gravel, and silt members that at most places dip 20° to 40° away from the crest of the hill. These deposits are locally cross-bedded. Fresh exposures are gray; weathered exposures are brownish yellow. DeLong (1941, p. 237–240) reports that the thickness of the exposed section is about 75 feet. The beds here exposed probably represent members from 200 to 300 feet above the base of the San Pedro formation. (See pl. 4, section *A–A′*.)

Deposits correlated tentatively with the San Pedro formation are exposed in the stream-cut bluffs of central Huntington Beach Mesa in the SW¼ sec. 34, T. 5 S., R. 11 W. Here a gravel pit exposes a 6-foot layer of loose, clean, white sand about 20 feet below the soil zone. This sand layer is underlain by an 18-foot member of unconsolidated coarse gravel enclosing layers of loose, cross-bedded pebbly sand from 0.5 to 2 feet thick. The gravel is well sorted in streaks and is highly permeable. Contained cobbles are as large as 6 inches in diameter and represent many types of igneous and metamorphic rocks.

About 2,000 feet north of this gravel pit and 300 feet northwest of the center of sec. 34 two other excavations reveal in downward succession a 10-foot layer of crossbedded pebbly sand, a 3-foot bed of fine-grained uniformly white sand containing gravel streaks from 1 to 2 inches thick, and a massive 6-foot bed of fine white sand. In lithologic character this sand exposed at the edge of Huntington Beach Mesa is indistinguishable from that in outcrops of the San Pedro sand at the type locality.

From stratigraphic relations as developed from data on wells (see pl. 4, section *A–A′*) it is inferred tentatively that these two outcrops are about 400 feet above the base of the San Pedro formation, although they have yielded no fossils to substantiate this assignment. Doubtless the materials exposed were deposited under littoral or near-shore conditions.

About half a mile east of this locality is an extensive gravel pit about 1,500 feet east of Golden West Avenue and immediately south of Talbert Avenue. Under a 12-foot cover of soil and silt the top 14 feet of a bed of sand and gravel is exposed. Pebbles as much as 1 inch in size are common. Pronounced crossbedding is emphasized by layers of pebbles that are tar-stained or heavily coated with iron oxide. The tar stain probably is not natural but is derived from oil-field waste waters that formerly may have been discharged into the pit and so dissipated. This sand-and-gravel member probably is a part of the San Pedro formation.

These exposures of permeable sand and gravel indicate that the central part of Huntington Beach Mesa within secs. 34 and 35, T. 5 S., R. 11 W., and the northern part of sec. 2, T. 6 S., R. 11 W., is underlain at shallow depth by permeable sand and gravel of probable San Pedro age. Water from waste fluids discharged into sumps in this material doubtless would percolate rather freely into underlying aquifers; thus the chemical quality of the natural waters in those aquifers might be deteriorated (Piper, Garrett, and other, 1953).

On Newport Mesa the San Pedro formation crops out only on the southwest edge of the mesa within a mile of the Coast Highway, and in a small area near the head of Newport Bay at the mouth of the Delhi Drainage Ditch (see pl. 3). It probably underlies all the mesa northward from a line through these two outcrop areas, and there dips gently northward. It is overlain unconformably by deposits of upper Pleistocene age that also dip northward, but even more gradually.

At the most southerly outcrop along the southwest edge of Newport Mesa the San Pedro formation is revealed in a bed of tough sandy silt, greenish to brownish gray, which dips 10° N. 40° W. This silt bed is overlain unconformably by deposits of upper Pleistocene age, chiefly fine, micaceous, incoherent, brownish-gray sand, but including a fossiliferous pebble bed at their base. As the unconformity is essentially parallel with and only a few feet above the alluvial plain of Santa Ana Gap, the outcrops of the San Pedro formation are small and discontinuous although they extend along the base of the stream-cut bluff for about a mile. Northward around the first point of land a second exposure of the San Pedro formation reveals a southwestward-dipping section of stratified silt overlain by a cemented coarse gravel. This gravel member of the San Pedro is truncated and unconformably overlain by gravel of similar character but of upper Pleistocene age. Structurally the exposures of the San Pedro formation in this area apparently occur on the two flanks of a westward-plunging syncline.

In the exposures near the head of Newport Bay, sand and gravel deposits of probable San Pedro age unconformably overlap semiconsolidated massive gray sandstone, which from its lithologic character and the depositional relationship is inferred to be of upper Pliocene age. Beds of tough, dark-gray, carbonaceous clayey silt here exposed also are tentatively assigned to the San Pedro formation, althought the stratigraphic relations are complicated by local faulting and by contortion of the San Pedro.

FAUNAL DATA FROM OUTCROPS AND FROM WELLS

The stratigraphy and faunal assemblages of the San Pedro formation at the type outcrop have been studied by many investigators. The stratigraphy was first described in some detail by the Arnolds (Arnold and Arnold, 1902, p. 120, 126–128; Arnold, 1903, p. 12, 23–30) who presented faunal lists for several localities. For the Lomita marl member the microfauna of the type locality was first discussed in a paper by Galloway and Wissler (1927). A few years later the type outcrop of the Timms Point silt member was examined by Clark (1931, p. 29) who collected both megafossils and microfossils but studied only the megafossils. His paper includes faunal lists for 155 species of mollusks, bryozoa, and brachiopods. Woodring (Woodring, Bramlette, and Kew, 1946, p. 43) has studied intensively the San Pedro sand and the related Lomita marl and Timms Point silt as they occur throughout the Palos Verdes Hills; he cites comprehensive lists of the megafossils collected at many localities. Descriptions of individual species have been assembled in a monograph by Grant and Gale (1931).

Other than in the type area the San Pedro formation is exposed only locally in the area with which this report is concerned. DeLong (1941, p. 229–252) has studied in detail the Pleistocene outcrops on Signal Hill and has published a list of 77 species of megafossils from the San Pedro formation. He reports that on the northwest bank of the small ravine about a mile northwest of Signal Hill there is a San Pedro faunal assemblage from an exposure stratigraphically about 450 feet above the base of the formation (see pl. 4, section A–A'); at that locality the San Pedro formation is very poorly exposed. For the outcrops of the San Pedro formation within the coastal zone southeast of the

Signal Hill uplift the writers know of no published account describing the stratigraphy or fauna.

In this report stratigraphic relations and age assignments have been extended from the outcrops largely by correlating drillers' logs and electric logs, but for certain localities this physical correlation can be substantiated by faunal evidence. Such paleontologic evidence is based chiefly on microfaunal assemblages in cores from oil wells or prospect holes; also on microfaunal assemblages and megafossils in samples of cuttings from wells. This evidence was accumulated by the paleontologists of several oil companies, and a very substantial amount of it was supplied confidentially to the Geological Survey for general application to the problems discussed in this report, but not for specific citation. Seldom was a faunal list made available. Thus the following discussion is hampered by certain restrictions that prevent a frank recitation of all the available data. Within the limits of these restrictions the localities affording paleontologic control for stratigraphic correlations are discussed briefly (see p. 66).

Before presenting the paleontologic evidence it should be noted that correlation by microfauna is accomplished principally by matching assemblages, so that commonly an exact age identification is not necessary and may be impossible. As most oil-producing zones of the area are in the lower Pliocene and Miocene rocks, local micropaleontologists have devoted little time to the upper Pliocene and even less to the Pleistocene. There is no uniform agreement as to the precise horizon at which the Pliocene and Pleistocene should be separated. At many places no clear faunal break exists at this horizon; at others deposits of lagoonal or continental origin extend from the land surface down to the probable base of the Pleistocene, or even below it, and contain no marine fauna. Hence demarcation between the Pleistocene and the Pliocene becomes largely a matter of unsubstantiated opinion, and these opinions differ widely. For example, in two papers published recently the thicknesses ascribed to the Pleistocene deposits of Signal Hill differed by at least 600 feet.

In order to develop the most uniform correlation of Pleistocene and Pliocene strata the nomenclature and faunal divisions employed by S. G. Wissler (1941, p. 212) are accepted in this report as the standard control, so far as feasible. In his recently published comprehensive paper on the stratigraphy of the oil fields in the Los Angeles Basin Wissler defines the foraminiferal zones employed by him for subdivision of the Pliocene rocks. He has worked for many years in the Los Angeles Basin and has examined many thousands of samples from both Pleistocene and Tertiary rocks; thus he has acquired a wide background concerning microfaunal associations in the complex sedimentary series of the area.

In the vicinity of Wilmington and a few hundred feet north of Cerritos Channel the basal beds of the San Pedro are underlain by a zone of silt and sandy silt about 250 feet thick (see pl. 4, section *B–B′*). Fossils of uppermost Pliocene (upper Pico) age occur in the upper 60 feet of this silt zone, the top of which, here about 1,000 feet below land surface, is accepted by petroleum geologists as the contact between Pleistocene and Pliocene. Wissler calls this layer "upper part of upper Pico" (oral communication). On the basis of paleontological determinations Bartosh uses the top of this layer as Pleistocene-Pliocene contact (oral communication; also Bartosh, 1938, p. 1053). No fauna are known to have been identified in the overlying sand and gravel; this coarse deposit commonly has been ascribed to the Pleistocene (San Pedro formation) because, as Bartosh (1938, p. 1053) reports, it lies unconformably on the upper silt zone of the Pico, and its lithologic character differs strikingly from that member.

At the west edge of Wilmington, paleontologic evidence has been gained from wells on the east flank of the hill immediately south of Bixby Slough. Microfauna in samples from well 5/13–6D2 were examined by Wissler (personal communication), who reports that the well probably was drilled in Pleistocene sediments to its full depth of 990 feet. From this evidence, and from lithologic and electric-log correlations extended from the Wilmington oil field to the north and east, it is inferred that this well penetrated essentially the full thickness of the San Pedro formation. Here the division between the unnamed upper Pleistocene deposits and the San Pedro formation is placed tentatively at about 100 feet below land surface.

Near the southeast end of this hill exploratory holes for oil have yielded microfossils which indicate that here the base of the Pleistocene (Timms Point-Lomita fauna) is about 1,100 feet below land surface in one hole and about 1,200 feet in another.

On Dominguez Hill Wissler (1943, p. 212; also from his unpublished data) obtained ditch samples from oil wells being drilled. From the paleontologic evidence he concludes that the San Pedro formation occurs from 175 to about 670 feet below land surface near the crest of the hill.

For the Signal Hill area Wissler (personal communciation) reports that fossils of upper Pico age have been found in a silt-and-clay member. Near the crest of the anticline a short distance west of the Pickler fault this upper member of the Pico occurs about 450 feet below land surface (see pl. 4, section *A–A′*) immediately beneath a thick section of fossiliferous sand and gravel (Silverado water-bearing zone, see p. 69) that Wissler assigns to the San Pedro formation.

In Dominguez Gap a number of core holes have been drilled to explore the possible extension of the Cherry-Hill fault. The silt member that lies immediately beneath the Silverado zone of the San Pedro formation has been assigned tentatively to the upper Pliocene (upper Pico) from paleontologic examination by a worker intimately familiar with the stratigraphic relations along the Newport-Inglewood zone.

For the area north and northeast of Signal Hill, diagnostic data by Natland (personal communication) are available from his examination of samples from water wells of the city of Long Beach. He reports a Timms Point-Lomita fauna in well 4/12-28H1 at intervals between 697 and 1,086 feet below land surfaces; in well 4/12-6K1 between 776 and 885 feet below land surface; in well 4/12-14P1 between 995 and 1,000 feet below land surface—no samples were taken from 830 to 995 feet, and Timms Point fauna may be present in that interval—and in well 4/12-14D1 between depths of 1,378 and 1,430 feet below land surface. According to Natland this faunal assemblage commonly occurs in a marly silt member that locally contains so many fossils as to resemble a coquina.

The suite of samples from well 4/12-28H1 was examined also by S. G. Wissler (oral communication). His faunal identification agrees with that by Natland. However, he suggests a further refinement of the faunal data; he identifies a Timms Point fauna in samples recovered between 697 and 800 feet below land surface and a Lomita fauna in the one sample available between depths of 936 and 1,086 feet.

Cores from water well 5/12-2P5 in Alamitos Gap were examined by W. D. Rankin (personal communication) of the Continental Oil Co., who reports that fossils of San Pedro age were recovered between 190 and 330 feet below land surface. (See pl. 4, section *A–A′*.) No core was taken above the 190-foot depth.

For the vicinity of Landing Hill paleontologists agree that the base of the Pleistocene is about 500 feet below land surface in Hellman Prospect well 1 (Barnes and Bowes, 1930, p. 12), in 5/12-12M. Here a Timms Point fauna is reported at the base of the Pleistocene beds.

In Bolsa Gap ditch samples collected by the Geological Survey from an oil well in 5/11-34M at the crest of the structural zone have been examined by Natland (oral communication) and Wissler (oral communication) for faunal identification and correlation. On the basis of their reports it is concluded, in the terminology of Wissler, that here the sediments from land surface to a depth of about 45 feet are nonmarine of Recent age, those from 45 feet to 480 feet below land surface are marine of San Pedro age, and the base of the Pleistocene deposits occurs at about 480 feet.

In Santa Ana Gap an oil-test hole was recently drilled near the intersection of Atlanta and Cannery Avenues in 6/10-7N. From examination of ditch samples Natland (personal communication) reports the contact between the Pleistocene and the Pliocene at about 280 feet below land surface. Here the base of the Talbert water-bearing zone of Recent age is about 150 feet below land surface; thus the sediments between a depth of 150 and 280 feet are assigned tentatively to the San Pedro formation.

For the southwest edge of Newport Mesa, data on the base of the Pleistocene are afforded by samples from a series of exploratory core holes drilled some years ago. Through R. W. Clark, of the Western Gulf Oil Co., who made the data available, and Dr. P. P. Goudkoff (written communication, Dec. 7, 1943) who reexamined the samples to determine the contact between Pleistocene and Pliocene in terms of Wissler's nomenclature, it is known that the base of the Pleistocene deposits is about 160 feet below land surface in 6/10–20G and that it dips generally northward to a depth of 300 to 350 feet in 6/10–17L, about 500 feet east of the Santa Ana River and 300 feet south of Hamilton Street.

For the south central part of Newport Mesa, at the Ajax Petroleum Co. well in 6/10–21C, Parker (1943, p. 333, fig. 139) has placed the base of the Pleistocene at about 150 feet below land surface. It is not known where the division between the unnamed upper Pleistocene deposits and the San Pedro formation occurs within this interval.

The stratigraphic interval here assigned to the San Pedro formation of lower Pleistocene age contains numerous beds of coarse water-bearing sand and gravel, especially the thick Silverado zone. Assignment of such coarse materials to the lower Pleisotcene is opposed to an earlier interpretation by Eckis (1934, p. 52–53), who states:

> From the standpoint of ground water, the change in sedimentation brought about by the mid-Pleistocene revolution is most important, for it marks the beginning of accumulation of the water-bearing alluvial gravel deposits in the three inland basins, and a change in the coastal plain basins from deposition of predominantly marine silts and clays to deposition of coarser material in which marine water-bearing sands and gravels formed a considerable part.
>
> The base of these water-bearing deposits has in most areas been considered to be the bottom of the ground water basin.

PHYSICAL CHARACTER

General features.—Data from wells show that the San Pedro formation underlies all the coastal zone of the Long Beach-Santa Ana area except the southern part of Newport Mesa. The general character and extent of the formation are shown on the cross sections on plate 4. Local details near the Newport-Inglewood zone are shown on plate 5. As these cross sections indicate, west of the San Gabriel River the San Pedro formation is composed largely of sand and gravel; finer materials generally are extensive only in the upper part of the formation. To the east in Orange County the formation commonly includes permeable sand and gravel, and impermeable or slightly permeable silt and clay, in about equal aggregate thicknesses; the sand and gravel members are relatively thin, and few appear to be extensive. This eastward change in general character of the formation is gradual but none the less appears to occur largely within a relatively narrow transition zone, whose alinement coincides roughly with that of Coyote Creek and the downstream reach of San Gabriel River. This transition zone roughly follows the boundary between Los Angeles County and Orange County. Accordingly, the character of the San Pedro formation as revealed in well logs can be discussed most advantageously in two parts.

Character of the formation in Los Angeles County.—In that part of the coastal zone within Los Angeles County the lower half or lower two-thirds of the San Pedro formation commonly is composed largely or exclusively of sand and gravel; the upper part is silt, clay, and fine sand at nearly all places. Typical sections for the district near Wilmington are shown by the logs for wells 4/13–23G2—Silverado well, city of Long Beach—and 4/13–31E4; for the vicinity of Dominguez Hill by the log for well 3/13–32F6; and for the area northeast of Signal Hill by the logs for wells 4/12–20C1 and 4/12–24M2 (see table 6).

These logs, except that for well 3/13–32F6 on the west flank of Dominguez Hill, show a dominant thick zone of sand and gravel at the bottom of the San Pedro formation. Beds of finer grain occur only in the upper, thinner part of the formation. In this area the sand-and-gravel zone within the San Pedro formation is so extensive and yields water so very copiously to wells that it is discriminated in this report as the Silverado water-bearing zone, from its typical occurrence in well 4/13–23G2 in Silverado Park within the city of Long Beach. It is inferred that this well entered the San Pedro formation at a depth of 280 feet below land surface. The log shows 42 feet of gravel from 238 to 280 feet, 316 feet of clay and sand from 280 to 596 feet, and 478 feet of sand and gravel from 596 to 1,074 feet below land surface. This basal 478-foot deposit of sand and gravel spans most of the Silverado water-bearing zone, which is inferred to be about 500 feet thick there (see pl. 4, section *B–B′*). The upper 300 feet of the zone is clean, loose, highly permeable sand and gravel; the lower 200 feet is chiefly coarse sand with interbedded layers of fine gravel. Samples of the gravel contain many pebbles as much as 2 inches in diameter, commonly of granite, metamorphic rocks, quartz, and gray chert. The sand particles are subrounded, gray, and arkosic; mica is present but not abundant. Plate 8 shows extent and thickness of the Silverado zone. Its water-bearing characteristics are discussed on pages 84 and 85. Within the area shown on plate 8 this water-bearing zone underlies some 68 square miles or 43,000 acres, slightly more than a third of all the area shown on plate 3.

In much of the Long Beach area between the coast and the Newport-Inglewood structural zone—most of the area shown on plate 8—the Silverado zone is a surprisingly uniform mass of sand and gravel with almost no interbeds of silt or clay. There the base of the Silverado zone is believed to be essentially the base of the San Pedro formation. (See p. 66.) For this particular part of the Long Beach area the contours on the base of the Silverado water-bearing zone as shown on plate 8 are in effect approximate structure contours on the base of the San Pedro formation.

At the very coast of the Long Beach area, however, the Silverado zone as a single, uniform mass of sand and gravel appears to finger out locally. On the south flank of the Wilmington anticline in the vicinity of Terminal Island it contains beds of silt and its permeability diminishes. To the east about 1,800 feet northwest of Belmont Pier at Long Beach the log of an early test hole for oil suggests that the deposits of Pleistocene age are chiefly silt and clay but contain two 100-foot sand members within 400 feet of the land surface. Apparently the Silverado lenses out somewhere west of Belmont Pier. Electric logs for wells along the flood-control channel near the west edge of the Long Beach Plain suggest that the Silverado zone is there distinctly silty; hence the fingering into silt may occur chiefly at the west edge of the plain.

Inland from the Newport-Inglewood structural zone the simple division of the San Pedro formation into an upper silty zone and a lower coarse-grained (Silverado) zone does not apply. In the district northeast of Signal Hill the Silverado zone locally spans the upper and middle parts of the San Pedro formation but includes many irregular layers or lenses of silt and clay that are notably discontinuous from well to well. Inland to well 4/12–15B1 near Carson Street at Bellflower Boulevard, the sand and some gravel of the Silverado zone make up half to three-fourths the thickness of the San Pedro formation (see pl. 4, section *C–C′*). The sand is typically medium to coarse grained, subrounded, fossiliferous, arkosic, and gray. The gravel commonly contains pebbles but few cobbles. It has been noted that at type well 4/13–23G2 gravel forms the upper part of the Silverado zone; in the inland district, however, gravel is found most commonly in the lowest part of the zone. It is the Silverado zone of this district that supplies about two-thirds of the water withdrawn by the municipal wells of the cities of Long Beach and Signal Hill.

Somewhat farther inland and also to the southeast, the Silverado zone apparently fingers out and its stratigraphic interval is occupied largely by silt and clay. Thus, because its remaining parts are fine-grained throughout the area, in these marginal districts of the Long Beach area the San Pedro formation is composed predominantly of silt and clay. As is shown by shading on plate 8 the formation has this character beneath the Alamitos Heights segment of the Signal Hill uplift, in a tongue trending northwestward and crossing the San Gabriel River east of Signal Hill, and locally along the inland margin of the coastal zone (see table 6, log for well 4/12–5G1).

In much of the district north of Signal Hill the Silverado zone of the San Pedro formation is underlain by basal Pleistocene deposits 550 feet thick, possibly more. In some of the few water wells that penetrate them these basal beds are largely silt and fine sand (see pl. 4, section *E–E'*, wells 4/12–21M4 and 4/12–15B1), but in other wells they contain highly permeable and relatively thick layers of coarse sand and gravel (see table 6, logs 4/12–6K1, 4/12–14D1, 4/12–14P1, and 4/12–28H1). Apparently these coarse-grained layers are discontinuous and are composed of stream-borne pebbles and cobbles but are accumulated under shallow-marine conditions. From faunal evidence (see p. 67) these basal beds are probably correlative with the Timms Point silt and the Lomita marl members of the San Pedro formation and hence are of Pleistocene age. Accordingly, for the part of the Long Beach area here discussed the contours on the base of the Silverado zone are not structure contours on the base of the San Pedro formation. Elsewhere in the Long Beach-Santa Ana area these basal members of the San Pedro formation have been identified by fauna only in a few oil-test wells near Wilmington and near Landing Hill, already cited.

Inland beyond the coastal zone, well logs show that under most of Downey Plain the deposits of Pleistocene age consist chiefly of fine sand, silt, and clay but include thin tongues, lenses, and interbeds of coarse sand and gravel. Here the San Pedro formation has not been discriminated, but its general character is suggested on plate 7, section *A–A'*. However, the wells whose logs are plotted on the inland part of that section do not penetrate the full thickness of the Pleistocene deposits.

Character of the formation in Orange County.—In the part of the coastal zone that is in Orange County the deposits of Pleistocene age are markedly heterogeneous and only locally can their component formations be discriminated by available data on the relatively few deep water wells. As encountered in wells, these deposits are composed of about equal proportions of permeable sand and gravel and of impermeable or only slightly permeable silt and clay. Their general character and thickness are shown on plates 4 and 5. In contrast to the thick and extensive Silverado water-bearing zone of Los Angeles County the coarse-grained members of the Pleistocene are relatively thin and somewhat discontinuous over most of Orange County, especially in the reach of the Newport-Inglewood zone from the

San Gabriel River to and across Bolsa Gap. Farther to the southeast under Huntington Beach and Newport Mesas the stratification of the Pleistocene deposits is fairly uniform, and sand and gravel layers predominate locally.

The lithologic character of the Pleistocene deposits in Orange County is best illustrated by the well logs in table 6; for example, logs for well 5/12–11G1 in Alamitos Gap; wells 4/11–28J1, 5/11–6A1, and 5/11–11M1 on Downey Plain; well 5/11–28K1 in Bolsa Gap; wells 5/11–26P3 and 5/11–35P3 on Huntington Beach Mesa; and wells 5/10–33D1, 6/10–8D6, and 6/10–18K3 in Santa Ana Gap. From these logs and others it is seen that the several layers of sand and gravel commonly are less than 50 feet thick, but locally in the lower part of the San Pedro formation they are as much as 200 feet thick. Inland more than a mile beyond the Newport-Inglewood zone the lower part of the San Pedro formation is reached only by the few wells more than about 600 feet deep; at the inland edge of the area shown on plate 3 it is not reached by any water wells. Thus, little is known concerning the physical character of the lower part of the formation except in and near the Newport-Inglewood zone.

Further information is available in the samples of cuttings taken from a number of water wells during drilling. Several suites of such samples were taken by Eckis (1934, p. 19), Gentry, and Kimble in connection with the geologic study of the South Coastal Basin by the California Division of Water Resources. In the course of the present investigation other suites have been taken by Newcomb, Paulsen, and Poland of the Geological Survey. From these samples certain general conclusions can be drawn concerning the lithology of the Pleistocene deposits, in particular concerning the following features that pertain largely to the deposits of San Pedro age in Orange County.

Commonly the sand and gravel layers are clean, well sorted, and unweathered. The sand is composed of subangular particles and usually is arkosic. Marine shells in the sand layers are reported rather frequently from the vicinity of the Newport-Inglewood zone but only rarely from districts farther inland. The gravel usually is of pebble size but at numerous places contains 3- to 4-inch cobbles. Elongated rocks 8 inches in greatest dimension have been recovered from well 5/11–2N1. These pebbles and cobbles are most commonly granite, gneiss, dark fine-grained igneous rocks (volcanic?), schist, and quartzite. Usually they are subrounded.

The "clay" reported so characteristically by drillers is usually silt or clayey silt, gray, brown, or green. Less generally, silty clay or clay is recovered in samples; these finest materials also are gray—blue when wet—brown, or green. Fragments of carbonized wood and vegetal fibers are numerous in many fine-grained samples. Layers of peat have been reported from a number of wells.

In the Pleistocene deposits of Orange County, within the area shown on plate 3, two relatively thick and extensive bodies of sand and gravel are disclosed by data on wells; one underlies Huntington Beach Mesa, the other underlies the north half of Newport Mesa.

Beneath Huntington Beach Mesa the Pleistocene deposits have been penetrated to their full thickness by very few water wells but by many oil wells. Together, logs of these wells reveal an upper part composed of alternating thin layers of silt or clay, sand, and gravel, underlain by a thick lower part composed almost exclusively of sand and gravel. This lower zone is tentatively concluded to be immediately above the base of the San Pedro formation (see pl. 4, section *A–A′*). As encountered in well 5/11–35P3 in the central part of the mesa the first water-bearing zone lies 60 to 110 feet below land surface and is 50 feet thick; the second is 187 to 245 feet below land surface and is 58 feet thick; and the basal zone is below 325 feet. This well penetrated 65 feet of sand and gravel from 325 to 390 feet, and was stopped in clay at 394 feet. Electric logs of nearby oil wells indicate that here this basal zone continues to a depth of about 575 feet and is about 250 feet thick. Well 5/11–26P3, one mile to the north, probably tapped most of this zone; it penetrated 208 feet of sand and gravel from 394 to 577 feet below land surface (see pl. 5, section b–b′ and table 7). Logs of water wells are not available to trace this basal zone northward beyond 5/11–26P3, but it is known to underlie all the central part of the mesa and to extend westward under Bolsa Gap. It persists with nearly uniform thickness southward to well 6/11–2M2, but coastward it contains an increasing proportion of silt and so decreases in permeability. At well 6/11–11E1 blue clay with streaks of coarse sand was reported for 213 feet below the thin second water-bearing zone, suggesting that the basal water-bearing zone has largely fingered out. Logs of wells show that the first and second water-bearing zones continue southward to well 6/11–11E1, within 0.5 mile of the ocean; they probably extend farther and crop out on the ocean floor.

The shallowest of these three layers of sand and gravel probably crops out near and on the west edge of the mesa (see pl. 3). Eastward it extends across the full width of the mesa and butts against the deposits of Recent age that fill Santa Ana Gap. Because this uppermost layer is less than 50 feet below land surface over much of the westerly part of the mesa it is exposed in several gravel pits that had been used in the past for the disposal of oil-field wastes and to some extent were still so used in 1944. Thus at times saline water has been able to enter this shallow water-bearing zone. Fortunately, a bed of silt that is relatively uniform and about 100 feet thick separates the uppermost gravel layer from the intermediate layer, which in turn is separated by another silt or clay bed from the thick and productive basal layer of sand and gravel.

Beneath the north half of Newport Mesa the Pleistocene deposits have been penetrated by many wells and are known to be relatively uniform in the succession and physical character of their component beds. They include an upper part composed of silt, clay, fine sand, and some gravel in thin layers, and a lower part composed largely of sand and gravel, at least at many places. Logs of wells report marine shells rather commonly both in the fine upper deposits and in the coarser lower deposits. For this reason, and because the several layers are relatively extensive, most deposits of Pleistocene age in this district probably were laid down under marine conditions.

The lower, coarse-grained materials include the thickest and most extensive water-bearing zone yet discriminated in Orange County within the area shown on plate 3. That zone apparently spans the central third of the San Pedro formation (see pl. 4, section *D–D'*). In certain respects it may be a counterpart of the thicker and more extensive Silverado zone of Los Angeles County. As encountered in well 6/10–11B2 this zone is about 300 feet thick, 236 to 541 feet below land surface; it includes coarse sand and gravel from 236 to 304 feet, blue clay to 338 feet, medium-to-coarse sand and gravel from 338 to 404 feet, and fine "blue" sand to 541 feet. The thickest known section of the zone was penetrated by well 6/10–1E2, 425 to 946 feet below land surface; even with 521 feet of penetration the well was bottomed within the zone. The cleanest and most productive water-bearing material was encountered from 660 to 946 feet.

This water-bearing zone extends eastward across Newport Boulevard into the Irvine tract where it is tapped by well I–6G1 and by the wells of the Newport Heights Irrigation District at Palisades Road (I–6E). The zone probably extends to the head of Newport Bay, where a local outcrop of the San Pedro formation (see pl. 3) includes a poorly exposed thin section of sand and gravel. In that reach, however, its continuity may be broken by a fault (see p. 104). Westward the zone extends across the mesa at least to well 6/10–3L1, in which it was encountered 386 to 552 feet below land surface (see pl. 4, section *D–D'*). No logs for deep water wells are available to trace it toward the Santa Ana River.

About 2.4 miles inland from well 6/10–1E2, near the intersection of Delhi Road and Main Street, well 5/10–25A2 encountered 132 feet of sand and gravel 1,065 to 1,197 feet below land surface. About 2 miles farther west, near Santa Ana Gardens, well 5/10–23L1 was drilled to a reported depth of 1,380 feet. No log of this well is available, but it probably is perforated near bottom, and the chemical character of its water is similar to that withdrawn from the deeper wells on Newport Mesa. Both wells probably tap the northward extension of this principal water-bearing zone of Newport Mesa. About 1.5 miles northwest of well 6/10–1E2, however, well 5/10–34H2 was drilled to a depth of 760 feet; its log reports "clay" almost continuously from 58 to 412 feet below land surface, and alternating layers of sand, fine sand, and clay from 412 to 760 feet. Only the materials more than 412 feet below land surface are assigned tentatively to the San Pedro formation; these include only one 8-foot layer of gravel (see log in table 6). Seemingly, at least the upper part of the principal water-bearing zone is not present here. Also, farther northwest beyond Talbert Avenue, the electric log of an oil-test hole suggests that fine-grained deposits, largely silt and sand, here occupy most of the stratigraphic interval of the San Pedro formation, and largely replace the coarser deposits of the principal water-bearing zone to the southeast.

Throughout the inland or northern part of Newport Mesa the San Pedro formation dips northward 3° to 4°, or about 300 feet to the mile (pl. 4, section *D–D'*), and its aggregate thickness increases northward, or inland.

In the central part of Newport Mesa the character of the San Pedro formation appears to be substantially as in the contiguous district to the north. However, with respect to the chemical character of certain of its waters (Piper, Garrett, and others, 1953) this central part of the mesa is inferred to be a distinct subprovince. Its northern boundary is placed along the fault inferred to pass just north of well 6/10–10D3 (see p. 104). Its deepest water well, 6/10–10D3, is 1,060 feet deep; its log is given in table 6. To a depth of 122 feet below land surface the well penetrates fine-grained materials tentatively ascribed to the deposits of upper Pleistocene age. From 122 feet to 1,053 feet below land surface about 70 percent of the footage is occupied by sand and gravel, seemingly reasonably well sorted; this 931-foot section, largely of coarse-grained materials, is assigned tentatively to the San Pedro formation. The well probably penetrates approximately to the base of that formation, hence relatively to the base of the deposits of Pleistocene age.

THICKNESS

General information as to the thickness of the San Pedro formation is given by the several geologic cross sections previously introduced. Specific information is given for certain areas in which the San Pedro formation and related deposits are extremely thick or extremely thin; not all these areas are transected by the geologic cross sections.

In the vicinity of Wilmington and Long Beach and between the Newport-Inglewood zone and the coast the deposits of Pleistocene age are thickest in the syncline that lies along the coastal flank of Signal Hill and Dominguez Hill (see pl. 8). This syncline extends northwestward from the Long Beach Plain across Dominguez Gap, passes south of Dominguez Hill, and extends beyond the area discussed in this report. The deepest part of this syncline is under Dominguez Gap, near the wells of the Dominguez Water Corp. The deepest of these wells, 4/13-15A6, is 1,226 feet deep and penetrates the alluvial deposits of Recent age from land surface to a depth of 145 feet, unnamed upper Pleistocene deposits from 145 to about 320 feet, and the San Pedro formation from about 320 feet to the bottom. Neither the top nor the base of the San Pedro formation is sharply defined in this well. The top is placed tentatively at 320 feet below land surface, on the basis of lithologic correlations; the base is somewhat below the bottom of the well, but probably not more than a few tens of feet; thus the San Pedro formation appears to be about 900 feet thick in this well. Here it is divisible into two zones about equally thick: an upper zone of sand and clay and a lower (Silverado) zone of sand and gravel.

Southward from this syncline the San Pedro formation thins to about 650 feet on the crest of the Wilmington anticline, then thickens again on the south flank of the anticline (see pl. 4, section *B–B′*). In well 5/13-6D2 near Wilmington it is 890 feet thick. On the north flank of the anticline the basal sand-and-gravel (Silverado) zone in the formation is thicker than the overlying zone of silt, clay, and sand. On the south flank, from about the Pacific Coast Highway to the coast, the Silverado zone is uniformly about 300 feet thick, but the overlying part of the San Pedro formation thickens coastward.

In the area west of Dominguez Gap and about on a line between Dominguez Hill and Palos Verdes Hills the San Pedro formation is rather uniformly about 500 to 600 feet thick, except in the sharp syncline on the flank of the Palos Verdes Hills (see pl. 8), where the formation thickens to about 800 feet in the vicinity of Bixby Slough. Although its over-all thickness is relatively constant, the thickness of its several lithologic zones changes strikingly along this profile. Near Bixby Slough the wells encounter as much as 700 feet of sand and gravel; thus, essentially the full thickness of the San Pedro formation is within the coarse-grained lower, or Silverado, zone. For example, well 4/13-31E1 penetrates about 600 feet of the coarse materials. Northward and northwestward from Bixby Slough the Silverado zone thins rapidly, as shown on plate 8. Within 2½ miles it thins to 81 feet in well 4/13-5J1, between 633 and 714 feet below land surface; the log of that well reports alternate layers of sand and "clay" from land surface to 633 feet, but the "clay", probably largely silt, constitutes about 65 percent of the section. Most of this 633-foot zone is within the San Pedro formation.

East of this locality and northeast of Signal Hill, in well 4/12–15B1, the San Pedro formation along Carson Street probably spans all the interval from about 220 feet below land surface to the bottom of the well at 1,570 feet; thus the formation there is about 1,350 feet thick. The relatively fine-grained upper zone is 350 feet thick, the coarser grained but irregular Silverado zone is 450 feet thick, and a fine-grained basal part of the formation—Timms Point silt and Lomita marl members—is 550 feet thick.

On Newport Mesa the Pleistocene deposits dip northward about 300 feet a mile, and at the inland edge of the coastal zone near the intersection of Smeltzer Avenue and Harbor Boulevard are 1,700 feet thick (see pl. 4, section *D–D'*), about the same thickness as at well 4/12–15B1 northeast of Signal Hill. Here, however, deposits are predominantly silt and clay and afford no basis or discriminating the thickness of the San Pedro formation or of zones within that formation.

Inland from the Newport-Inglewood zone the several formations of Pleistocene age dip gently, commonly between 1° and 2°, beneath Downey Plain. Along the inland edge of the coastal zone between Los Alamitos and Westminster the base of the San Pedro formation is estimated at 500 to 1,000 feet lower than along the crest of the Newport-Inglewood zone, and 1,200 to 1,800 feet below the land surface.

Along the axis of the Newport-Inglewood structural zone within the area shown on plate 3 the Pleistocene deposits range in thickness from a thin edge on the south part of Newport Mesa to about 850 or 900 feet beneath Sunset Gap (see pl. 4, section *A–A'*). Throughout a considerable part of the reach these deposits are of the San Pedro formation, except for the thin surficial mantle of Palos Verdes sand and terrace cover. In succession from the northwest among the several hills and mesas of this structural zone, the depth from land surface to the base of the San Pedro formation ranges from about 800 feet on the west flank of Dominguez Hill to 650 feet at the crest and 725 feet on the east flank of the hill; in the Los Cerritos segment of the Signal Hill uplift, from 625 to 500 feet; at the crest of Signal Hill about 160 feet; in the Alamitos Heights segment of that uplift 600 to 550 feet; at Landing Hill 625 to 525 feet; beneath Bolsa Chica Mesa 850 to 700 feet; beneath Huntington Beach Mesa 600 to 475 feet; and on Newport Mesa 350 feet to a thin edge. These particular depths are thicknesses of the Pleistocene at the several localities. In considerable part they are estimated from the general structural position of the underlying rocks of Pliocene age; accordingly they are here given to the nearest whole multiple of 25 feet.

Among the several gaps across the coastal hills and mesas where it is overlain by the alluvial deposits of Recent age, the Pleistocene is estimated at 425 to 600 feet thick in Dominguez Gap, 400 feet across Alamitos Gap, 625 to 850 feet in Sunset Gap, 325 to 575 feet in Bolsa Gap, and 125 to 275 feet in Santa Ana Gap.

The position of the base of the San Pedro formation relative to sea level is a critical element in consideraing the effectiveness of the Newport-Inglewood structural zone as a barrier against encroachment of ocean water. It is critical because the San Pedro formation includes permeable zones throughout its vertical range nearly everywhere in the area, especially to the northwest; because, except for certain stratigraphic and structural discontinuities elsewhere described, these zones extend continuously from the coast inland across all the Long Beach-Santa Ana area; and because these water-bearing zones of the San Pedro formation are the sources of water for many public-supply and industrial wells or large capacity.

In effect, the base of the formation along the axis of the Newport-Inglewood structural zone is a lip above which ocean water must pass in order to reach the productive water-bearing zones farther inland, by movement within any particular stratigraphic zone. This lip is substantially below sea level along nearly the full reach of the structural zone within the Long Beach-Santa Ana area; everywhere except in the highest part of the Signal Hill uplift, where it is 200 feet above sea level, and in the southern part of Newport Mesa, where it is 100 feet above sea level. Elsewhere along the structural zone, in succession from the northwest, the estimated depth of this lip below sea level is 475 to 750 feet in the west flank of Dominguez Hill, decreasing eastward toward the crest of the hill; it increases southeastward to 700 feet in the central part of Dominguez Gap; beneath the Los Cerritos segment of the Signal Hill uplift it decreases gradually southeastward and is from 425 to 525 feet; across the Alamitos Heights segment of that uplift and across Alamitos Gap it decreases gradually and is from 450 to 550 feet; across Landing Hill and into the central part of Sunset Gap it increases to 900 feet; across Bolsa Chica Mesa and Bolsa Gap it decreases generally southeastward to 350 feet; and across Huntington Beach Mesa and Santa Ana Gap and onto the near half of Newport Mesa it decreases southeastward from 525 feet to sea level. The relation between this feature of the San Pedro formation and the possibility of ocean-water encroachment is developed in general terms on page 121.

ENVIRONMENTS OF DEPOSITION

In the San Pedro formation the present conditions of ground-water occurrence and the chemical character of the contained water are both determined by features intimately related to the environment at the time the materials were deposited. Certain of these features are so involved and so unusual that the environment of deposition is here developed at some length.

Principles of sedimentation in coastal-plain areas.—The present lowland segments of the Long Beach-Santa Ana area and some adjacent terrain were a coastal plain throughout much of early Pleistocene (San Pedro) time. To such areas sediments are transported largely by streams, although they may be deposited either on land or in the ocean. On land the sediments accumulate as flood-plain or stream-channel deposits; tongues and lenses of permeable sand and gravel are dispersed at random in a matrix of flood-plain silt. Permeable conduits developed in a continental environment are distributaries radiating from the apex of an alluvial fan or from the narrows at the inland margin of a coastal plain; their alinement commonly coincides with the direction of general ground-water movement and they function as ground-water arteries coursing toward the ocean.

If the stream-borne sediments enter a lagoonal environment—such as now exists locally in Alamitos, Sunset, and Bolsa Gaps—silt and clay of low permeability commonly are deposited in layers of considerable but irregular extent. Such deposits characteristically undergo some physical and chemical modification by organisms. Vegetation may thrive for many years and then be buried by silt as a flooding stream surges over the lagoonal reach; beds of peat are so formed. As discussed elsewhere (Piper, Garrett, and others) beds of peat and carbonaceous deposits in the Long Beach-Santa Ana area may have afforded some of the base-exchange media by which certain of the ground waters have been softened naturally. Highly permeable zones are not characteristic of lagoonal deposits.

Stream-borne sediments that reach the ocean are deposited in either a littoral or a marine environment. The littoral zone is defined as the area exposed at low tide but covered at high tide. In either environment the sediments are reworked by waves and currents; sand- or gravel-size particles become assorted and commonly are concentrated on the beaches or within the littoral zone. Coarse materials dumped into the ocean from a single flooding stream may subsequently be distributed for several miles along the coast by longshore currents and wave action; they may then be buried under later sediments and their initial content of salt water flushed out by fresh-water circulation; in this way they may become fresh-water aquifers. In such bodies the greatest freedom of circulation is parallel with the shoreline of deposition, commonly at right angles to tongues of fluviatile sand and gravel formed inland under the continental environment. If the inland fluviatile tongues extend to and merge with coarse-grained longshore deposits, as in the Long Beach-Santa Ana area, a system of trunk ground-water conduits is created in a pattern somewhat like the spokes and rim in a sector of a wheel.

Silt- or clay-size particles transported to the ocean commonly come to rest in deeper water beyond the reach of most longshore currents or waves; their deposits usually incorporate organic material from the marine flora and fauna and they may form extensive layers of very low permeability.

In the marine environment both chemical and physical alterations occur in the sediments. For example, the mica flakes so commonly transported in large quantities to shallow marine sediments may be altered to glauconite, a mineral having marked base-exchange capacity; much of the biotite mica at Monterey Bay is now being altered to glauconite, as shown by Galliher (1935, p. 1569–1601). When formed in the marine environment this mineral is rich in sodium, but if the marine deposits are later flushed by fresh ground water rich in calcium, the sodium base of the glauconite and the calcium base of the water may be exchanged and the water thereby softened.

Evidence pertaining to environments of deposition during San Pedro time.—Evidence on this deposition is drawn largely from logs and samples of cuttings for water wells and oil wells, from papers by Eckis and Wissler, previously cited, and from papers by Edwards (1934, p. 786–812) and Morse (1943, p. 477–479). The most comprehensive information is afforded by samples collected during the construction of several water wells by the city of Long Beach. Certain of the more complete suites of samples from these wells were examined by Natland, micropaleontologist with the Richfield Oil Corp., primarily for purposes of correlation by microfaunal assemblages; these wells are 4/12–6K1 (North Long Beach well 4), 4/12–14D1 (Commission well 1), 4/12–14P1 (Wilson Ranch well), 4/12–15B1 (Commission well 3), and 4/12–28H1 (Alamitos well 9). From this examination Natland drew conclusions on the environments of deposition, based on lithologic character, heavy-mineral assemblages, and organic remains as well as contained fauna. The most complete evidence, that from well 4/12–28H1, is summarized in table 3.

As it occurs at well 4/12–28H1 the San Pedro formation evidently was accumulated largely, if not exclusively, as beach or shallow-marine deposits. From his study of the remaining suites of samples Natland (personal communication) concludes that the materials of the San Pedro formation penetrated by each of the five wells were deposited chiefly under littoral or shallow-marine conditions; lagoonal and fluviatile deposits predominate in the samples to a depth of 100 to 300 feet below land surface, but these represent deposits of upper Pleistocene age. Three of these wells probably penetrate the full thickness of the San Pedro formation.

Natland also examined samples from well 3/12–32P2 (city of Signal Hill well 7), about 4.5 miles north of Signal Hill and just beyond the

TABLE 3.—*Generalized log for well 4/12–28H1 (city of Long Beach, Alamitos well 9)*[1]

Material	Thickness (feet)	Depth (feet)	Environmental conditions and remarks
Upper Pleistocene deposits, undifferentiated:			
Soil and yellow clay	52	52	Barren of microfauna. Continental.
Dark clay and peat	58	110	Lagoonal deposits.
San Pedro formation:			
Sand, sandy clay, and fine gravel	183	293	Samples contain only coarse sand and gravel barren of fossils; garnet, tourmaline, and magnetite abundant, but mica relatively scarce. Probably beach deposits.
Dark sandy clay	23	316	*Elphidium hannai* abundant, suggesting littoral[2] environment. Heavy minerals scarce, with mica predominant.
Sand and gravel with some clay	216	532	Molluscan fragments abundant to rare; echinoid spines, *Elphidium articulatum*, and other species indicative of littoral zone or shallow neritic[3] conditions.
Sand and gravel	120	652	Barren of fossils; heavy minerals abundant from 532 to 552 feet. No samples from 552 to 652 feet. Probably littoral and shallow neritic deposits.
Fine sand	45	697	Barren of fossils; heavy minerals abundant. Littoral to shallow neritic deposits.
Silt and sandy clay, blue; with some sand and gravel	107	804	Fauna similar to Timms Point and Lomita fauna—*Cassidulina limbata*, *Cassidulina tortuosa*, and bryozoan fragments abundant. Fauna suggest deposition in water 125 to 300 feet deep.
Coarse sand and gravel with some clay	132	936	Fossils not noted; heavy minerals rare. Probably neritic.
Sandy clay, blue	150	1,086	Fauna similar to that of interval from 697 to 804 feet.
Sand, gravel, and sandy clay	112	1,148	No fossils noted; heavy minerals rare.

[1] Stratigraphic correlations, tentative, by J. F. Poland. Statements on mineral and faunal assemblages and on environments of deposition by M. L. Natland of Richfield Oil Corp., are by personal communication, January 1944. A conventional log in greater detail is given in table 6.

[2] The littoral zone is defined as the area exposed at low tide but covered at high tide; in the broad sense, all beach deposits are included in the span of the littoral zone.

[3] The neritic zone is commonly defined as that part of the sea bottom extending from low tide to a depth of about 100 fathoms (600 feet); the shallow neritic zone as used here extends from low tide to a depth of about 125 feet.

area shown on plate 3; for this well he reports continental and lagoonal deposits to a depth of about 600 feet and alternating littoral and lagoonal deposits from 600 to 1,000 feet.

In the vicinity of Stanton in the center of Downey Plain, Natland (personal communication) reports continental deposits to about 1,000 feet below land surface, alternating continental and lagoonal deposits from 1,000 to 3,200 feet, which enclose a few thin tongues of marine sediments, and rocks of marine origin below that depth.

General environment in the Long Beach-Santa Ana area.—The deposits that constitute the San Pedro formation in this area were transported by streams that flowed across a broad coastal plain whose inland margin lay beyond the present Repetto and Puente Hills. The shore line apparently oscillated somewhat throughout the time the San Pedro was being deposited—in early San Pedro time, across the central part of the area now occupied by Downey Plain; in later San Pedro time, across the oceanward half of the same area; probably it never crossed to the southwest of the Newport-Inglewood uplift. For the shoreline to have ranged no more widely than within the present Downey Plain while more than 2,000 feet of San Pedro sediments accumulated, subsidence must have gone on about in pace with the sedimentation. Barrier beaches existed along the shore then as they do today; inland from these beaches extensive lagoons supported an abundant vegetal growth which flourished, died, and was buried with accumulating sediments.

Strong longshore currents swept an unobstructed reach from Santa Monica to the San Joaquin Hills. During at least part of San Pedro time the Palos Verdes Hills may have been a fairly large island (Woodring, Bramlette, and Kew, 1946) lying 10 to 12 miles offshore.

During early and middle San Pedro time streams transported an abundance of coarse sand and gravel to and largely across the coastal plain and deposited most of this coarse detritus in the shallow marine waters. In late San Pedro time the streams carried finer sediments and deposited only sand, silt, and clay over much of the area shown on plate 3.

Environment southwest of the present Newport-Inglewood zone.—In the area between Long Beach and Torrance and southwest of the Newport-Inglewood zone shallow marine conditions apparently persisted through most if not all of San Pedro time. Here in early and middle San Pedro time was deposited a thick and nearly uniform body of sand and gravel that now constitutes the Silverado water-bearing zone. The fine sediments that must have formed a part of the stream load in transit to the ocean apparently were swept away by the waves and longshore currents so that only sand and gravel remained. The thickest section of this coarse deposit was laid down near Bixby Slough where 700 feet of sand and gravel were deposited without interbeds of clay or silt.

The extent and distribution of the land masses that contributed this local extraordinarily thick body of coarse sediments are not known. Without substantiating evidence, not known to exist, its nearness to the Palos Verdes Hills does not indicate that the body is composed of detritus from a land mass in the same general area; in fact, information now available is opposed to such a conclusion. The gravel beds of San Pedro age do not contain large quantities of detritus from Miocene rocks such as compose the present Palos Verdes Hills. Moreover, the area of the Palos Verdes Hills is known to have been relatively depressed in San Pedro time, and the San Pedro sand of the type locality is of much finer grain than is the sand and gravel of the Silverado water-bearing zone to the northeast, farther from the present hills.

Environments inland from the Newport-Inglewood zone.—Within the part of Los Angeles County shown on plate 3, inland from the Newport-Inglewood structural zone, beach and littoral environments prevailed. Sand and gravel accumulated in local deposits along an oscillating strand line that remained essentially parallel to the structural zone; therefore the mass of permeable deposits so formed is elongated in that direction. This mass forms the inland margin of the Silverado water-bearing zone and is part of the rim in the wheel pattern of trunk aquifers. Near the inland edge of the area shown on plate 3 the littoral and beach environments merged into lagoonal and flood-plain environments, successively; sediments along the boundary of the area and inland beyond it were chiefly silt with enclosed lenses and permeable tongues of fluviatile sand and gravel probably deposited at right angles to the elongate mass of littoral and beach deposits and extending inland across the full width of the coastal plain of San Pedro time. They have at least some hydraulic continuity with the littoral deposits of the marginal part of the Silverado water-bearing zone and correspond to the spokes in the wheel pattern of trunk aquifers.

In the part of Orange County shown on plate 3 the environments of sedimentation during San Pedro time corresponded to those of Los Angeles County but differed in areal range. Thus a shallow-marine environment may have reached inland to and beyond Santa Ana in earliest San Pedro time, but during much of San Pedro time this environment prevailed only near the present coast and in part of Newport Mesa. During most of San Pedro time the littoral and beach environments apparently were roughly fixed in position about 1 to 3 miles inland from the present Newport-Inglewood zone, although they probably ranged transiently. Owing to these conditions coarse-grained shallow-marine and littoral deposits analogous to those of the Silverado zone did not form extensively within the present land area. During most of San Pedro time the environments inland ranged successively from lagoonal, through flood plain, onto alluvial cone, and in these successive environments the heterogeneous deposits so characteristic of the Pleistocene in much of Orange County presumably were laid down by an ancestral Santa Ana River. In Orange County the trunk aquifers in the San Pedro formation have somewhat the same wheel pattern as those in Los Angeles County, but the present land area includes only the inland-marginal part of the rim and spans relatively more of the spokes.

GENERAL WATER-BEARING FEATURES

All the beds of coarse sand and gravel in the San Pedro formation are confined-water conduits, except locally in the central part of the Signal Hill uplift where they are above the zone of saturation. From them a very large aggregate quantity of water is withdrawn by the deeper wells in all parts of the area shown on plate 3 especially from the thick and extensive Silverado zone, which sustains numerous public-supply and industrial wells in the vicinity of Long Beach and Wilmington. In general the permeability of these beds is only moderate, about one-third to one-half that of the Gaspur and Talbert zones in the alluvial deposits of Recent age. The San Pedro formation sustains certain wells of very large capacity, about in proportion to the aggregate footage of coarse-grained materials penetrated. It is the great thickness and relatively great extent rather than the permeability of these materials that imparts great productivity to the Silverado water-bearing zone in the general vicinity of Long Beach and Wilmington and to the somewhat analogous zones beneath Huntington Beach Mesa and the north half of Newport Mesa. Beyond those three zones water-bearing beds commonly are relatively thin, are dispersed among beds of low permeability, and constitute only about half the aggregate thickness of the San Pedro formation. Under such conditions only wells of considerable penetration into the formation have large sustained capacities.

In the aggregate a very large quantity of water is withdrawn from the San Pedro formation, largely for public supply and for industrial use but in part for irrigation. As of 1941 the withdrawal from the Silverado zone within the Los Angeles County area or plate 3 was 30,000 to 35,000 acre-feet a year, an average rate of about 30,000,000 gallons a day. Of this amount about 19,000 acre-feet a year was withdrawn between the Newport-Inglewood zone and the coast, largely for public supply and industrial use. During World War II the requirement for war industries increased very substantially the withdrawal from the Silverado zone in this particular district. This withdrawal from the Silverado zone was only slightly more than half the total withdrawal from all the San Pedro formation within the area shown on plate 3. As of 1940–43 about 9,000 to 11,000 acre-feet was withdrawn yearly from the basal Pleistocene water-bearing zones containing Timms Point and Lomita faunas in the district north of Signal Hill. This withdrawal afforded part of the public supply for Long Beach. From all the Pleistocene deposits of the area shown on plate 3 the aggregate withdrawal as of 1941 is estimated at about 45,000 acre-feet a year in Los Angeles County and 15,000 acre-feet a year in Orange County. Nearly all was withdrawn from water-bearing zones in the San Pedro formation.

In effect each stratum of coarse sand or gravel in the San Pedro formation is a distinct confined-water conduit; between the several conduits there appears to be little or no natural interchange of water within most of the area shown on plate 3. In the northwestern part of that area the thick and extensive Silverado zone is a single major conduit, apparently with unimpeded hydraulic continuity virtually throughout. Within that zone, water is effectively confined. In the longshore area southwest of Long Beach the zone is confined by overlying silt and silty clay several hundred feet thick (pl. 4, section *B–B′*). Those confining beds constitute an upper zone of the San Pedro formation and are virtually impermeable. Farther inland, through Dominguez Gap and into the district north and northeast of Signal Hill, certain of the beds become sandy and doubtless are somewhat permeable. Nevertheless the upper zone as a whole remains an effective confining member, as is shown by distinct differences in the chemical character of waters native to the Silverado zone and those native to overlying sources.

Beyond the Silverado zone, both inland within Los Angeles County and very extensively in Orange County, it has been shown that the San Pedro formation includes a succession of water-bearing zones, each commonly no more than about 50 feet thick. Because the water of these several zones is under about the same pressure head some hydraulic continuity between zones might be inferred, but marked differences in the chemical character of their waters suggest that continuity is largely apparent rather than real. Within the area shown on plate 3, probably little water moves naturally from one zone to another through the intervening confining beds, except by way of the transverse conduit probably afforded by a zone of fractures in the Newport-Inglewood structural zone. (See p. 113.)

Initially the water-bearing zones of the San Pedro formation were under sufficient head to yield flowing wells throughout much of the area inland from the Newport-Inglewood zone. Under natural conditions the movement of water through the formation was only that necessary to sustain natural discharge along and near the coast. Leakage to the land surface probably occurred at the fracture zone along the Newport-Inglewood zone, and some water may have percolated to offshore fresh-water springs. Under present conditions of use, however, withdrawals from the San Pedro formation have diminished the head until the water levels in wells are now below the land surface throughout most of the area, and locally are several tens of feet below sea level. Obviously, local withdrawals have exceeded replenishment.

Permeable beds of the San Pedro formation crop out locally in the Newport-Inglewood belt of hills and mesas, or are there overlain by only a thin cap of the fairly permeable materials that form the Palos Verdes sand and the terrace cover. Under such conditions some rain may penetrate the permeable land surface and reach a zone of saturation in the San Pedro formation; in the main, however, the confined water bodies that yield copiously to wells are not replenished from rainfall within the area of use. Almost all replenishment to the productive water-bearing zones of the area shown on plate 3 must be derived from remote inland areas and be conveyed to those zones through the two regional ground-water arteries in the overlying alluvial deposits of Recent age, the Gaspur and Talbert water-bearing zones (see p. 49). The long-term average replenishment to water-bearing zones in the San Pedro formation must be limited by the conveyance capacity of the two arteries, particularly by the transmission capacity of those trunk conduits of the San Pedro that are in hydraulic continuity with these overlying arteries.

TERTIARY SYSTEM

PLIOCENE SERIES

Semiconsolidated and consolidated rocks of Pliocene age underlie the deposits of the Quaternary system in nearly all the Long Beach-Santa Ana area, although they crop out at only a few places. On the basis of microfaunal zones the Pliocene has been divided into two stratigraphic units, the Pico formation above and the Repetto formation below (Woodring, 1938, p. 3–4). No unconformity is recognized between these two formations, although one exists within the Pico formation.

The Pico formation, of upper Pliocene age and almost wholly of marine origin, is subdivided by micropaleontologists into upper, middle, and lower divisions on the basis of distinct faunal assemblages (1941, p. 212–213). Discrimination of the upper division is pertinent here, because in much of the area shown on plate 3 the base of this upper division coincides approximately with the base of the zone to which fresh ground waters are native; in this report the upper division is discussed in some detail because it is a potential source of large quantities of ground water, although to date it has been tapped by only a few wells. The middle and lower divisions are mostly of low permeability, and the permeable sand zones within them contain connate saline water except locally beneath the central part of Downey Plain; in most of the area they occur at depths greater than 2,000 feet, far below the normal penetration depth for water wells. Therefore, they will be treated very briefly here; they are discussed in detail in many geologic reports and papers concerned with the geology of the oil-bearing rocks of the Los Angeles Basin.

PICO FORMATION, UPPER DIVISION

PHYSICAL CHARACTER AND THICKNESS

The upper division of the Pico formation consists of semiconsolidated sand, silt, and clay members of marine origin. Locally, beds of gravel occur in the upper part of the division; these also probably are of marine origin.

In the area shown on plate 3, the only exposure of the upper division of the Pico is along the east bluff of Newport Canyon just inland from The Narrows and about 3 miles from the ocean. According to Wissler (1941, p. 213), the upper Pico here is unconformably superimposed on the Repetto formation. The upper Pico at this locality comprises buff to gray compact sandstone and siltstone with prominent calcareous layers that contain hard concretions. On plate 3 this exposure of the Pico is not differentiated from the rocks of lower Pliocene and Miocene age. The upper Pico underlies all the area shown on plate 3 except the south part of Newport Mesa and the eastern margin of the Palos Verdes Hills. Plate 4, sections *A–A′* and *B–B′*, show its physical character and thickness as revealed in a few cored wells and as inferred from many electric logs.

At most places along the Newport-Inglewood structural zone and in the vicinity of Wilmington the uppermost few hundred feet of the upper Pico are chiefly silt and clay; but the lower 600 to 1,000 feet include several extensive zones of fine- to medium-grained gray sand and sandstone, commonly ranging in thickness from 20 to 100 feet and separated by thinner beds of massive micaceous siltstone. In the southern part of the Wilmington area, as inferred from electric logs of oil wells near water well 5/13–3D1, about half the upper Pico deposits are sand of fair permeability. On the other hand, about 2½ miles southwest of Dominguez Hill, well 4/13–17D1 was drilled through essentially the entire thickness of the upper Pico, 683 to 1,701 feet below land surface (see log, table 6). In this interval the driller reported 10 layers of sand ranging in thickness from 17 to 50 feet and totaling 282 feet, the remaining 736 feet being clay; thus, in this well, only about 28 percent of the upper Pico was reported sand. The casing of this well was never perforated so neither the productivity of the formation nor the chemical character of the water is known. Probably this is the only water well that to 1945 has penetrated the sand zones of the upper Pico on the coastal side of the Newport-Inglewood zone.

Inland from the Newport-Inglewood zone, in the area north and east of Signal Hill, the upper Pico deposits are not known to be tapped by water wells. The two public-supply wells of the city of Long Beach that have the greatest stratigraphic penetration, wells 4/12–14P1 and 4/12–21M4, may have passed through the top few hundred feet of the Pico formation (see logs, table 6), but neither encountered water-bearing materials in these deposits of probable Pliocene age.

In Orange County, as indicated by electric logs from oil-test holes inland from the Newport-Inglewood zone, bodies of permeable sand and gravel are rather common in the topmost few hundred feet of the upper Pico. For a distance of 3 to 5 miles inland from the structural zone these coarse-grained zones may be tapped ultimately by a few deep water wells; still farther inland the upper Pico is 1,500 feet or more below land surface, so deep that probably few water wells will be drilled to it.

So far as known, these deposits are tapped by only one active water well: in Bolsa Gap and about 1 mile inland from the Newport–Inglewood zone, well 5/11–28K1 penetrated 136 feet of highly permeable gravel and sand between 713 and 866 feet below land surface (see log, table 6); this water-bearing zone is assigned tentatively to the upper Pico. The general stratigraphic relations near this well are shown on plate 5, section *b–b'*.

Some information on the character of the upper Pico inland beyond the area shown on plate 3 is afforded by electric logs and samples from a few oil-test holes on Downey Plain. There also, within the stratigraphic range identified by micropaleontologists as upper Pico, the deposits are almost wholly of marine origin and of the same general character as the upper Pico proximate to the Newport–Inglewood zone.

Along the inland margin of the coastal plain are local beds of conglomerate of Pliocene age, described by Edwards (1934, p. 786–812). Some of these may occur within the upper division of the Pico formation. The paper by Edwards is concerned primarily with source areas for the conglomerate and derives certain basic conclusions with respect to the history and paleogeography of late Tertiary and early Quaternary time. His conclusions concerning source areas have been challenged in part in a later paper by Bellemin (1940, p. 636–648).

Within the area shown on plate 3 the upper division of the Pico formation ranges in thickness from 1,800 feet at the west end of the Dominguez anticline to a thin edge beneath the central part of Newport Mesa. Its thickness is about 800 feet on the crest of the Wilmington anticline, 1,000 feet at the central part of the Signal Hill uplift, and 1,400 feet under Alamitos Gap; it thins southward to Huntington Beach to about 1,200 feet in the "old field," and wedges out from Huntington Beach onto Newport Mesa. In the south part of Newport Mesa the upper Pico is absent; the very thin Pleistocene deposits rest directly on rocks of Miocene age (see pl. 4, section *A–A′*). Inland beyond the area shown on plate 3 the upper Pico probably increases in thickness to considerably more than 2,000 feet.

STRATIGRAPHIC RELATIONS

The upper Pico was deposited on a surface of unconformity, at least locally. Along and near the Newport-Inglewood zone it overlaps the middle Pico and at certain places rests upon the lower division of the Pico formation or on the Repetto formation. In part of the Wilmington area it rests on beveled middle Pico, but in the harbor district of the Wilmington oil field it rests directly on the Repetto (Wissler, 1941, p. 213). Southwestward from Dominguez Hill to Huntington Beach Mesa the upper Pico rests on a thick section of middle Pico, but on Newport Mesa overlaps it successively onto lower Pico and Repetto.

The stratigraphic relation of the upper Pico to the overlying Pleistocene is not clear for all parts of the Long Beach-Santa Ana area, although locally the two appear to be unconformable. At several places along the Newport-Inglewood zone an unconformity is inferred by Wissler (1941, p. 212) because the Timms Point fauna at Seal Beach has not been found in the Long Beach and Dominguez oil fields. In the vicinity of the Wilmington oil field Bartosh (1938, p. 1053) reports that the Pleistocene lies unconformably on upper Pico. Farther inland, under Downey Plain and other areas structurally low, it is probable that no unconformity exists and that sediments were for the most part deposited continuously from late Pliocene (upper Pico) into Pleistocene time.

Beneath much of the central Downey Plain, at least in Orange County, certain fine-grained deposits commonly are assigned by micropaleontologists to the upper division of the Pico formation, on the basis of a contained marine fauna that is considered diagnostic. These deposits occur 3,000 feet and more beneath the land surface. Almost all the overlying deposits are definitely of continental—

alluvial or lagoonal—origin; microfauna found in the lagoonal facies at a very few places are not diagnostic as to age. Generally, but arbitrarily, the Pico formation commonly is considered to include only the fine-grained deposits that contain the marine fauna, and all the overlying continental deposits are assigned to the Pleistocene. This arbitrary assignment is made because precise determination of the contact between Pliocene (Pico) and Pleistocene there has little bearing on the search for oil.

According to the assignments by Wissler in the Dominguez Hill area, the stratigraphic range of continental deposits extends downward only through the upper Pleistocene; all the underlying deposits of lower Pleistocene (San Pedro) and Pliocene (Pico) ages are marine. Beneath the central Downey Plain in Orange County the stratigraphic range of continental deposits extends downward to the known Pico and thus spans the entire San Pedro formation, at least. A change of facies from marine to continental that transgresses a time interval so long and deposits so thick (at least 2,000 feet) may well transgress the time horizon of the top of the Pico formation as currently established along much of the Newport-Inglewood structural zone. In this connection Natland (1933, p. 225–230) shows that many species of microfauna found in rocks of late Tertiary and Quaternary ages in southern California are now living off the California coast and that the vertical range of the living faunas is determined primarily by depth of water. Thus the microfaunal correlations extended inland to the central part of Downey Plain may well transgress time horizons.

Therefore it is probable that certain segments of the 3,000-foot section of continental deposits beneath the central part of Downey Plain in Orange County may be time correlatives not only of the San Pedro formation but also of the topmost part of the upper division of the Pico formation as delimited along the Newport-Inglewood zone. This suggested correlation may be confirmed at some future time by examination of plant remains that can be recovered by careful sampling of the continental sediments. For the present it is suggested that several hundreds of feet of these continental sediments may some day be assigned to the Pliocene (upper Pico) rather than the Pleistocene.

WATER-BEARING CHARACTERISTICS

Throughout most of the area shown on plate 3 the upper division of the Pico formation contains relatively coarse-grained members that certainly are water bearing and that probably would yield water rather freely to wells. In the vicinity of Wilmington and along the crest of the Newport–Inglewood zone from Dominguez Hill southeastward to Huntington Beach the water-bearing zones of the upper Pico occur in the lower part of the division and are layers of semiconsolidated sand. The productivity of these sand layers is not known but in the aggregate it might be several hundred gallons a minute to a single well. The sand here is rather uniformly medium- to fine-grained but probably is not greatly consolidated. To obtain a yield of several hundred gallons a minute of sand-free water a well probably would need to penetrate all the sand members and be constructed with a slotted screen or with a gravel envelope surrounding the casing.

Fragmentary information derived largely from electric logs of oil wells and prospect holes suggests that in much of that area the water of the upper Pico is essentially nonsaline and is possibly of a quality suitable for certain industrial uses.

In the area northeast of the Newport-Inglewood zone, both in Los Angeles and Orange Counties, the general water-bearing character of the upper Pico is inferred chiefly from electric logs of oil-test holes. These indicate that here the upper Pico cannot be divided into an upper fine-grained unit and an underlying coarser-grained unit, but rather that bodies of permeable sand and gravel are fairly common in the top few hundred feet of the division. The upper Pico has been penetrated by only a few wells whose logs have yielded definite information on productivity of the aquifers or quality of the contained water. Only well 5/11–28K1 in Bolsa Gap is known to be producing water from the upper Pico (see p. 88). The yield of this well is not known, but from the log (see table 6) it is inferred that the water-bearing zones within but near the top of the upper Pico are highly permeable and similar in transmissibility to those in the overlying San Pedro formation. For the area as a whole, however, it is doubtful that the water-bearing zones within the upper Pico are as permeable as those of the San Pedro formation. Regarding water quality, two oil-test holes, 4/11–19R1 near Los Alamitos and 5/11–23P at the north edge of Huntington Beach Mesa, have yielded samples for chemical analyses (Piper, Garrett, and others) which reveal that at least some aquifers in the upper Pico contain soft water with a relatively low content of dissolved solids.

Within almost all the area shown on plate 3 southeastward to and including Huntington Beach Mesa these permeable sand zones of the upper Pico may afford a large reserve source of fresh water, now virtually untapped. To tap them would require wells at least 1,500 feet deep and, along the inland edge of the area, as much as 3,000 feet deep. For this reason, also owing to the special type of construction necessary to restrain the water-bearing sand, development of this source would be rather costly.

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PICO FORMATION, MIDDLE AND LOWER DIVISIONS

The middle and lower divisions of the Pico formation do not crop out within the coastal zone of the Long Beach-Santa Ana area. As encountered by oil wells they comprise alternating layers of claystone, siltstone, and sandstone. In color the finer sediments commonly range from olive gray to dark brown; the sandstone is usually gray. According to Wissler (1941, p. 214) the proportion of sand in the middle Pico ranges from 22 percent at Huntington Beach (old field) to 60 percent at Dominguez Hill, and in the lower Pico from 37 percent at Huntington Beach (old field) to 78 percent at Dominguez Hill.

Along the Newport-Inglewood structural zone from Dominguez Hill to Huntington Beach and near the crests of the several oil-field structures the combined thickness of the middle and lower divisions of the Pico ranges from 1,300 feet at Seal Beach to 700 feet at Huntington Beach (see pl. 6). The thickest section reported by Wissler is 1,420 feet in the northwest extension of the Long Beach field. In and near the Wilmington oil field the middle Pico is only about 100 feet thick and the lower Pico is absent. According to Wissler (1941, p. 227), deformation and erosion in that area in middle Pico time resulted in the removal of all the lower Pico, and the area then was overlapped by middle Pico deposits. In turn, these deposits are separated from the overlying upper Pico by another widespread unconformity.

Parker (unpublished data) suggests that the lower Pico is present in the central part of Newport Mesa. Farther south, however, all Pliocene sediments thin out and Miocene rocks lie directly beneath deposits of upper Pleistocene age (see pl. 4, sections *A–A′* and *D–D′*).

Throughout most of the coastal zone these rocks are far below the depths reached by the deepest water wells. Along the Newport-Inglewood zone the depth from land surface to their top ranges from 1,200 feet at Signal Hill to 2,500 feet in some of the structurally low areas such as Dominguez and Sunset Gaps. Southeast of Huntington Beach their top rises gradually across Santa Ana Gap (see pl. 4, section *A–A′*); it is not known whether they are present under the southwest segment of Newport Mesa.

Any water in the sand zones of the middle and lower divisions of the Pico is believed to be saline everywhere within the area shown on plate 3. Electric logs from scattered wildcat oil wells suggest that under much of Downey Plain, however, essentially fresh water is contained in the sandier zones of the middle Pico.

OLDER ROCKS OF TERTIARY AGE

The coastal zone of the Long Beach-Santa Ana area is underlain at depths of several thousand feet by thick sedimentary rocks of lower Pliocene age (Repetto formation) and of Miocene age. The general physical character of these rocks and their known range in thickness are summarized in the chart (p. 38); their distribution and thickness as penetrated in the several oil fields of the area are summarized on plate 6. They include most of the oil-producing horizons of the Los Angeles Basin area, and thus have been discussed in detail in many reports concerned with the development of the oil resources of that area. (See Reed, 1933; Reed and Hollister, 1936; Jenkins and others, 1943; Wissler, 1943, p. 210–234; Woodring, 1938; Woodring, Bramlett, and Kleinpell, 1936; Hoots, 1931, p. 83–134; English, 1926; Eckis, 1934.)

GEOLOGIC STRUCTURE

REGIONAL FEATURES

The thick succession of sedimentary rocks underlying the coastal plain in Los Angeles and Orange Counties has been deposited in a broad synclinal depression frequently referred to as the Los Angeles Basin. In this basin the sedimentary rocks of Pliocene and Quaternary age are 5,000 to 13,000 feet thick; the underlying sedimentary rocks of earlier Tertiary and greater (?) age may be even thicker. This basin of Tertiary and Quaternary sedimentation is bordered on the north and east by rocks that range in age from Triassic to Pliocene and that in the aggregate are 25,000 to 40,000 feet thick (Hoots, 1932, p. 23). These enclosing rocks have been elevated, intricately folded and faulted; locally around the margins of the basin they have been stripped away by erosion to reveal a complex assemblage of igneous and metamorphic basement rocks (see fig. 2).

The coastal plain does not span a simple regional syncline, however, but includes several local structural features whose axes are roughly parallel and trend northwest. Of these local features the most extensive is the Newport-Inglewood structural zone, a composite belt of anticlinal folds and subsidiary faults that extends from Newport Mesa to Beverly Hills. This feature is topographically gentle but structurally prominent; in effect it divides the coastal-plain area into two synclinal troughs. To the northeast, or inland, a broad syncline underlies Downey Plain and extends from Hollywood on the northwest to and beyond Santa Ana on the southeast. This main syncline is flanked in turn on the northeast by the Coyote Hills uplift, a regional anticlinal fold that probably is bordered on its south flank by a northward-dipping reverse fault of considerable displacement. Beyond the Coyote Hills the rocks are depressed in the relatively small synclinal La Habra Basin and then are abruptly displaced at the Whittier fault, which strikes southeast across the coastal flank of the Puente Hills.

From the southwest, or coastal flank of the Newport-Inglewood zone, the Tertiary and Quaternary rocks dip gently down into the relatively narrow syncline that extends from Long Beach to Santa Monica. Beyond this syncline they are warped over the Torrance-Wilmington anticlinal axis and then locally flexed sharply upward into the Palos Verdes Hills. At depth along the north flank of the Palos Verdes Hills a fault is suggested by data from oil-prospect holes, but the Pleistocene rocks at the land surface are not ruptured. According to Woodring (Woodring, Bramlette, and Kew, 1946, p. 110) this inferred subsurface fault has been designated the San Pedro fault.

Regarding the general synclinal structure beneath the coastal plain and the regional anticlinal warping along the Newport-Inglewood zone, all rocks older than the alluvial deposits of Recent age are deformed. In the successive epochs of deformation in late Miocene and in subsequent time the same general structural pattern has prevailed, so that flexure in the younger rocks is repeated in the successively older rocks in similar form and with a common axis but in progressively increasing amplitude. However, much of the structural deformation was developed in Quaternary time, chiefly in the so-called mid-Pleistocene revolution, which followed deposition of the San Pedro formation and during which the major land-form elements of today were created (Reed and Hollister, 1936, p. 49–50, 114–135; Gale, 1932, p. 8; Eaton, 1941, p. 203–206; Edwards, 1934, p. 810–811; Dudley, 1936, p. 358–378). The topographic relief along the Newport-Inglewood zone is of structural and even later origin, developed in very late Pleistocene time after the Palos Verdes sand and the continental(?) terrace cover had been deposited (see p. 17).

NEWPORT-INGLEWOOD STRUCTURAL ZONE

GENERAL FEATURES

The Newport-Inglewood zone is a regional anticlinal fold that extends northwestward from Newport Mesa to Beverly Hills, a distance of 40 miles. At the land surface it is marked by the common alinement of low hills and coastal mesas—the Beverly, Baldwin, Rosecrans, Dominguez, Signal, and Landing Hills, and the less conspicuous Bolsa Chica, Huntington Beach, and Newport Mesas. The continuity of these hills and mesas is broken by six low-level gaps in succession from the northwest—the Ballona, Dominguez, Alamitos, Sunset, Bolsa, and Santa Ana Gaps (see pl. 1).

From the axis of this structural zone the rocks dip generally downward, both oceanward and landward. Superposed on this regional structure are successive closed anticlines or domes, with intervening structural saddles. The domes, and to a lesser degree the saddles, are broken by nearly vertical normal faults and reverse faults that are discontinuous and arranged in echelon. The faults are more numerous at depth, although a number continue to the land surface and disrupt it.

Several geologists have suggested that at great depth this structural zone is underlain by a continuous fracture that separates an upthrown block of metamorphic rocks (Franciscan?) on the southwest from a downthrown block of granitic rocks on the northeast. Some of the arguments in favor of such an hypothesis have been ably marshalled by Reed and Hollister (1936, p. 125–133). To the southwest of the Newport-Inglewood zone, oil wells have encountered the Franciscan(?) schist at 5,500 feet in the Playa del Rey field, 7,000 feet in the El Segundo field, 5,000 feet in the Torrance field, and 6,800 feet in the Wilmington field. One deep well on the west flank of Dominguez Hill encountered the Franciscan(?) schist at a depth of 12,415 feet (Bravinder, 1943, p. 398). Thus the basement complex of metamorphic rocks doubtless extends continuously along the southwest side of the Newport-Inglewood zone. Little is known concerning the character of the basement rock on the northeast, beyond the general conclusion from seismological evidence that it is much deeper beneath the land surface.

The Newport-Inglewood zone has been a locus of structural activity throughout much of Tertiary and Quaternary time. Wissler (oral communication) believes that it has been active since early upper Miocene time. That it continues to be an area of active deformation is attested by the major Inglewood earthquake in 1921, the major Long Beach earthquake in 1933, and a minor earthquake in 1941 that damaged several oil wells of the Dominguez field (Bravinder, 1942, p. 388).

In the Newport-Inglewood zone the structural forms, both folds and faults, are critical with respect to the effectiveness of the zone as a barrier to inland movement of salt water from the ocean. For example, the structural form at the top of certain impermeable rocks at depth in the core of the zone determines the alinement and depth of a lip below which ocean water cannot pass inland and so reach the permeable zones from which fresh water is withdrawn from wells on Downey Plain. In alinement this lip coincides with the general structural axis of the zone. The range of its depth below sea level is discussed on page 78.

The present land forms along the zone afford much critical information about minor structural forms that create traps impeding the movement of ground water. Thus, as discussed on pages 16–18, except in the several gaps between the coastal hills and mesas, the land forms indicate in fair detail the patterns of folding and faulting in late Pleistocene and Recent (post-Palos Verdes) time. Each land-surface form is similar to the structural form of underlying water-bearing zones, but commonly of less relief. At least locally, the land-surface relief appears to be about half the structural relief in water-bearing zones of the San Pedro formation, which sustains the principal fresh-water withdrawals for municipal and industrial uses in the Long Beach-Santa Ana area.

FOLDS

The domes along the Newport-Inglewood zone are marked in general by topographic highs, the alined coastal hills. In the reach under consideration the zone includes four such folds, which in succession from the northwest are marked by Dominguez Hill, Signal Hill, Alamitos Heights and Landing Hill (terminal elements of the Seal Beach anticline which in the unexposed rocks spans Alamitos Gap), and Huntington Beach Mesa. Because an oil field has been developed on each of these four structural elevations—the Dominguez, Long Beach, Seal Beach, and Huntington Beach fields, respectively—their subsurface geology is known in considerable detail.

The most regular domal structure underlies Dominguez Hill whose general outer form reflects the deeper structural pattern to a lesser degree. The crest of Dominguez Hill is only about 150 feet above the surrounding plains, but the structural relief at the base of the Pleistocene is about 400 feet. (See pl. 8.) According to Grinsfelder (1943, p. 318), mapping on successive stratigraphic horizons indicates that the effect of the tectonic forces is progressively greater at increasing depth and that "mapping on horizons as deep as 4,000 feet reveals an elliptical anticline with a northwest-trending axis, steep flanks on the southwest, with dips of from 15° to 20°." Thus the structural development of this anticline has gone on recurrently through much of Tertiary and Quaternary time.

The Long Beach (Stolz, 1943, p. 320–324) structure is an elongate, faulted, asymmetric anticline about 5 miles long whose axis trends northwest. The dip is steeper on the southwest flank; at a depth of several thousand feet the beds on the southwest flank dip 40° to 45° but those on the northeast flank dip only about 15°. The anticline is broken by three known longitudinal faults and one probable transverse fault. (See pl. 3.) At the crest of this structure, under Signal Hill, impermeable rocks of late Pliocene age have been elevated by folding and faulting to a height of about 200 feet above sea level (pl. 4, section *A–A'*), considerably above the top of the main ground-water body farther inland.

The Seal Beach structure consists of two elongate domes separated by a gentle saddle; the more northerly dome underlies Alamitos Heights; the southerly and larger dome has its apex in Alamitos Gap under the present channel of the San Gabriel River. This composite anticline is cut by the Seal Beach fault (Bowes, 1943, p. 325–328), which is about parallel to its axis. However, as shown on plate 4, section *A–A'*, the fresh-water-bearing beds within 2,000 feet below the land surface are flexed only slightly in this structure.

The Huntington Beach uplift is structurally the most complex element of the Newport-Inglewood zone. Although it is divided by faults into structural blocks (see p. 102) its central segment includes a broad anticline that extends from the eastern edge of Huntington Beach Mesa northwestward nearly to Bolsa Chica Mesa. On the northeast flank of the anticline the Quaternary and Tertiary rocks dip rather gently, as indicated by the slope of the mesa surface; southwesterly, or up dip, they pass into a complicated shear zone that apparently terminates the broad structural elevation. The position of this shear zone is indicated on plate 3 by an inferred fault that crosses Golden West Avenue about 0.4 mile south of its intersection with Garfield Avenue. The highest part of this broad anticline, at least in the Pleistocene deposits, is in section 34; electric logs of oil wells there show that permeable Pleistocene deposits are bent upward and beds of probable San Pedro age are exposed on the west edge of the mesa. (See pl. 4, section *A–A'*.) To the northwest the Pleistocene and uppermost Pliocene rocks are nearly horizontal, as indicated by electric logs from oil wells at the extreme eastern end of Bolsa Bay. Locally the Pleistocene water-bearing zones dip slightly southward, but the underlying uppermost Pliocene (upper part of upper Pico) dips 1°–2° N. At still greater depth, about 1,600 feet below land surface, the base of the fresh-water-bearing beds (approximate base of upper Pico) dips 7° N. Thus the dip increases substantially with depth.

Another but much smaller anticline occurs along the shore. At depth its axis lies about 1,000 feet seaward from and parallel to the wave-cut mesa front (Weaver and Wilhelm, 1943, p. 330, fig. 138).

FAULTS

Within the area shown on plate 3, especially in the central reach from Dominguez Gap to Santa Ana Gap, a nearly continuous set of faults is alined along the general crest of the Newport-Inglewood structural zone. (See pl. 3.) The position, character, and continuity of these faults are basic with respect to the circulation of ground water; accordingly all are described in some detail.

DOMINGUEZ HILL AREA

For the Dominguez anticline Bravinder (1942, p. 390) reports two well-defined sets of faults: high-angle, normal and reverse faults that strike obliquely across the general axis of the dome; and south-dipping reverse faults that strike nearly parallel to the axis. Bravinder (1942, p. 398) states that detailed study of the subsurface geology in the Dominguez oil field yields evidence that indicates horizontal movement or strike slip along the set of oblique faults. Along both sets stratigraphic displacement or throw is greatest in the Miocene rocks; from Grinsfelder's statement (Grinsfelder, 1943, p. 318) that the effects of faulting become evident below 4,000 feet it is inferred that the displacement dies out near the top of the Repetto formation. No known faults continue to the land surface on Dominguez Hill within the area shown on plate 3; they occur at depths so great that they appear to offer little or no impediment to free movement of water across the Newport-Inglewood zone: this possibility is discussed elsewhere (Poland and others, 1946).

CHERRY-HILL FAULT

The most clearly defined fault of the Newport-Inglewood zone within the area shown on plate 3 extends southeastward from Dominguez Gap and passes along the south side of Signal Hill; it was designated the Cherry–Hill fault by Stolz (1943, p. 323). Stolz did not hyphenate the name, but as it probably is compounded from the names of two streets, it is hyphenated in this report. The fault has a demonstrated length of about 4 miles from the east side of Dominguez Gap to and beyond the southwest flank of Signal Hill. Within this reach the Cherry–Hill fault dips steeply to the northeast, and its upthrown side is to the northeast; thus it is a reverse fault. Within the limits of the fault escarpment (see p. 21) the displacement of the land surface ranges from a few feet to more than 100 feet. At a depth of several thousand feet, however, the throw is as much as 1,000 feet in Miocene rocks (Stolz, 1943, p. 324, fig. 133). At the base of the San Pedro formation the throw is about 200 feet near California Avenue, which is a mile due west from the summit of Signal Hill; and about 300 feet near Cherry Avenue, which is 0.3 mile west of Signal Hill. Thus at this horizon the throw here increases toward the southeast about 100 feet in 0.9 mile along the fault trace. At the presumed base of the upper division of the Pico formation—that is, at the base of the fresh-water-bearing zone—the throws at these two places are about 300 feet and 500 feet or more, respectively. Thus at this deeper horizon both the throw and the southeastward increase in throw are greater. Extension of the Cherry–Hill fault northwestward for about 2 miles beyond Los Cerritos, or nearly across Dominguez Gap, is inferred from geologic and hydrologic evidence. For nearly half a mile this extension is soundly substantiated by geologic information obtained in drilling or prospecting for oil; beyond, it is projected to the far side of the gap along an apparent hydraulic discontinuity in the Silverado water-bearing zone. Robin Willis (oral communication) believes that in this northwest extension into Dominguez Gap the dip of the fault plane changes gradually from northeast to southwest. There is no geologic evidence that this fault displaces the deposits of Recent age in Dominguez Gap.

The vertical displacement of water-bearing members is considerable for several miles along the Cherry–Hill fault, thus greatly affecting the circulation of ground water. Robin Willis (oral communication) believes that there has been horizontal displacement of many hundreds of feet, at least near the east edge of Dominguez Gap, and that the block southwest of the fault has moved northwestward. The vertical displacement or thow is so great that hydraulic continuity in the thick Silverado water-bearing zone is very much impeded at the Cherry–Hill fault. In the block to the southwest, or toward the coast, this zone is 400 to 500 feet thick. Owing to the displacement, at least the lower half of the zone terminates landward against upthrown underlying rocks of relatively low permeability. At Signal Hill the rocks of low permeability in the upthrown block rise above the zone of saturation; there, at least, hydraulic continuity in the Silverado zone is almost completely severed. (See pl. 4, section *C–C′*.)

NORTHEAST FLANK FAULT

The Northeast Flank fault (Stolz, 1943, p. 321, 323) extends southeastward for about a mile along the northeast flank of Signal Hill and on to the southwest flank of Reservoir Hill. It dips steeply to the southwest and at the land surface forms a prominent escarpment. Signal Hill is an uptilted block between this fault and the Cherry–Hill fault. Topographic features suggest that the vertical displacement or throw decreases southeastward along the Northeast Flank fault; at a depth of 4,000 feet below land surface this throw is 500 feet at Signal Hill, but only 50 feet at Reservoir Hill (Stolz, 1943, p. 321, fig. 133). Plate 4, section *C–C′* shows structural relations near the northern end of the fault; as indicated on plate 4, section *C–C,′* the throw is probably about 200 feet at the base of the Silverado zone—base of San Pedro formation—and 250 feet at the base of the upper Pico. The throw decreases southeastward and dies out completely along the west flank of Reservoir Hill. At Signal Hill, however, the throw is sufficient to offset completely the coarse lower part of the Silverado zone and, as at the Cherry–Hill fault, to impede substantially the movement of water through the Silverado zone toward or away from the coast.

PICKLER FAULT

On the north the Northeast Flank fault probably terminates against a transverse fault that strikes southwest along the northwest face of Signal Hill. This transverse fracture is named the Pickler fault by Stolz, who has inferred its existence largely from a marked difference in the productivity of oil wells on either side. Its probable existence is confirmed by a known discontinuity in the principal water-bearing zones. At the Pickler fault the vertical displacement at the base of the San Pedro—base of the Silverado water-bearing zone—is believed to be about 150 feet directly opposite the crest of Signal Hill. The Pickler fault can have little effect on regional ground-water movement, however, except as it terminates a block (Signal Hill) in which rocks of low permeability are upthrown above the local water table.

RESERVOIR HILL FAULT

The northeast flank of Reservoir Hill is about a mile long. A normal fault that dips steeply to the northeast and is alined with the scarp can be demonstrated from the electric logs for oil wells on Reservoir Hill, and for oil wells and test holes on the plain immediately to the northeast. It is named the Reservoir Hill fault in this report. Along this fault and about opposite the crest of Reservoir Hill the vertical displacement or throw is 280 feet, both at the top and at the base of the San Pedro formation; also at the base of the fresh-water zone, the presumed base of the upper division of the Pico formation. (See pl. 4, section *A–A'*.) Available information does not indicate whether displacement is greater in any underlying formations. Land forms suggest that the displacement, at least in the Pleistocene rocks, diminishes markedly to the southeast.

This particular fault was inactive during accumulation of the upper Pico and San Pedro deposits, but along it the displacement in post San Pedro time has been about 280 feet. The crest of Reservoir Hill is about 210 feet above sea level, or about 140 feet above the plain to the northeast. Accordingly it is inferred that about half the 280-foot displacement occurred during the so-called mid-Pleistocene revolution, which followed the deposition of the San Pedro, and that the remaining half occurred in post Palos Verdes time. This interpretation involves the antecedent inference that the San Pedro formation was beveled to a horizontal surface after the mid-Pleistocene revolution, and that the Palos Verdes sand and related terrace cover were deposited on that beveled surface. (See p. 17.) The Palos Verdes sand has not been found in place on Reservoir Hill, but DeLong (1941, p. 237) reports finding fossils of Palos Verdes age in a spoil dump on the east slope of the hill, presumably of material stripped from the top of the hill in grading foundations for the municipal water-storage tanks.

SEAL BEACH FAULT

In the oil-producing zones the Seal Beach anticline is bisected roughly along its axis by a fault, called the Seal Beach fault, that extends about 3 miles from Alamitos Heights to Landing Hill (Bowes, 1943, p. 325–327). This fault is inferred by both Bowes and the writer to be essentially continuous with the Reservoir Hill fault. According to Bowes the Seal Beach fault dips at a high angle to the northeast and about 4,500 feet beneath the San Gabriel River displaces the oil-producing zones from 150 to 200 feet. At this depth the fault separates beds that dip rather steeply (20°) toward Downey Plain on the northeast from beds that dip gently toward the ocean on the southwest. The displacement is less in the Alamitos Heights area. The amount of displacement in the deposits of Pleistocene age in Alamitos Gap is not known, but data on wells indicate that in aquifers only slightly more than 100 feet below land surface there is a striking discontinuity in ground-water level and in ground-water quality across the fault known to exist at depth. Also, on Landing Hill, deposits of late Pleistocene age have been displaced along the common alinement. Data on observation wells no more than 20 feet deep in Alamitos Gap indicate no rupture within the uppermost alluvial and coastal deposits of Recent age. Hence it is concluded that the fault transects all deposits of Pleistocene or greater age.

Along a considerable part of the Reservoir Hill fault, and to a lesser degree the Seal Beach fault, the vertical displacement in the Pleistocene rocks may be sufficient to offset a large part of the water-bearing zones in the same rocks. At the fault, therefore, certain water-bearing zones may terminate against non-water-bearing materials, and hydraulically the blocks on either side may be extensively discontinuous.

FAULTING FROM LANDING HILL TO HUNTINGTON BEACH MESA

As indicated on plate 3, faults that transect all rocks underlying the alluvial deposits of Recent age are inferred to extend essentially continuously along the Newport-Inglewood zone from Landing Hill, across Sunset Gap, Bolsa Chica Mesa, and Bolsa Gap, to Huntington Beach Mesa.

In the central part of this reach the topography of Bolsa Chica Mesa reveals substantial displacement of the late Pleistocene deposits along a line parallel to and about 0.5 mile inland from the coast. Here the land surface is displaced about 40 feet and is lower on the southwestern or coastal block. Extension of this topographic displacement northwestward into Sunset Gap is suggested by two hillocks, about 0.5 mile and 1.0 mile, respectively, from Bolsa Chica Mesa, that are underlain by deposits of probable Pleistocene age. The more northerly hillock is known as Hog Island.

This fault or fault zone that is inferred from land-form features is substantiated by some geologic evidence; the positions of one producing oil well and of several nonproducing wells on Bolsa Chica Mesa are believed to define the fault rather closely at depth in that area, but geologic evidence to substantiate the inferred fault zone across Sunset Gap is not known.

Southeastward from Bolsa Chica Mesa, as indicated by electric logs for many oil wells east of Bolsa Bay, faults transect the Pico formation and at least the lower part of the overlying San Pedro formation.

The more northerly of the two fault zones inferred in the eastern part of Bolsa Gap is so substantiated. Although numerous transverse faults complicate the interpretation of geologic structure, the displacement on the master longitudinal fault is locally 100 to 200 feet at the base of the fresh-water zone, which is roughly the base of the upper Pico and which is here about 1,500 feet below land surface.

Because geologic evidence is meager concerning the character of the Newport-Inglewood structural zone between Landing Hill and Huntington Beach Mesa and because there were no water wells available for hydrologic and chemical evidence on the coastal side of the structural zone, three pairs of observation wells were drilled in this area: wells 5/12–13D1 and 5/12–13D2 on Landing Hill, 5/11–18N1 and 5/11–18P1 in Sunset Gap near Hog Island, and 5/11–29E1 and 5/11–29E2 on Bolsa Chica Mesa. Detailed descriptions and logs for these six wells are given in table 5. As indicated on plate 3, all are on the coastal side of the Newport-Inglewood zone, but proximate to its general axis. For the two pairs of these wells on Landing Hill and on Bolsa Chica Mesa, respectively, plate 5, sections *a–a′* and *b–b′*, affords comparison of stratigraphy and chemical character of ground water with corresponding features for water wells inland across the structural zone. These plates bring out a striking change in chemical quality of water across the fault. At both places, as well as at Hog Island, only strongly saline water is present on the coastal side of the inferred fault, but water of excellent quality is yielded by heavily pumped wells on the inland side. Hydrologic evidence on the three pairs of wells, presented in a separate report (Poland and others, 1946) shows a striking hydraulic discontinuity across the fault zone. Chiefly on the basis of this chemical and hydrologic evidence it is concluded that a fault zone extends almost continuously from Landing Hill into Bolsa Gap and transects all rocks except the alluvial deposits of Recent age—that is, all the rocks of Pleistocene or greater age.

FAULTS ON HUNTINGTON BEACH MESA AND IN SANTA ANA GAP

The geologic structure of Huntington Beach Mesa is complex and not fully known, but probably at least two fault zones strike southeastward across the mesa nearly parallel to the shore. This conclusion is derived from fragmentary data on structure in the oil-producing zones; from features revealed by outcrops, water-well logs, and a few oil-well electric logs that begin at shallow depth below land surface; and from land forms. However, the present concept of the structure is not sufficiently definite to warrant a graphic section in this report.

The inland one of the two inferred fault zones traverses the mesa about a mile from the shore; along this alinement a zone of flexure and faulting is known to exist at depth in the oil-producing zones (Weaver and Wilhelm, 1943, p. 329–331). Electric logs of a few wells near the southeast edge of the mesa show that across this inferred fault the water-bearing zones in the deposits of Pleistocene age are displaced little if at all, but apparently change in thickness and physical character. Along the extension of this inferred fault zone into Santa Ana Gap in sec. 12, T. 6 S., R. 11 W., Pliocene and Miocene rocks are known to be displaced greatly. Still farther southeast in sec. 18, T. 6 S., R. 10 W., logs of water wells indicate a zone of faulting in the deposits of Pleistocene age that underlie the Talbert water-bearing zone of Recent age. This fault zone is known to pass south of wells 6/10–18C4 and 6/10–18G5, but north of wells 6/10–18K1, 6/10–18K3, and 6/10–18K4. Well 6/10–18K2 encountered cemented material below 150 feet, hence the southern margin of the fault zone is believed to pass close to this well. (See p. 105.) The over-all vertical displacement is at least 180 feet; this displacement appears as a series of steps. The logs of water wells within the zone show a progressive downward displacement of the base of the water-bearing deposits from 150 feet below sea level at well 6/10–18C4 to about 330 feet below sea level at well 6/10–18K3. Consequently certain water-bearing beds of lower Pleistocene age in the downthrown coastal block butt against non-water-bearing silt of Pleistocene or uppermost Pliocene age. This is shown on plate 5, section *c–c′*. Features of structure exposed on the southwest escarpment of Newport Mesa show that these fault-terminated water-bearing beds in sec. 18 probably dip south from the fault.

The second probable fault zone on Huntington Beach Mesa is about 0.5 mile inland from the shore. As shown on plate 3 it is inferred to merge with the inland fault toward the northwest in Bolsa Gap and to strike the mouth of the Santa Ana River southeastward. The position and alinement of this fault are deduced partly from the land forms and partly from general structural features of the rocks at depth. Geologic, hydrologic, and geochemical evidence from the water wells of the district neither proves nor disproves that this inferred fault transects the deposits of Pleistocene age.

About 0.3 mile west of the Santa Ana River in secs. 7 and 18, T. 6 S., R. 10 W., a subsidiary fault probably strikes northward, transverse to the general axis of the Newport-Inglewood zone. This fault is inferred from logs and geochemical data for water wells, also from geophysical evidence. In sec. 18, water-bearing beds of lower Pleistocene age to the east appear to be downthrown into contact with non-water-bearing deposits of lower Pleistocene or upper Pliocene age to the west. (See pl. 4, section *A–A′*.)

Movement of water in the permeable zones of the Pleistocene rocks must be substantially influenced by these fault zones, which are inferred to extend the Seal Beach fault southeastward into Santa Ana

Gap. Although the amount of fault displacement is known for only a few places along the 10-mile reach southeast of Landing Hill, water-bearing and non-water-bearing zones probably are offset against one another somewhat extensively. Certain structural traps doubtless impede the movement of water across this reach of the Newport-Inglewood zone, locally if not generally. The barrier effect of such traps and of other features along the zone are summarized on pages 119–125.

FAULTS IN NEWPORT MESA AREA

In the central part of Newport Mesa a fault probably passes generally westward through the northern part of sec. 10, T. 6 S., R. 10 W., a short distance north of well 6/10–10D3. (See pls. 3 and 4, section *D–D'*.) In its north wall the water-bearing beds in the lower part of the San Pedro formation appear to be upthrown more than 300 feet. Evidence for this fault is derived from the stratigraphic correlation and geochemical relations shown on plate 4, section *D–D'*, also from hydrologic data. Well 6/10–10D3 was drilled in 1939 on the site of a former resort at Fairview Spring and near the south wall of the inferred fault. Waring (1915, p. 37) reported in 1915 that originally the Fairview Spring flowed naturally,

> but a casing that was sunk to a depth of 700 feet into it has converted it into a flowing artesian well. * * * The water rises with a temperature of 96° and supplies a swimming plunge and tub baths. The discharge varies somewhat with the season; in December, 1908, it was about 15 gallons a minute.

This former hot spring is cited as evidence tending to substantiate the fault. Evidence, largely geochemical, shows that this fault probably was of paramount importance in impeding southward movement of water through the San Pedro formation from the northern to the central and southern parts of Newport Mesa. Also, it may be a structural barrier to movement of ground water from the surface outcrop of the San Pedro formation at the inland end of Newport Bay northward into the thick water-bearing zone underlying the northern part of the mesa.

Several faults are known to cut the Miocene rocks in the southern part of Newport Mesa, and in general to strike northwestward. (See pl. 3.) It is not known whether any of these extend northward into the Pleistocene water-bearing deposits or have any influence on the movement of water.

ZONES OF CEMENTATION IN THE PLEISTOCENE ROCKS

The deformation in the Newport-Inglewood zone doubtless caused numerous minor fractures and shear zones in addition to the extensive master faults. Probably these were most numerous adjacent to the master faults and so along the axial part of the structural zone. At least locally these fracture zones have been filled by cementation.

The best exposures of these fractures are along the Signal Hill uplift between California Avenue and the southeast flank of Signal Hill and less than 1,000 feet northeastward from the master Cherry–Hill fault. They occur in the San Pedro formation and commonly terminate upward at the unconformity with the Palos Verdes sand in the few places where exposures reveal fractures in contact with the unconformity. In two such exposures, however, much more thinly cemented fractures continue upward through the Palos Verdes sand to land surface, although neither is a direct continuation of the fracture plane in the San Pedro formation beneath. To ascertain the chemical character of the cementing materials, samples were collected from 10 cement-filled fractures in the San Pedro formation at several places. Six of these samples were treated with hot, dilute hydrochloric acid. Three disintegrated completely, leaving a residue of clean sand grains; the other three were partly digested by the acid, but in each a porous, latticelike, siliceous mass remained. It is therefore inferred that an acid-soluble carbonate, calcium carbonate in large part, was the exclusive cement in three samples and the predominant cement in the other three. Because the cement-filled fractures so tested were similar in physical appearance to many others not tested, it is inferred that calcium carbonate is the dominant cement filling the fracture-systems associated with the Cherry–Hill fault as exposed within the San Pedro formation.

Outcrops on the southwest flank of Signal Hill disclose permeable sand and gravel of the San Pedro formation once transected by a zone of closely spaced fractures. The fractures doubtless were first opened by uplift along the Cherry–Hill fault. Now, however, they have been extensively closed by deposition of calcium carbonate, iron oxide, or silica. Locally the cementing materials have invaded either wall of the fracture and so have formed a dense matrix between the sand grains and pebbles. Exposures along the cemented zone now reveal several vertical or steeply-dipping, impermeable, membranelike layers which range in thickness from less than an inch to as much as a foot and which are separated by bodies of uncemented permeable sand and gravel. The zone of fractures is about parallel to the Cherry–Hill fault. In the zone of saturation it would constitute an effective barrier to movement of water along the strata of the San Pedro formation.

On the coastal side of the Newport-Inglewood zone cemented sand and gravel of Pleistocene age was encountered in drilling observation wells 5/11–18P1 and 5/11–18N1 in Sunset Gap. These two wells are respectively about 530 feet and 700 feet southwest of Hog Island, which is presumed to be a high point on the inland wall of the master fault. Both were drilled with a light rotary rig. In well 5/11–18P1, "rough" drilling was experienced intermittently from 48 feet to 236 feet below land surface, probably owing largely to partial cementation in coarse water-bearing material. At a depth of 236 feet, very hard conglomerate—cemented gravel—was encountered. In this material a rock bit made only 3.7 feet of progress in 10 hours, so that the hole was bottomed at that depth. The rig was moved 170 feet farther away from the master fault, and well 5/11–18N1 was drilled at the new location. There the same cemented gravel or conglomerate was encountered 236 feet below land surface, but was much less dense and was penetrated without recourse to a rock bit. These facts suggest that the layer of gravel at 236 feet was completely cemented within a few hundred feet of the master fault but only partly cemented 170 feet farther away.

Other cemented fracture zones at some distance from, but probably related to, the master faults of the Newport–Inglewood structural zone have been encountered by a number of wells. For example, near Watson and about 2 miles southwest of the Cherry–Hill fault, well 4/13–22D1 was drilled to a depth of 1,128 feet with cable tools, but yielded no water when tested although it penetrated the full thickness of the Silverado water-bearing zone; wells about 1,000 feet to the north and to the south yield copiously from that zone. Hard material was encountered and tight drilling experienced for the full depth; the 18-inch casing froze after it had been driven down to 425 feet, and the 16-inch casing froze at 467 feet. Open hole was drilled below 500 feet, or through the entire Silverado zone, which elsewhere commonly is loose sand and gravel. Thus the consolidation of the water-bearing zone, the mechanical difficulties and slow progress experienced in drilling, and the failure to produce water after completion, all substantiate the conclusion that the well was drilled in an impermeable, tightly cemented fracture zone that persisted from 164 feet below land surface to the bottom of the well. This fracture zone probably strikes about southeast and is related structurally to the double nob of Pleistocene deposits exposed about half a mile east of Watson station. (See pl. 3.)

About 2 miles to the northwest well 4/13–17D1 encountered the same type of drilling, and its casing was never perforated. (See p. 87.)

It is quite possible that both wells may have been drilled into the same fracture system. On the other hand it is very doubtful that a single continuously cemented fracture extends between these wells, because such a cemented zone would greatly impede coastward movement of water through the Pleistocene water-bearing deposits and would cause a discontinuity of water levels in wells on either side. Available data on ground-water levels indicate that such a regional discontinuity, if it exists at all, is of small magnitude.

To the northeast of the Newport-Inglewood structural zone other wells have encountered similar hard drilling, cemented water-bearing zones, and low yield. One such well, 4/12–26C1, was drilled about 2 miles northeast of the Reservoir Hill fault, another in sec. 33, T. 3 S., R. 12 W., about 5 miles northeast of the Cherry–Hill fault.

These zones of cementation probably were formed by deposition of mineral matter from waters ascending to the land surface along fracture-zone conduits, largely from permeable beds in the San Pedro formation. Such deposition necessarily would be in upper Pleistocene and Recent time, subsequent to deformation of the San Pedro. It seems probable that along the axis of the Newport-Inglewood zone nearly vertical and substantially impermeable membranes have been so formed extensively. It is not likely that a single such membrane spans either the full reach from Dominguez Hill to Santa Ana Gap or the full vertical range of the San Pedro formation. Rather, discontinuous membranes probably are set en echelon, horizontally and perhaps vertically. Their range in depth below land surface is least certain. (See p. 123.) However, in cross section along the Newport-Inglewood zone, a substantial part of the San Pedro formation doubtless is spanned by these barriers against horizontal movement of water.

Zones of cementation are known to exist also in the rocks of Tertiary age that underlie the San Pedro formation. In the Long Beach field, oil wells near the Cherry–Hill fault have yielded cores of indurated and cemented sandstone containing veins of calcite. It is not known that any such zones of cementation at depth are continuous with those of the San Pedro formation. However, whether continuous vertically or not they probably impede upward circulation of saline connate water from the Tertiary rocks into the overlying fresh-water bodies.

SUMMARY OF GEOLOGIC FEATURES RELATED TO GROUND-WATER REGIMEN

REGIONAL BODIES OF GROUND WATER

In general, at least three distinct bodies of ground water exist in the Long Beach-Santa Ana area. In downward succession these are: (1) A body of semiperched water that occurs in the upper part of the alluvial deposits of Recent age and that is essentially continuous from the ocean, through the five gaps between the coastal hills and mesas and far onto the Downey Plain; (2) the principal body of naturally fresh ground water that occurs chiefly in the lower division of the alluvial deposits of Recent age, in nearly all the deposits of Pleistocene age, and in certain parts of the underlying Pliocene rocks; and (3) a body or bodies of saline connate water that underlies the principal fresh-water body throughout the area.

The body of semiperched water is essentially unconfined and supplies only a relatively few water wells of small capacity. In the several gaps across the coastal belt of hills and mesas it occurs only in the upper 20 to 50 feet of the Recent deposits, and at many places it is separated from the underlying fresh-water zone by relatively impermeable beds. As is developed specifically elsewhere (Piper, Garrett, and others) this semiperched water body ranges widely in chemical character. Over much of Downey Plain inland from the Newport-Inglewood zone it is naturally a calcium bicarbonate water suitable for most ordinary uses. Locally, however, its chemical quality has deteriorated greatly by accumulations of irrigation sewage or industrial wastes. Everywhere between the general axis of the Newport-Inglewood zone and the coast it has been naturally of inferior and irregular quality. At some places on the coastal tidelands the shallowest part of this water is somewhat more than twice as saline as the water of the ocean; locally, it has been grossly contaminated by waste fluids from industrial operations. Thus, in the area from the coast to the inland flank of the coastal hills and mesas this semiperched saline water is a potential source from which the underlying principal fresh-water body may become contaminated by way of wells not adequately cased in the Recent alluvium. If localized contamination of the fresh-water body from this source is not ultimately to become a common occurrence, it is essential that all deep wells be maintained with tight casings through the zone of semiperched water, and that abandoned wells be adequately plugged above the fresh-water body.

The principal body of naturally fresh ground water occupies (1) the lower division of the alluvial deposits of Recent age—the Gaspur and Talbert water-bearing zones; (2) all deposits of Pleistocene age—any correlatives of the terrace cover and Palos Verdes sand that may exist beneath Downey Plain—and chiefly the unnamed upper Pleistocene deposits and the underlying San Pedro formation in all parts of the area except the very highest segments of the Newport-Inglewood zone and certain areas along the coast; and (3) a considerable part of the Pico formation of upper Pliocene age. In the area shown on plate 3 the base of this fresh-water body coincides approximately with the base of the upper division of the Pico formation and reaches a maximum depth of about 2,600 feet below sea level along the crest of the Newport-Inglewood zone. (See pl. 4.) As plate 1 shows, however, under the central part of Downey Plain the body extends to depths as great as 8,000 feet below land surface, or nearly down to the top of the Repetto formation of lower Pliocene age. Hence the total volume of materials occupied by the principal fresh-water body is very large indeed, but the greater part of it lies at depths greater than that to which it is now practicable to drill for water.

The main body of connate water occurs in rocks of Tertiary age at depth beneath all the Long Beach-Santa Ana area. Its upper boundary is relatively abrupt; electric logs of oil wells and oil-test holes indicate that in much of the area there is no general zone of transition between waters that are essentially fresh and those decidedly saline; locally, however, there is a transition zone several hundred feet in thickness. As a whole the containing rocks are largely impermeable; the connate waters exist in sandy members that are of relatively low permeability, separated by impermeable members substantially thicker, and probably not in free hydraulic continuity with one another. Most of these deep connate waters range from about half to the full salinity of ocean water.

GENERAL FEATURES OF THE PRINCIPAL FRESH-WATER BODY

DISPLACEMENT OF SALINE CONNATE WATER

In most parts of the Long Beach-Santa Ana area the native waters of the upper part of the principal fresh-water body, the part now tapped by water wells, contain considerably less than 50 parts per million of chloride and commonly less than 25 parts. Within the area shown on plate 3 this upper part is contained in deposits predominantly of marine origin, but within the remainder of the area it is contained in deposits very largely of continental origin. In fact, inland beneath the central part of Downey Plain, materials of continental origin extend to about 3,000 feet below land surface and span nearly 40 percent of the vertical range of the fresh-water body. (See pl. 1.) The greater part of the body as a whole, however, is contained in materials of marine origin; as deposited, these materials must have been saturated with ocean water. Saline connate water must have been flushed or displaced from these materials throughout a zone that ranges from a thin edge to as much as 5,000 feet thick, and whose base is approximately from sea level to some 8,000 feet below present sea level.

It appears to be physically impossible for a connate water as saline as that of the ocean to have been progressively diluted with fresh water from the land until the chloride content was reduced to that of the principal fresh-water body—less than 50 parts per million. Rather the connate water probably was displaced without having been greatly or extensively diluted. Specifically, as an area of marine sedimentation became land, fresh water penetrated below the land surface and floated on the underlying body of saline connate water; as the volume of fresh ground water increased, the connate water was displaced downward and oceanward in approximate hydrostatic balance with the floating fresh-water body; and finally, all the connate water was expelled from the present fresh-water zone.

Even though the materials beneath the coastal plain include a succession of permeable and impermeable strata, the potential depth of displacement was determined by the relative densities of the fresh water and the connate water, and by the height of the fresh-water table above sea level. The density of the connate water is such that the depth of displacement below sea level would have been at least some 40 times the height of the water table above sea level. Thus the initial fresh-water head of historic time was such that the potential depth of displacement below land surface ranged from 7,000 to 8,000 feet in the vicinity of Huntington Park and Whittier Narrows to some 5,000 feet in the vicinity of Anaheim—about coincident with the known vertical range of the fresh-water body. (See pl. 1.) In theory, to have displaced connate water in this manner the necessary volume of land-derived fresh water would have been no greater than that now in storage within the area. That saline connate water probably was displaced from the Long Beach-Santa Ana area in somewhat this manner is substantiated by the chemical character of the sodium-bicarbonate waters. (See p. 118.)

In the part of the fresh-water zone that occupies the San Pedro formation the displacement of saline connate water probably began before the end of San Pedro time, but took place largely during the epoch of structural revolution in mid-Pleistocene time. About all the saline connate water of the San Pedro formation probably was displaced prior to the last considerable deformation of the Newport-Inglewood zone in post-Palos Verdes time. Accordingly, the oceanward extent of displacement probably had been determined before barrier features of the structural zone were well developed. In the part of the fresh-water zone that occupies the upper part of the Pico formation, however, displacement of saline connate water probably began earlier than in the San Pedro formation. It may have begun even before San Pedro time, at the beginning of which the base of the Pliocene deposits in the central part of the Long Beach-Santa Ana area was much higher with relation to sea level than now—possibly as much as 3,000 feet higher. (See pl. 1, section *A–A′*.)

These theoretical considerations lead to a critical conclusion of practical import concerning the potential utility of the upper division of the Pico formation as a reserve source of fresh water. The essentially nonsaline character of the water now in the upper part of the Pico formation probably developed considerably before the mid-Pleistocene revolution ended. Hence its nonsaline character does not require present hydraulic continuity with any overlying part of the fresh-water zone or with any present area of ground-water replenishment.

All saline connate water inland from the Newport-Inglewood zone and somewhat extensively beyond that zone toward the ocean was expelled naturally from the full vertical range of the San Pedro formation. Connate or diluted connate waters are native to the formation in a few areas, as in local districts beneath the flank of the Palos Verdes Hills, beneath the Long Beach Plain, and beneath the eastern margin of Santa Ana Gap and the adjacent central and southern parts of Newport Mesa. In these districts structural traps apparently have impeded free movement of water. On the south flank of the Wilmington anticline in the vicinity of Terminal Island the water in the Silverado zone becomes progressively more saline eastward and southward. This is indicated by the electric logs of numerous oil wells and by the record of well 5/13–3K1, which was drilled in 1913 at the plant of the Southern California Edison Co. at the east end of Terminal Island and which is reported to have encountered salty water. Saline water in this area may indicate either the initial oceanward reach of the fresh-water body or the present inland reach of the ocean-water drive engendered by rise of sea level during the Recent epoch. In at least a part of the coastal reach from Landing Hill to Bolsa Chica Mesa, both inclusive, water whose salinity is practically equal to that of the ocean occupies the Pleistocene deposits to a moderate depth below land surface (see pl. 5, sections *a–a′* and *b–b′*) and may well extend to the base of the San Pedro formation. Locally this salt-water body extends inland to, but apparently not beyond, the master faults of the Newport-Inglewood zone. Here the salt-water body probably results from reoccupation of the permeable materials by ocean water following the development of barrier features in the Newport-Inglewood zone. In its present extent this reoccupation may well have been controlled by the rise of sea level during the Recent epoch.

In the upper division of the Pico formation, saline connate water was displaced from virtually all parts of the Long Beach-Santa Ana area inland from the crest of the Newport-Inglewood zone. Beyond that zone, toward the ocean, data indicating the extent of the fresh-water body are available only for the area west of Long Beach, for which electric logs of oil wells indicate that the saline connate water was displaced at least to the coast, some 5 miles beyond the structural zone.

REPLENISHMENT AND CIRCULATION

Over nearly all the Long Beach-Santa Ana area the principal fresh-water body is effectively confined by overlying deposits of clay or silt; it can be replenished from the land surface in substantial amounts only beyond those confining deposits. Mainly it is replenished by infiltration from the major streams in permeable reaches of their channels near the inland hills; specifically, within the intake or so-called forebay areas below Whittier Narrows on the San Gabriel River and the Rio Hondo, also below the canyon of the Santa Ana

River. In those areas, materials of relatively high permeability extend continously from the land surface to the bottom of the alluvial deposits of Recent age and locally into the underlying deposits of Pleistocene age. Some replenishment is derived by underflow from the inland valleys (see fig. 2) and doubtless by infiltration of irrigation water and rain within the intake areas. In relatively very small amount replenishment may take place by infiltration over outlying inland areas in which permeable rocks of Pleistocene or upper Pliocene age crop out. Water is replenished mainly to the Gaspur and Talbert zones in the deposits of Recent age which serve as regional ground-water arteries conveying water to conduits in the underlying deposits.

Under natural conditions the water of the principal body moved generally oceanward throughout the Long Beach-Santa Ana area, but was considerably restrained. Coastward beyond the intake areas beds of silt and clay intervene between the successive water-bearing members and doubtless cause hydraulic discontinuity between those members at many places. In general such discontinuities are slight within the intake areas, and inland from them, but become more numerous and more extensive toward the coast as the water-bearing members tend to grade into the beds of silt and clay or finger out between them. Obviously movement of water is least restrained in the coarsest materials such as constitute the Gaspur and Talbert zones in the deposits of Recent age, and also in the more permeable members of the San Pedro formation. In these, under a hydraulic gradient of 5 to 10 feet in a mile, such as prevailed initially over much of the coastal plain, movement is comparatively rapid but probably no more than a mile every few years. Movement is much slower through the materials of finer texture but probably occurs to some extent in all but the finest-grained silt and in the clay. In effect, the principal fresh-water body occupies and moves through a succession of water-bearing members that are dispersed throughout the vertical range of the lowest alluvial deposits of Recent age, all the deposits of Pleistocene age, and the upper part of the Pico formation. Only in the two intake areas are these members in hydraulic continuity with one another through a considerable vertical range. Toward the coast, in the general direction of water movement, hydraulic discontinuity between water-bearing members becomes progressively greater and probably is nearly complete from the central part of Downey Plain to the inland flank of the Newport-Inglewood zone, and beyond that zone to the coast.

Along some parts of the Newport-Inglewood structural zone, if not all of it, the oceanward movement in the principal fresh-water body is under even greater restraint; there, owing to substantial barrier features (see p. 119) the restraint was sufficiently effective to produce a belt of flowing wells extending inland some miles, and presumably to cause considerable leakage from the deeper water-bearing members by upward movement in fracture-zone conduits adjacent to the master faults. Thus when certain water-bearing zones in the lower part of the San Pedro formation were tapped by the initial well of the so-called Bouton group, the static head of the water was found to be about 80 feet above land surface, or 150 feet above sea level. This well, 4/12–8P5, was constructed in 1891 on the inland flank of the Signal Hill uplift. Lower but substantial fresh-water head existed in the uppermost part of the principal fresh-water body, the Gaspur and Talbert zones of the alluvial deposits of Recent age. Under natural conditions the fresh-water head on the inland side of the Newport-Inglewood zone was so great in the Gaspur and Talbert water-bearing zones and in permeable members of the San Pedro formation that wherever it moved across the Newport-Inglewood zone fresh water moved oceanward to the very coast. It was hydraulically impossible for ocean water to move inland across the structural zone to Downey Plain.

Under the heavy ground-water withdrawals of the past several decades the initial head on the principal fresh-water body has been largely dissipated, at least within the Gaspur and Talbert zones and in the San Pedro formation. By the end of the dry period that culminated in 1936 the water level in wells had been drawn down nearly to sea level over much of the coastal plain, and substantially below sea level from the coast inland as far as Buena Park, a distance of 10 miles. Thus the initial oceanward hydraulic gradient of the fresh-water body has been reversed, any permeable conduits that have hydraulic continuity across the Newport-Inglewood zone no longer convey fresh water to the very coast, and in some such conduits water now is moving inland toward and locally across the structural zone. From 1936 into 1944 the fresh-water head recovered substantially and extensively during a succession of wet years and even rose above land surface locally. With the onset of World War II, however, withdrawals from the Silverado zone of the San Pedro formation increased greatly until in 1944 the head of its water was several tens of feet below sea level in a local area southwest of the Newport-Inglewood zone between Long Beach and Wilmington. If another protracted dry period should ensue and the fresh-water body inland from the Newport-Inglewood zone again should be extensively overdrawn for irrigation and other uses, a marked landward hydraulic gradient would result inevitably, and the barrier effect of the Newport-Inglewood zone would be the sole natural defense against widespread invasion of the fresh-water body by ocean water.

PERMEABILITY AND TRANSMISSIBILITY OF THE WATER-BEARING MATERIALS

The deposits that contain the principal fresh-water body range widely in capacity to transmit water. Three general zones may be discriminated fairly sharply; in downward succession these are the lower division of the Recent alluvial deposits, the San Pedro formation, and the upper division of the Pico formation. In each of these the water is effectively confined.

The lower division of the Recent alluvial deposits, chiefly the Gaspur and Talbert water-bearing zones, is of relatively uniform physical character and moderately large permeability throughout. Its average permeability is considerably greater than that of all other major water-bearing zones in the Long Beach-Santa Ana area; as estimated from the performance of wells and expressed in Meinzer's units its coefficient of permeability is approximately 3,000 within the several gaps across the Newport-Inglewood zone, and it probably increases several-fold inland across the coastal plain. The field coefficient of permeability is the rate of flow of water, in gallons a day, through a cross section 1 mile wide and 1 foot thick, under a hydraulic gradient of 1 foot per mile, and at the field temperature. Within the area shown on plate 3 the aggregate capacity of the lower division of the Recent deposits to transmit water across the Newport-Inglewood zone under natural conditions has depended on the permeability; the aggregate cross-sectional area, some 1,500,000 square feet or 0.05 square mile; and the hydraulic gradient, shown by Mendenhall (1905b, pl. 4) to have been about 10 feet to the mile in Dominguez Gap as of 1904. Taking this hydraulic gradient as equal to the average of the natural gradients through the several gaps, the aggregate seaward transmission of water under natural conditions was about 9,000,000 gallons a day—that is, about 13 second-feet or some 10,000 acre-feet a year.

The San Pedro formation comprises successive water-bearing strata in alternation with beds of silt and silty clay that doubtless have very little permeability. The aggregate thickness of all its water-bearing strata is estimated roughly half that of the formation, and the average permeability of those strata is about one-third that of the overlying materials. However, the effective cross-sectional area is much greater. As transected by a vertical section along the axis of the Newport-Inglewood zone the aggregate cross-sectional area of the San Pedro formation is estimated at 2.2 square miles within the area shown on plate 3. The corresponding area of its water-bearing strata would therefore be 1.1 square miles, or 30,000,000 square feet—that is, some 20 times the area of the lower division of the Recent deposits. Hence, at the Newport-Inglewood zone the aggregate capacity of the San Pedro formation to transmit water appears to be some seven times that of the overlying Recent deposits, if it is assumed that the hydraulic gradients of the two hydrologic units are equal, and that the movement of water in the San Pedro is not impeded by barrier features of the Newport-Inglewood zone. Barrier features do exist, however (see p. 119), and they are fairly effective in impeding movement of water across the structural zone, locally if not generally.

Concerning the transmission capacity of fresh-water-bearing rocks below the San Pedro formation, only general information is available, largely that from electric logs of certain oil wells and oil-test holes. Along the axis of the Newport-Inglewood zone this deepest part of the principal fresh-water body is contained by the upper division of the Pico formation. In the reach from Dominguez Hill southeast across Sunset Gap its vertical range below the San Pedro is about 850 to 1,750 feet (see pl. 4, section *A–A'*). The lower part of this range, in a stratigraphic zone roughly 500 to 1,000 feet thick, is very largely in members of permeable sand. As a fresh-water-bearing zone the upper Pico here may well exceed the San Pedro formation in effective thickness. However, its average permeability doubtless is less than one-tenth that of the San Pedro. Farther southeast, from Bolsa Chica Mesa to Santa Ana Gap, both permeability and effective thickness diminish considerably for the rocks that contain the lower part of the fresh-water body.

Inland from the Newport-Inglewood zone, under the central part of Downey Plain, this lower part of the principal fresh-water body extends some 5,000 feet vertically into the Pico formation, which here consists very largely of siltstone and shale layers that are wholly impermeable. The electric log of an oil-test hole a few miles west of Anaheim shows that essentially fresh water exists in the Pico about 3,300 to 8,100 feet below land surface, but that impermeable layers occupy about 85 percent of the vertical range. The permeable layers are chiefly marine sand of fine or medium texture compacted under the load of overlying sediments averaging about a mile in thickness; therefore their permeability and porosity are much less than those of coarse water-bearing deposits such as the Gaspur and Talbert zones in the deposits of Recent age. Thus the volume of fresh water in the 5,000-foot section of the Pico probably is substantially less than that in the 3,000-foot section of overlying deposits.

CHEMICAL CHARACTER

The principal fresh-water body of the Long Beach-Santa Ana area ranges widely in chemical character but only broad features of that character need be introduced in this summary of the relation between geologic features and ground-water regimen, because it is developed specifically elsewhere (Piper, Garrett, and others, 1953). The principal fresh-water body may be divided into an upper range occupied by calcium bicarbonate waters, an intermediate range occupied by sodium bicarbonate waters, and a lower range whose water quality is largely unknown. These three ranges appear to span distinct stratigraphic zones; they are not identical with the zones into which the fresh-water body has been divided with respect to permeability of the containing materials.

The range of native calcium bicarbonate waters spans all strata down to about middepth in the San Pedro formation, the stratigraphic horizon of the top of the Silverado water-bearing zone. From this range is drawn most of the water for irrigation and for private domestic use, a considerable amount for public supply, and some for industries. Nearly all the water is of the calcium bicarbonate type, but the native waters differ somewhat in chemical character from one water-bearing stratum to another and from place to place in any particular stratum. Over most of the Long Beach-Santa Ana area their content of dissolved solids commonly ranges between 250 and 500 ppm, and their hardness between 150 and 350 ppm. Few of these waters contain a large proportion of noncarbonate hardness. Commonly their chloride content is substantially less than 50 ppm. Thus these native calcium bicarbonate waters are chemically suitable for most common uses. In and near the Irvine Tract in the southeasternmost part of the area, and at a few places elsewhere, native fresh waters from this upper range exceed the upper limits of concentration cited.

In the uppermost part of their range the calcium bicarbonate waters are now contaminated and abnormally saline locally between the Newport-Inglewood zone and the coast. The two most extensive areas of contamination are in the Gaspur and Talbert water-bearing zones in the alluvial deposits of Recent age in Dominguez Gap and Santa Ana Gap, respectively. A less extensive area of contamination occurs in the underlying deposits of Pleistocene age beneath Huntington Beach Mesa. In all these areas of contamination the water-bearing strata are very permeable and formerly were drawn upon heavily by numerous wells; from the same strata large quantities of fresh water are being withdrawn currently farther inland. Thus the extent of the contaminated waters is not stable and will inevitably increase if the fresh-water withdrawal farther inland continues sufficiently large so that the fresh-water head there is drawn down below sea level. This hazard that the inland reach of contamination will increase is compounded by the fact that numerous wells pass through the bodies of contaminated water to reach the uncontaminated water below, especially near Dominguez Gap in the industrial area west of Long Beach and on Huntington Beach Mesa. Accordingly any such well that is not tightly cased through the waters now contaminated, or that is not adequately plugged if abandoned, affords a conduit through which contaminated water can move downward. There is a serious hazard that the very large body of fresh water in the Silverado zone of the San Pedro formation, which now sustains a large withdrawal for public supply and industrial use, might in this manner become contaminated extensively.

Within the area shown on plate 3 the range of the native sodium bicarbonate waters spans the lower part of the San Pedro formation and extends somewhat into the underlying Pico formation. In the northwestern part of that area the top of the range is at or somewhat below the top of the Silverado zone in the San Pedro formation; elsewhere in that area, at least roughly, at a corresponding stratigraphic horizon. From this range is drawn the greater part of the water for public supply and a considerable part of that for industries, but only a minor part for irrigation. Within the Silverado zone itself the waters of this range commonly contain from 175 to 300 ppm of dissolved solids, and no more than about 25 ppm of chloride. Hardness is entirely of the carbonate variety, decreases with increasing penetration into the range, and is as little as 11 ppm. In the lower part of the range water temperature averages 95° F. Beyond the Silverado zone, but within the area shown on plate 3, waters similar to these are found at corresponding stratigraphic horizons, but their content of dissolved solids commonly is somewhat greater, as much as about 400 ppm. On the central and inland parts of Downey Plain very few water wells are sufficiently deep to reach the lower part of the San Pedro formation; the few data on the chemical character of water from the deepest wells suggest that soft, sodium bicarbonate waters may exist extensively, at least in Los Angeles County. There, however, only very rough stratigraphic correlations are afforded by available data, and the vertical range of sodium bicarbonate waters is not known at all closely.

The lower limit of the range of sodium bicarbonate waters is not known, because data on water quality are available for only a few wells that tap the basal members of the San Pedro formation, and for even fewer wells that enter the upper division of the Pico formation. Thus below the San Pedro formation the chemical character of the principal fresh-water body is known only imperfectly from three chemical analyses and from electric logs of certain oil wells and oil-test holes. These data suggest that in this deepest segment of the fresh-water body the dissolved solids commonly are not more than some 750 ppm, and locally are as low as 300 ppm. Therefore this segment may contain water of a quality suited to extensive use, even if not suitable for public supply. If so, there exists in the Long Beach-Santa Ana area a very large reserve source of water, virtually untapped but at some places within practicable reach by drilling.

ORIGIN OF THE SODIUM BICARBONATE WATERS

It has been brought out that water in the intermediate part of the principal fresh-water body, water native to the lower part of the San Pedro formation, is soft and contains sodium and bicarbonate as principal dissolved constituents. This water occurs in materials of shallow-marine and littoral origin, in which sodium base exchange media well might have developed (see p. 78). With respect to origin of these sodium-bicarbonate waters it is inferred that: Saline connate water has been displaced by nonsaline water derived from a land surface; the displacing nonsaline water was initially of the hard, calcium bicarbonate type such as now occurs in the upper part of the fresh-water body; in contact with base-exchange media in the water-bearing material the displacing calcium bicarbonate water has been softened to the sodium bicarbonate type; and the sodium bicarbonate water is currently in chemical equilibrium with its containing material, whose capacity for softening by base exchange cannot have been exhausted. This substantiates the previous conclusion that the saline connate water was expelled by displacement. It indicates also that there has been little circulation of calcium bicarbonate water; otherwise the available sodium of the base-exchange media almost certainly would have been exhausted, those media would now be calcium-base, and the residual water now present would be of the unsoftened calcium bicarbonate type.

Only the deeper waters of the sodium bicarbonate range are extremely soft; in these the content of sodium plus potassium (Na+K) is as much as 18 times the content of calcium plus magnesium (Ca+Mg). To these only is ascribed an origin in strict accord with the ideal explanation formulated. For waters in the upper part of the range the content of sodium plus potassium is no more than about three times that of calcium plus magnesium. Here too, however, the water-bearing materials are of shallow-marine or littoral origin and as deposited presumably contained sodium-base exchange media. It is inferred that these waters also are in chemical equilibrium with base-exchange media in the containing materials, and that therefore in these media a considerable part of the sodium initially available has been expended. In other words, in the upper part of the range of sodium bicarbonate waters the permeable materials probably have conveyed and softened substantially more land-derived water than have those below. The aggregate volume conveyed has been sufficiently great so that waters now in passage find exchange media with considerably less available sodium.

This analysis leads to a further conclusion concerning the chemical character of water in the upper part of the principal fresh body, which is of the calcium bicarbonate type. In part that water is contained in the upper part of the San Pedro formation, which is also of shallow-marine origin and so might be inferred initially to have contained sodium base exchange media. It seems clear that either the upper part of the marine San Pedro did not contain base-exchange media as deposited, or that the exchange capacity of any such media has been exhausted by passage of calcium bicarbonate water in large aggregate volume. The second of these conditions is believed the more likely; thus, after the saline connate water had been expelled, calcium bicarbonate water circulated with relative freedom and ultimately converted all the exchange media to calcium-base. This last conclusion is substantiated by certain chemical reactions that are taking place locally as native calcium bicarbonate waters have become contaminated by strongly saline waters. These reactions are discussed at some length (Piper, Garrett, and others, 1953, p. 87).

These deductions from the chemical composition of waters now native to the principal fresh-water body lead to further conclusions regarding the probable vertical range of the cemented zones along the axis of the Newport-Inglewood zone. These conclusions are developed under the next topic, which summarizes the barrier features of that structural zone.

BARRIER EFFECT OF THE NEWPORT-INGLEWOOD STRUCTURAL ZONE

GENERAL FEATURES

One fundamental objective of this cooperative investigation in the Long Beach-Santa Ana area is to evaluate the effectiveness of the Newport-Inglewood structural zone as a barrier opposing encroachment of ocean water into the principal fresh-water body farther inland. That body is the source of the very large ground-water withdrawals that sustain fully 75 percent of the water requirement for all uses in the area, except within the city of Los Angeles. Salt-water encroachment has taken place locally on the coastal side of the Newport-Inglewood zone, and more extensive encroachment would very seriously threaten the integrity of the inland fresh-water supply. The geologic features of the Newport-Inglewood zone that determine its barrier effect are here summarized as a physical background for other reports that develop critically the present extent and degree of salt-water encroachment (Piper, Garrett, and others, 1953) and also the effectiveness of the barrier in restraining further encroachment (Poland and others, in preparation).

In only the extreme southeastern part of the area shown on plate 3, does the Newport-Inglewood zone interpose a completely impermeable barrier between the ocean and the inland fresh-water body. Elsewhere in the area, northwestward from the central part of Newport

Mesa to and beyond Dominguez Gap, its rocks contain permeable members to a depth as great as 2,500 feet below sea level. In that reach its barrier effect is determined by the interaction of lithologic discontinuities, structural traps, and zones of cementation. The joint effectiveness of these several barrier features is not uniform along the structural zone nor at all depths below land surface. The diversity in effectiveness is best discussed according to four stratigraphic ranges, which in succession downward include the alluvial deposits of Recent age, the unnamed upper Pleistocene deposits together with the much thicker and underlying San Pedro formation, the upper division of the Pico formation, and the rocks of the connate-water zone. Barrier features in these several ranges are discussed on pages 120–126.

ALLUVIAL DEPOSITS OF RECENT AGE

Tongues of the alluvial deposits of Recent age extend to the coast through each of the several gaps across the Newport-Inglewood zone, and in these tongues there is little or no barrier to water movement at the structural zone. An upper division of these several alluvial tongues is composed largely of silt and fine sand and is only slightly permeable; the water is unconfined and semiperched above the principal fresh-water body and is naturally of inferior quality over all the area from the coast inland to the structural zone and locally beyond. Because of its low permeability, this upper division of the alluvial deposits can transmit little water and thus does not decrease the watertightness of the structural zone. A lower division of the several alluvial tongues, however, is the most critical feature in the Long Beach-Santa Ana area, because it is composed of extremely permeable materials, offers little or no impediment to movement of water across the zone, contains the topmost element of the principal fresh-water body, and currently has been invaded by salt water from the coast inland nearly to the structural zone.

This lower division of the alluvial deposits of Recent age includes the Talbert water-bearing zone in Santa Ana Gap, the Gaspur water-bearing zone in Dominguez Gap, and the so-called 80-foot gravel in the intervening Bolsa Gap. Relatively thin and limited counterparts of the division may exist in Alamitos Gap but probably do not exist in Sunset Gap. These several segments of the lower division functioned naturally as ground-water arteries conveying fresh water through the respective gaps to the coast; they can function with equal effectiveness as arteries of invasion conveying salt water across the Newport-Inglewood structural zone to the main part of the principal fresh-water body beneath Downey Plain. As arteries of invasion their potential capacity to transmit salt water is considerable. It has been shown that at the axis of the Newport-Inglewood zone their aggregate cross-sectional area is some 1,500,000 square feet or 0.05 square mile, and their aggregate transmission capacity about a million gallons a day for each foot per mile of hydraulic gradient. Of this aggregate transmission capacity about 55 percent is ascribed tentatively to the Talbert zone in Santa Ana Gap, about 30 percent to the Gaspur zone in Dominguez Gap, and the remainder to their smaller counterparts in Bolsa and Alamitos Gaps.

With respect to Santa Ana Gap, if the withdrawals from the Talbert water-bearing zone farther inland should be sustained at the current rate during a protracted future drought, or if they should increase as is altogether likely, the present body of contaminated water in that zone very probably would extend itself inland well across the Newport-Inglewood structural zone. Such extension more than about a mile beyond the present front of contamination—more than about a mile inland from Atlanta Avenue—probably would permit salt water to pass into highly productive water-bearing strata of the San Pedro formation which there dip inland, underlie the Talbert water-bearing zone, and seem to be in hydraulic continuity with that zone (see pl. 5, section *c–c′*). In all the Long Beach-Santa Ana area this constitutes the gravest menace that the main body of fresh ground water will become more extensively contaminated.

The present body of contaminated water in the Gaspur zone of Dominguez Gap is not likely to increase greatly in northward extent unless withdrawals farther inland should increase very substantially. However, any such increase beyond the present inland front of contamination which is within the gap and about three-fourths of a mile north of Del Amo Street, would enlarge the already extensive area within which contaminated water might pass downward through wells with defective casings into the underlying Silverado zone of the San Pedro formation (see pl. 4, section *B–B′*). The thick Silverado zone is the principal source from which a very large quantity of water is withdrawn for industrial and municipal use at Long Beach and to the west.

DEPOSITS OF PLEISTOCENE AGE—SAN PEDRO FORMATION

Along the axis of the Newport-Inglewood structural zone the deposits of Pleistocene age (largely the San Pedro formation) extend continuously from Dominguez Hill southeastward to the central segment of the Signal Hill uplift and beyond that segment to the central part of Newport Mesa, to depths as great as 900 feet below sea level, and contain water-bearing strata with an aggregate cross-sectional area previously estimated at about 30,000,000 square feet or 1.1 square miles. (See pl. 4, section *A–A′*.) These permeable strata are almost exclusively in the San Pedro formation. Within them movement of water across the structural zone is restrained by stratigraphic discontinuities, by structural traps, and by the zones of cementation previously described. Jointly these several barrier features are largely but probably not completely effective. Upon their effectiveness, however, depends to a considerable degree the integrity of fresh-water supplies that are withdrawn from these permeable strata in very large aggregate quantity farther inland, chiefly for public supply at Long Beach and Huntington Beach, for industrial purposes in the area between Long Beach and Wilmington, and for irrigation and other uses throughout the Long Beach-Santa Ana area.

DISCONTINUITIES IN WATER-BEARING STRATA

As brought out in the discussion of their physical character, and as indicated by the typical well records shown in table 6, both the unnamed upper Pleistocene deposits and the underlying San Pedro formation are widely diverse in physical character within the Long Beach-Santa Ana area. Except locally in the lower part of the San Pedro formation, individual water-bearing strata appear to be neither thick nor extensive, and irregularly to finger between non-water-bearing materials or grade into them. These discontinuities, which obviously impede the movement of water, are neither genetically related nor peculiar to the Newport-Inglewood structural zone; however, they very materially supplement the barrier effects of structural traps and zones of cementation.

Within the area shown on plate 3, the most striking stratigraphic discontinuity now known in the San Pedro formation is that which closes the Silverado water-bearing zone on the southeast (and southwest?). This moderately extensive water-bearing zone lies athwart the axis of the Newport-Inglewood structural zone in Los Angeles County from Dominguez Hill to Alamitos Heights and in that reach is a comparatively homogeneous mass of coarse sand and pebble gravel as much as 500 feet thick (see pls. 4, section *A–A′*, 8). However, beneath Alamitos Heights and the San Gabriel River its full stratigraphic range grades or fingers into silt and clay that are largely impermeable. Probably more than any other geologic feature of the district that discontinuity is an effective local barrier against encroachment of ocean water into the Silverado zone from which very heavy withdrawals are made currently and which have been sustained for years from the public-supply wells of the Alamitos, Citizens, and Development fields of the city of Long Beach, 3 to 4 miles inland from the coast.

To the southeast, beneath Huntington Beach Mesa, strata of permeable sand and gravel compose much of the San Pedro formation and doubtless in part extend across the Newport-Inglewood zone. (See pl. 4, section *A–A′*.) To either side, however, beneath Bolsa Gap and Santa Ana Gap, these strata appear largely to grade or feather out into silt and clay. Stratigraphic discontinuities here would tend to canalize any movement of water across the structural zone.

STRUCTURAL TRAPS

The San Pedro formation commonly is displaced from a few feet to several hundred feet at the master faults, which appear to be en echelon along the general axis of the Newport-Inglewood zone almost continuously from the eastern flank of Dominguez Hill southeastward into Santa Ana Gap. Structural traps doubtless impede or prevent movement of water across the faults at many places. In Los Angeles County, in the northwestern part of the area shown on plate 3, the master faults transect the Silverado zone of the San Pedro, but their displacement appears commonly to be less than the thickness of that water-bearing zone. Accordingly, movement of water through the zone is impeded but not wholly checked at the faults by partial structural traps. (See pl. 4, section *C–C′*.) On the other hand, at some places the displacement along a master fault and the vertical interval between certain water-bearing beds appear to be such that no structural trap exists; a water-bearing bed in one wall is offset against another water-bearing bed stratigraphically higher or lower in the opposing wall. Altogether, structural traps probably substantially impede but certainly do not wholly prevent the movement of water across the Newport-Inglewood zone within permeable strata of the San Pedro formation.

ZONES OF CEMENTATION

Zones of cementation such as have been observed in coarse-grained materials of the San Pedro formation on the flank of Signal Hill and in wells 5/11–18P1 and 5/11–18N1 of Sunset Gap (p. 105) would doubtless be effective ground-water dams under heads of ordinary magnitude. Although inferred to be extensive along the general axis of the Newport-Inglewood structural zone, and so possibly principal elements of the barrier, certain theoretical considerations as to origin suggest that these zones may not be extensive in the lower part of the San Pedro formation.

Four of these considerations are inferred or known:

1. The cementing materials—calcium carbonate, silica, and some iron oxide—were deposited in fracture-zone conduits that transect the San Pedro formation adjacent to the master faults of the Newport-Inglewood zone and that were opened chiefly during the mid-Pleistocene and in lesser part the late Pleistocene stage of deformation—post-San Pedro and post-Palos Verdes time, respectively—also, that they were deposited by waters of continental origin circulating to the land surface from depth in the formation.

2. The waters currently native to the upper part of the San Pedro formation contain calcium and bicarbonate as dominant dissolved constituents and on the inland side of the Newport-Inglewood zone were historically under sufficient head to escape to the land surface

through any available conduits. Presumably analogous conditions have existed ever since the saline connate water was displaced and calcium bicarbonate water had exhausted the available sodium of any base-exchange media present.

3. Water of this chemical character discharged from depth in the San Pedro formation would dissipate its pressure head as it rose to the land surface. With loss of head, carbon dioxide might be expelled and normal calcium carbonate formed; as normal carbonate is only slightly soluble in water it would be precipitated as a cementing material. Iron might be precipitated likewise.

4. Waters currently native to the lower part of the San Pedro formation contain sodium and bicarbonate as dominant constituents and presumably have been of that chemical character ever since saline connate water was expelled. Sodium bicarbonate water discharged from depth would not tend to precipitate carbonate as a cementing material within the lower part of the formation, because, even if formed, sodium carbonate is rather highly soluble in water.

These theoretical considerations imply that little or no carbonate-depositing water ascended the fracture-zone conduits from rocks below the San Pedro formation. That this is substantially true is concluded tentatively from the available fragmentary data on the chemical character of waters native to the underlying rocks, and on the pressure head of those waters.

From the foregoing discussion it follows that cementation by calcium carbonate, such as that in the zone exposed on the flank of Signal Hill and penetrated by the wells of Sunset Gap, may be peculiar to the San Pedro formation, and largely peculiar to the range of calcium bicarbonate waters in the upper part of that formation; in other words, zones of calcium carbonate cementation may be neither numerous nor extensive in the lower part of the San Pedro. This tentative deduction is critical with respect to the barrier effect of the Newport-Inglewood structural zone, because the lower part of the San Pedro contains at least two thick water-bearing zones that lie athwart the structural zone, the very productive Silverado zone of Los Angeles County, and certain water-bearing strata beneath Huntington Beach Mesa; because the Silverado zone in particular sustains the heaviest withdrawals of fresh water on the inland side of the structural zone; and because in both these thick water-bearing zones the master faults are not fully effective as structural traps. Thus in the very zones that sustain the heaviest withdrawals of fresh water in all the area shown on plate 3, it would seem that neither zones of calcium carbonate cementation nor structural traps may be highly effective as barriers, also that only very imperfect protection against invasion of ocean water may be afforded by minor discontinuities.

UPPER DIVISION OF THE PICO FORMATION

In the area shown on plate 3, the principal fresh-water body extends below the San Pedro formation to the bottom of the next underlying stratigraphic unit, the upper division of the Pico formation. Thus along the axis of the Newport-Inglewood zone from Dominguez Hill to the eastern part of Huntington Beach Mesa it extends approximately from 850 to 1,750 feet below the San Pedro, and 800 to 2,600 feet below sea level. (See pl. 4, section *A–A′*.) In this range below the San Pedro formation the native waters seem to be essentially fresh and many of the strata moderately permeable northwestward from the central part of Huntington Beach Mesa. The uppermost part of this range is penetrated by a few of the deepest water wells in the area, but so far as is known to the writers its native waters are withdrawn for use from only one well.

Movement of ocean water inland through the upper division of the Pico formation is dependent on at least two possible conditions. First, if there is no hydraulic continuity with water bodies in the overlying San Pedro formation (p. 110) the essentially fresh native water of the upper Pico is immobile regardless of the head under which it is confined; salt water cannot move inland through the upper Pico until such time as native water of that formation may be withdrawn; also salt water could not reach the San Pedro from below except through inadequately cased wells. Secondly, if the water bodies of the upper Pico are in hydraulic continuity with those of the overlying San Pedro, the initial fresh-water head of historic time was sufficiently great so that it was hydraulically impossible for water in the upper Pico to have moved inland across the Newport-Inglewood zone. However, with the fresh-water head currently dissipated in large part, ocean-water drive may be tending to force native upper Pico waters into the overlying San Pedro and so into the areas of influence of water wells now in existence. In theory such displacement of upper Pico waters ultimately would bring ocean water to existing well fields, but in practice the volume necessary to be displaced is so great that salt-water invasion in this way seems very remote.

These two conditions are mutually opposed, but the first seems the more likely. Under either condition any barrier features in the upper division of the Pico formation at the Newport-Inglewood structural zone would further assure the integrity of inland fresh-water supplies. Presumably such features would be analogous to those of the overlying San Pedro formation, with structural traps of greater effectiveness but with zones of cementation that probably are less effective. Whether the over-all barrier effect in the upper Pico is large or small, salt-water encroachment beyond the Newport-Inglewood zone probably is much more remote by movement through the upper Pico than through the overlying San Pedro, unless large sustained withdrawal from the upper Pico should come to pass.

ROCKS OF THE CONNATE-WATER ZONE

The rocks beneath the upper Pico—the middle and lower divisions of the Pico formation, the Repetto formation, and underlying rocks—are largely impermeable to water, and those members which are permeable contain only saline connate waters. Below their crest in the core of the Newport-Inglewood structural zone these rocks of Pliocene and greater age constitute a virtually impermeable barrier to the inland movement of water from the ocean. Because that crest, however, ranges between 800 and 2,600 feet below sea level along the 20-mile reach from Dominguez Hill into Santa Ana Gap (pl. 4, section *A–A′*), these rocks offer virtually no barrier to water movement between the ocean and the fresh-water-bearing zones that are tapped by wells on Downey Plain. In the extreme southeastern part of the area shown on plate 3 these rocks extend above sea level in the southern part of Newport Mesa; only there do they constitute a wholly impermeable barrier between the ocean and the inland fresh-water-bodies.

SELECTED RECORDS OF WELLS

The general physical character of materials in the full stratigraphic range penetrated by water wells in the area shown on plate 3 is indicated by the selected records of wells given in tables 4, 5, and 6.

Table 4 includes records of 28 of the 64 shallow observation wells bored by the Geological Survey in alluvial deposits of Recent age in the five gaps through the coastal hills and mesas. Table 5 includes the records of 6 deep observation wells drilled on the coastal side of master faults in the Newport-Inglewood structural zone for the Geological Survey and the four cooperating local agencies. Table 6 covers 44 representative wells from among the many hundreds for which drillers' logs were made available to the Geological Survey by cooperating and collaborating agencies or which were collected during the investigation.

TABLE 4.—*Materials penetrated by typical shallow observation wells in the coastal zone of the Long Beach-Santa Ana area*

[Wells bored by the Geological Survey in alluvial deposits of Recent age in the five gaps through the coastal hills and mesas. Materials classified through field inspection by R. C. Newcomb and others. Altitude based on sea-level datum of 1941]

DOMINGUEZ GAP

4/13-2K1. Del Amo Estate Co. About 0.25 mile west of Los Angeles River and 2,640 feet north of Del Amo Street. Altitude 43.8 feet.

Material	Thickness (feet)	Depth (feet)
Flood-plain deposit:		
Silt	8	8
Silty clay	2	10
Fine sand	1	11
Silt	4	15
Sand, medium to coarse	4	19
Clayey silt	3	22
Fine sand and silt	2.5	24.5

4/13-10F1. Dominguez Estate Co. About 1½ miles west of Los Angeles River and 26 feet south of Dominguez Street. Altitude 28.1 feet.

Flood-plain deposit:		
Silt	1.5	1.5
Fine sand and silt	5.5	7
Fine sand, silt, and brown peat	1	8
Silt and clay	4	12
Sand and silt, loose	6	18

4/13-11D2. Los Angeles County. About 1 mile west of Los Angeles River and 25 feet south of Del Amo Street. Altitude 33.8 feet.

Flood-plain deposit:		
Silt	1	1
Silty sand, brown	10.5	11.5
Fine sand, gray	5.5	17
Sandy clay, brown	13	30
Fine silty sand	1.5	31.5

4/13-11L3. Los Angeles County. About 0.6 mile west of Los Angeles River and 12 feet west of Santa Fe Avenue. Altitude 33.5 feet.

Flood-plain deposit:		
Silty sand	3	3
Silt and clay	2	5
Peat and silty clay	2.5	7.5
Silty sand	1	8.5
Silt and clay	2.5	11
Medium sand, light-brown	4	15
Silty sand, gray	6	21
Silt and clay	1	22
Coarse sand	6.5	28.5

4/13-14F3. Los Angeles County. About 0.6 mile west of Los Angeles River and 1,000 feet north of 223d Street. Altitude 23.5 feet.

Flood-plain deposit:		
Silt	5	5
Silt and clay, brown	5	10
Fine sand, brown and gray	8	18
Coarse sand, gray	4	22

TABLE 4.—*Materials penetrated by typical shallow observation wells in the coastal zone of the Long Beach-Santa Ana area*—Continued

DOMINGUEZ GAP—Continued

4/13–14K6. City of Long Beach. About 0.1 mile west of Los Angeles River and 1.3 miles north of Willow Street. Altitude 28.9 feet.

Material	Thickness (feet)	Depth (feet)
Flood-plain deposit:		
Silt	4	4
Medium sand, gray	9	13
Silt and clay	2	15
Silty sand	1	16
Coarse sand	4.5	20.5

4/13–23F2. City of Long Beach. About 0.5 mile west of Los Angeles River and 50 feet north of Spring Street. Altitude 22.3 feet.

Flood-plain deposit:		
Silty sand	10	10
Peat, black, and silty clay	.5	10.5
Sand and silt	1.5	12
Silt and clay	9	21
Silty sand	1	22
Silt and clay	2.5	24.5

4/13–26P6. City of Long Beach. About 0.5 mile west of Los Angeles River and 160 feet north of State Street. Altitude 12.3 feet.

Flood-plain deposit:		
Silty sand, brown	8	8
Silty sand, gray	1	9
Silty clay, gray, plastic	4	13
Fine sand, silty	3	16
Silty clay, plastic	.5	16.5

ALAMITOS GAP

5/12–1D1. I. W. Hellman Ranch. About 0.2 mile east of San Gabriel River and 42 feet south of Garden Grove Boulevard. Altitude 9.5 feet.

Flood-plain deposit:		
Silt, gray, dry	4	4
Clay, plastic, with thin sandy streaks and calcareous concretions	10	14
Silty sand	1	15
Clay, plastic	4	19

5/12–2K1. Bryant Ranch. About 0.3 mile west of San Gabriel River and 0.6 mile south of East Seventh Street. Altitude 4.3 feet.

Flood-plain and lagoonal deposits:		
Soil, silty	1	1
Clay, black, peaty	3.5	4.5
Silty clay, light-brown, micaceous	2.5	7
Clay, blue, with peat	2	9
Silt, blue	1	10
Peat, silty, brown	4	14
Clay, sticky, blue	1	15
Fine sand, silt, micaceous, blue	2.5	17.5

TABLE 4.—*Materials penetrated by typical shallow observation wells in the coastal zone of the Long Beach-Santa Ana area*—Continued

ALAMITOS GAP—Continued

5/12–10H1. City of Long Beach. About 0.5 mile northwest of San Gabriel River and 0.4 mile southeast of U. S. Highway 101. Altitude 5.8 feet.

Material	Thickness (feet)	Depth (feet)
Flood-plain and lagoonal deposits:		
Silt, blue	1	1
Sand	2	3
Clay and silt, blue	2	5
Peat, black, and clay	.5	5.5
Silt, sandy, blue; shell fragments numerous at 8 feet	6	11.5

5/12–10P1. City of Long Beach. About 350 feet southwest of Alamitos Bay and 0.4 mile northwest of San Gabriel River. Altitude 4.7 feet.

Material	Thickness (feet)	Depth (feet)
Shoreline deposit:		
Artificial fill	0.5	0.5
Medium sand, yellow and gray, shells abundant below 4 feet	5.5	6
Sand	3	9

5/12–11D1. Fred H. Bixby Co. About 0.4 mile northwest of San Gabriel River and 800 feet northeast of U. S. Highway 101. Altitude 2.7 feet.

Material	Thickness (feet)	Depth (feet)
Flood-plain and lagoonal deposits:		
Road fill	0.5	0.5
Sandy silt, gray-brown	4.5	5
Clay, brown, with concretions	.5	5.5
Sandy silt, tough, blue, with streaks of sand	6.5	12

SUNSET GAP

5/11–7G1. I. W. Hellman Ranch. About 2 miles northeast of Seal Beach and 0.5 mile north of Bolsa Avenue. Altitude 7.0 feet.

Material	Thickness (feet)	Depth (feet)
Flood-plain deposit:		
Soil, silty	4	4
Clay, semiplastic, dark-gray	1	5
Sandy clay, light-brown	.5	5.5
Silty sand	1.5	7
Clay, silty, dark, with some peat	11	18
Medium sand, gray	4	22

5/11–18B1. State of California. About 2 miles east of Seal Beach and 30 feet south of Bolsa Avenue. Altitude 5.3 feet.

Material	Thickness (feet)	Depth (feet)
Flood-plain and lagoonal deposits:		
Soil, silty, brown	1	1
Silty clay, dark-brown	2	3
Sandy silt, brown, with calcareous concretions	1	4
Fine sand, micaceous, brown	2	6
Clayey silt, with peat layers	3	9
Fine sand, micaceous, gray	1	10
Clay, sticky, gray, with sand and peat layers	5	15
Sandy silt, brown	6.5	21.5
Medium sand, brown	2	23.5

TABLE 4.—*Materials penetrated by typical shallow observation wells in the coastal zone of the Long Beach-Santa Ana area*—Continued

SUNSET GAP—Continued

5/11–18G2. Alamitos Land Co. About 2 miles east of Seal Beach and 0.5 mile south of Bolsa Avenue. Altitude 3.1 feet.

Material	Thickness (feet)	Depth (feet)
Flood-plain and lagoonal deposits:		
Silt, sandy	2	2
Clay, sticky, gray	5	7
Peat, black, with some clay	3	10
Clay, sticky, gray	1.5	11.5
Fine sand, silt, gray	1.5	13
Medium-coarse sand, with shell fragments	7.5	20.5

5/11–18P3. Alamitos Land Co. About 2 miles east of Seal Beach and 0.9 mile south of Bolsa Avenue; 400 feet southeast of Hog Island. Altitude 4.3 feet.

Flood-plain and lagoonal deposits:		
Artificial fill	1	1
Silty clay, dark-gray, with vegetable remains	12	13
Sandy silt, brown	2	15
Silt, clayey, yellow, with calcareous concretions	4	19
Medium sand, with streaks of clay	4	23

5/12–24H1. Alamitos Land Co. About 2 miles southeast of Seal Beach and 63 feet north of U. S. Highway 101. Altitude 10.1 feet.

Shoreline deposit:		
Medium to fine sand, yellow, wind-blown	9	9
Sand, bluish-gray	6	15

BOLSA GAP

5/11–26N3. Orange County. About 3 miles north of Huntington Beach and 23 feet east of Golden West Avenue. Altitude 3.8 feet.

Flood-plain and lagoonal deposits:		
Peat, black	8	8
Clay and sand, brownish-gray	2	10

5/11–27B2. Orange County. About 4 miles north of Huntington Beach and 0.5 mile west of Golden West Avenue. Altitude 5.2 feet.

Lagoonal and flood-plain deposits:		
Artificial fill	4	4
Silt, clayey, yellow	2	6
Peat	1	7
Sandy silt	2	9
Peat, black	1	10
Silty sand, with peat layers	2	12
Clay, sticky	2	14
Silty sand	1	15
Clay, sticky	5	20
Silt, with streaks of clay	4.5	24.5

5/11–28J2. Orange County. About 3.5 miles northwest of Huntington Beach and 0.25 mile south of Slater Avenue. Altitude 2.8 feet.

Flood-plain and lagoonal deposits:		
Silt	4	4
Fine sand, gray	1	5
Clay, silty, yellowish-gray	2	7
Silty sand, blue, shells abundant	7	14

TABLE 4.—*Materials penetrated by typical shallow observation wells in the coastal zone of the Long Beach-Santa Ana area*—Continued

BOLSA GAP—Continued

5/11–33M1. Bolsa Land Co. About 3 miles northwest of Huntington Beach and 1,200 feet northeast of U. S. Highway 101. Altitude 1.1 feet.

Material	Thickness (feet)	Depth (feet)
Lagoonal and flood-plain deposits:		
Medium sand, brown	3	3
Medium to fine sand, silty, dark-blue, with shells abundant	8.5	11.5

5/11–33N1. Bolsa Land Co. About 3 miles northwest of Huntington Beach and 100 feet northeast of U. S. Highway 101. Altitude 3.4 feet.

Shore-line and lagoonal deposits:		
Medium and fine sand, yellow, wind-blown	3	3
Silty sand and peat	1	4
Medium sand, silty, dark-gray, with shells abundant	2	6
Medium and fine sand, dark-gray	6	12

SANTA ANA GAP

6/10–7L4. Orange County. About 0.85 mile west of Santa Ana River and 0.5 mile north of Atlanta Avenue. Altitude 8.4 feet.

Flood-plain deposit:		
Silt	5	5
Silty clay	1	6
Clay, gray, plastic	6	12
Very fine sand, blue	6	18

6/10–18C5. Orange County. About 0.7 mile west of Santa Ana River and 18 feet south of Atlanta Avenue. Altitude 7.8 feet.

Flood-plain and lagoonal deposits:		
Silt	4	4
Clay, silty, plastic, with peat layers at 6.5 feet	5	9
Sand, silty, gray	5	14
Sand, gray, with shells abundant	2	16

6/10–18L1. Orange County. About 0.6 mile west of Santa Ana River and 10 feet south of Hamilton Street, projected. Altitude 7.2 feet.

Flood-plain and lagoonal deposits:		
Sand and silt, gray	4	4
Clay, plastic	4	8
Fine sand, silty, gray	1.5	9.5
Clay, plastic	1	10.5
Sandy silt, blue, with shells abundant	2.5	13
Sand with shells	2	15

6/10–19C1. Orange County. About 0.5 mile west of Santa Ana River and 0.6 mile northeast of the Pacific Ocean. Altitude 6.0 feet.

Lagoonal and flood-plain deposits:		
Silt	2.5	2.5
Clay, plastic	3.5	6
Sandy silt, light-gray, with shells	5	11
Fine sand, silty, dark-gray, with shells abundant	4	15

TABLE 4.—*Materials penetrated by typical shallow observation wells in the coastal zone of the Long Beach-Santa Ana area*—Continued

SANTA ANA GAP—Continued

6/10-19L1. Orange County. About 0.45 mile west of Santa Ana River and 0.15 mile northeast of the Pacific Ocean. Altitude 6.9 feet.

Material	Thickness (feet)	Depth (feet)
Shoreline and lagoonal deposits:		
Fine to medium sand, pebbly, with shells	2	2
Silt, yellowish-gray	.6	2.6
Medium to fine sand	8.6	11.2

TABLE 5.—*Records of six deep observation wells on the coastal side of the Newport-Inglewood structural zone*

[Wells drilled for the Geological Survey and four local agencies in connection with this cooperative investigation. Materials classified through field inspection by J. F. Poland and R. C. Newcomb. Altitude based on sea-level datum of 1941. Stratigraphic correlations by J. F. Poland are tentative]

5/11-18N1. Alamitos Land Co. About 2 miles southeast of Seal Beach, 5,350 feet south of Bolsa Avenue, 9,700 feet west of Bolsa Chica Road, about 700 feet southwest of Hog Island, and 168 feet southwest of 5/11-18P1. Altitude 4.8 feet. Hard-red steel casing, 6-inch diameter to 70 feet; taper reducer, 4-inch diameter 70 to 250 feet; all joints welded; perforated 179-209 and 229-249 feet. Bell, 8-inch diameter, welded on casing and landed at 157 feet. Shallow water shut off by cementing casing above bell, then placing Aquagel-thickened mud from cement to land surface.

Material	Thickness (feet)	Depth (feet)
Coastal deposit: Clay, blue and brown, silty, with shells	30	30
Deposits of upper Pleistocene age, undivided: Clay, brown, with calcareous concretions and iron-stained quartz pebbles	18	48
San Pedro formation:		
Coarse gravel, tight; pebbles up to ¾-inch diameter	14	62
Sand and fine gravel, tight; coarser below 65 feet	14	76
Clay, gray, silty and tough, with shells; sandy from 92 to 99 feet; pebbly below 105 feet	37	113
Coarse gravel and tight sand, carrying shells	12	125
Clay, silty to sandy, gray and brown, with shells and with scattered pebbles at 132 feet	18	143
Clay, gray, sandy, tough, with sandy streaks	17	160
Sand and shells, cemented, with some gray and brown sandy clay	9	169
Clay, gray	3	172
Medium to fine sand, tight, with some clay and shells	4	176
Medium to coarse gravel, with sand and shells, loose; clay streak 181 to 183 feet	20	196
Sand, coarse, brown; and gravel, fine to medium	16	212
Clay, gray, silty, tough	9	221
Gravel, medium to fine, and sand, with some gray sandy clay	10	231
Sand and gravel	20	251
Clay, brown and gray, with some streaks of gravel imbedded	37	288
Clay, gray and brown, tough, with shells and with 2-foot gravelly streak at bottom	11	299
Clay, gray and brown, silty, with gravel streaks below 306 feet and shells below 338 feet	73	372
Clay, dark-gray, silty, tough	8	380

TABLE 5.—*Records of six deep observation wells on the coastal side of the Newport-Inglewood structural zone*—Continued

5/11-18P1. Alamitos Land Co. About 2 miles southeast of Seal Beacl, 5,200 feet south of Bolsa Avenue, and 9,600 feet west of Bolsa Chica Road. Altitude, 4.8 feet. Hard-red steel casing, 6-inch diameter, to 125 feet; all joints welded; perforated 109-124 feet. Deeper water shut off by cementing hole from 150 to 135 feet; rubber packer placed on casing and landed at 80 feet. Surface water shut off by placing Aquagel-thickened mud from packer to land surface.

Material	Thickness (feet)	Depth (feet)
Coastal deposit:		
Clay, gray	10	10
Fine sand, clayey, with silt and abundant shells	18	28
Clay, blue and brown, with shells	5	33
Deposits of upper Pleistocene age, undivided: Clay, soft brown; limey concretionary streaks near top, more sandy downward	15	48
San Pedro formation:		
Medium gravel and sand, with some clay	18	66
Clay, sandy	2	68
Medium gravel and sand	6	74
Clay, blue, silty	16	90
Sand, gray, soft	8	98
Clay, blue and gray, sandy	12	110
Medium to coarse sand with shells, pebbles abundant in upper 4 feet and at bottom	37	147
Gravel	1	148
Medium sand, gray, with shells	19	167
Sand and fine gravel, loose	7	174
Sand and gravel with shells	30	204
Clay, gray silty, with fine gray sand	21	225
Coarse gravel and sand	11	236
Conglomerate, very hard (cemented pebbly gravel)	4	240

5/11-29E1. United States of America (formerly Bolsa Land Co.). About 1 mile southeast of Sunset Beach, 58.5 feet south and 2,000 feet east of the center-line intersection of U. S. Highway 101 and Los Patos Avenue; in pasture. Altitude 7.6 feet. Hard-red steel casing, 6-inch diameter to 60 feet; taper reducer, 4-inch diameter 60 to 220 feet; all joints welded; perforated 169-219 feet. Bell, 8-inch diameter, welded on casing and landed at 135 feet. Shallow water shut off by cementing casing above bell, then placing Aquagel-thickened mud from cement to land surface.

Deposits of late Pleistocene age, undivided:		
Soil, reddish clay	7	7
Sand with some pebbly gravel	2	9
Clay, brown and sandy	16	25
San Pedro formation:		
Sand, brown, coarse and pebbly	9	34
Clay, brown	3	37
Gravel, fine to medium; some sand	6	43
Clay, sandy, brown with blue streaks	32	75
Sand, clayey; coarser downward	11	86
Gravel, medium, and sand carrying shells	5	91
Clay	3	94
Sand and gravel, fine to medium, with shells	34	128
Clay, gray and brown	30	158
Sand and gravel, medium to coarse, loose; shells in lowest 15 feet	49	207
Sand, gravel, and clay	5	212
Clay, gray, silty; thin streaks of peat in upper part; scattered pebbles at 224 feet	12	224
Clay and imbedded pebbles; shells common	12	236
Sand and gravel, loose	5	241
Clay, gray, silty; some sand and gravel	39	280
Gravel, sand, and clay	10	290
Clay, gray, silty, with sand and a little gravel; some shells	40	330
Clay, gray, silty; shells to 370 feet; sticky, 370 to 380 feet	75	405
Clay, gray, with scattered pebbles	5	410

TABLE 5.—*Records of six deep observation wells on the coastal side of the Newport-Inglewood structural zone*—Continued

5/11–29E2. United States of America (formerly Bolsa Land Co.). About 1 mile southeast of Sunset Beach, 58.5 feet south and 2,050 feet east of the center-line intersection of U. S. Highway 101 and Los Patos Avenue, and 50 feet east of well 29E1; in pasture. Altitude 6.6 feet. Hard-red steel casing, 6-inch diameter, to 120 feet; all joints welded; perforated 100 to 120 feet. Rubber packer placed on casing and landed at 79 feet. Surface water shut off by placing Aquagel-thickened mud from packer to land surface.

Material	Thickness (feet)	Depth (feet)
Deposits of late Pleistocene age, undivided:		
Soil, reddish clay loam	5	5
Clay, brown, with a little included coarse sand and fine to medium gravel	10	15
Clay, brown and sandy	6	21
Sand, medium-grained; some sandy brown clay	4	25
San Pedro formation:		
Sand, medium and coarse-grained, with some fine gravel	5	30
Gravel, fine; lower part clayey	8	38
Clay, sandy, brown and gray; some fine gravel; sandy 75–85 feet	47	85
Sand, medium and coarse, with a little fine gravel	44	129
Clay (struck by drill but not penetrated)		

5/12–13D1. United States of America (formerly I. W. Hellman Ranch). In the city of Seal Beach, 55 feet south and 110 feet east of the center-line intersection of Bolsa and Westminster Avenues; in cultivated field. Altitude 24.6 feet. Hard-red steel casing, 6-inch diameter to 60 feet, taper reducer, 4-inch diameter to 210 feet; all joints welded; perforated 190 to 210 feet. Rubber packer placed on casing and landed at 155 feet. Shallow water shut off by cementing casing above packer, then placing Aquagel-thickened mud from cement to land surface.

Deposits of late Pleistocene age, undivided:		
Soil and subsoil, loam	5	5
Sand, yellowish, coarse- and medium-grained	6	11
Sand, fine	7	18
San Pedro formation:		
Sand, medium- and coarse-grained	20	38
Sand, medium- and fine-grained	18	56
Sand, clayey, moderately firm	6	62
Sand, coarse; clayey streaks at 75–77 feet and 94–102 feet	45	107
Sand, coarse, with some fine gravel and shell fragments	16	123
Sand, coarse, and fine gravel	27	150
Clay, gray silty, infrequent shells	10	160
Gravel, fine	5	165
Silt, grayish, infrequent shells	18	183
Gravel, fine, with coarse sand	42	225
Sand, mixed fine, medium- and coarse-grained	21	246
Gravel, fine, and coarse sand	12	258
Silty clay, gray, abundant shells	77	335
Clay with sand and gravel in thin ill-defined layers	25	360
Clay, small shells	8	368
Clay with thin gravel and sand partings, shells	10	378
Cobbles cemented or imbedded in clay	3	381

5/12–13D2. United States of America (formerly I. W. Hellman Ranch). In the city of Seal Beach, 55 feet south and 160 feet east of the center-line intersection of Bolsa and Westminster Avenues, 50 feet east of well 5/12–13D1; in cultivated field. Altitude 25.6 feet. Hard-red steel casing, 6-inch diameter to 60 feet; taper reducer, 4-inch diameter to 140 feet; all joints welded; perforated 130 to 140 feet. Rubber packer placed on casing and landed at 82 feet. Surface water shut off by placing Aquagel-thickened mud from packer to land surface.

Deposits of late Pleistocene age, undivided:		
Soil, loam	4	4
Sand, fine to coarse, reddish-brown, loose	36	40
San Pedro formation:		
Coarse sand and fine gravel with some thin clay interbeds, loose	12	52
Clay	4	56
Clay and silt with thin interbeds of sand and fine gravel, yellowish	69	125
Gravel, fine- and medium-grained, with some coarse sand	25	150
Gravel, sand, and clay; probably finely interbedded	8	158
Clay	2	160

TABLE 6.—*Materials penetrated by typical water-supply wells in the coastal zone of the Long Beach-Santa Ana area*

[Data based on drillers records except as indicated. Stratigraphic correlations by J. F. Poland are tentative]

3/13-32F6. Edward Cost. On west edge of Dominguez Hill. Altitude 43 feet. Casing perforated 560 to 580, 605 to 612, and 640 to 652 feet. Yield not known.

Material	Thickness (feet)	Depth (feet)
Terrace cover and Palos Verdes(?) sand:		
Soil	4	4
Clay, hard	8	12
Sand	8	20
Sand, with few scattered marine shells	10	30
Unnamed upper Pleistocene deposits:		
Clay, yellow	95	125
Sandy clay, blue	39	164
Sand, yellow	8	172
Unclassified:		
Clay, tough, blue	66	238
San Pedro formation:		
Sand, fine, gray; with marine shells abundant	24	262
Sand, firm	63	325
Fine sand with medium gravel	5	330
Quicksand	42	372
Medium gravel	2	374
Fine sand, firm	51	425
Sandy clay, tough and firm	57	482
Fine sand with some gravel	13	495
Clay with streaks of sandstone	5	500
Clay, tough, blue	30	530
Silverado water-bearing zone:		
Fine sand	10	540
Sand, sharp, and medium gravel	20	560
Coarse gravel, 1- to 4-inch size	20	580
Sand, sharp, with some gravel	25	605
Sandstone and cemented gravel	7	612
Fine sand	13	625
Coarse gravel, 1- to 3-inch size	27	652
Fine sand	8	660
Clay, tough, blue	2	662

4/11-28J1. Bryant Ranch. On Downey Plain about 2.5 miles east of Los Alamitos. Altitude 36 feet. Casing perforated 435 to 460 and 500 to 530 feet. Initial head in April 1913 reported 18.5 feet above land surface. Well flowed about 830 gallons a minute and yielded 1,350 gallons a minute when pumped.

Material	Thickness (feet)	Depth (feet)
Alluvial deposits:		
Soil	5	5
Sand	2	7
Clay	76	83
Gravel	8	91
Unnamed upper Pleistocene deposits: Clay	319	410
San Pedro formation:		
Sand	25	435
Fine gravel	25	460
Sand	10	470
Clay	25	495
Coarse gravel	35	530
Clay	30	560
Sand	40	600
Clay	170	770
Sand	15	785
Coarse sand, water-bearing	10	795
Clay	165	960
Fine sand	7	967
Clay and sand	18	985
Clay	16	1,001

TABLE 6.—*Materials penetrated by typical water-supply wells in the coastal zone of the Long Beach-Santa Ana area*—Continued

4/12-5G1. Frank Burke. On Downey Plain about 4 miles north of Signal Hill. Altitude 51 feet.

Material	Thickness (feet)	Depth (feet)
Alluvial deposits:		
Soil	3	3
Sand	3	6
Clay	39	45
Unclassified: Gravel	15	60
Unnamed upper Pleistocene deposits:		
Clay	10	70
Sand	13	83
Clay	24	107
Sand	5	112
Unclassified: Clay	410	522
San Pedro formation:		
Sand	23	545
Clay	20	565
Sand, black	5	570
Clay	115	685
Sand	75	760
Clay	375	1,135
Fine gravel	5	1,140
Sand	30	1,170
Coarse sand	5	1,175
Gravel	4	1,179
Coarse sand	6	1,185
Fine gravel	5	1,190
Unclassified: Clay	55	1,245

4/12-6K1. City of Long Beach, North Long Beach well 4. In North Long Beach about 1.5 miles east of Los Angeles River. Altitude 47 feet. Casing perforated 972-1,142 feet. Yield 1,720 gallons a minute with drawdown of 31 feet.

Material	Thickness (feet)	Depth (feet)
Alluvial deposits:		
Soil and silt	6	6
Soil, sticky, black	3	9
Deposits of upper Pleistocene age, undivided:		
Clay, sticky, blue, with cemented streaks	7	16
Sandy clay, yellow	29	45
Clay, hard, blue	20	65
Clay, yellow	37	102
Clay, blue	28	130
Fine sand and gravel, blue	16	146
Sand and coarse gravel	10	156
Clay, yellow	24	180
Unclassified:		
Fine sand and clay, compact, blue	46	226
Fine sand, blue, loose	26	252
Clay, blue, with gravel and shells	10	262
Fine sand and clay, compact, blue	13	275
Clay, blue, very hard	30	305
San Pedro formation:		
Silverado water-bearing zone:		
Fine sand and some fine gravel, blue	49	354
Fine sand with clay and some shells, compact, blue	46	400
Sand and fine gravel, blue	44	444
Sand and gravel, coarse, blue	40	484
Clay, blue	11	495
Clay, hard, blue	29	524
Sand and coarse gravel, blue	166	690
Sand and gravel, loose, blue	50	740
Fine sand, blue	36	776
Basal deposits containing Timms Point and Lomita fauna: [1]		
Sandy clay with shells, blue	19	795
Clay, hard, blue	61	856
Shale, blue	6	862
Clay, hard, blue	23	885
Fine sand, compact, blue	63	948
Sand and gravel, blue	6	954
Clay, blue	6	960
Fine sand, loose, blue	10	970
Very coarse gravel with streaks of sand and sandstone	60	1,030
Sand and gravel, blue	16	1,046
Sand, blue, very coarse gravel	54	1,100
Sandy clay, compact	4	1,104
Sand, blue, very coarse gravel	44	1,148
Pico formation, upper division(?): Sandy clay, compact, blue	12	1,160

[1] Microfaunal determinations by M. L. Natland.

TABLE 6.—*Materials penetrated by typical water-supply wells in the coastal zone of the Long Beach-Santa Ana area*—Continued

4/12–8P1. Montana Land Co. (Bouton well 1). About 2.5 miles north of Signal Hill. Altitude 69 feet. Casing perforated 674–714 feet. Well drilled about 1895 by J. B. Proctor. Initial head reported about 80 feet above land surface. A. C. Hansen visited well in July 1903 and reported initial flow 8.5 inches over top of the 14-inch casing, which suggests initial flow of about 3,000 gallons a minute.

Material	Thickness (feet)	Depth (feet)
Deposits of upper Pleistocene age, undivided: Clay	120	120
Unclassified:		
Sand	110	230
Clay	6	236
San Pedro formation:		
Coarse sand	54	290
Clay	20	310
Sand	8	318
Clay and sand	12	330
Clay	12	342
Silverado water-bearing zone:		
Fine gravel, water-bearing	57	399
Clay	7	406
Gravel	4	410
Clay	8	418
Coarse gravel, very little sand	32	450
Fine sand	100	550
Sand and shells, cemented	70	620
Fine sand	50	670
Clay	4	674
Clay and gravel	24	698
Gravel	16	714

4/12–14D1. City of Long Beach, Commission well 1. About 3.5 miles northeast of Signal Hill. Altitude 45 feet. Record chiefly from description of samples by J. C. Kimble, California Division of Water Resources. Casing perforated 1,361–1,378, 1,402–1,410, 1,430–1,478, and 1,560–1,655 feet. Yield 1,590 gallons a minute with drawdown of 57 feet.

Alluvial deposits:		
Soil, sandy	26	26
Clay, blue	10	36
Sand and gravel, compact, yellow	16	52
Clay, yellow	40	92
Deposits of upper Pleistocene age, undivided:		
Silt, gray	28	120
Fine to medium sand, gray, arkosic	8	128
Fine sand, compact, blue	14	142
Silt, gray; much organic material, chiefly decomposed wood	18	160
Fine sand, silty, calcareous; and clay, blue, very hard	55	215
Unclassified:		
Gravel, clean and well sorted	7	222
Coarse sand and fine gravel, poorly sorted and compact, with streaks of clay	48	270
Coarse sand and gravel, yellow	36	306
Silt, very hard, gray	40	346
Fine to coarse sand and shells, arkosic	24	370
Sandy clay and arkosic sand, blue	66	436
Silty clay, sticky, dark blue	10	446
Clay and arkosic sand, hard, yellow	29	475
San Pedro formation:		
Fine to coarse sand, blue, arkosic, subangular, loose	71	546
Sandy silt and fine sand, gray, fossiliferous	44	590
Coarse sand with some gravel, arkosic, subangular, loose	30	620
Sandy silt, gray	10	630
Sandy silt, gray, fossiliferous	20	650
Silt, gray	45	695
Sandy silt, whitish-gray	8	703
Silt, gray	147	850
Sandy silt, whitish-gray	8	858
Clay, blue	12	870
Fine sand and silt, gray	50	920
Clay, hard, blue	35	955
Coarse sand and fine gravel, subangular and fossiliferous	25	980
Fine to coarse sand, poorly sorted, subangular, micaceous, arkosic, fossiliferous	54	1,034
Coarse sand and gravel, yellow	36	1,070
Silty clay, gray	25	1,095
Sand and fine gravel, gray	15	1,110

TABLE 6.—*Materials penetrated by typical water-supply wells in the coastal zone of the Long Beach-Santa Ana area*—Continued

Material	Thickness (feet)	Depth (feet)
San Pedro formation—Continued		
Coarse sand and gravel, subangular, arkosic, fossiliferous	38	1,148
Fine gravel and sand, fossiliferous	20	1,168
Fine sand, blue	10	1,178
Fine sand, compact, blue, fossiliferous	72	1,250
Clay, hard, blue	50	1,300
Silt and clay, soft, blue	20	1,320
Sandy clay, blue	39	1,359
Clay, hard, black	2	1,361
Basal deposits containing Timms Point and Lomita faunas: [1]		
Fine sand and gravel	4	1,365
Coarse sand and gravel, blue	5	1,370
Gravel	8	1,378
Silty clay, gray, fossiliferous	24	1,402
Fine gravel, fossiliferous	8	1,410
Siltstone, gray, fossiliferous	20	1,430
Coarse gravel and sand	34	1,464
Fine gravel	14	1,478
Sand and fine gravel, blue	26	1,504
Fine sand	24	1,528
Medium gravel and sand	20	1,548
Silty clay, gray	12	1,560
Coarse gravel and sand, loose with well-rounded cobbles	108	1,668

[1] Microfaunal determinations by M. L. Natland.

4/12–14P1. City of Long Beach, Wilson Ranch well 1. About 3.5 miles northeast of Signal Hill and about 1 mile southeast of well 4/12–14D1. Altitude 27 feet. Casing perforated 1,024–1,232 and 1,260–1,354 feet. Yield 1,850 gallons a minute with drawdown of 22 feet.

Alluvial deposits:		
Sandy clay, yellow	3	3
Sandy clay, blue	10	13
Clay, brown	7	20
Sandy clay, blue	10	30
Deposits of upper Pleistocene age, undivided:		
Gravel, yellow, cemented	28	58
Clay, sticky, blue, with streaks of gravel	12	70
Clay, sticky, yellow	14	84
Sandy clay, yellow and blue	16	100
Fine sand, compact, blue	10	110
Clay, brown, very hard	10	120
Clay, sticky, yellow	10	130
Sand, very hard, yellow	20	150
Clay, sticky, blue	12	162
Unclassified:		
Fine sand, with streaks of clay, blue	18	180
Fine sand, very hard, blue	30	210
Clay, hard, blue, with some gravel	10	220
Clay, hard, black	5	225
Clay, very hard, blue, with cemented gravel	20	245
Sandy clay, yellow	4	249
Clay, very sticky, yellow and blue	16	265
Fine sand and clay, blue	10	275
Sandy clay, blue	7	282
San Pedro formation:		
Silverado water-bearing zone:		
Fine sand and shells, blue	30	312
Sand and gravel, blue; with shells, wood fragments, and tar	15	327
Fine sand, blue	25	352
Sand and gravel; with shells, fragments of wood, and tar	16	368
Fine sand, compact, yellow	32	400
Fine sand, compact, blue	30	430
Sand, very hard	30	460
Sand, compact, blue	10	470
Fine sand, gray, with shells and fragments of wood, loose	10	480
Gravel, sand, and shells; good water-bearing material	4	484
Fine sand, with shells, blue	26	510
Fine sand, compact, yellow	40	550
Fine sand and clay, very hard, blue	31	581
Clay, with calcareous concretions	1.5	582.5
Fine sand, compact, blue	47.5	630
Clay, sticky, blue, with some sand	46	676
Fine sand, very compact, gray	44	720
Fine sand and shells, compact, blue	20	740
Sand and gravel, with shells and tar	90	830
Fine sand, blue	70	900
Sand, very compact, blue, with some clay and shells	95	995

TABLE 6.—*Materials penetrated by typical water-supply wells in the coastal zone of the Long Beach-Santa Ana area*—Continued

Material	Thickness (feet)	Depth (feet)
San Pedro formation—Continued		
Basal deposits containing Timms Point and Lomita faunas: [1]		
Sand, hard, dry, blue	29	1,024
Coarse gravel	18	1,042
Sandy clay, blue	14	1,056
Sand and gravel	10	1,066
Gravel, cemented	22	1,088
Fine sand, blue	112	1,200
Gravel, good water-bearing material	16	1,216
Fine sand, with streaks of clay, blue	44	1,260
Fine sand, blue, loose	40	1,300
Gravel, good water-bearing material	16	1,316
Fine sand and clay, with some gravel, blue	22	1,338
Gravel, good water-bearing material	16	1,354
Unclassified (may be Pico formation, upper division):		
Fine sand and clay, compact, blue	250	1,604
Fine sand and clay, compact, with a few shells	33	1,637
Fine sand, blue, loose	1	1,638
Fine sand and clay, compact, with a few shells	68	1,706

[1] Microfaunal determinations by M. L. Natland.

4/12–20C1. City of Long Beach, Development well 3. About 1.2 miles north of Signal Hill. Altitude 50 feet. Casing perforated 153–190, 286–300, 315–330, and 390–602 feet. Yield 3,650 gallons a minute with drawdown of 27 feet.

Deposits of upper Pleistocene age, undivided:		
Soil, black adobe	2	2
Clay and marl	138	140
Unclassified:		
Clay, with shells	13	153
Coarse sand	37	190
Clay, black, with streaks of sand	96	286
San Pedro formation:		
Silverado water-bearing zone:		
Coarse sand and gravel	14	300
Clay	15	315
Medium gravel	15	330
Coarse sand and gravel, cemented	60	390
Fine gravel, cemented and loose in streaks	100	490
Sand and gravel, cemented	50	540
Clay	2	542
Sand and some gravel	60	602
Sand, cemented	7	609
Sand, black, and streaks of clay	41	650
Basal deposits?: Clay, hard, blue	102	752

4/12–21M4. City of Long Beach, Citizens well 6. About 1.1 miles northeast of Signal Hill. Altitude 33 feet. Casing perforated 467–514, 560–600, 755–765, and 785–792 feet. Yield 1,140 gallons a minute with drawdown of 37 feet.

Deposits of upper Pleistocene age, undivided:		
Soil	8	8
Fine sand	4	12
Clay	23	35
Sand	5	40
Clay, hard	50	90
Clay, soft	24	114
Clay, hard	56	170
Clay, soft	7	177
San Pedro formation:		
Sand and shells	18	195
Clay, hard	17	212
Silverado water-bearing zone:		
Sand	49	261
Clay, hard	27	288
Sand and shells	11	299
Clay, hard	19	318
Clay, soft	8	326
Fine sand	55	381
Clay	26	407
Sand, cemented	13	420
Fine gravel	21	441

TABLE 6.—*Materials penetrated by typical water-supply wells in the coastal zone of the Long Beach-Santa Ana area*—Continued

Material	Thickness (feet)	Depth (feet)
San Pedro formation—Continued		
Silverado water-bearing zone—Continued		
Sand, cemented	18	459
Sand	8	467
Medium gravel	47	514
Fine gravel	56	570
Medium gravel	30	600
Fine sand	44	644
Fine sand, cemented	16	660
Basal deposits:		
Clay, blue	95	755
Coarse gravel	10	765
Fine sand	20	785
Fine gravel	7	792
Fine sand	16	808
Sandy clay	12	820
Sea mud	20	840
Sand and shells	20	860
Clay, soft	20	880
Clay, hard	20	900
Pico formation, upper division (?):		
Shale, black	50	950
Clay, blue	20	970
Sand and shale	27	997
Clay, blue	108	1,105
Shale, brown	30	1,135
Conglomerate	2	1,137
Sandy shale, hard	8	1,145
Clay, blue	32	1,177
Clay, hard, blue	126	1,303
Shale, hard, brown	27	1,330
Fine sand, gray	8	1,338
Clay, soft	27	1,365
Shale, brown	5	1,370
Clay, soft	8	1,378
Clay, sandy	44	1,422

4/12–24M2. City of Long Beach, Wise Ranch well 1. About 1.5 miles west of Los Alamitos and 0.3 mile west of San Gabriel River. Altitude 22 feet. Record from description of samples by J. C. Kimble, California Division of Water Resources. Casing perforated 330–410, 570–600, 632–654, 874–938, and 953–980 feet. Yield 1,370 gallons a minute with drawdown of 16 feet.

Alluvial deposits:		
Soil	2	2
Sandy clay, yellow	10	12
Sandy clay, blue	16	28
Clay, hard, brown	12	40
Fine sand, yellow	10	50
Coarse gravel and sand, yellow	10	60
Deposits of upper Pleistocene age, undivided:		
Clay and silt, grayish-blue	12	72
Sandy silt and sand, gray	28	100
Clay, blue and brown, with shells	10	110
Clayey silt, dark-blue, sticky, with streaks of sand	35	145
Sandy clay, blue and brown	12	157
Clay, sticky, yellow	13	170
Unclassified:		
Sand, very hard, blue	11	181
Fine silty sand and clay, blue and gray, few shell fragments	27	208
Silty clay, hard, bluish-gray, fossiliferous	27	235
Fine sand, compact, blue	6	241
Silt with streaks of clay, bluish-gray	29	270
San Pedro formation:		
Silverado water-bearing zone:		
Fine sand, blue	30	300
Fine silty sand, blue	30	330
Medium gravel and coarse sand; subrounded, loose; contains wood fragments	36	366
Fine sand, blue, and shells	22	388
Medium gravel and coarse sand, with shell fragments, loose	12	400
Medium to fine sand, arkosic, very fossiliferous	38	438

TABLE 6.—*Materials penetrated by typical water-supply wells in the coastal zone of the Long Beach-Santa Ana area*—Continued

Material	Thickness (feet)	Depth (feet)
San Pedro formation—Continued		
Silverado water-bearing zone—Continued		
Sandy clay, gray, fossiliferous	2	440
Conglomerate, gray	10	450
Medium to fine sand with clay, arkosic, fossiliferous	20	470
Fine sand, yellow	29	499
Medium to fine sand, arkosic, fossiliferous	17	516
Sand, compact, very fine, blue	54	570
Coarse sand and fine gravel, loose, fossiliferous	18	588
Coarse gravel, arkosic, fossiliferous	4	592
Fine sand, yellow and blue	40	632
Fine sand and clayey silt, fossiliferous	22	654
Sand, silt, and sticky clay	18	672
Fine clayey sand and hard blue clay	68	740
Clay, sticky and sandy in streaks, blue	12	752
Fine sand, compact, gray	50	802
Fine sand, blue clay, and shells	72	874
Coarse sand with some gravel; arkosic, micaceous, slightly fossiliferous	26	900
Medium to coarse gravel	14	914
Fine sand, gray, loose	18	932
Fine sand, gray, with some gravel and shells	6	938
Clay, sticky and hard, blue	15	953
Gravel with some sand; subangular, arkosic, contains some shells	27	980
Basal deposits:		
Fine sand, silt, with thin, hard streaks	61	1,041
Sand, hard, blue, with some clay and shells	39	1,080
Clay, hard, blue	6	1,086

4/12–27K2. Bryant Ranch. About 2 miles east of Signal Hill. Altitude 17 feet. Casing perforated 500–570, 695–735, and 745–815 feet. When completed in January 1915, initial head reported 33.5 feet above land surface; flow reported 3,470 gallons a minute.

Alluvial deposits:		
Sandy clay	25	25
Clay	35	60
Deposits of upper Pleistocene age, undivided:		
Sand	15	75
Fine gravel and shells	20	95
Sand	25	120
Clay	40	160
San Pedro formation:		
Silverado water-bearing zone:		
Sand	55	215
Clay	15	230
Fine gravel, water-bearing	11	241
Clay	5	246
Coarse sand	14	260
Sand	105	365
Clay	15	380
Sand	15	395
Gravel	25	420
Clay	30	450
Sand	45	495
Medium gravel	63	558
Coarse gravel	16	574
Clay	8	582
Sandy clay	28	610
Sand	62	672
Coarse gravel	12	684
Coarse sand	11	695
Medium gravel	20	715
Sand	15	730
Coarse sand	70	800
Sand and shells	15	815
Fine sand	7	822
Basal deposits: Clay	13	835

TABLE 6.—*Materials penetrated by typical water-supply wells in the coastal zone of the Long Beach-Santa Ana area*—Continued

4/12–28H1. City of Long Beach, Alamitos well 9. About 1.5 miles east of Signal Hill. Altitude 23 feet. Casing perforated 768–774, 804–936, and 1,086–1,148 feet. Yield 2,190 gallons a minute with drawdown of 38 feet.

Material	Thickness (feet)	Depth (feet)
Alluvial deposits: Soil	6	6
Deposits of upper Pleistocene age, undivided:		
Clay, yellow	46	52
Clay, dark	38	90
Peat	20	110
San Pedro formation: Sandy clay, dark	26	136
Silverado water-bearing zone:		
Fine sand	10	146
Sand and fine gravel	30	176
Sandy clay, dark	10	186
Sand and fine gravel	20	206
Sand and shells, with clay	12	218
Fine sand, brown	13	231
Sandy clay, dark	9	240
Fine sand, dark	53	293
Sandy clay, dark	23	316
Fine sand and shells	12	328
Sand and clay, dark	30	358
Fine sand, gravel, and shells	12	370
Coarse sand	24	394
Sand, fine gravel, and shells	12	406
Sand and clay, dark	26	432
Sand and fine gravel, loose	28	460
Fine sand, with some clay	10	470
Clay, compact, dark	20	490
Fine sand and clay	9	499
Fine sand, blue	9	508
Sand, fine gravel, and shells	24	532
Sand and gravel, gray	120	652
Fine sand, gray	45	697
Basal deposits containing Timms Point and Lomita faunas: [1]		
Silt and sandy clay, blue	12	709
Clay, blue	47	756
Fine sand with shells, blue	12	768
Sand and gravel	6	774
Sand and clay, blue	30	804
Fine sand and coarse gravel	8	812
Sand and fine gravel	30	842
Sand and coarse gravel	20	862
Sand and very fine gravel	6	868
Sandy clay, blue	30	898
Sand and gravel, medium to fine	12	910
Sand and very fine gravel	10	920
Sand and gravel	16	936
Sandy clay, blue	150	1,086
Coarse sand	10	1,096
Sand and gravel	18	1,114
Sand and fine gravel	16	1,130
Sandy clay, soft	8	1,138
Sand and coarse gravel	10	1,148
Pico formation, upper division(?): Shale, hard, gray	4	1,152

[1] Microfaunal determinations by M. L. Natland and S. G. Wissler.

4/13–2P1. Del Amo Estate Co. In Dominguez Gap, northwest of Long Beach. Altitude 37 feet. Casing perforated 90–117 feet. Yield 360 gallons a minute with drawdown of 11 feet.

Alluvial deposits:		
Sand	21	21
Clay	8	29
Sand	54	83
Gaspur water-bearing zone:		
Fine gravel	7	90
Gravel	27	117
Unclassified: Clay	1	118

TABLE 6.—*Materials penetrated by typical water-supply wells in the coastal zone of the Long Beach-Santa Ana area*—Continued

4/13-11L2. Dominguez Estate Co. In Dominguez Gap, northwest of Long Beach. Altitude 34 feet. Casing perforated 89-115 feet. Yield not known.

Material	Thickness (feet)	Depth (feet)
Alluvial deposits:		
Soil	3	3
Sand	28	31
Clay	19	50
Gaspur water-bearing zone:		
Sand	27	77
Fine gravel	3	80
Fine sand	9	89
Coarse gravel	26	115
Unnamed upper Pleistocene(?) deposits: Clay	29	144

4/13-15A6. Dominguez Water Corp. In Dominguez Gap. Altitude 28 feet. Casing perforated 780-800, 830-1,000, and 1,040-1,050 feet.

Alluvial deposits:		
Soil	10	10
Sand	8	18
Clay	19	37
Sand	64	101
Clay	2	103
Gaspur water-bearing zone: Gravel	42	145
Unnamed upper Pleistocene(?) deposits:		
Clay	15	160
Sand, dead	4	164
Clay	153	317
San Pedro formation:		
Sand	6	323
Clay	38	361
Sand	30	391
Clay	116	507
Sand	5	512
Fine gravel	3	515
Sand	15	530
Sand, packed	90	620
Clay	86	706
Sand	3	709
Clay	16	725
Sand	17	742
Clay	33	775
Silverado water-bearing zone:		
Gravel	20	795
Fine gravel	65	860
Gravel	120	980
Fine gravel	20	1,000
Sand	40	1,040
Fine gravel	10	1,050
Sand	65	1,115
Fine gravel	6	1,121
Sand	105	1,226

4/13-17D1. Dominguez Water Corp. On Torrance Plain north of Wilmington. Altitude 26 feet. Casing not perforated.

Deposits of upper Pleistocene age, undivided:		
Soil	11	11
Sand	4	15
Clay	128	143
San Pedro formation:		
Sand	55	198
Sand, packed	22	220
Sand	42	262
Gravel	3	265
Sand	45	310
Sand, dead	70	380
Clay	124	504

TABLE 6.—*Materials penetrated by typical water-supply wells in the coastal zone of the Long Beach-Santa Ana area*—Continued

Material	Thickness (feet)	Depth (feet)
San Pedro formation—Continued		
Silverado water-bearing zone:		
Gravel	7	511
Clay	10	521
Gravel	27	548
Fine gravel	15	563
Sand	17	580
Gravel	35	615
Sand	15	630
Gravel	38	668
Sand	15	683
Pico formation, upper division:		
Clay	365	1,048
Sand, dead	16	1,064
Clay	31	1,095
Sand	36	1,131
Clay	108	1,239
Sand	27	1,266
Clay	97	1,363
Sand	17	1,380
Clay	18	1,398
Sand	50	1,448
Clay	7	1,455
Sand	31	1,486
Clay	19	1,505
Sand	35	1,540
Clay	7	1,547
Sand	26	1,573
Clay	37	1,610
Sand	18	1,628
Clay	4	1,632
Sand, packed	26	1,658
Clay	43	1,701

4/13-23G2. City of Long Beach, Silverado well. In Dominguez Gap. Altitude 25 feet. Drillers record, with modifications based on description of samples by J. C. Kimble, of California Division of Water Resources, and by W. W. Paulsen, of Geological Survey. Casing perforated 650-900 feet. Well not used.

Material	Thickness (feet)	Depth (feet)
Alluvial deposits:		
Soil and sand	20	20
Clay	45	65
Sand	3	68
Clay	10	78
Gaspur water-bearing zone: Gravel	44	122
Unnamed upper Pleistocene(?) deposits:		
Clay, yellow	20	142
Clay	96	238
Gravel and coarse sand, loose	42	280
San Pedro formation:		
Silty clay, gray	50	330
Fine sand	60	390
Clay, hard, blue	10	400
Fine gravel, dirty	6	406
Clay	4	410
Fine sand	22	432
Sandy clay	34	466
Clay	96	562
Sand with some gravel	14	576
Clay	20	596
Silverado water-bearing zone:		
Gravel, clean and loose, with few streaks of coarse sand	124	720
Gravel, muddy	10	730
Gravel, clean and loose	170	900
Sand, coarse, gray	50	950
Fine gravel	8	958
Coarse sand	40	998
Fine gravel and sand	34	1,032
Coarse sand, unweathered, loose, well-rounded, and arkosic	34	1,066
Sand, cemented	8	1,074

TABLE 6.—*Materials penetrated by typical water-supply wells in the coastal zone of the Long Beach-Santa Ana area*—Continued

4/13–27M3. The Texas Co., well 5. On Torrance Plain, northeast of Wilmington. Altitude 34 feet. Casing perforated 226–256 and 420–800 feet. Yield on test 4,800 gallons a minute; drawdown not known.

Material	Thickness (feet)	Depth (feet)
Terrace cover and Palos Verdes sand:		
Soil	2	2
Clay, brown	8	10
Sand and shells	16	26
Unnamed upper Pleistocene deposits:		
Clay, yellow	18	44
Clay, blue	28	72
Fine sand, blue	16	88
Clay, blue	2	90
Unclassified: Fine sand, blue	50	140
San Pedro formation:		
Sand, blue, hard-packed, with shells	60	200
Clay, blue	10	210
Fine sand with some gravel, blue	16	226
Gravel	30	256
Clay, blue	10	266
Sand, shells, and clay, blue	124	390
Silverado water-bearing zone:		
Sand and shells, blue	30	420
Gravel	130	550
Gravel, cemented	10	560
Coarse gravel	240	800
Pico formation, upper division: Sand and clay, hard-packed, blue	146	946

4/13–31E4. City of Los Angeles, Lomita plant, well 4. In Wilmington, on north bank of Bixby Slough. Altitude 21 feet. Casing perforated 440–560 and 605–655 feet. Yield on test 4,000 gallons a minute with drawdown of 10.3 feet.

Deposits of Pleistocene age, undivided:		
Soil	11	11
Sand	33	44
Sand and clay, blue	6	50
Sand	53	103
Sand and hard clay, blue	82	185
San Pedro formation:		
Silverado water-bearing zone:		
Coarse sand	23	208
Gravel	7	215
Sand and gravel	9	224
Clay and sand	6	230
Sand, gravel, and shells	18	248
Coarse sand	42	290
Coarse sand and shells	30	320
Gravel, small	20	340
Coarse sand	84	424
Gravel, small	136	560
Sand	12	572
Sand and small gravel	33	605
Gravel	50	655
Sand	25	680

4/13–33D1. City of Los Angeles, Wilmington plant, well 14. In Wilmington. Altitude 34 feet. Record chiefly from description of samples by J. C. Kimble, of California Division of Water Resources. Casing perforated 720–800 feet. Yield on test 2,500 gallons a minute with drawdown of 19 feet.

Deposits of Pleistocene age, undivided:		
Soil	12	12
Fine sand, yellow and micaceous, containing shell fragments	40	52
Clay, olive drab	2	54
Medium sand, gray, granitic	55	109
Silt, blue, micaceous	19	128
Medium sand, gray	10	138
Fine sand and gravel	6	144
Clay, blue, hard	9	153
Sea mud	108	261

TABLE 6.—*Materials penetrated by typical water-supply wells in the coastal zone of the Long Beach-Santa Ana area*—Continued

Material	Thickness (feet)	Depth (feet)
San Pedro formation:		
Silverado water-bearing zone:		
Sand, blue	5	266
Sand and gravel, gray, granitic	9	275
Clay and sand	4	279
Cap rock	1	280
Sand and gravel, gray	11	291
Fine to coarse sand, gray, granitic	114	405
Sand and gravel, gray, fossiliferous; pebbles up to 1 inch in diameter	11	416
Clay and sand	17	433
Silt, gray	39	472
Clay, sand, and shells	18	490
Sea mud	18	508
Medium sand, gray, granitic	73	581
Marl, hard, gray	1	582
Fine medium sand, gray, granitic	17	599
Sea mud and sand	25	624
Fine sand, gray, granitic	5	629
Sea mud and sand	6	635
Silt, blue-gray (sea mud)	34	669
Medium sand, gray, granitic	38	707
Sand with some gravel, gray, granitic	53	760
Sand and gravel with shell fragments	29	789
Medium sand, gray, granitic	11	800
Pico formation, upper division:		
Medium sand with some micaceous silt, gray, fossiliferous	52	852
Fine sand, gray	63	915
Silt, greenish-gray, with hard calcareous streaks	5	920
Fine sand, gray, granitic	45	965

4/13–35M3. Southern California Edison Co., Ltd. In Dominguez Gap, east of Wilmington. Altitude 10 feet. Casing perforated 115–139 feet. Yield not known.

Alluvial deposits:		
Soil and sand	12	12
Silt and fine sand	55	67
Gaspur water-bearing zone:		
Fine sand	38	105
Fine sand and fine gravel	14	119
Coarse gravel with some fine sand	18	137
San Pedro(?) formation: Silt, blue	64	201

5/10–19H1. Huntington Beach Co. On Downey Plain northeast of Huntington Beach. Altitude 38 feet. Casing perforated 50 feet between 75–144 feet, also 274–276 and 277–281 feet. Yield on test 1,465 gallons a minute with drawdown of 16 feet.

Alluvial deposits:		
Not reported	16	16
Sand	9	25
Clay	2	27
Sand, blue	8	35
Clay	16	51
Sand	6	57
Clay	8	65
Talbert water-bearing zone:		
Sand	10	75
Sand and gravel	69	144
Unnamed upper Pleistocene(?) deposits:		
Clay	3	147
Sand	11	158
Clay	7	165
Sand	10	175
Clay	5	180
Sand	11	191
Clay	13	204
Sand, hard	9	213
Quicksand	21	234

TABLE 6.—*Materials penetrated by typical water-supply wells in the coastal zone of the Long Beach-Santa Ana area*—Continued

Material	Thickness (feet)	Depth (feet)
Unnamed upper Pleistocene(?) deposits—Continued		
Cement rock	1	235
Sand and sea shells	23	258
Clay	16	274
Sand	2	276
Clay	1	277
Gravel	4	281
Clay	2	283
Sand	13	296
Clay	4	300

5/10–30Q1. Edward Muller. In Santa Ana Gap near Talbert. Altitude 26 feet. Casing perforated 104–138 feet. Yield not known.

Alluvial deposits:		
Soil	8	8
Clay, soft	17	25
Peat	4	29
Clay	16	45
Sand	15	60
Clay, blue	5	65
Talbert water-bearing zone:		
Sand	39	104
Gravel	34	138
Unclassified: Clay	2	140

5/10–31R3. Mrs. Acres. In Santa Ana Gap south of Talbert. Altitude 14 feet. Casing perforated 70–90 feet. Yield not known.

Alluvial deposits:		
Sand	1	1
Peat, brown (top 30 feet reported very loose)	50	51
Clay	19	70
Talbert water-bearing zone:		
Coarse sand and gravel	20	90

5/10–33D1. Agricultural Laboratories. Near Santa Ana River east of Talbert. Altitude 35 feet. Casing perforated 506–529 feet. Reported yield 800 gallons a minute; drawdown not known.

Alluvial deposits:		
Sand	2	2
Clay, sandy	28	30
Fine sand	4	34
Unnamed upper Pleistocene(?) deposits:		
Clay, blue, sticky	78	112
Sand and gravel	8	120
Clay, blue, sticky	81	201
Fine sand and pea gravel	15	216
Clay, blue	37	253
Fine sand, brown	19	272
Clay, blue, sticky	25	297
Fine sand and sea shells	12	309
Clay, yellow	43	352
Fine sand	7	359
Clay, yellow	38	397
San Pedro formation:		
Sandstone, hard	43	440
Fine sand	12	452
Coarse sand and little gravel	42	494
Clay, blue	8	502
Sand and gravel, good water-bearing material	23	525
Clay, blue	43	568

TABLE 6.—*Materials penetrated by typical water-supply wells in the coastal zone of the Long Beach-Santa Ana area*—Continued

5/10-34H2. Charles Griset. On north edge of Newport Mesa. Altitude 33 feet. Perforations and yield not known.

Material	Thickness (feet)	Depth (feet)
Alluvial deposits:		
Soil	6	6
Clay	42	48
Unnamed upper Pleistocene(?) deposits:		
Gravel	10	58
Clay	68	126
Sand, clayey	4	130
Clay	16	146
Sand	4	150
Clay	262	412
San Pedro formation:		
Sand	18	430
Clay	20	450
Sand	60	510
Clay	30	540
Fine sand	8	548
Clay and sand	4	552
Fine sand	8	560
Clay	40	600
Sand, blue	20	620
Sand, hard	10	630
Clay	40	670
Fine sand	40	710
Clay	36	746
Gravel	8	754
Clay	2	756
Fine sand	2	758
Clay	2	760

5/11-6A1. I. W. Hellman Ranch. About 3 miles northeast of Seal Beach. Altitude 17 feet. Casing perforated 818-841 and 925-975 feet. Yield not known.

Alluvial deposits: Clay	72	72
Unclassified: Sand	43	115
Unnamed upper Pleistocene deposits:		
Clay	60	175
Gravel	4	179
Sand	48	227
Clay	54	281
San Pedro formation:		
Gravel	3	284
Sand	15	299
Clay	23	322
Sand	31	353
Fine gravel	16	369
Sand	32	401
Clay	44	445
Sea mud	30	475
Gravel	6	481
Fine sand	104	585
Clay, hard, yellow	26	611
Sand and clay, yellow	14	625
Sand, yellow	16	641
Sandstone, cemented	3	644
Clay	59	703
Sand	12	715
Clay	34	749
Sand	7	756
Clay	7	763
Sand and gravel	18	781
Sand and clay	34	815
Gravel	26	841
Sand	84	925
Gravel	50	975
Sea mud	55	1,030

TABLE 6.—*Materials penetrated by typical water-supply wells in the coastal zone of the Long Beach-Santa Ana area*—Continued

5/11-11M1. H. O. Smith. About 1 mile southwest of Westminster. Altitude 32 feet. Casing perforated 358-363, 371-395, 754-765, 768-787, and 789-795 feet. Yield about 600 gallons a minute; drawdown not known.

Material	Thickness (feet)	Depth (feet)
Alluvial deposits:		
Sand	20	20
Clay	41	61
Sand	21	82
Clay	15	97
80-foot gravel: Gravel	16	113
Unnamed upper Plesitocene(?) deposits:		
Clay	127	240
Sand, dead	20	260
Clay	30	290
San Pedro formation:		
Sand	17	307
Clay	16	323
Gravel	15	338
Clay	12	350
Sand	8	358
Gravel	5	363
Clay	8	371
Gravel	24	395
Clay	9	404
Coarse sand	2	406
Clay	14	420
Sand and clay	30	450
Clay	110	560
Sand	11	571
Clay	7	578
Coarse sand	2	580
Clay	26	606
Coarse sand	4	610
Clay	10	620
Sand	10	630
Clay	50	680
Sand, black	4	684
Clay	6	690
Sand and shells	7	697
Clay	15	712
Sand	7	719
Clay	35	754
Fine gravel and clay	11	765
Clay	3	768
Gravel	19	787
Clay	2	789
Gravel	6	795
Clay	20	815

5/11-18R1. Lomita Land and Water Co. About 3 miles east of Seal Beach. Altitude 4 feet. Casing perforated 700-830 feet. Well flowing 640 gallons a minute on April 27, 1942; static level 9.7 feet above land surface.

Alluvial deposits:		
Soil	9	9
Sand	5	14
Unnamed upper Pleistocene(?) deposits:		
Clay	27	41
Sand	15	56
Clay	48	104
San Pedro formation:		
Sand and shells	22	126
Clay	32	158
Sand	14	172
Clay	1	173
Sand	4	177
Gravel	9	186
Clay	18	204
Gravel	15	219
Clay	2	221
Gravel	3	224

TABLE 6.—*Materials penetrated by typical water-supply wells in the coastal zone of the Long Beach-Santa Ana area*—Continued

Material	Thickness (feet)	Depth (feet)
San Pedro formation—Continued		
Clay	6	230
Fine gravel	12	242
Clay	4	246
Fine sand	23	269
Clay	18	287
Sand	26	313
Clay	22	335
Sand, packed	21	356
Clay	117	473
Sand and sandstone	22	495
Clay	2	497
Sandstone	23	520
Clay	27	547
Sand, packed	6	553
Clay	124	677
Gravel	158	835
Sand	54	889
Clay	6	895

5/11-26P3. Standard Oil Co. of California. On northwest edge of Huntington Beach Mesa about 3 miles north of Huntington Beach. Altitude 25 feet. Casing perforated 488-548 feet. Reported yield 330 gallons a minute. When completed in September 1921, initial head reported 30 feet above land surface.

Material	Thickness (feet)	Depth (feet)
Deposits of Pleistocene age, undivided:		
Soil and sand	7	7
Sand	13	20
Clay	3	23
San Pedro formation:		
Sand	37	60
Coarse gravel	3	63
Fine gravel	7	70
Coarse gravel	7	77
Clay	3	80
Gravel	17	97
Coarse gravel	9	106
Coarse sand	16	122
Clay	1	123
Black sand and shells	7	130
Shale and shells	12	142
Clay, blue	30	172
Quicksand and clay	8	180
Clay	13	193
Sand	6	199
Fine gravel	6	205
Sand	14	219
Clay	17	236
Fine sand	5	241
Coarse sand	1	242
Clay	11	253
Fine gravel	6	259
Shells and clay	33	292
Fine sand	11	303
Clay	13	316
Fine sand	21	337
Sand and clay	14	351
Gravel	3	354
Clay	2	356
Sand, sea	7	363
Clay	31	394
Coarse sand	5	399
Fine sand	22	421
Coarse sand	3	424
Fine sand	6	430
Clay	9	439
Coarse sand	15	454
Fine sand	6	460
Gravel (reported still in gravel at bottom of well)	117	577

TABLE 6.—*Materials penetrated by typical water-supply wells in the coastal zone of the Long Beach-Santa Ana area*—Continued

5/11-28K1. Bolsa Land Co. Bolsa Gap, about 1½ miles from ocean. Altitude about 4 feet. Casing perforated 292–332, 391–396, 721–749, 766–782, 810–817, and 840–848 feet. Yield not known.

Material	Thickness (feet)	Depth (feet)
Alluvial deposits:		
Sand and clay	5	5
Clay	47	52
Sand	2	54
80-foot gravel	18	72
San Pedro formation:		
Clay, soft	14	86
Sand	39	125
Clay	20	145
Sand	6	151
Clay	118	269
Clay, sand, and gravel	3	272
Gravel	58	330
Clay	29	359
Sand, dead	6	365
Gravel	3	368
Clay	22	390
Gravel	4	394
Unclassified (probably chiefly San Pedro formation): Clay	316	710
Pico formation, upper division(?):		
Clay and gravel	3	713
Gravel	34	747
Clay	5	752
Sand, clay, and gravel	3	755
Clay	1	756
Sandy clay and gravel	8	764
Gravel, poor water-bearing material	14	778
Gravel, sandy, good water-bearing material	2	780
Sand	5	785
Coarse sand	3	788
Sand	18	806
Gravel	9	815
Sand	9	824
Coarse sand	3	827
Sand	9	836
Fine gravel	10	846
Sand	16	862
Gravel	1	863
Sand	3	866
Clay	20	886
Sand	4	890
Gravel	1	891
Clay	26	917

5/11-29C2. Sunset Land and Water Co. On Bolsa Chica Mesa. Altitude 47 feet. Record chiefly from description of samples by A. W. Gentry, of California Division of Water Resources. Casing perforated 460–505 and 603–614 feet. Yield not known.

Deposits of upper Pleistocene age, undivided:		
Soil	2	2
Clay, hard, red	28	30
Unclassified:		
Sand	10	40
Clay, brown	23	63
San Pedro formation:		
Sand	67	130
Sea mud, blue	10	140
Clay, blue, fossiliferous	196	336
Gravel	14	350
Sand with some gravel; few well-rounded cobbles up to 3 inches in diameter	40	390
Gravel and sand	10	400
Sand with some gravel; few rounded cobbles up to 3 inches in diameter	60	460
Gravel	45	505
Clay, blue, and some gray sand	25	530
Clay, sandy	10	540
Sand	63	603
Gravel and well-sorted gray sand	11	614
Sand	10	624
Sand and silt, compact, blue	6	630

TABLE 6.—*Materials penetrated by typical water-supply wells in the coastal zone of the Long Beach-Santa Ana area*—Continued

5/11-35P3. Holly Sugar Co., well 4. On Huntington Beach Mesa. Altitude 69 feet. Casing perforated 216-246, 328-334, and 341-358 feet. Yield not known.

Material	Thickness (feet)	Depth (feet)
Deposits of Pleistocene age, undivided:		
Soil	2	2
Hardpan (clay?)	58	60
San Pedro formation:		
Sand	23	83
Clay	4	87
Clay, gravel, and shells	23	110
Clay	77	187
Clay, gravel, and shells	24	211
Gravel	34	245
Clay	80	325
Gravel	9	334
Clay	6	340
Gravel	18	358
Sand	32	390
Clay	4	394

5/12-2B4. Bryant Ranch. In Alamitos Gap. Altitude 8 feet. Casing perforated 43-77 and 451-555 feet. Yield not known. Well drilled in 1912, abandoned before 1940.

Alluvial deposits:		
Soil	20	20
Deposits of Pleistocene age, undivided:		
Clay	7	27
Clay, hard	16	43
San Pedro formation:		
Gravel	34	77
Clay	52	129
Sand	40	169
Clay	24	193
Sand	56	249
Gravel	14	263
Sand	22	285
Clay	14	299
Sand, black	62	361
Clay	64	425
Sand, black	21	446
Clay	5	451
Gravel	24	475
Sand, water-bearing	80	555
Sand, black	86	641
Pico formation, upper division(?):		
Clay	34	675
Sand	25	700
Clay	30	730

5/12-11G1. Bryant Ranch (Associated Oil Co. lessee). In Alamitos Gap about 0.1 mile east of San Gabriel River. Altitude 5 feet. Casing probably perforated 70-92 and 187-214 feet. Yield not known.

Alluvial deposits:		
Soil (and silt(?))	54	54
Sand	16	70
Unclassified: Gravel and clay in streaks	22	92
San Pedro formation:		
Clay, blue	95	187
Sand and silt	27	214
Sea mud and sand	15	229
Clay, blue	30	259
Sand and silt, blue	95	354
Unclassified: Shale, sandy, blue (probably San Pedro formation to about 500 feet and upper division of Pico formation below 500 feet	368	722

TABLE 6.—*Materials penetrated by typical water-supply wells in the coastal zone of the Long Beach-Santa Ana area*—Continued

5/12–12P6. City of Seal Beach, well 5. On Landing Hill. Altitude 30 feet. Drillers record, with modifications based on description of samples by R. C. Newcomb, of the Geological Survey. Casing perforated 540–575, 598–604, and 626–637 feet. Yield 340 gallons a minute with 11-foot drawdown.

Material	Thickness (feet)	Depth (feet)
Deposits of Pleistocene age, undivided:		
Clay, brown	16	16
Clay, blue	21	37
Clay, sandy, blue	33	70
San Pedro formation:		
Sand, blue	54	124
Clay, blue	14	138
Clay, sandy, blue	7	145
Clay, hard, blue	12	157
Sand and gravel, with cobbles up to 3 inches in diameter	6	163
Sand and fine gravel	7	170
Clay, blue	13	183
Fine sand, blue	55	238
Clay, blue, tough, with some fine sand and shells	103	341
Coarse sand and gravel, with pebbles up to 2 inches in diameter	8	349
Fine sand with streaks of clay	23	372
Clay, blue	25	397
Clay, sandy, blue	75	472
Quicksand, blue	12	484
Sand and gravel, with pebbles up to 1 inch in diameter	8	492
Coarse sand	16	508
Coarse sand and gravel, with pebbles up to 2 inches in diameter	8	516
Coarse sand	10	526
Sand and gravel, with cobbles up to 3 inches in diameter	56	582
Coarse sand, with some gravel	16	598
Coarse sand and gravel, with cobbles up to 3 inches in diameter	4	602
Sand, with some gravel	24	626
Coarse sand and gravel, good water-bearing material	10	636
Clay, blue	34	670

6/10–1E2. Santa Ana Heights Water Co. On north edge of Newport Mesa. Altitude 35 feet. Casing perforated 720–926 feet. Yield 2,250 gallons a minute with drawdown of 21 feet.

Deposits of upper Pleistocene age, undivided:		
Soil, black	2	2
Clay, yellow	4	6
Gravel	4	10
Brown formation (silt?)	22	32
Sand	10	42
Clay, blue	8	50
Clay, brown	105	155
Cement formation (sand?)	5	160
Clay, blue	45	205
Sand, cemented	3	208
Clay, brown	17	225
Clay, blue	10	235
Unclassified: Sandy clay, blue	75	310
San Pedro formation:		
Sand	6	316
Sand, packed	8	324
Sand, packed and cemented	11	335
Sand	13	348
Clay, blue, hard	77	425
Gravel, blue	10	435
Packed sand with gravel, blue	10	445
Sand, packed very hard	5	450
Gravel and sand, hard and cemented	20	470
Clay, blue	10	480
Sand and gravel, blue, packed	25	505
Gravel, blue, cemented	3	508
Gravel and sand, cemented	6	514
Quicksand, blue, packed	26	540
Sand, packed and cemented	40	580
Coarse gravel	16	596
Fine sand and gravel	14	610
Gravel and sand	15	625
Fine sand and gravel	5	630
Coarse gravel, cemented	30	660
Coarse gravel and sand	120	780
Gravel and sand, very good water-bearing material	166	946

TABLE 6.—*Materials penetrated by typical water-supply wells in the coastal zone of the Long Beach-Santa Ana area*—Continued

6/10-8B2. C. J. Segerstrom Sons. In Santa Ana Gap east of river. Altitude 13 feet. Record from description of samples in field by R. C. Newcomb, of Geological Survey. Casing perforated 70-126, 130-155, and 168-172 feet. Yield about 1,250 gallons a minute.

Material	Thickness (feet)	Depth (feet)
Alluvial and coastal deposits:		
Fine to medium sand, buff	5	5
Sandy clay, reddish-brown	1	6
Sand	1	7
Clay, bluish-gray, plastic	23	30
Sandy silt, greenish-blue, includes peat layers up to 2 inches thick; marsh gas reported	15	45
Sandy silt, dark-bluish-gray, with abundant shells and some peat	7	52
Silty clay, blue, plastic	18	70
San Pedro(?) formation:		
Fine sand, clay, and gravel; subangular pebbles of granite and schist up to 3 inches in diameter	3	73
Gravel, medium and coarse	2	75
Medium gravel, compact	2	77
Fine gravel, loose	2	79
Sand, medium to coarse	1	80
Sand and gravel, with cobbles up to 4 inches in diameter; pebbles of dark schist abundant	5	85
Medium gravel with very little sand	7	92
Sand, coarse to medium, quartz grains predominant	4	96
Fine gravel and coarse sand, contains pebbles of greenish clay with fragments of wood	26	122
Fine to medium gravel; some clam shells	4	126
Coarse sand with some pebbles, gray	8	134
Medium sand with interbedded dark-greenish-gray silt layers up to 6 inches thick	21	155
Coarse sand, uniform, chiefly quartz grains	11	166
Medium sand, uniform	17	183
Silt, dark-greenish-gray, micaceous; fragments of wood and worm tubes	21	204
Sandy silt with shell fragments	4	208
Silt, compact, with sandy layers; abundant shell fragments and concretionary nodules	12	220
Silty sand with some pebbles; abundant shells and concretionary nodules; also thin layers of tar	4	224
Silt, compact, greenish-gray, with a few shells	1	225

6/10-8D6. City of Newport Beach, well 11. In Santa Ana Gap west of river. Altitude 12 feet. Record chiefly from description of samples in field by R. C. Newcomb, of Geological Survey. Casing perforated 82-116 feet. Yield about 1,000 gallons a minute.

Alluvial deposits:		
Soil and sand	9	9
Fine sand, brown	15	24
Clay, blue	16	40
Sandy silt, dark-gray and highly micaceous; mica estimated 20 percent by volume, largely muscovite with some biotite; occasional small greenish-colored patches on mica flakes probably representing transition to glauconite	10	50
Silt, dark-greenish-gray, moderately plastic, contains decayed vegetable matter and marine shells	16	66
Talbert water-bearing zone:		
Gravel, subangular, granitic	8	74
Coarse sand, cemented	1	75
Gravel and sand, pebbles up to 3 inches in diameter, chiefly granitic	3	78
Gravel and coarse sand, poorly sorted, cobbles up to 4 inches in maximum diameter	14	92
Coarse gravel	4	96
Fine gravel, poorly sorted, subangular pebbles of granitic, gneissic, and metamorphic rocks	2	98
Medium gravel	4	102
Gravel and sand with cobbles; some quartz pegmatite and granitic pebbles, angular	10	112
San Pedro(?) formation:		
Clayey silt, dark-greenish-brown, micaceous, some peat	8	120
Clayey silt, dark gray, tough; some brown peat streaks containing mica; some shell fragments	36	156
Sandy silt with some gravel, marine shells abundant, strong flow of marsh gas, sulfurous odor	4	160

TABLE 6.—*Materials penetrated by typical water-supply wells in the coastal zone of the Long Beach-Santa Ana area*—Continued

Material	Thickness (feet)	Depth (feet)
San Pedro(?) formation—Continued		
Silt, dark-bluish-gray and compact, with fragments of wood	30	190
Clayey silt, dark-bluish-gray, with shells	10	200
Sandy silt, dark-gray, with abundant shells	1	201
Coarse sand with pebbles; shells abundant	1	202

6/10–10D3. Irvine Co. On Newport Mesa. Altitude 65 feet. Casing perforated 725–770 and 850–1,045 feet. Brackish water produced on test. Bottom perforations cemented off at 844 feet. Yield through upper perforations reported 900 gallons a minute with drawdown of 49 feet.

Deposits of upper Pleistocene age, undivided:		
Soil, hard, black	4	4
Clay, reddish-brown	20	24
Clay, blue	4	28
Sandy clay, hard	37	65
Sandy clay, blue	37	102
Clay, blue	20	122
San Pedro formation:		
Coarse sand and gravel	158	280
Clay, blue	20	300
Coarse gravel and sand	82	382
Sandy clay, blue	8	390
Coarse gravel	50	440
Sandy clay, blue	60	500
Sand and gravel with clay	10	510
Clay, blue	46	556
Gravel and sandy clay	4	560
Gravel	20	580
Clay, blue	90	670
Gravel and blue clay	20	690
Sandy clay, blue	20	710
Gravel	54	764
Gravel and clay	22	786
Sand, packed	16	802
Sandy clay, soft	20	822
Fine sand and gravel	6	828
Sandy clay, soft	7	835
Fine gravel and sand	9	844
Coarse gravel, good water-bearing material	40	884
Coarse sand	6	890
Gravel	80	970
Sand and gravel, cemented	14	984
Gravel	41	1,025
Coarse sand, fine gravel	15	1,040
Coarse sand and gravel	13	1,053
Clay, hard, blue	7	1,060

6/10–11B2. United States of America. On Newport Mesa. Altitude 51 feet. Record from inspector, U. S. Engineer Department. Casing perforated 271–292, 298–301, and 338–372 feet. Yield 800 gallons a minute with drawdown of 21 feet.

Deposits of upper Pleistocene age, undivided:		
Clay, yellow	30	30
Sand, yellow	16	46
Clay, blue	14	60
Sandy clay, blue	10	70
Unclassified:		
Fine sand, blue	76	146
Clay, blue	24	170
Silty clay, blue	62	232
San Pedro formation:		
Sandy clay, very hard	4	236
Coarse sand and gravel, pebbles ½ inch in diameter	10	246
Fine sand and gravel, blue, pebbles ¼ inch in diameter	4	250
Coarse sand and gravel, large, pebbles ½ inch in diameter	9	259
Clay, hard, blue	12	271
Sand and gravel, large, pebbles 1 inch in diameter	31	302
Clay and gravel, blue	2	304

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TABLE 6.—*Materials penetrated by typical water-supply wells in the coastal zone of the Long Beach-Santa Ana area*—Continued

Material	Thickness (feet)	Depth (feet)
San Pedro formation—Continued		
Clay, blue	34	338
Coarse sand and gravel, large, pebbles 1 inch in diameter	22	360
Medium sand and fine gravel, blue	44	404
Fine sand, blue	126	530
Fine sand, hard and blue, with shells	11	541
Clay, blue, very hard	45	586

6/10-18C1. Laguna Beach County Water District, well 3. Santa Ana Gap. Altitude 9 feet. Casing perforated 100–136 feet. Yield 820 gallons a minute with drawdown of about 18 feet.

Alluvial deposits:		
Soil, silt, and sand	12	12
Sandy clay, hard	8	20
Clay, blue	68	88
Gravel	2	90
Sand and soft blue clay	5	95
Talbert water-bearing zone:		
Gravel	15	110
Coarse sand	5	115
Gravel, coarse, cobbles up to 5 inches in diameter	21	136
San Pedro formation:		
Clay, blue	54	190
Coarse sand and clay	1	191
Clay, blue	5	196

6/10-18J6. Newport Mesa Irrigation District. Santa Ana Gap near river. Altitude 7 feet. Casing perforated initially 194–222 and 265–314 feet; water from this zone was of inferior quality. Casing subsequently plugged from bottom to 101 feet and perforated 65–101 feet. Yield not known. Well has been abandoned.

Alluvial deposits:		
Soil and silt	20	20
Clay, blue, tough	45	65
Talbert water-bearing zone:		
Sand with some gravel	36	101
San Pedro formation:		
Clay, blue	71	172
Fine gravel	22	194
Coarse gravel	28	222
Fine gravel and sand	43	265
Coarse gravel	49	314
Fine gravel	11	325
Shale, blue	7	332

6/10-18K3. City of Newport Beach, well 5. In Santa Ana Gap. Altitude 6 feet. Casing perforated 190–260, 276–306, and 312–330 feet. Yield not known. Well abandoned after quality of water deteriorated.

Alluvial and coastal deposits:		
Soil	12	12
Shells	2	14
Clay	74	88
Talbert water-bearing zone:		
Sand	10	98
Sand and gravel	22	120
Coarse gravel	20	140
San Pedro formation:		
Clay	16	156
Coarse gravel	20	176
Clay	14	190
Coarse gravel	70	260
Clay	16	276
Coarse gravel	30	306
Clay	6	312
Coarse gravel	18	330
Clay	6	336

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INDEX

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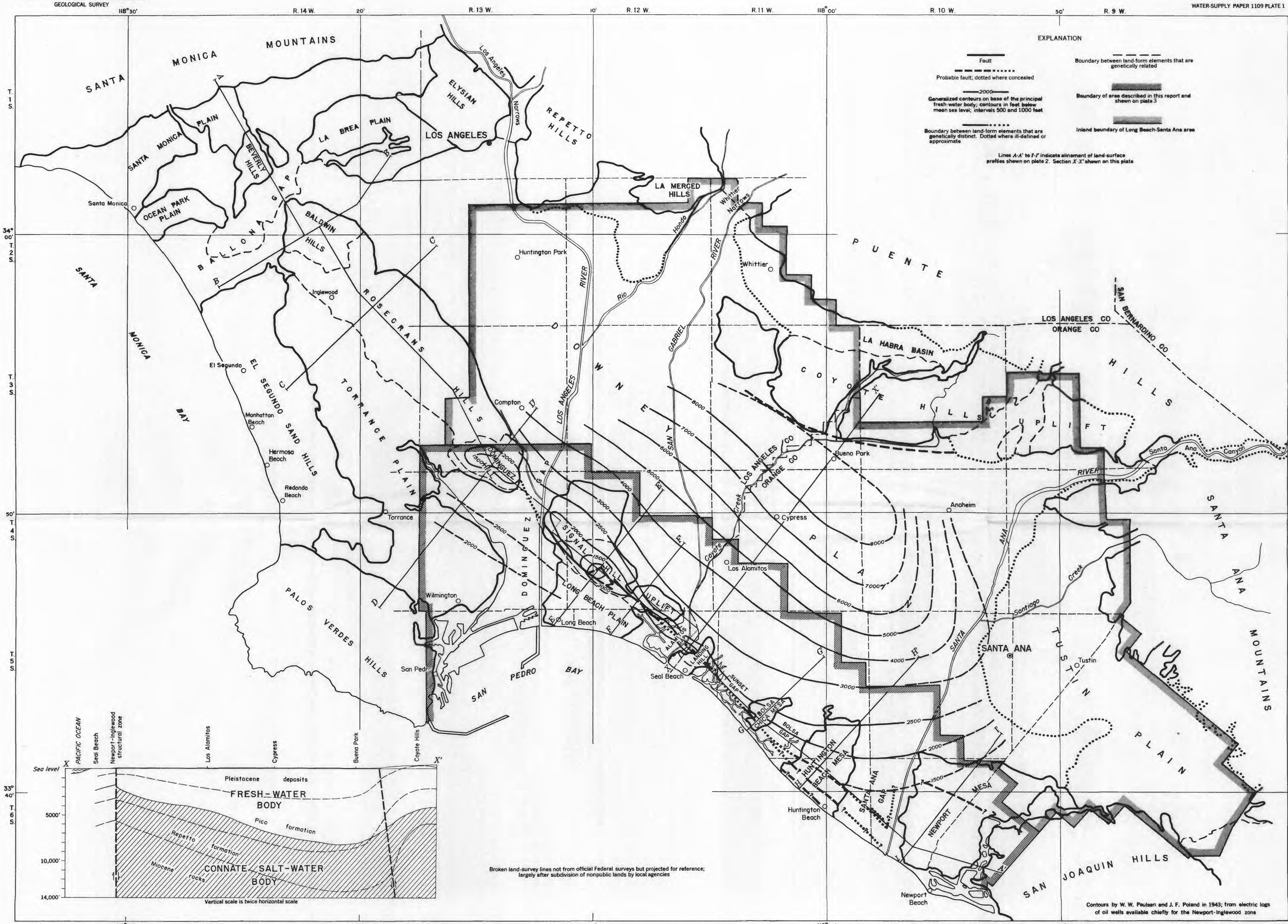
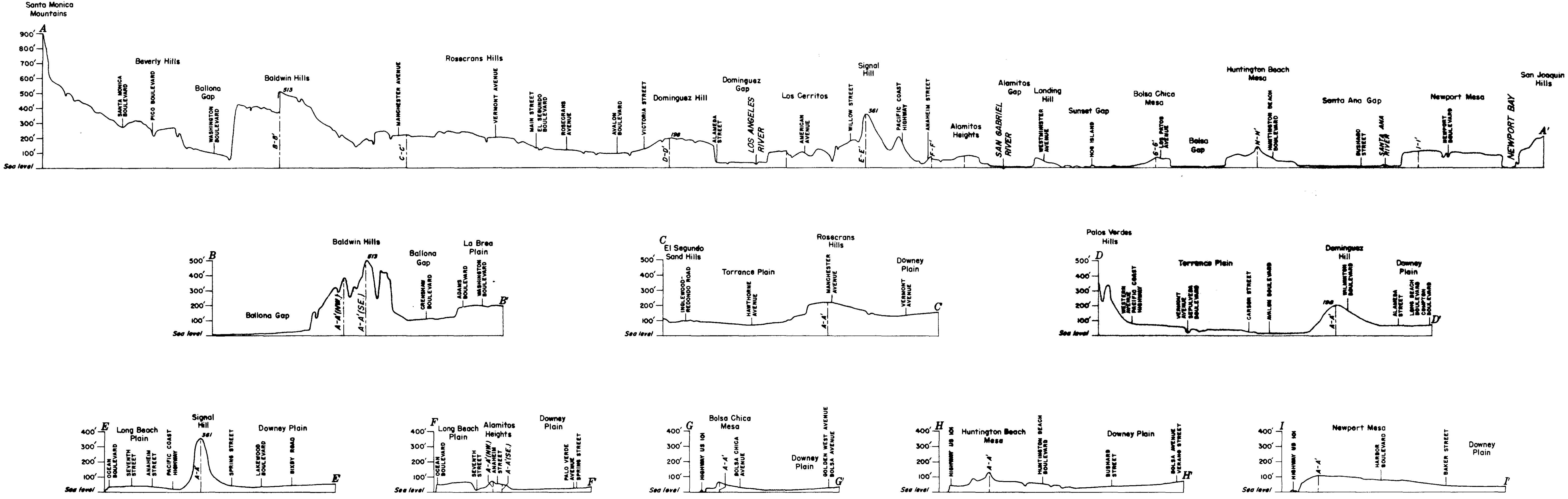


MAP OF THE LONG BEACH–SANTA ANA AREA, CALIFORNIA, SHOWING LANDFORM ELEMENTS AND GENERALIZED CONTOURS ON BASE OF PRINCIPAL FRESH-WATER BODY

5 0 10 Miles

346109 O - 56 (In pocket)



LAND-SURFACE PROFILES ALONG AND ACROSS THE NEWPORT-INGLEWOOD BELT, LONG BEACH-SANTA ANA AREA, CALIFORNIA

5 0 10 Miles

See plate 1 for location of profile
Vertical scale is 15 times horizontal scale

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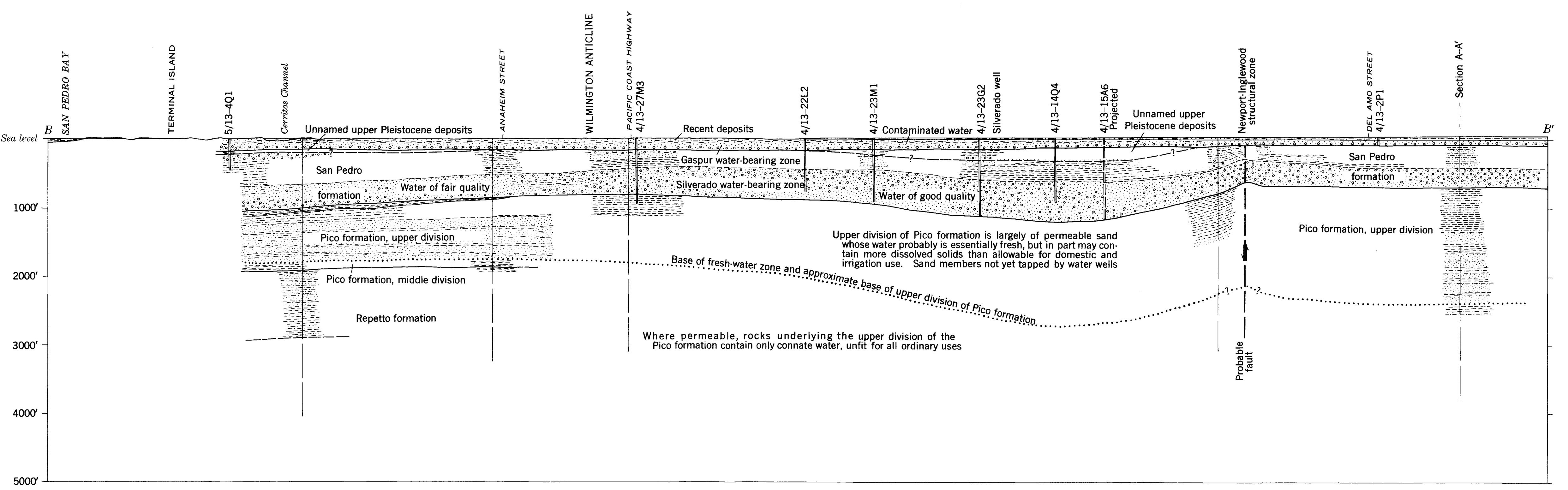
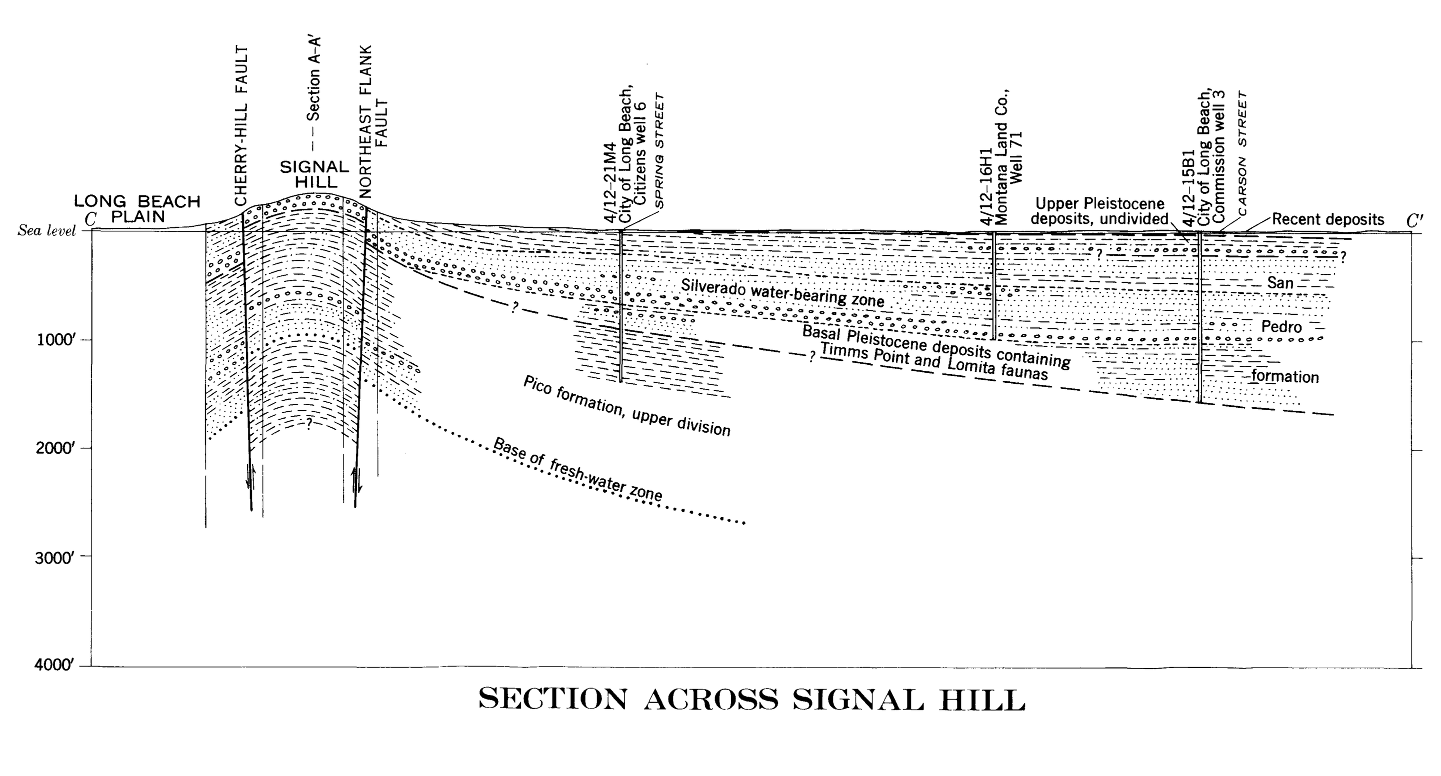
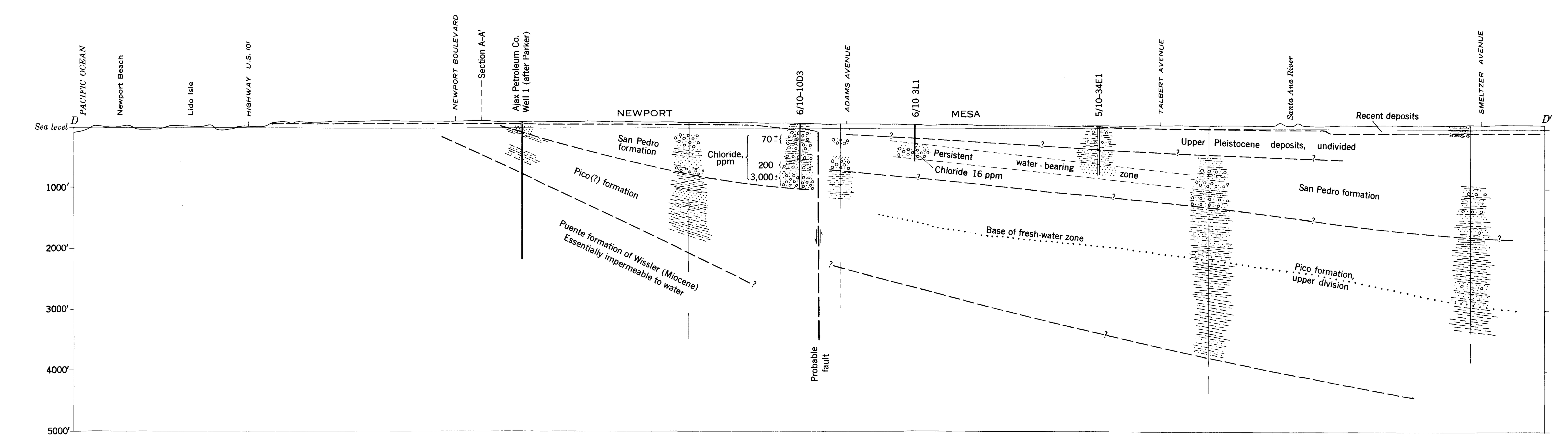
SECTION ALONG NEWPORT-INGLEWOOD STRUCTURAL ZONE FROM DOMINGUEZ HILL TO NEWPORT MESA



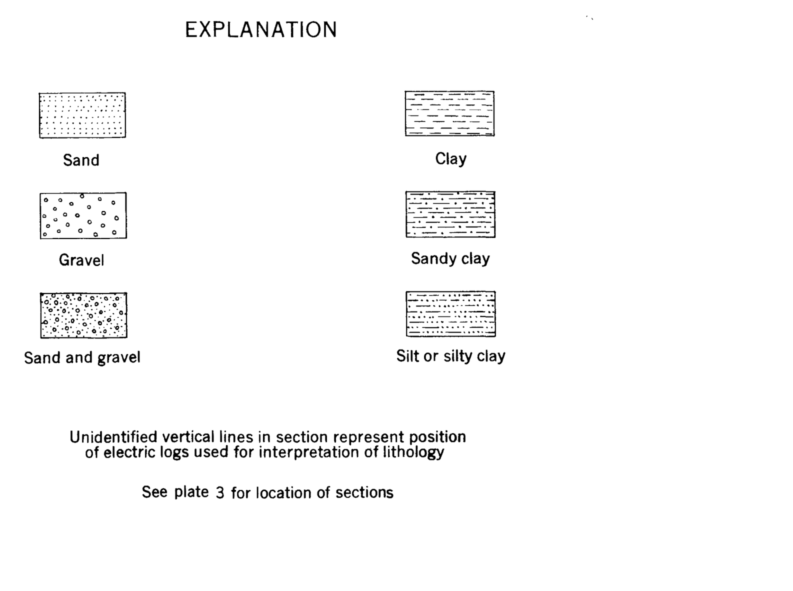
SECTION FROM TERMINAL ISLAND THROUGH DOMINGUEZ GAP



SECTION ACROSS SIGNAL HILL



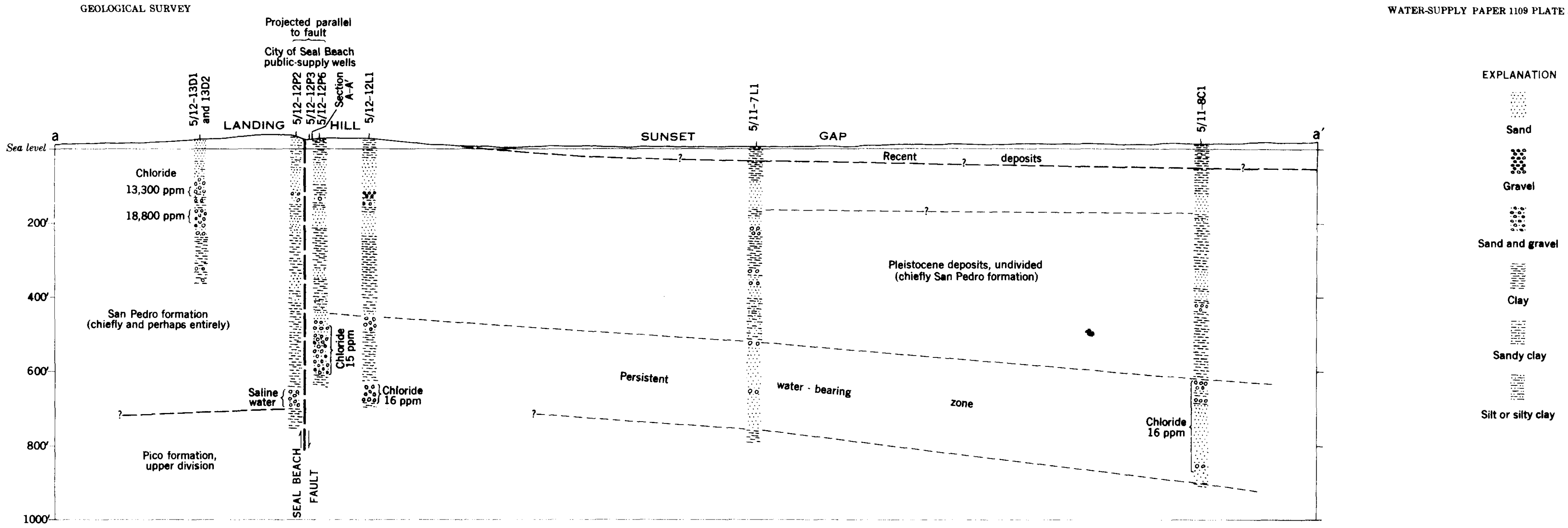
SECTION FROM NEWPORT BEACH NORTHWARD ACROSS NEWPORT MESA



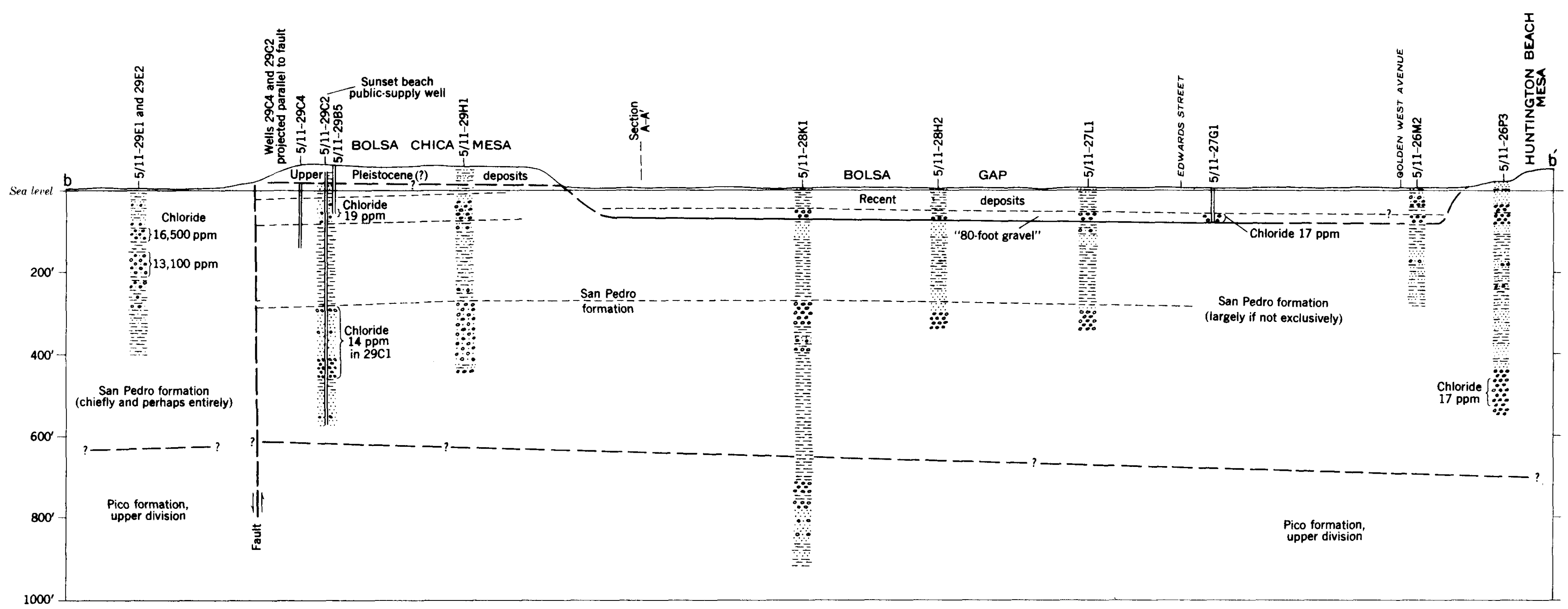
GEOLOGIC SECTIONS IN THE LONG BEACH-SANTA ANA AREA, CALIFORNIA

Scale 1:31,680

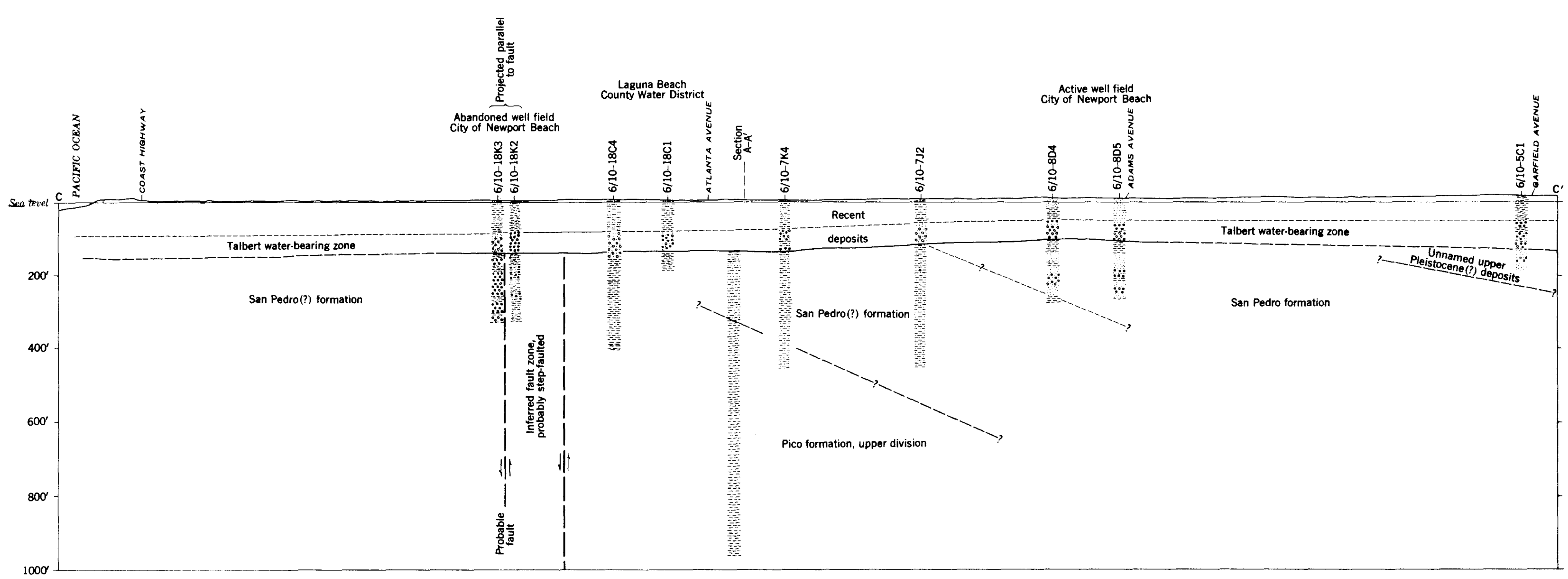
Vertical scale is twice the horizontal scale



SECTION FROM LANDING HILL DIAGONALLY ACROSS SUNSET GAP



SECTION FROM BOLSA CHICA MESA TO HUNTINGTON BEACH MESA



SECTION THROUGH SANTA ANA GAP

DETAILED GEOLOGIC SECTIONS IN THE LONG BEACH-SANTA ANA AREA, CALIFORNIA

Scale 1:24,000

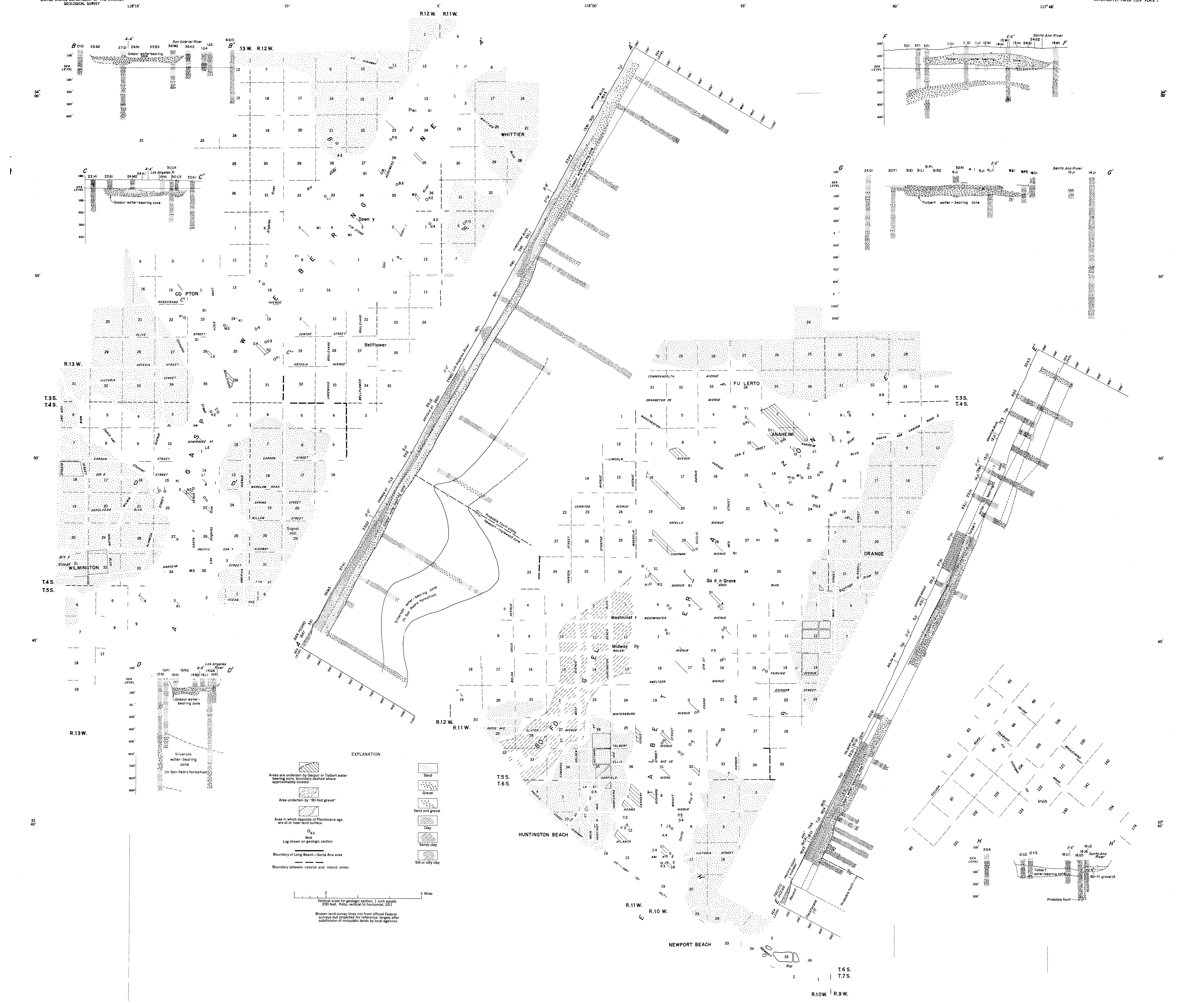
1 0 2 Miles

1,000 0 12,000 Feet

Vertical scale is five times horizontal scale

See plate 3 for location of sections

346109 O - 56 (In pocket)



MAP AND GEOLOGIC SECTIONS SHOWING EXTENT, THICKNESS, AND CHARACTER OF THE GASPUR AND TALBERT WATER-BEARING ZONES IN THE DEPOSITS OF RECENT AGE, LONG BEACH–SANTA ANA AREA, CALIFORNIA

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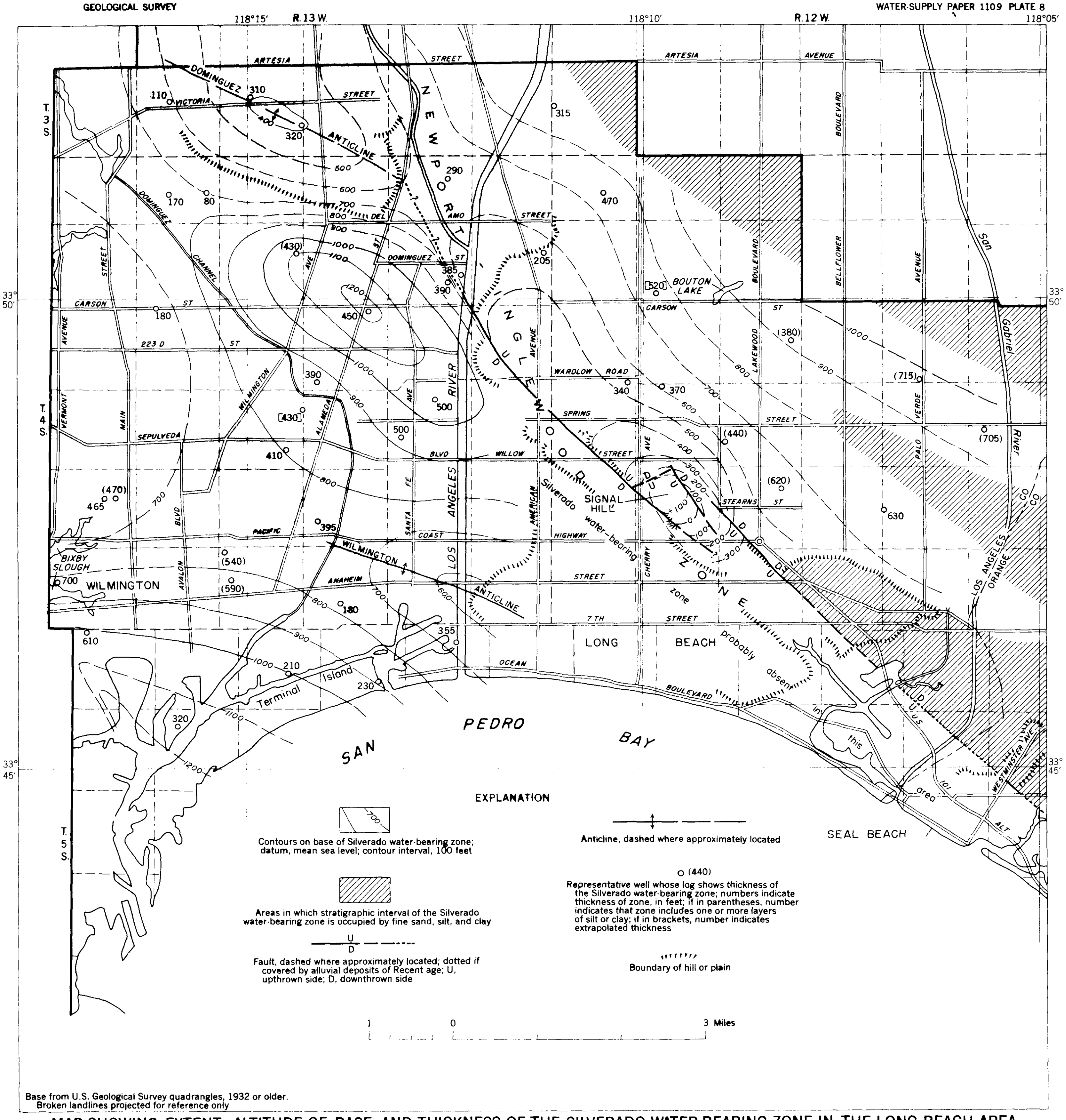
UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY



MAP SHOWING EXTENT, ALTITUDE OF BASE, AND THICKNESS OF THE SILVERADO WATER-BEARING ZONE IN THE LONG BEACH AREA, LOS ANGELES COUNTY, CALIFORNIA

346109 O - 56 (In pocket)