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GEOLOGICAL SURVEY
Ground Water Branch

GEOLOGY, HYDROLOGY, AND QUALITY OF WATER
IN THE TERRA BELLA-LOST HILLS AREA
SAN JOAQUIN VALLEY, CALIFORNIA

By

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PART A

GEOLOGY OF THE TERRA BELLA-LOST HILLS AREA,
SAN JOAQUIN VALLEY, CALIFORNIA

By G. S. Hilton, R. L. Klausning, and Fred Kunkel

ABSTRACT

The Terra Bella-Lost Hills area in the southeastern part of the San Joaquin Valley includes about 1,700 square miles of Kings, Tulare and Kern Counties. This part of the San Joaquin Valley has mild winters, long hot summers, and little precipitation, almost all of which occurs during the fall and winter months. The area is a basin of interior drainage and the streams are tributary to Tulare Lake.

The Terra Bella-Lost Hills area is characterized by dissected uplands, low alluvial plains and fans, river-flood plains and channels, and overflow land and lake bottoms.

Deficiency of supply, conjunctive use of surface and ground water, floods, subsidence of land surface, and protection and maintenance of water quality are the most critical water-use problems in the Terra Bella-Lost Hills area. This report is the first of three dealing with water-use problems in the area and provides the framework for subsequent reports on the hydrology and chemical quality of water.

The San Joaquin Valley is a structural downwarp between the tilted block of the Sierra Nevada on the east and the complexly folded and faulted Coast Ranges on the west. During much of the Cretaceous and Tertiary Periods, the San Joaquin Valley was the site of marine deposition. Overlying the marine rocks are continental deposits of late Tertiary and Quaternary age. In the Terra Bella-Lost Hills area it is estimated that there are at least 15,000 feet of continental and marine deposits of Tertiary and Quaternary age.

The geologic units of the Terra Bella-Lost Hills area are divided into two groups: (1) consolidated rocks which include basement complex of pre-Tertiary age, and non-marine and marine sedimentary rocks of Tertiary age; and (2) unconsolidated deposits which include continental deposits undifferentiated and the Tulare Formation of Tertiary and Quaternary(?) age and older alluvium, terrace deposits, younger alluvium, flood-basin deposits, and dune sand of Quaternary age.

The basement complex, which is composed of metamorphic and igneous rocks, is dense, is of low permeability, and yields ground water only in quantities sufficient for stock and domestic use.

The nonmarine sedimentary rocks of Tertiary age consist principally of consolidated and poorly permeable shale, siltstone, and conglomerate. These deposits, like the basement complex, yield only minor quantities of ground water, sufficient only for domestic and stock uses.

The marine rocks of Tertiary age are composed of moderately permeable sandstone to relatively impermeable siltstone; the more permeable units either are or can become important sources of ground water. The unconsolidated deposits of late Tertiary and Quaternary age are highly to poorly permeable and supply the major part of the ground water pumped in the area. Ground water contained in the permeable deposits occurs in several distinct aquifers and aquifer systems.

Two principal aquifer systems in the area include virtually all the unconsolidated deposits of Quaternary and Tertiary age. One of the aquifer systems contains a semiconfined water body within the unconsolidated deposits that overlie the Corcoran Clay Member of the Tulare Formation and the deposits that overlie the marine rocks where the Corcoran is absent. The other aquifer system contains a confined water body within unconsolidated deposits that underlie the Corcoran. For the most part, the two aquifer systems are not connected vertically. However, along the east and south margins of the Corcoran the two aquifer systems are horizontally interconnected and comprise parts of a single ground-water reservoir.

Underlying about 800 square miles along the eastern margin of the area at depths ranging from 1,000 to 2,000 feet below land surface the Santa Margarita Formation of Diepenbrock (1933), ranges in thickness from about 200 to 600 feet and consists primarily of sandy beds. Locally this formation is ^a confined aquifer and constitutes an important source of ground water.

Underlying the Santa Margarita Formation of Diepenbrock (1933) by about 200 to 300 feet is another zone of permeable deposits ranging in thickness from 100 to 450 feet. These deposits, the Olcese Sand of Diepenbrock (1933), are also a confined aquifer and may become an important source of ground water locally.

INTRODUCTION

Location and General Features of the Area

The San Joaquin Valley, the southern part of which is shown on figure 1, includes roughly the southern two-thirds of the Central Valley of California. The San Joaquin Valley is bounded by the Sierra Nevada on the east, the Coast Ranges on the west, and the Tehachapi and San Emigdio Mountains on the south. In the north the combined deltas of the Sacramento and San Joaquin Rivers separate the Sacramento Valley from the San Joaquin Valley. The San Joaquin Valley extends 250 miles southeasterly, from the delta area near Stockton to Grapevine, about 30 miles south of Bakersfield.

The Terra Bella-Lost Hills area, which occupies about 1,700 square miles in the southeastern part of the San Joaquin Valley, lies between 35°30' and 36°00' north latitude and 118°52'30" and 119°45' west longitude. The area is part of the Tulare Lake drainage basin, a surface basin of interior drainage. Within the area the flow of the streams originating in the Sierra Nevada moves toward the valley trough and thence northward via sloughs and canals to Tulare Lake (fig. 2). Most streams in the area are intermittent, poorly integrated, and flow only during periods of heavy rainfall. One exception, Poso Creek, flows all year owing to the continual dumping of oilfield-waste water into its drainage system.

About 1,400 square miles of the area studied is valley area underlain by unconsolidated deposits. Most of the valley area is irrigated, except for alkali lands on the valley floor. Low foothills and mountains occupy about 300 square miles along the eastern margin of the area. This area is underlain respectively by unconsolidated and consolidated deposits, and the granitic complex of the Sierra Nevada. Most of this area is used for grazing and dry land farming.

Mild winters, long hot summers, and little precipitation, are typical of the Terra Bella-Lost Hills area. Most of the precipitation falls as rain during the fall and winter months. Because of the long growing season, more than one crop per year can be harvested from the same acreage.

The area is accessible readily via U.S. Highway 99, State Highways 65 and 33, and U.S. Highway 466 which extends westward from U.S. Highway 99 at Famoso. The Southern Pacific and the Atchison, Topeka, and Santa Fe railroad provide both passenger and freight service to the larger cities and towns. (See fig. 1.)

Delano, the largest town in the area, had a population of 11,809 in 1960. Wasco, Shafter, and McFarland in Kern County and Alpaugh, Ducor, and Earlimart in Tulare County are business and service centers for the agricultural industry that is predominant in the economy of the area.

Purpose and Scope of the Investigation

As part of the program of ground-water investigations in cooperation with the California Department of Water Resources, the U.S. Geological Survey, in July 1956, began a geohydrologic study of the Terra Bella-Lost Hills area to define the ground-water reservoir system and to provide information pertinent to the solution of the principal water problems of the area. The principal problems related to water use in the San Joaquin Valley are: (1) deficiency of supply, (2) floods, (3) how best to utilize surface and ground water conjunctively (California Dept. Water Resources, 1957, p. 209), (4) subsidence of land surface, (5) protection and maintenance of water of good chemical quality. Of these, only flooding is not a critical problem in the Terra Bella-Lost Hills area.

The results of the study are reported in three parts. This report, the first part, describes the geologic units of the area, their water-bearing character, and the framework within which ground water occurs and moves. Geology is presented first because it is fundamental to an understanding of the problems that are related to hydrology and chemical quality of ground water in the area.

The second part (Part B - Hydrology) describes the hydrologic aspects of the investigation and hydrologic principles in general as they pertain to the source, occurrence, and movement of both surface and ground water in the area. These principles of hydrology are then related to the specific problems of deficiency of supply, floods, and conjunctive use of surface and ground water. The third part (Part C - Quality of Water) discussed the problem of protecting and maintaining water of good quality in the Terra Bella-Lost Hills area.

The investigation was begun under the supervision of G. F. Worts, Jr., and completed under the supervision of H. D. Wilson, Jr., successive district supervisors in charge of ground-water investigations of the Geological Survey in California. Fieldwork was done by G. S. Hilton, R. L. Klausning, R. H. Dale, and D. C. Blakely. The data compilation was done by G. S. Hilton, R. L. Klausning, E. J. McClelland. Data analysis and preparation of the report was by the authors.

Previous Investigations

Many agencies and individuals have made investigations of specific problems and areas in the southern part of the San Joaquin Valley. However no detailed study of the Terra Bella-Lost Hills area has been made previously. Pertinent previous studies for areas including or adjacent to the Terra Bella-Lost Hills area were made by Mendenhall and others (1916), California Division of Engineering and Irrigation (1922), Harding (1927 and 1949), and Davis and others (1959). In addition the U S. Bureau of Reclamation and California Department of Water Resources have made geologic and water-supply studies for several water conservation districts.

Acknowledgments

Throughout the investigation wholehearted cooperation and assistance were received from Federal, State, and local governmental agencies, and from private companies and individuals in the San Joaquin Valley. Drillers' logs and chemical analyses of water were furnished by well owners, local well drillers, California Department of Water Resources, U.S. Bureau of Reclamation, and the Kern County Land Co. Copies of electric logs of oil and water wells were made available, with the permission of the landowners, by Eastman Oil Well Survey Co., Lane Wells Co., Schlumberger Well Survey Corp., U.S. Bureau of Reclamation, many oil companies, and the California Division of Oil and Gas. Water-level records were supplied by the Bureau of Reclamation; the California Department of Water Resources; Alpaugh, Saucelito, Delano-Earlimart, and Shafter-Wasco Irrigation Districts; the Buena Vista and North Kern Water Storage Districts; the Southern San Joaquin Municipal Utility District; the Rag Gulch Mutual Water Co.; Pacific Gas and Electric Co., Southern California Edison Co., and Kern County Land Co. Engineers of the Pacific Gas and Electric Co. and the Southern California Edison Co. supplied data on which the estimate of ground-water pumpage is based. In addition, excellent cooperation was extended by the Kern County Land Co. in furnishing permission and assistance for pumping tests on their wells.

Well-Numbering System

The well-numbering system shows the location of wells according to the rectangular system of public-land surveys. For example, in the number 25/25-24K1, assigned to a well $1\frac{1}{2}$ miles south of Delano, the part of the number preceding the slash indicates the township (T. 25 S.); the number between the slash and the hyphen indicates the range (R. 25 E.); the digit between the hyphen and the letter indicates the section (sec. 24); and the letter following the section number indicates the 40-acre subdivision of the section, as shown in the accompanying diagram.

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

Within each 40-acre tract the wells are numbered serially, as indicated by the final digit of the well number. Letters indicating cardinal directions appear in the township and range description only when an area spans two or more quadrants of a particular base and meridian. As all of the Terra Bella-Lost Hills area is on the southeast quadrant of the Mount Diablo base and meridian, cardinal directions are not indicated in the numbers.

GEOMORPHOLOGY

The geographic units of the Terra Bella-Lost Hills area have been classified, after Davis and others (1959, p. 15-35), as the Sierra Nevada, dissected uplands, low alluvial plains and fans, river flood plains and channels, and overflow lands and lake bottoms, which are shown on figure 2.

The Sierra Nevada is largely one gigantic block that has been tilted slightly westward, owing to faulting and uplifting along the eastern edge of the range. The western slopes of the range trend in a general north-northwest direction and form the eastern boundary of the Terra Bella-Lost Hills area.

The dissected uplands are areas of moderate relief that include such features as Buttonwillow Ridge, Semitropic Ridge, Lost Hills and a belt of low foothills along the western front of the Sierra Nevada. Buttonwillow Ridge, which separates Jerry Slough from Buena Vista Slough, is about 2 miles wide and 15 miles long, and has a maximum altitude of 300 feet and a maximum relief of about 65 feet. Semitropic Ridge, bounded by Jerry Slough on the west, low alluvial fans on the east, and overflow lands on the north, is a low ridge approximately 15 miles long, 2 miles wide. It has a maximum altitude of 300 feet and is about 65 feet above the level of Jerry Slough. On the east side of the area the dissected uplands range in width from about 1 mile near Terra Bella to a maximum of about 14 miles near Famoso. The maximum elevation of this unit is in the southeastern part of the area and is about 1,800 feet above sea level.

The low alluvial plains and fans unit is represented in the eastern part of the Terra Be la-Lost Hills area by the relatively flat and featureless fans of Poso Creek, Rag Gulch, White River, and Deer Creek (fig. 3). On the west side the unit is represented by an area of coalescing fans and plains built up by streams entering the valley from the Coast Ranges. In the eastern belt the land surface slopes in a general westerly direction from about 12 feet per mile on the Deer Creek fan to about 30 feet per mile on the Rag Gulch fan. These plains and fans occupy a large part of the valley floor and constitute an intensively developed agricultural area.

The river flood plains and channels, lying along Poso Creek, White River, and Deer Creek, are well defined where they are incised below the level of the dissected uplands and low plains and fans. Sandy material characterizes deposits in the channels and silty material makes up most of the flood-plain deposits.

Overflow land and lake bottoms include the beds of Tulare and Goose Lakes and the lowlands in the axial trough. Tulare Lake, a nearly flat featureless plain, once was believed to have been formed by the damming of the Kings River and Los Gatos Creek drainages. However, the subsurface geology, based on an interpretation of electric logs of oil and water wells, indicates that Tulare Lake is actually a structurally negative area formed by downwarping (Davis and others, 1959, p. 29). At present the lake is restricted to the northwestern part of the original lake bed by dikes and levees. In the historical past, whenever the level of the lake reached an elevation of 210 feet above mean sea level, it overflowed northward into the San Joaquin River. Such overflow last occurred in 1878 (Harding, 1949, p. 29-30).

Goose Lake and Jerry Slough (fig. 2) are south of Tulare Lake between Semitropic and Buttonwillow Ridges. Jerry Slough is 1 to 2 miles wide and slopes gently toward Goose Lake. Excess flow from the Kern River discharges into Goose Lake, and during times of excessive runoff, Goose Lake overflows into Tulare Lake via canals.

Buena Vista Slough, the northern part of which lies in the Terra Bella-Lost Hills area, connects Tulare Lake with Buena Vista Lake, 40 miles to the south. Only during times of excessive runoff does overflow from Buena Vista Lake and the Kern River spill into the slough from which it subsequently discharges into Tulare Lake. Inflow to Tulare Lake probably last occurred in 1952; thereafter, flood waters of the Kern River have been regulated by Isabella Dam, about 35 miles northeast of Bakersfield.

GENERAL GEOLOGY

The Central Valley is a structural trough more than 400 miles long, extending from Red Bluff in north-central California to Wheeler Ridge, about 25 miles south of Bakersfield. The San Joaquin Valley, the southern part of the Central Valley, is underlain by as much as 28,000 feet of marine and continental deposits of Tertiary and Quaternary age (Dibblee and Oakeshott, 1953, p. 1503). Several lines of evidence suggest that deposition of this sedimentary section occurred in an asymmetrical trough whose principal axis lies near and approximately parallels the west border of the valley. Vaughn (1943, p. 68) concludes on geophysical evidence that the Sierra Nevada block continues westward beneath the valley to the flanks of the Coast Ranges. Wells drilled to rocks of the basement complex along the east side of the valley and as far west as the topographic trough (May and Hewitt, 1948, pl. 1) confirm this. That wells of equal or greater depth on the west side do not reach the basement rocks further confirms the asymmetrical character of the valley.

During the Cretaceous Period and throughout much of the Tertiary Period, the structural trough was the locale for deposition of marine sediments. These sediments attain their maximum thickness in the Coast Ranges, west of the present valley, and decrease in thickness easterly toward the Sierra Nevada, where they pinch out against the westward-sloping surface of the basement rocks. Interfingering of the marine sediments with continental deposits of early and middle Tertiary age occurs in the eastern part of the valley. Fluvial and lacustrine deposits of late Tertiary and Quaternary age overlie the marine sediments throughout most of the valley. In the Terra Bella-Lost Hills area these deposits are about 2,500 feet thick (Lyons and Nicklen, 1956, p 2).

Although the Coast Ranges and Sierra Nevada have been established for a long period of geologic time, their present form is chiefly a result of tectonic movement during late Tertiary and Quaternary time. Deformation of late Tertiary and Quaternary deposits along the valley border and in the valley itself is due to these movements. Structural deformation was more intense along the western and southern borders of the valley in contrast to the moderate tilting and folding that occurred along the eastern edge.

The Coast Ranges trend northwesterly roughly parallel to the axis of the valley. They are composed chiefly of sharply folded and intricately faulted sedimentary rocks. The Lost Hills, Buttonwillow Ridge, and Semitropic Ridge are the surface expressions of anticlines related in time to the folding in the Coast Ranges.

The westward-tilted Sierra Nevada fault block is composed of metamorphic and igneous rocks of the basement complex of pre-Tertiary age. Along its western edge a narrow belt of consolidated marine and nonmarine sedimentary rocks of Tertiary age mantles the basement complex of the Sierra and dips gently beneath the unconsolidated deposits of late Tertiary and Quaternary age of the San Joaquin Valley. These sediments are broken both at the surface and in the subsurface by north- to northwest-trending faults. The principal events in the geologic history that are applicable to the Terra Bella-Lost Hills area of the San Joaquin Valley and the bordering mountains are summarized in table 1.



GEOLOGIC UNITS AND THEIR WATER-BEARING CHARACTER

Ground water occurs and moves within the framework of the various geologic units, thus a knowledge of the geology of an area is essential to an analysis of water-use problems. Accordingly, the geologic units of the Terra Bella-Lost Hills area are distinguished and described herein both as to their physical composition, stratigraphic position, and their water-bearing character. Because the scope of the investigation precluded extensive geologic mapping, the geology, in large part, is a compilation based on soils maps of Anderson and others (1942) and Storie and others (1942). Based on these previous studies, the geologic units of the Terra Bella-Lost Hills area were divided into two principal groups: (1) consolidated rocks, which include the basement complex of pre-Tertiary age and nonmarine sedimentary rocks and marine rocks of Tertiary age and (2) unconsolidated deposits which include continental and lacustrine deposits of late Tertiary and Quaternary age.

The areal extent and stratigraphic sequence of the geologic units are shown in figure 3. The stratigraphic sequence, lithologic character, thickness, and water-bearing properties of the units are summarized in table 2. Geologic sections (fig. 4) show generalized structure, stratigraphic correlations, and lithologic character of the water-bearing deposits as interpreted from drillers' logs and electric logs of water and oil wells.

Consolidated Rocks

Basement Complex

Metamorphic and igneous rocks of the Sierra Nevada crop out along the eastern margin of the area and slope westward beneath the sedimentary rocks of Tertiary and Quaternary age in the San Joaquin Valley. The igneous rocks range in composition from granite to gabbro and the metamorphic rocks consist largely of quartzite, schist, gneiss, and crystalline limestone.

Although the rocks of the basement complex are relatively impermeable, they may yield sufficient water from fractures and joints for domestic and stock use. They are present at great depth beneath the intensively cultivated area of the valley, but are of no importance as a source of water supply except around the margins of the valley where they underlie the foothill areas which receive the major part of the precipitation within the drainage area. It is runoff from these mountainous areas that contributes the largest amount of recharge to the ground-water body.

Nonmarine Sedimentary Rocks

Nonmarine sedimentary rocks of Tertiary age crop out along the east edge of the Terra Bella-Lost Hills area (fig. 3) and overlie the granitic rocks of the basement complex at depth beneath the San Joaquin Valley floor. These deposits consist of poorly sorted, consolidated, coarse sandstone and conglomerate with interbedded greenish shale and occasional beds of volcanic ash. This sedimentary section, referred to as the Walker Formation by Wilhelm and Saunders (1927, p. 9), is characterized by rapid facies changes and lensing of individual beds. A few miles west of the outcrop area toward the central part of the valley the formation is fine grained and probably grades into the marine rocks. In the outcrop area the beds strike in a north to northwesterly direction and dip 7° to 10° toward the west. Their maximum thickness, as observed by Albright and others (1957, p. 13), is approximately 850 feet.

The nonmarine sedimentary rocks generally are poorly permeable; even the coarse-grained sandstone and conglomerate yield only small quantities of water to wells. Ground water in and near the outcrop area (fig. 3) generally is fresh, but down dip and at moderate depths it becomes brackish to highly mineralized.

Wilhelm and Saunders (1927, p. 9) considered the formation to be Miocene in age. However others such as Park and Weddel (1959, pl. 3), considered the formation to be Eocene to Miocene in age.

Marine Rocks

In the southern part of the area marine rocks of Miocene age crop out in a 5- to 6-mile-wide belt which thin to less than 2 miles in the north (fig. 3). The beds strike from north to northwest and dip 6° to 10° to the west. Predominately northwest- and east-trending faults transect the outcrop in the vicinity of Poso Creek. In the Poso Creek area three units, one predominantly silty and two sandy, can be distinguished in the outcrops.

In the San Joaquin Valley north of the Kern River, oil geologists have identified at least eight marine units that are recognizable in the subsurface of the Terra Bella-Lost Hills area and are shown on the generalized stratigraphic section (fig. 3). Table 3 lists seven units pertinent to this study. The San Joaquin Formation is not described because it is predominantly clay and occurs only in the central and western parts of the valley; generally it is not tapped by water wells.^{1/} In the subsurface, a maximum thickness in

1. Subsequent to the preparation of this report preliminary studies (Klausing, R. L., and Lohman, K. E., written communication, 1963) suggest that a section of marine Pliocene occurs at Richgrove and should be assigned to the San Joaquin Formation.

excess of 3,000 feet is indicated for marine deposits of Tertiary age (Albright and others, 1957, p. 13). which in the subsurface range in age from Eocene to Pliocene

The Etchegoin Formation, the Round Mountain Silt of Diepenbrock (1933, p. 14-16) and the Freeman-Jewitt Silt of Albright and others (1957, p. 13) are not now sources of water and are not considered potential sources of water. The Santa Margarita Formation of Diepenbrock (1933, p. 13) and the Olcese Sand of Diepenbrock (1933, p. 14) are now sources of water and the Pyramid Hill and Veader Sand of Albright and others (1957, p. 13) are potential sources of water.

The Santa Margarita Formation of Diepenbrock (1933).-- The Santa Margarita Formation of Diepenbrock (1933, p. 14) of Miocene age (table 3) described in this area for the first time, underlies an area of approximately 800 square miles between U.S. Highway 99 and the foothills of the Sierra Nevada. The top of the formation, as shown by figure 5, indicates that it trends northwest, paralleling the trough of the valley. The northern extent of the aquifer has not been determined but it is known to underlie much of T. 22 S., R. 27 E. Because of insufficient control, however, the subsurface contours on the top of the aquifer have not been extended south of Poso Creek.

The Santa Margarita Formation (table 3) and overlying Etchegoin Formation is overlain by poorly permeable clay and silt of the basal part of the continental deposits undifferentiated and is underlain by the relatively impermeable Round Mountain Silt of Diepenbrock (1933, p. 14)

A representative electric log (fig 6) of a well drilled in the SW $\frac{1}{4}$ sec 29, T 24 S., R 27 E shows the nature of the formation from 1,750 to 2,000 feet below land surface. Resistivity and spontaneous potential curves, characteristic of the formation throughout the Richgrove area, also are shown in figure 4, profiles A, B, and C. The top and bottom of the formation usually are well delineated in the electric log by sharp changes in the resistivity and spontaneous potential. The thickness of the formation as shown by figure 7 ranges from about 200 to 600 feet.

More direct determinations of the nature of the deposits have been made from the examination of core samples collected from test wells. A test hole drilled by the Geological Survey, in cooperation with the State of California, reached a depth of 2,200 feet in the NE $\frac{1}{4}$ sec. 36, T. 24 S., R. 26 E., and penetrated approximately 300 feet of the Santa Margarita Formation (Diepenbrock, 1933). Core samples from the hole consisted of very fine to very coarse, angular to subrounded grains of greenish-gray sand. Predominant constituents of the sand were quartz, feldspar, and mica. The major part of the cored interval consisted of loose sand; the remainder was well-cemented sandstone. The sand generally was clean and well sorted.

The Santa Margarita appears to be highly permeable. Wells drilled into the formation are reported to yield several hundred to as much as 1,950 gpm (gallons per minute). However, because the wells drilled into the formation generally are perforated in the semiconfined aquifer system, the percentage of the water that comes exclusively from the Santa Margarita cannot be determined. Westward development of the aquifer will probably be restricted by the base of the fresh water, estimated position shown on figure 5.

Because the material both above and below the formation is of low permeability it is assumed that the Santa Margarita functions as a single hydraulic unit and that it contains a confined water body.

Olcese Sand of Diepenbrock (1933, p 14) --The Olcese Sand underlies about 800 square miles of Terra Bella-Lost Hills area along the east side of the San Joaquin Valley. Contours (fig 8) on the top of the sand show that it trends northwest parallel to the trough of the valley. It extends north and probably south of the study area. The northern extent of the aquifer has not been determined but it is known to extend as far north as T 22 S , R. 26 E. Insufficient control prevents the extension of the subsurface contours south of Poso Creek.

The top of the sand lies 200 to 300 feet below the base of the Santa Margarita and ranges from about 1,500 to 2,700 feet below land surface in the vicinity of Richgrove and Jasmin. The thickness of the sand ranges from less than 100 to more than 450 feet.

The Olcese Sand of Diepenbrock (1933, p. 14) is overlain by relatively impermeable beds of the Round Mountain Silt (Diepenbrock, 1933, p. 14), and is underlain by silt and clay of the Freeman-Jewett Silt (Albright and others, 1957, p. 13). Confinement at the base of the sand probably is not effective throughout the area because sandy lenses are present in the Freeman-Jewett Silt (Albright and others, 1957, p. 13).

An electric log of an oil-test well (fig. 9) in the SW $\frac{1}{4}$ sec. 29, T. 24 S., R 27 E , shows the nature of the sand from 2,280 to 2,570 feet below land surface.

The Olcese Sand probably functions as a single hydraulic unit and contains a confined water body. Hydraulic connection, with the overlying Richgrove aquifer if any, is poor because of the intervening poorly permeable deposits of the Round Mountain Silt.

Pyramid Hill and Vedder Sands of Albright and others (1957, p. 13).--

The Pyramid Hill and Vedder Sands (Albrigt and others, 1957) which underlie the poorly permeable Freeman-Jewett Silt (Albright and others, 1957) may represent possible sources of water for a limited area east of Richgrove.

Little information concerning the Pyramid Hill and Vedder Sands is available. However, electric logs indicate that the deposits are permeable and do contain water.

East of Richgrove these deposits occur at depths 0' up to 2,700 feet below land surface, and at the present are not used as a source of water.

Unconsolidated Deposits

In the Terra Bella-Lost Hills area the unconsolidated deposits have been divided into seven units and from oldest to youngest include: (1) continental deposits, undifferentiated, (2) Tulare Formation, (3) older alluvium, (4) terrace deposits, (5) younger alluvium, (6) flood-basin deposits, and (7) dune sand.

The unconsolidated deposits were derived from similar source areas and, except for the flood-basin deposits, were laid down in subaerial environments. For the most part, the unconsolidated deposits have similar lithologies and are difficult to differentiate in the subsurface. Along the valley margin recognizable differences in topographic expression and amount of stream dissection serve in part as a basis for differentiation of the units. The flood-basin deposits generally are finer grained than the younger and older alluvium.

The lithologic character of the unconsolidated deposits is dependent upon several factors, chiefly the competence and capacity of the stream that deposited the sediment, the environment in which the deposit was laid down, and the type of rocks in the source area.

The competence of a stream is measured by the largest size particle it can transport, whereas the capacity is measured by the amount of detritus that it can carry. Both increase exponentially with increase in the volume of flow and the gradient of the stream bed, that is, increases in flow and steepening of gradient result in greater ability to transport load. The volume of flow reflects chiefly the amount of precipitation on the watershed.

Streams tributary to the San Joaquin Valley have flatter gradients in the valley than in their upland and mountain watersheds. Competence and capacity decrease with the decrease in gradient; consequently, much of the load, including most of the coarse detritus, is deposited where the streams leave the dissected uplands on the east side of the area.

Rock types in the source area influence the grain size, mineral composition, texture, and color of the deposits. Influence of source area on grain size can be readily illustrated by comparing detritus from a source area underlain by fine-grained sediments or rocks with one underlain by, say, a coarse-grained sandstone. Streams draining the fine-grained rocks would have no sand or coarse-grained materials to deposit; the streams draining the coarse-grained sandstone would deposit coarse sand predominantly. All the streams tributary to the Terra Bella-Lost Hills area, however, derive their sediment load from several types of source rocks. Poso Creek, Rag Gulch, and White River drain areas underlain by granitic rocks of the Sierra Nevada which supply sand and by fine-grained sedimentary rocks which supply silt or clay. Deer Creek probably deposits mostly sand because it drains an area composed largely of granitic rocks of the Sierra Nevada; sedimentary rocks of Tertiary age are not exposed extensively in its drainage area.

Continental Deposits Undifferentiated

The unit continental deposits undifferentiated (fig- 3) includes the informally named Kern River Formation as restricted by Diepenbrock (1933, p. 12-29) and older deposits of continental origin that rest on an erosion surface truncating Miocene and older marine rocks along the eastern border of the San Joaquin Valley. These deposits, which accumulated on alluvial fans, form the continental equivalent of Tertiary marine units deposited in the San Joaquin basin.

Diepenbrock (1933, p. 12-29) determined from stratigraphic and paleontologic information obtained from oil wells in the Kern Front area of the Kern River oilfield that the so-called Kern River Series contained a fossil-bearing claystone of marine origin, and, on this basis, divided the series into three units, which he called the Kern River, Etchegoin, and Chanac Formations.

Elsewhere along the eastern margin of the San Joaquin Valley, logs of oil wells show that near the margins of the valley the continental deposits undifferentiated grade downward into marine rocks of late Miocene age and that farther basinward the continental beds grade laterally into marine rocks of Miocene and Pliocene age. The exact contact between the continental deposits and the underlying marine rocks, therefore, is difficult to recognize, and it is virtually impossible to separate Diepenbrock's Kern River Formation from the underlying Chanac Formation.

For these reasons the continental deposits along the east border of the San Joaquin Valley in southern Tulare and Kern Counties are referred to here as continental deposits undifferentiated.

The Etchegoin Formation is not exposed along the east border of the San Joaquin Valley and because of its depth below land surface is not a source of water to wells; hence it is not discussed further in this report.

In the outcrop, the continental deposits undifferentiated are exposed in a belt that decreases in width from 10 to 12 miles wide in the south to 7 to 9 miles in the north; this belt is traversed by north-trending faults. The beds strike north to northwest and dip 4° to 7° to the west; they decrease in thickness from north to south. These deposits are exposed best in bluffs paralleling the south bank of the Kern River near Bakersfield; they are 500 to 600 feet thick and dip gently (4° - 6°) westward beneath the younger alluvial deposits of the San Joaquin Valley. Where overlain by younger sediments, these deposits range in thickness from about 500 feet to about 2,000 feet.

The deposits consist of sandy clay interbedded with loosely consolidated, generally poorly bedded, and ill-sorted sand and gravel. Exposed basal beds are generally fine grained and greenish-yellow to greenish-blue in color, whereas the middle and upper beds are generally fine grained and brown to reddish-brown in color.

In the subsurface, these deposits comprise three general types: the upper part includes the coarser and more permeable brown deposits, the middle part is characterized by a change in color from brown to green, and an increase in the percentage of fine-grained materials. The basal part contains interstratified greenish marine and nonmarine fine-grained sand and clay

These sediments and the related deposits of the Tulare Formation yield most of the ground water to wells in the Terra Bella-Lost Hills area. Based on well-yield characteristics and examination of drillers' logs, the most permeable and productive water-bearing units probably are the youngest beds.

In the part of the Terra Bella-Lost Hills area bounded by McFarland on the north, Shafter on the south, Semitropic Ridge on the west and Highway 99 on the east, the continental deposits undifferentiated apparently are relatively coarse and very permeable. Well-yield characteristics and examination of drillers' logs substantiate this conclusion. It is believed that the ancestral Kern River transported most of this detritus into the subarea. Small streams, such as Poso Creek, probably contributed a small amount of poorly sorted material

Tulare Formation

The fresh-water deposits of ~~gyp~~siferous sand and clay exposed along the west border of the San Joaquin Valley were assigned to the Tulare Formation by F. M. Anderson (1905, p. 181). The Tulare Formation includes those deposits derived from the west side of the San Joaquin Valley that are usually folded or tilted and overlie marine sedimentary rocks of Miocene or Pliocene age. In the Terra Bella-Lost Hills area the Tulare Formation is believed to be equivalent in part to the uppermost beds of the continental deposits undifferentiated and is late Pliocene and early Pleistocene(?) in age.

In the Terra Bella-Lost Hills area the Tulare Formation is exposed in the Lost Hills anticline. The exact thickness of the Tulare Formation is unknown because it is almost impossible to distinguish, with any degree of certainty, the contact between the Tulare Formation and the alluvium above and the San Joaquin Formation below.

In the subsurface the Tulare consists of yellow and blue sediments which may total as much as 2,200 feet thick. Primarily, bluish sand, clay, and gravel are found in the subsurface in the vicinity of the Tulare Lake where deposition took place in a subaqueous environment during Pliocene and Pleistocene time. Farther to the south, yellow gypsiferous sand, gravel, and clay interfinger and interstratify with bluish sediments; therefore, subaqueous and subaerial conditions alternated as streams debouching from the Coast Ranges deposited materials on alluvial fans and in deltas, swamps, and lakes in the valley trough.

In the subsurface one persistent and extensive stratum, a diatomaceous silty clay can be traced from the type area, north of the town of Corcoran, south into the Terra Bella-Lost Hills area. The clay was named the Corcoran Clay by Frink and Kues (1954) and designated the Corcoran Clay Member of the Tulare Formation by Poland and others (1958, p. 117-119). The extent and approximate thickness of the Corcoran in the Terra Bella-Lost Hills area is shown on figure 10 and the altitude of the base of the Corcoran is shown on figure 11.

In the western part of the Terra Bella-Lost Hills area the Tulare Formation, on the average, is moderately permeable and wells that tap it both above and below the Corcoran yield most of the ground water pumped in the area. A representative electric log of a well that penetrates the Corcoran is shown on figure 12.

Older Alluvium

Older alluvium crops out along the east side of the valley in a discontinuous belt, ranging in width from 6 to 8 miles in the south to 2 to 10 miles in the north. Older alluvium also crops out along the southwest side of the valley beneath Antelope Flain and in the central part of the valley beneath Buttonwillow Ridge and Semitropic Ridge

Along the east side of the valley the older alluvium is composed of poorly sorted lenticular deposits of clay, silt, sand, and gravel that are loosely consolidated to cemented. Along the west side of the valley the older alluvium is composed of silt or fine sand. In both areas the deposits are brown to reddish-brown in color. Hardpan and cemented zones occur in surface and subsurface sections. Beneath Buttonwillow Ridge and Semitropic Ridge the older alluvium virtually is indistinguishable from the fine-grained dark colored flood-basin deposits.

The older alluvium cannot be differentiated from the underlying deposits in the subsurface and the thickness of the older alluvium has not been determined. However the thickness probably does not exceed 200 feet.

Based on its stratigraphic position, the older alluvium at depth probably is late Pleistocene in age. However, because the older alluvium in the subsurface cannot be differentiated from the overlying younger alluvium, the older alluvium as mapped could be Recent in age in part. The older alluvium, though locally very permeable, probably is less permeable on the average than the younger alluvium, owing to the presence of cemented zones and a greater degree of consolidation.

Terrace Deposits

Terrace deposits border the lower and middle reaches of the larger streams in the Terra Bella-Lost Hills area. They are poorly bedded, ill sorted, and no greater than 50 feet thick. The poorly sorted sand and gravel, composed of fragments of granitic and metamorphic rocks and some clay, characterize these deposits. Locally the deposits may be cemented.

The terrace deposits are Pleistocene in age. Remnants of low relief along active streams may be Recent in age. Though moderately permeable, they are thin, generally occur above the saturated zone, and are of little significance as a source of ground water.

Younger Alluvium

The younger alluvium (fig. 3) includes the deposits in stream channels and the materials underlying active alluvial fans. For the most part it is of Recent age but in part at depth may be late Pleistocene.

These deposits consist of a complex of interstratified and discontinuous beds of unsorted to fairly well-sorted sand, silt, gravel, and clay. Usually, these deposits are coarsest near the apexes of the alluvial fans and become finer grained and better sorted toward the valley trough; they interfinger and are interstratified with the flood-basin deposits.

The younger alluvium probably is no thicker than 100 feet in the Terra Bella-Lost Hills area. Cemented zones or hardpan characteristic of the underlying older alluvium and the other geologic units are absent in the younger alluvium.

The younger alluvium, although quite permeable, is thin and therefore probably yields water sufficient in quantity for domestic and stock use only. The younger alluvium serves as a permeable medium through which recharge from streams percolates downward to water bodies in the underlying older geologic units.

Flood-Basin Deposits

Flood-basin deposits include those fine-grained materials underlying Tulare Lake and other fine-grained materials deposited on overflow lands and in slough areas in the trough of the valley by sluggish flood waters discharging into Tulare Lake. Chiefly they are composed of relatively impermeable silt and clay interbedded with some moderately to poorly permeable sand layers that interfinger with and are the age equivalent of the younger alluvium. The thickness of the flood-basin deposits is unknown because they overlie fine-grained lacustrine and swamp deposits which are a facies (fig. 4) of the older alluvium and other unconsolidated deposits of Tertiary and Quaternary age that cannot be differentiated from the flood-basin deposits. However it is estimated that the flood-basin deposits probably are on the order of 50 feet thick. The fine-grained lacustrine and swamp deposits that underlie and are indistinguishable from the flood-basin deposits are considered to be the fine-grained facies of the older deposits.

Because the quality of the water throughout much of the flood-basin deposits may be inferior and because the deposits generally are of low permeability, they are not considered a major source of water supply. Locally, however, the deposits yield sufficient quantities of water for domestic and stock uses.

Dune Sand

Dune sand of Recent age mantles ridges which represent former strand lines of Tulare Lake; the sand represents beach sand of the lake which has been winnowed and reworked by wind action. The dunes are very limited in area and parallel in alignment the former strand lines.

Dune sand is composed of loose, well-sorted, gray sand; it is chiefly a quartz sand and is no greater than 4 feet in thickness. This unit is not a source of water to wells as the deposits occur above the saturated zone.

GEOLOGY IN RELATION TO HYDROLOGY

The unconsolidated continental deposits of late Tertiary and Quaternary age and the permeable beds in the upper part of the marine rocks of Tertiary age comprise the ground-water reservoir of the Terra Bella-Lost Hills area. These deposits comprise three relatively distinct aquifer systems which are herein called: (1) semiconfined aquifer system, (2) confined aquifer system, and (3) confined aquifers in marine rocks

The vertical boundaries of the aquifer systems are well defined and within the marine rocks these boundaries correspond with formational boundaries. However, the lateral boundaries of the aquifer systems are not always well defined, also some of the boundaries lie outside the Terra Bella-Lost Hills area.

Semiconfined Aquifer System

Where the Corcoran Clay Member of the Tulare Formation is present (fig. 5), that part of the semiconfined aquifer system above it, as shown on figure 4, consists of younger alluvium, flood-basin deposits, older alluvium, the upper part of the Tulare Formation, continental deposits undifferentiated, and lacustrine and swamp deposits that are the equivalents of older alluvium, Tulare Formation, and continental deposits undifferentiated. These deposits range in thickness from about 280 to 500 feet.

Beyond the eastern and southern boundaries of the Corcoran the semiconfined aquifer system extends throughout the full vertical extent of the saturated deposits down to the top of the marine rocks or to the first extensive and relatively impermeable bed overlying the marine rocks; it comprises younger alluvium, flood-basin deposits, older alluvium, and possibly the Tulare Formation, continental deposits undifferentiated, and the lacustrine and swamp deposits that are the equivalents of older alluvium, Tulare Formation, and continental deposits undifferentiated. These deposits range in thickness from zero to about 2,000 feet

The semiconfined aquifer system in general, consists of lenticular deposits of clay, silt, sand and gravel. These deposits have different permeabilities; the clay and the silt are the least permeable and the well-sorted sand and gravel are the most permeable. In addition each type of material has different vertical and horizontal permeabilities. However, the differences in permeabilities are differences of degree only and thus the group of deposits forms an aquifer system that contains a semiconfined water body that functions as a single hydraulic unit.

Confined Aquifer System

The confined aquifer system comprised the unconsolidated deposits underlying the Corcoran and for the most part consist of (fig. 4) the Tulare Formation, consisting of generally poorly sorted sand, silt, and clay of lacustrine, deltaic, and flood-plain, origin. In the area where the thickness of the Corcoran is greater than about 60 feet (fig. 5) the deposits largely consist of poorly permeable silt and clay and occasional lenses and beds of poorly sorted to well-sorted sand. In that part of the area where the thickness of the overlying Corcoran is less than about 60 feet the deposits usually become more sandy and therefore somewhat more permeable.

The confined aquifer system has little vertical hydraulic interconnection with the semiconfined aquifer system overlying the Corcoran. However, beyond the eastern and southern margins of the Corcoran, the confined aquifer system grades laterally into the semiconfined system (fig. 13), where there is direct horizontal hydraulic interconnection between the two systems.

Confined Aquifers in Marine Rocks

Along the east side of the Terra Bella-Lost Hills area, consolidated marine rocks of Tertiary age underlie the undifferentiated continental deposits at depths ranging from about 1,000 feet to about 3,100 feet below land surface. These marine rocks consist of alternating poorly permeable claystone, siltstone, and permeable sand. The sand beds are confined locally and where they are penetrated by water wells, they function as confined aquifers. Although these rocks were deposited in a marine environment, the saline connate water has been flushed out and replaced by fresh water.

The marine sand comprises at least two distinct confined aquifers: the Santa Margarita Formation of Diepenbrock (1933, p. 13) which is an important source of water in the vicinity of Richgrove and the Olcese Sand of Diepenbrock (1933, p. 14) which at the present time is only slightly utilized but may become an important source of water. In addition the Pyramid Hill and Vedder Sands of Albright and others (1957, p. 13), which presently are not used as a source of water may also represent a potential source of water for future development.

Geologic Sections as Indicators of
Aquifers and Aquifer Systems

Four east-west geologic sections (fig. 4), constructed from representative drillers' logs and electric logs of oil-test and water wells, show the subsurface geology of the Terra Bella-Lost Hills area and the boundaries of the semiconfined and confined aquifer systems. The alignment of these sections and the location of water wells for which electric and drillers' logs were plotted on the sections are shown on figure 3.

Section A-A'

Geologic section A-A' (fig. 4) trends westward along a line (fig. 3) passing 2 miles south of Terra Bella, through Alpaugh, and ending at the west edge of Tulare Lake. Electric and drillers' logs indicate the water-bearing deposits tapped by wells and the extent and thickness of the Corcoran Clay Member of the Tulare Formation and the underlying Santa Margarita Formation.

The section shows that the Corcoran extends eastward about 25 miles from well 23/21-8E to about well 23/25-8L1. It shows also, that the thickness of the clay ranges from 100 feet in well 23/21-10H to about 40 feet in well 23/24-16R1. Beneath Tulare Lake, from well 23/23-14M1 to well 23/21-10H, the Corcoran dips gently toward the center of the lake bed. East of Tulare Lake, the Corcoran rises about 70 feet per mile.

The poorly sorted, fine-grained deposits of the semiconfined aquifer system extend from about $2\frac{1}{2}$ miles east of well 23/28-7F to about 1 mile west of well 23/21-8E. From well 23/25 8L1 to well 23/21-8E the semiconfined aquifer overlies the Corcoran and has a maximum thickness of about 800 feet. East of well 23/25-8L1 the semiconfined aquifer system overlies the marine deposits except near well 23/28-7F where it overlies the basement complex. The thickness of the aquifer system ranges from 0 to about 1,950 feet.

The confined aquifer system underlying the Corcoran Clay Member of the Tulare Formation extends from the western edge of the section to about 1 mile east of well 23/25-8L1 where the overlying confining clay pinches out and the deposits of the confined aquifer merge with those of the semiconfined aquifer. Electric logs of wells in the west part of the area show that the deposits underlying the Corcoran are fine grained.

The Santa Margarita is correlated, in this section, from well 23/26-18A past well 23/26-LJ1; the aquifer thins rapidly to the east and apparently pinches out in the subsurface. The top of the aquifer dips about 200 feet per mile to the west from well 23/26-LJ1 to well 23/26-18A; the thickness is 420 feet in well 23/26-18A.

The Olcese Sand is not shown on this section because it is not penetrated by wells in this immediate area.

Section B-B'

Geologic section B-B' extends from the south edge of Tulare Lake on the west to near White River on the east, passing $1\frac{1}{2}$ miles north of Richgrove. It shows the deposits penetrated by both oil and water wells and the extent, thickness, and structure of the Corcoran Clay Member of the Tulare Formation and parts of Santa Margarita and Olcese Sand.

Along this section the Corcoran extends from near well 24/21-19N to past well 24/24-22R, a distance of at least 23 miles. From near well 24/21-19N to well 24/23-20G, the Corcoran rises gently about 20 feet per mile to the east, its thickness decreases from about 120 feet in well 24/22-29A1 to about 40 feet in the vicinity of well 24/23-20G. From well 24/22-29A1 to well 24/24-20A2 the configuration of the Corcoran reflects the subsurface anticlinal structure of the Trico gas field; the thickness ranges from 80 feet in well 24/22-27B1 to 40 feet in well 24/24-20A2. The Corcoran rises gently, about 30 feet per mile, from well 24/24-20A2 to well 24/24-22R; it has not been recognized east of well 24/24-22R.

The semiconfined aquifer system extends westward from the vicinity of White River to the western edge of the section. From the western edge of the section to about 1 mile east of well 24/24-22R the aquifer overlies the Corcoran and consists of blue, fine-grained sand and clay deposits which attain a maximum thickness of about 600 feet 1 mile west of well 24/22-29A1.

East of well 24/24-25A1 the semiconfined aquifer system is composed of fine-grained deposits which predominate in the vicinity of the sedimentary rock-basement complex contact at the eastern end of the section, poorly-sorted and poorly-permeable materials were derived from the small streams draining the Sierra Nevada. Coarser materials in wells 24/26-27F1 and 24/25-25R1, reflect the depositional environment of White River and Rag Gulch alluvial fans, these deposits become more fine grained toward the trough of the valley and attain a maximum thickness of about 1,600 feet.

The confined aquifer system below the Corcoran consists largely of lacustrine and deltaic deposits. These deposits extend from the west edge of the section to the vicinity of well 24/24-25A1 where they merge with the deposits of the semiconfined aquifer.

The Santa Margarita Formation and the Olcese Sand occur only in the subsurface on the east side of the San Joaquin Valley. East of well 24/27-26K both aquifers lose their identity as recognizable units, either by pinching out or by appreciable increases in sand content of the clays lying above and below the aquifers. West of well 24/27-26K the Santa Margarita has been extensively penetrated by water wells.

Section C-C'

Geologic section C-C' trends eastward passing 7 miles north of Lost Hills, through the small community of Pond, 3 miles south of Delano and ends near Rag Gulch. This section indicates the deposits penetrated by oil and water wells and the extent, thickness, and structure of the Corcoran Clay Member, and the Santa Margarita Formation and Olcese Sand.

The Corcoran extends eastward from well 25/22-30N past well 25/23-29A1; the thickness ranges from 40 feet in 25/22-30N to 60 feet in well 25/23-29A1. Insufficient data prevents the extension of the Corcoran west of well 25/22-30N. The Corcoran dips about 20 feet per mile to the west from well 25/23-29A1 to well 25/22-30N.

The semiconfined aquifer system above the Corcoran is composed largely of flood-basin and lacustrine deposits. These represent the lacustrine and swamp deposits, equivalents of the younger and older alluvium and the continental deposits undifferentiated. At the extreme west end of the section older alluvium interfingers with sand and clay of the flood-basin deposits about $4\frac{1}{2}$ miles west of 25/22-30N--that is, from well 25/22-30N to the vicinity of well 25/23-29A1. Farther east these deposits are intercalated with the younger and older alluvium and possibly with the undifferentiated continental deposits. East of where the Corcoran pinches out the semiconfined aquifer system consists of fine-grained and poorly consolidated deposits which underlie the line of section to its eastern end. These deposits are included in the older alluvium and Kern River Formation of Diepenbrock (1933), and older continental deposits.

The confined aquifer system below the Gorcoran extends eastward from well 25/22-30N to the eastern edge of the Gorcoran where the confined aquifer system merges with the semiconfined aquifer system.

The Santa Margerita Formation and the Olcese Sand underlie a limited area roughly between wells 25/27-31J and 25/27-35B. East of well 25/27-35B, these aquifers lose their identities as hydrologic units

The Pyramid Hill and Vedder Sands which are present in well 25/27-35B cannot be correlated either up dip or down dip because of insufficient data.

Section D-D'

Geologic section D-D' extends eastward from the alluvial-fan deposits of west-side streams through Shafter (fig. 3) to the dissected uplands south of Poso Creek. The line of section traverses Buena Vista Slough, Buttonwillow Ridge, Jerry Slough, and Semitropic Ridge. The section shows the logs of oil and water wells which penetrate the deposits of the semiconfined aquifer system.

West of well 28/22-9Ll the older alluvium of west-side streams crops out, these deposits interfinger with the fine-grained materials underlying Buena Vista Slough. Deposits of older alluvium are present on Buttonwillow and Semitropic Ridge, whereas fine-grained flood-basin deposits underlie Buena Vista and Jerry Sloughs. East of well 28/24-4Pl, the older alluvium is overlain by sandy younger alluvium

In the dissected uplands, adjacent to the eastern end of section D-D', fine-grained deposits of the continental deposits undifferentiated unconformably overlie the marine rocks of Tertiary age. To the west the ~~continental deposits undifferentiated~~ are in turn overlain by older alluvium.

The Santa Margarita Formation and the Olcese Sand probably are represented in the subsurface near the east edge of the section. However they are fine grained and cannot definitely be defined. Valleyward the aquifers are progressively downfaulted as shown by the faults in the vicinity of wells 28/27-11N and 28/27-9C. Analysis and interpretation of available electric logs indicate that in this part of the Terra Bella-Lost Hills area the aquifers probably contain saline water. Therefore, in this part of the area the Santa Margarita Formation and Olcese Sand are unimportant as future sources of ground water.

SUMMARY

This report furnishes the geologic framework prerequisite to an understanding of the subsequent sections of the overall report describing the hydrology and chemical quality of water as they relate to water-use problems in the Terra Bella-Lost Hills area. Geologic units recognized in the area have been described as to their areal extent, thickness, and water-bearing character.

Two main aquifer systems are contained within the unconsolidated deposits; a semiconfined aquifer system which lies above the Corcoran and above the marine rocks where the Corcoran is absent and a confined aquifer system that lies below the Corcoran and above the marine rocks

At least two confined aquifers occur within the sequence of marine rocks along the eastern margin of the area. The Santa Margarita Formation of Diepenbrock (1933, p. 13) and the Olcese Sand of Diepenbrock (1933, p. 14) are important sources of water in the vicinity of Richgrove. In addition the Pyramid Hill and Vedder Sands of Albright and others (1957, p. 13) may represent important potential sources of water for future development

Representative subsurface hydrogeologic sections of the Terra Bella-Lost Hills area show the physical character of the deposits penetrated by oil and water wells, the extent, thickness, and structure of the Corcoran Clay Member of the Tulare Formation and of the sedimentary deposits which comprise the various aquifer systems

Succeeding parts of the overall report will describe the hydrology (Part B), and the chemical quality of the water (Part C).

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PART B

HYDROLOGY OF THE TERRA BELLA-LOST HILLS AREA,
SAN JOAQUIN VALLEY, CALIFORNIA

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ABSTRACT

The Terra Bella-Lost Hills area in the southeastern part of the San Joaquin Valley includes about 1,700 square miles in Kings, Tulare, and Kern Counties. Mild winters, hot summers, and low precipitation, most of which occurs during the fall and winter months are characteristic of the area.

This part of the San Joaquin Valley is tributary to Tulare Lake, a basin of interior drainage. Deficiency of supply, floods, conjunctive use of surface and ground water, subsidence of land surface, and water quality are the most critical water problems in the area. This report, the second of three dealing with the appraisal of the water resources of the area, describes the hydrology; Part A discusses the geology, and Part C the quality of water.

Late in the 19th century, about 23,000 acres was irrigated in the Terra Bella-Lost Hills area. Irrigated acreage, using both surface and ground water, increased to about 500,000 acres by 1958.

Investigation has defined a semiconfined and confined aquifer system and two confined aquifers in marine rocks. The semiconfined aquifer system underlies most of the area and is separated into a shallow and a principal pumped zone. The shallow zone extends to depths ranging from 100 to 300 feet below land surface. The principal pumped zone extends down from the base of the shallow zone to extensive confining beds or to the base of the fresh water and ranges in thickness from about 100 to 2,000 feet.

In the northwestern part of the area a confined aquifer system extends downward from the base of the Corcoran to the base of the fresh water. Two confined aquifers in marine rocks, the Santa Margarita Formation of Diepenbrock (1933) and the Olcese Formation of Diepenbrock (1933), underlie the east side of the area. These two aquifers are confined above and below and are separated from each other by relatively impermeable material.

Solution of the problems of deficiency of supply, floods, conjunctive use of surface and ground water, subsidence of land surface must be met primarily with imported water and some small flood-control dams. Conjunctive use of ground water and surface water to provide adequate supply through climatic cycles of wet and dry years will require artificial recharge of the ground-water bodies during wet years and pumping from storage during dry years. Recharge probably can be most effectively instituted in the channels and alluvial fans of Poso Creek, White River, and Deer Creek. Elsewhere restrictions to downward movement of water are present at relatively shallow depths which will probably prevent any large scale recharge.

INTRODUCTION

Purpose and Scope of the Investigation

As part of the program of ground-water investigations in cooperation with the California Department of Water Resources the U.S. Geological Survey, in July 1956, began a study of the Terra Bella-Lost Hills area to provide information pertinent to the solution of the principal water problems of the area. The principal water problems related to water use in the San Joaquin Valley are (1) deficiency of supply, (2) floods, (3) how best to utilize surface and ground water conjunctively, (4) subsidence of land surface, and (5) protection and maintenance of water of good chemical quality. Of these, only flooding is not a critical problem in the Terra Bella-Lost Hills area.

The study of water-use problems in the Terra Bella-Lost Hills area is reported in three parts. The first part, part A, geology, describes the geologic units of the area and their water-bearing character. Geology is presented first because it is fundamental and provides the framework necessary for an understanding of the problems that are related to the hydrology and chemical quality of ground water in the area.

This report describes the hydrologic aspects of the investigation and hydrologic principles in general as they pertain to the source, occurrence, and movement of water in the area. These principles of hydrology are then related to the specific problems of deficiency of supply, floods, conjunctive use of surface and ground water, and subsidence of the land surface. The third part, Part C, quality of water, discusses the problem of protecting and maintaining water of good quality in the Terra Bella-Lost Mills area.

The investigation was begun under the supervision of G. F. Worts, Jr., and completed under the supervision of H. D. Wilson, Jr., successive district supervisors in charge of ground-water investigations of the Geological Survey in California. Fieldwork was done by G. S. Hilton, R. L. Klausling, R. H. Dale, and D. Haskaley. Analysis of data and compilation of records were done by G. S. Hilton, R. L. Klausling, E. J. McClelland, and Fred Kunkel.

Climate

Climate, in the final analysis, is responsible for the abundance or lack of water in an area because precipitation is the ultimate source of all the water that might become available. Mild winters, long hot summers, and little precipitation, most of which falls during the fall and winter months, are typical of the Terra Bella-Lost Hills area. Moisture-laden air moving eastward from the coast is cooled and condensed as it rises over the Coast Ranges; consequently most of the precipitation is on the mountain ranges, and by the time the air mass reaches the San Joaquin Valley, it is relatively dry. Approximately 7 inches of precipitation per year is the average for the valley part of the area, whereas 20 inches may fall at Glenville in the low foothills of the Sierra Nevada.

Precipitation and temperature data for weather stations at Wasco, Angiola, and Glenville-Morrow Ranch (fig. 1) are considered representative for the Terra Bella-Lost Hills area. These data are reported in official publications of the U.S. Weather Bureau. Figure 14 shows the total monthly and long-term annual average precipitation data for the three stations. Figure 15 shows the average monthly precipitation.

The mean annual temperature at Wasco, which is typical of the entire area, is 62.7°F. Summer temperatures are quite high, frequently above 105°F, and the winter minimums are seldom below 30°F. The average frost-free period is approximately 250 days, usually from early in March to the latter part of November. Monthly mean maximum and minimum temperature data for the three stations in and near the Terra Bella-Lost Hills area are plotted on figure 16.

Precipitation directly on the floor of the valley is of little importance to the hydrology of the area--it is too little and of too short duration. On the other hand, precipitation that occurs in the mountains is of great importance in providing water at the right time and in the right quantity. Precipitation at the higher elevations is in the form of snow and thus the snowpack performs a storage function. Use of snowmelt by way of surface reservoirs permit delivery of the water during the periods of little or no precipitation.

HISTORY OF WATER DEVELOPMENT

Late in the 19th century about 23,000 acres were irrigated in the Terra Bella-Lost Hills area (Hall, 1886, sheet 1). Most of the water for irrigation was furnished by the Kern River via the Lerdo and Calloway Canals of the Kern County Land Co. In addition some water was furnished from a few flowing wells. In 1905, Mendenhall (1916, p. 252-295) reported about 26 irrigation wells in Tulare County, 1 irrigation well in Kings County, and 37 irrigation wells in Kern County all within the area of this investigation. By 1920-21 the irrigated acreage had risen to 98,000 acres. Development centered around the towns of Alpaugh, Pixley, Earlimart, Delano, McFarland, Wasco, and Shafter. Subsequently land was developed around these centers.

Detailed information is lacking for the period before 1935; however, the available data indicate that from 1920-21 to 1934-35 water use increased gradually. Surface waters were little utilized during the period 1920-35 except for those of Lear Creek and the Kern River via the Lerdo and Calloway Canals. However even this water generally was not available during June, July, and August; so for these months ground water became virtually the only source. During the period from 1920 to 1935, water levels declined and most of the flowing wells mentioned above, ceased to flow.

Pumpage in the Terra Bella-Lost Hills area increased gradually from 1935 to 1945. By 1939, the total irrigated acreage had increased to 279,000 acres, and there was a twofold increase in the acreage being supplied by ground water. The Kings, Kaweah, and Tule Rivers supplied surface water to 30,000 acres in Tulare Lake west of Alpaugh, whereas the Kern River served as a source of supply for lands adjacent to the Kern River channel, and for lands east of Wasco.

At the end of World War II pumpage began to increase (fig. 17) as land was developed both to the east and west of the previously established centers, particularly east of Pixley, west of McFarland, Wasco, and Shafter, and east of U.S. Highway 99.

In 1947-48 the rate of agricultural development of land by irrigation with ground water reached an all-time high. As a result of this rapid growth water levels declined steeply over widespread areas. By 1950 water levels near Delano had declined to depths of nearly 450 feet below land surface. Ground-water pumpage in the area reached its maximum during the year, May 1, 1950 to April 30, 1951; the estimated total was in excess of 800,000 acre-feet. The following table gives figures for irrigation water for the years 1935 to 1959.

Table 4-Estimated ground-water pumpage, water imported and total water for irrigation in the Terra Bella-Lost Hills area, Calif.

Year	Pumpage (acre-feet)	Surface water (acre-feet)	Total (acre-feet)
1935-36	180,000	110,000	290,000
1936-37	210,000	110,000	320,000
1937-38	250,000	190,000	440,000
1938-39	220,000	120,000	340,000
1939-40	230,000	120,000	350,000
1940-41	250,000	130,000	380,000
1941-42	200,000	140,000	340,000
1942-43	280,000	130,000	410,000
1943-44	260,000	140,000	400,000
1944-45	330,000	190,000	520,000
1945-46	350,000	180,000	530,000
1946-47	400,000	90,000	490,000
1947-48	650,000	40,000	690,000
1948-49	680,000	60,000	740,000
1949-50	760,000	100,000	860,000
1950-51	800,000	180,000	980,000
1951-52	650,000	320,000	970,000
1952-53	560,000	380,000	940,000
1953-54	640,000	420,000	1,060,000
1954-55	600,000	380,000	980,000

Table 4 Estimated ground-water pumpage, water imported and total water
for irrigation in the Terra Bella-Lost Hills area, Calif.--Continued

Year	Pumpage (acre-feet)	Surface water (acre-feet)	Total (acre-feet)
1955-56	620,000	570,000	1,190,000
1956-57	500,000	440,000	940,000
1957-58	440,000	550,000	990,000
1958-59	450,000	430,000	880,000

Until 1951 the amounts of water imported into the area remained relatively small (fig 17), but in 1951 water was first imported from the San Joaquin River system via the Friant-Kern Canal of the U.S. Bureau of Reclamation and used for irrigation in the vicinity of Delano. In 1951-52 pumpage decreased significantly and continued to decrease as new irrigation districts received imported water. Expansion continued in the area served by this major source of imported water from 1951 to 1958. The largest increase in use of this imported water occurred in the first 2 or 3 years after 1951, following the completion of the Friant-Kern Canal system. In 1958, about 550,000 acre-feet of water was imported into the area from the San Joaquin, Kern, Kings, Kaweah, and Tule Rivers.

In 1958, about 500,000 acres were irrigated in the Terra Bella-Lost Hills area (fig. 18).

The principal source of irrigation water has been a combination of ground water pumped from wells and surface water imported from the San Joaquin River via the Friant-Kern Canal, the Kern River via the Lerdo and Calloway Canals, the Kern River channel, and the Kings, Kaweah, and Tule Rivers via canals into Tulare Lake. Throughout the growing season ground water is pumped to supplement water imported from the Friant-Kern Canal. During dry years, and especially during the late summer months, larger quantities of ground water must be pumped.

On the Tulare Lake bed, a definite quantity of imported water usually is available throughout the growing season. Water from the Kings River is regulated by Pine Flat reservoir for irrigation use in the San Joaquin Valley. Reservoirs have been constructed (1962) to regulate flows of the Kaweah and Tule Rivers.

Present heavy pumpage is concentrated in the Pixley area, near Ducor, west of Pond, and east and west of Wasco (fig. 18). Water now is imported into the areas near Earlimart, Delano, and McFarland. Small quantities of water are imported into the Wasco area, where water levels continue to decline though at a lesser rate than in areas wholly dependent upon ground water.

GROUND WATER

Occurrence, Source, and Movement

The overall hydrology of an area requires an understanding of how water circulates through the atmosphere and the earth's crust. This circulation, defined by the term "hydrologic cycle," includes the precipitation of water from the atmosphere to the earth and its return to the atmosphere by evaporation and transpiration.

The hydrologic cycle, as shown on figure 19, has no beginning or ending because the water in the cycle is kept in motion continually by the forces of nature. Water rises salt free by evaporation from the ocean and is wind-borne across the land in the form of vapor or as the tiny condensed droplets of clouds and fog. Some of this air-held moisture falls back to the earth as snow, rain, sleet, or hail. Once on the earth distribution of the water is varied. A minor fraction makes a quick return to the ocean as runoff. Some goes underground to become ground water and either seeps slowly back to the ocean or feeds plant roots, but most earthbound water returns to the atmosphere by evaporation from land and water surfaces, and by transpiration from plants.

Water beneath the land surface occurs in a zone of aeration and a zone of saturation. In the zone of aeration voids between the mineral particles are filled partly with air and partly with water, whereas in the underlying zone of saturation, all the voids between the mineral particles are filled with water. This water below the zone of saturation is ground water.

Ground water generally occurs either under water-table (unconfined) or artesian (confined) conditions. The water table, or surface of an unconfined water body, is the upper surface of the zone saturated with water under hydrostatic pressure; it is the level at which the hydrostatic pressure is equal to atmospheric pressure. Above it is the capillary fringe, the lower part of which also may be saturated, but with water at less than atmospheric pressure. Artesian water is contained in aquifers overlain by materials of sufficiently low permeability to hold water in the aquifer under artesian pressure. An ideal confined aquifer has free movement of water within and no movement across its boundaries. It is similar to a pipe carrying water under pressure which instantly reflects through the system any change in pressure at any point in the system. From this analogy, if a well tapping a confined aquifer is pumped, a reduction in pressure should be reflected throughout the aquifer. Similarly, cessation of pumping should result in an increase in pressure throughout the aquifer. The aquifers under discussion here are not that perfect. Even the least permeable confining beds in the area permit slow, perhaps imperceptible, movement into or out of the artesian aquifer. On the other hand, owing to differences in horizontal and vertical permeability, water bodies that generally are considered to be unconfined may react to fluctuations in pressure due to pumping in much the same manner as confined water bodies, but the amplitude of such fluctuations will be less.

Because of the heterogeneous character of most unconsolidated alluvial deposits, confinement in them is commonly a matter of degree, and the time element must be considered. In most alluvial deposits there is enough hindrance to the movement of ground water between separate permeable zones that differences in head between the zones exist during periods of heavy pumping. During periods of little draft, the head in all the permeable zones may recover to a level common with the water table. Such conditions of occurrence commonly are called semiconfined, to indicate that, although various permeable zones are subject to pressure effects over short periods, the head adjusts to equilibrium with the water table over long periods of time and under steady-state conditions.

In the Terra Bella-Lost Hills area ground water that economically can be withdrawn for uses by man occurs chiefly in the unconsolidated deposits of late Tertiary and Quaternary age and locally in the upper part of the marine rocks. These rocks and deposits, as described in Part A of this report, constitute the storage reservoir for ground water. Generally, the unconsolidated deposits are more permeable than the consolidated rocks. However usable ground water occurs also in the Santa Margarita Formation of Diepenbrock (1933) and the Olcese Sand of Diepenbrock (1933), which for the most part are permeable beds within the upper part of the marine rocks. As shown on figure 13 the reservoir system contains a semiconfined aquifer system, a confined aquifer system, and two confined aquifers in marine rocks. The areal extent of these aquifers is shown on figure 20.

In the central and northwestern part of the area a widespread confining bed, the Corcoran Clay Member, underlies and separates the semiconfined aquifer system from an underlying confined aquifer system. In the eastern part of the area the semiconfined aquifer system is separated from two underlying confined aquifers in marine rocks, by widespread beds of silt and clay. In turn, these confined aquifers in marine rocks are separated from each other and are confined above and below by beds of silt and clay of marine origin. The semiconfined aquifer system owing to differences in water levels in wells can be separated into two units, a shallow-water zone and a principal-pumped zone. These two zones occur throughout most of the area. Domestic and a few irrigation wells tap the shallow zone, whereas most irrigation wells pump from the principal pumped zone.

The ultimate source of all the ground water is precipitation, most of which for the Terra Bella-Lost Hills area falls in the mountains within the water shed to the east of the area. Very little of the average annual precipitation falling directly on the area reaches the ground-water body. Most of the precipitation goes to satisfy the soil-moisture deficiency or is lost by evapotranspiration. However, part of the precipitation on the valley floor and part of the snowmelt reaching the valley floor infiltrate to the ground-water body and move from points of high head or recharge to points of low head or discharge. Under the natural conditions that prevailed before water was imported into the area and before pumping from wells began, all the ground water probably moved west and northwest from the east and southeast and discharged either by evapotranspiration in the west or by underflow to the north and northwest of the Terra Bella-Lost Hills area.

Semiconfined Aquifer System

The semiconfined aquifer system underlies most of the Terra Bella-Lost Hills area (fig. 20). As described under this heading in Part A of this report, the semiconfined aquifer system occupies parts or all of the geologic units younger than the marine sedimentary rocks of Tertiary age. The water-bearing units include basin deposits, younger alluvium, older alluvium, the Tulare Formation, and continental deposits undifferentiated. However, the bulk of the water pumped from the aquifer system occurs in the Tulare Formation and the continental deposits undifferentiated.

Within the aquifer system the degree and nature of the confinement varies laterally and vertically throughout the area. In the eastern and western parts of the area (fig. 21) the deposits are relatively impermeable and the degree of confinement is relatively great. Along Deer Creek, White River, Rag Gulch, Poso Creek, and the intervening areas along U.S. Highway 99 the deposits are relatively permeable and the degree of confinement is relatively low. In the area between Wasco, Famoso, and McFarland the deposits to a depth of about 200 feet below land surface are the most permeable in the area.

Initially, ground-water development was from shallow wells that were less than 300 feet in depth. As water levels declined, deeper wells were drilled, and the shallow wells were either abandoned or else restricted to the production of domestic supplies. Most ground water is pumped from wells that are perforated in the interval 200 to 1,700 feet below the land surface.

In general, and in contrast to natural conditions, the deep wells now have lower water levels than the shallow wells. Thus, water levels in wells perforated above 200 or 300 feet may be as much as 100 feet above those in wells perforated below 200 or 300 feet.

Shallow Zone

Occurrence.--Within the semiconfined aquifer system the shallow-water zone is separated from the principal-pumped zone by poorly permeable materials whose presence is primarily inferred from differences in water levels. These poorly permeable materials probably underlie most of the low alluvial fans and plains to depths ranging from 100 to 300 feet below the land surface.

In the southwestern part of the area, in the vicinity of the overflow lands of Buena Vista and Jerry Sloughs, and in the vicinity of Buttonwillow and Semitropic Ridges (fig. 21), data are insufficient to demonstrate separation of the semiconfined aquifer system into a shallow zone and a principal-pumped zone.

Movement.--Natural discharge from the shallow zone virtually ceased by the late 1920's. As ground-water pumpage for irrigation increased, water levels in the shallow zone declined rapidly. In areas of intense development, such as Earlimart, Delano, McFarland, Wasco, and Shafter, the demand soon exceeded the available supply from the shallow zone. Gradually, this zone was dewatered or sufficiently depleted so that it was largely abandoned as a source of irrigation water. Wells were then drilled deeper to obtain irrigation water from the "principal-pumped zone." Few wells today tap the shallow zone exclusively. Available records of water levels of the shallow zone indicate gentle hydraulic gradients toward the valley trough.

Recharge.--Recharge to the aquifer system takes place from the downward percolation of water from stream beds, such as Deer Creek, White River, Rag Gulch, and Poso Creek. Other sources of recharge are the overflow waters from the Kern River, which enter the area via Buena Vista and Jerry Sloughs, the water losses from canals and ditches, the application of irrigation water in excess of plant requirements, and the subsurface inflow of ground water from the southeast and northeast. Because the average annual precipitation is only about 6 inches and the evapotranspiration rates are high, probably little precipitation penetrates to the ground-water reservoir. The bulk of this water becomes soil moisture and is lost to evaporation and transpiration.

Recharge from the streams that cross the area is small, the estimated average annual flow of all the streams between the Kern and Tule Rivers is only 84,700 acre-feet and much of this water is lost to evapotranspiration and is not available for recharge (California State Water Resources Board, 1951, p. 407). Lerdo and Calloway Canals deliver water from the Kern River to an area bounded by an east-west line through McFarland on the north, by U.S. Highway 99 on the east, and by the road through Wasco and Shafter on the west. According to the Kern County Land Co., approximately 120,000 acre-feet was lost by seepage and evaporation from the canals during 1958 north of an east-west line through Shafter. Recharge to the semiconfined aquifer system in this same area has been supplemented since 1936 by spreading water on the land surface whenever surplus water is available from the Kern River (Trowbridge, 1950, p. 33). Application of irrigation water in excess of plant requirements may allow some water to percolate downward to the semiconfined aquifer system.

Ground-water inflow moves into the shallow zone from the northeast and southeast because water levels are higher in the semiconfined aquifers outside the area in these directions.

Discharge.---Prior to substantial ground-water development in the Terra Bella-Lost Hills area, ground water was discharged naturally by springs and seeps wherever the water table intersected the land surface. This natural discharge ceased in the late 1920's as the water table was lowered because of ground-water withdrawal. At this time, nearly all discharge from the shallow zone occurs in the form of pumping from domestic and some irrigation wells.

Water-level fluctuations.--Owing to low yields and locally to poor water quality, the shallow-water zone is not pumped extensively and thus few wells are available in which to measure water-level fluctuations. Hydrographs (fig. 22) of wells 23/23-33A1 (tube A-5), 23/25-15A1, 24/27-11C1, and 25/24-15B1 (tube D-3) whose locations are shown on figure 23 are considered representative of the water-level fluctuation in the shallow zone, although considerable irregularity in shallow-water levels exists locally. The irregularity suggests that locally the hydraulic continuity in the shallow zone may be poor.

The following table lists the wells shown on hydrographs and indicates the aquifer system tapped by each well. Where a tube number is listed in addition to the usual well number, the well is a U.S. Bureau of Reclamation test well with piezometer tubes installed at selected depths and packers set above and below the depth zones indicates on the chart.

Table 5.--Hydrographs

Well number	Perforations: : feet below : : lsd :	Altitude: : lsd : : (feet) :	Aquifer system	Figure : number
22/27-36N1	250-696	513	Semiconfined (principal)	28
23/23-33A1				
Tube A-5	0-250		Semiconfined (shallow)	22
Tube A-1	940-1,200	210	Confined (below Corcoran)	22
23/25-14C1	Depth 305	300	Semiconfined (principal)	22
15A1	Depth 126	---	Semiconfined (shallow)	22
24/26-28Q1	250-1,184	418	Semiconfined (principal)	27
29R1	288-1,245	400	do.	27
33M1	189-977	432	do.	27
24/27-11C1	0-100	537	Semiconfined (shallow). In White River channel	22
25/22- 2R1	200-625	212	Composite (above and below Corcoran)	28
2R2	270-354	212	Semiconfined (principal above Corcoran)	28
25/24-15H1				
Tube D-3	0-170	247	Semiconfined (shallow above Corcoran)	22
Tube D-1	380-600	---	Composite (above and below Corcoran)	22
26/26-10R1	400-1,000	503	Semiconfined (principal)	28
27/23- 1R1	270-610	267	Semiconfined (principal)	28
27/24-10Q1	Depth 430	305	Semiconfined (principal)	29
10Q2	240-264	306	Semiconfined (shallow and principal)	29
28/22-11M1	102-402	249	Semiconfined (mostly shallow and in part principal)	28

The hydrograph for well 23/23-33A1 (tube A-5) is characteristic of water-level fluctuations in the shallow zone in an area underlain by the Corcoran Clay Member; well 23/25-15A1 shows the fluctuations observed near the eastern edge of the Corcoran. Wells 25/24-15H1 (tube D-3) and 24/27-11C1 depict shallow zone water levels in the central and northeastern parts of the area. Water levels in all four wells have similar fluctuations, are little affected by pumpage, and have prompt response to any recharge. The fluctuations of these wells show little relationship to the fluctuations of deeper water levels indicating that the downward movement of water probably is restricted. Well 24/27-11C1 fluctuates more radically than the other three wells; these fluctuations are attributed to the surface and subsurface flow in the White River channel.

The hydrographs of wells 23/25-15A1 and 24/27-11C1 indicate a moderate seasonal fluctuation in the northeast and central parts of the area and the hydrographs of wells 23/23-33A1 (tube A-5) and 25/24-15H1 (tube D-3) indicate little or no fluctuations in the area near and underlain by the Corcoran Clay Member.

Long-term fluctuations as indicated by the hydrographs of wells 23/23-33A1 (tube A-5) and 25/24-15H1 (tube D-3) show a general but not always consistent decline in water levels; the water level in well 25/24-15H1 (tube D-3) declined in excess of 3 feet per year. Well 23/25-15A1 is an exception in that it reached a 9-year high in the spring of 1959. Water-level declines in the shallow zone range from less than 1 to about 10 feet per year, which in general is about one-third as great as the declines in the principal-pumped zone.

Future development.--Currently, only domestic and small irrigation supplies could be developed from the shallow zone. Limited further development of the shallow zone could occur in the western and northwestern part of the area where there are relatively few wells. With little or no recharge accruing to the zone, water levels can be expected to decline steadily with increased development.

Principal Pumped Zone

Occurrence.--The term "principal pumped zone" encompasses that part of the semiconfined aquifer system beneath the base of the shallow zone, about 100 to 300 feet below the land surface, and above any extensive confining bed or the base of the fresh water (fig. 13). The thickness of this zone ranges from about 100 feet near the western boundary of the area to 2,000 feet in the vicinity of Delano. Perforated intervals of irrigation wells tapping this zone range from about 200 to 1,500 feet below land surface.

In the northwestern and central part of the Terra Bella-Lost Hills area, the Corcoran Clay Member serves to separate the principal-pumped zone from a deeper, confined water body (figs. 13 and 20). Where the Corcoran is absent, the bottom of the principal-pumped zone is the base of the fresh water which may be as great as 1,700 feet below the land surface or the top of the confining beds overlying the Santa Margarita Formation of Diepenbrock (1933).

In the area underlain by the Corcoran Clay Member, water levels in the principal-pumped zone above the clay differ from those in the confined water body below the clay. However, where the Corcoran is thin or absent, the principal-pumped zone has a head common to both the principal-pumped zone above the Corcoran and the confined water body below it, and there is direct hydraulic interaction between them.

In the southwestern part of the area the semiconfined water body is characterized by apparently anomalous water levels. The altitude of the water surface beneath Jerry and Buena Vista Sloughs, as shown on figure 24, is about 100 feet shallower than beneath Buttonwillow and Semitropic Ridges. The higher water surface beneath the sloughs suggests the possibility of a semiperched water body. However limited well-log data indicate no widespread relatively impermeable deposits beneath the sloughs. Also, as shown by figure 25, the water-level contours beneath Buena Vista and Jerry Sloughs appear to merge with the water-level contours of the principal-pumped zone north of the confluence of the sloughs. Therefore, based on existing data, a shallow zone in the vicinity of Buena Vista and Jerry Sloughs has not been positively identified.

Movement.--Prior to substantial ground-water development in the area, water levels were at or near land surface, gradients probably were toward the trough of the valley, and ground water was discharged into swamps or seep zones. This is substantiated by water-level profiles (figs. 24 and 26) which show that the 1921 water-level gradients were toward the valley trough.

With development of ground water for irrigation, natural discharge virtually was halted by the late 1920's. By 1952 water levels had declined nearly 200 feet below the levels of 1921 (fig. 26). Maximum declines were observed in the vicinity of Pixley, Delano, and Shafter where ground-water supplies for irrigation have been developed extensively.

Beginning in 1950, imports of water by the Friant-Kern Canal locally resulted in a substantial reduction of pumpage and a recovery of water levels, as shown by figure 27.

The water-level contours of the principal-pumped zone for the spring of 1959 (fig. 25) show an overall water-level gradient to the west and local ground-water mounds in the Delano and Famoso area that probably are due to the use of imported surface water and a decrease in the withdrawal of ground water. Specifically, ground water is moving into the area from the northeast where higher water levels exist beneath Deer Creek and associated alluvial fans. Ground-water gradients slope northward from the alluvial fan of the Kern River, as shown by the broad ground-water mound extending northward as far as McFarland. This mound has resulted from heavy pumping of ground water to the west and east and to the long-continued application of irrigation water that is imported from the Kern River through canals. Water-level contour maps for the years subsequent to this report are available on request from the State Department of Water Resources.

Recharge and discharge.--Throughout the area water levels are higher in the shallow zone than in the principal-pumped zone. Therefore, wherever hydraulic interconnection between the shallow and principal-pumped zone is effective some of the water from the shallow zone probably recharges the principal-pumped zone. Ground-water movement into the area from the east probably represents inflow of water infiltrating the continental deposits undifferentiated (fig. 3) and moving down gradient westward as shown by the water-level contours (fig. 25).

Prior to substantial ground-water development in the Terra Bella-Lost Hills area, ground water was discharged naturally by springs and seeps wherever the water table intersected the land surface and in the trough of the valley. Upward movement of semiconfined and confined water through the confining layers gave rise to swampy conditions in many areas of the valley. Natural discharge ceased in the late 1920's when ground-water withdrawals began to reach significant proportions. Currently, nearly all discharge is artificial and predominantly consists of ground water withdrawn from the principal-pumped zone pumped for irrigation.

Water-level fluctuations.--The principal-pumped zone occurs for the most part below 200 feet throughout the Terra Bella-Lost Hills area. During periods of pumping, water levels show fluctuations characteristic of a confined-water body but during periods of no pumping, they tend to recover and maintain static levels similar to those in the overlying shallow zone. This behavior indicates hydraulic connection between the two zones, but this connection is restricted by intervening beds of relatively low permeability.

Hydrographs of wells 22/27-36N1, 25/22-2N1, 26/20-10R1, 27/23-1R1, and 28/22-11L1 (fig. 28); 23/25-14C1 (fig. 22); 24/26-28Q1 and 33H1 (fig. 27); and 27/24-10Q1 and 10Q2 (fig. 29) show fluctuations of water level in the principal-pumped zone of the semiconfined water bodies. The hydrographs show that water levels in these wells have immediate response to pumping, wide seasonal fluctuations, and fairly regular trends over a period of years. The degree of confinement in the principal-pumped zone is not uniform; some fluctuations correlate with water levels in the shallow zone whereas others tend to correlate better with water levels in the confined water body below the Corcoran.

Water levels in well 23/25-14C1 (fig. 22) near the eastern edge of the Corcoran Clay Member show seasonal fluctuations on the order of 30 feet and an irregular annual decline of 2 to 3 feet per year. The reversal of this trend in 1958-59 is due to the reduced pumpage following the wet winter in 1957-58 and the importation of water for irrigation. The 2 years of record for well 26/26-10R1 indicate seasonal fluctuations of 20 to 30 feet but do not establish any long-term trend.

Hydrographs for wells 27/24-10Q1 and 10Q2 (fig. 29) show long-term water-level fluctuations. The water level in these wells, measured monthly by the owner, Mr. Ellie Crettol, show that for the period 1930-45 the yearly high levels were nearly the same. Extensive development, starting in 1945-46, caused a rapid decline of the static water level. Water levels dropped from about 60 feet to about 140 feet below land-surface datum by January 1957, and seasonal fluctuations were greater than 100 feet. This hydrograph shows much less drawdown during the 1958 pumping season probably because of the wet year in 1957-58 and because water was imported into the Shafter-Wasco Irrigation District via the Friant-Kern Canal. These two events combined to reduce pumpage in this locality.

Section B-B' (fig. 26) and hydrographs of wells 25/24-15H1, Tube D-1 (fig. 11) and 27/23-1R1 (fig. 17), show that water levels in the principal-pumped zone continued to decline from 1952 to 1959, except in the Delano area (fig. 27) where importation of water and a decrease in ground-water use caused water levels to start their upward trend. Water levels along the southern profile continued to decline from 1952 to 1959 (fig. 24).

Hydrologic properties.--Ground water moves, in accordance with natural laws, in an intricate network of voids within a framework of mineral particles. The rate and direction of this movement are controlled by the properties of the framework and the contained fluid, the forces of molecular attraction, and gravity. The most important of the framework properties are porosity^{1/} and permeability.^{2/}

1. Porosity, the ratio of the aggregate volume of interstices in a rock or soil to its total volume.
 2. Permeability, the capacity of a rock or soil to transmit fluid.
-

Commonly the permeability of an aquifer differs in the horizontal and vertical directions. Bedding planes and stratification of the various deposits restrict flow to some extent and therefore permeability usually is greatest parallel to the bedding.

Aquifer properties may be determined in the field by aquifer tests. The results of these tests are expressed as the coefficient of transmissibility (T), which is the rate of flow of water, in gallons a day, at the prevailing water temperature, through each vertical strip of the aquifer having a height equal to the thickness of the aquifer and under a unit hydraulic gradient, and as the coefficient of storage (S), which is the volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in the component of head normal to that surface.

Aquifer tests in the semiconfined aquifer system were made at five locations in the Terra Bella-Lost Hills area (fig. 23) on the property, and with the assistance and cooperation, of the Kern County Land Co. The results of the five pumping tests are given below. The heterogeneity of the deposits tested precludes determination of absolute values for coefficients of transmissibility and storage. The results shown in the following table may indicate relative magnitude of T between tests but make no allowance for leakage from storage in semipermeable materials in the aquifer and possibly related compaction of the aquifer, or for leakage through semipermeable material above or below the aquifer. Values for S are not given because all of the tests were too short.

Table 6.--Results of aquifer tests

Well pumped	T gpd/ft	Approximate interval tested (below land surface datum)
26/24-4 (204-4) ^{1/}	350,000	150-500
26/25-26N1	300,000	340-800
27/24-35K1	450,000	200-550
27/25- 3J2	290,000	350-800
27/26-30F1	460,000	250-750

1. Well location by Kern County Land Co.

Future development.--Future development of the principal-pumped zone for most of the area is restricted by lack of recharge. At present, by far the largest quantities of ground water in the area are extracted from this zone. With the exception of the northwestern and western parts, the principal pumped zone is developed intensely throughout most of the area.

Further development of the principal pumped zone for water supplies might be undertaken in the area between Alpaugh and Pixley and the area west of Pond and Wasco, north of Semitropic Ridge, and south of Tulare Lake (fig 20). Any further development in these two areas will be affected and restricted by several factors: (1) the occurrence locally of inferior chemical quality of water in the shallow zone and the upper part of the principal pumped zone, (2) the occurrence of saline waters at depth, and (3) continuous decline in water levels because of lack of recharge and possibly by an increase in the rate of decline to accompany the increased withdrawal of ground water.

Confined Aquifer System

A confined fresh-water aquifer system underlies about 650 square miles of the northwestern part of the Terra Bella-Lost Hills area beneath the Corcoran Clay Member and above an interface between fresh and saline water. Beneath the Corcoran this aquifer ranges in thickness from less than 100 feet near the western edge of the area, to as much as 1,400 feet near the eastern edge of the Corcoran.

In 1905 Mendenhall reported that this confined aquifer system was under sufficient head to cause wells to flow throughout much of the central part of the San Joaquin Valley. About 250 flowing wells were reported in the Terra Bella-Lost Hills area alone (Mendenhall and others, 1916, p. 256-280, 284-288, 295-306). By 1959, artesian pressures had declined to the point that the head in the overlying semiconfined aquifer system was higher than in the deeper confined aquifer system.

The hydraulic gradient in the confined aquifer system prior to 1952, based on the little information available, probably was toward the center of the valley from areas of recharge to the east and west. Water-level contours of the confined aquifer system below the Corcoran Clay Member as of the spring of 1959 are shown on figure 30. Although control points for the contours are few, the water-level contour map shows the hydraulic gradient sloping to the west and north at 1 to 5 feet per mile.

The water-level depression centering around Alpaugh probably results from the combined effects of the permeability of the water-bearing deposits and the pumping, rather than the pumping alone. This is based on geologic evidence which indicates that the deposits are fine grained near Alpaugh. The heaviest pumping is actually farther east in a thicker section of more permeable material but the lesser permeability around Alpaugh causes water levels to be lower than those in the area of heaviest pumpage.

Most of the recharge to the confined aquifer system comes from subsurface inflow from the principal pumped zone of the semiconfined water beyond the effective limit of confinement by the Corcoran Clay Member. Ground water moves in this zone under semiconfined conditions, but once it moves north or west to where it is effectively confined by the Corcoran Clay Member, it becomes part of the confined aquifer system (figs. 13 and 20). Some replenishment also probably occurs by slow downward percolation of water through the Corcoran Clay Member and by movement through well casings and gravel packs where the water level in the confined aquifer is lower than that in the overlying principal pumped zone of the semiconfined aquifer system.

In the central part of the San Joaquin Valley before 1920, flowing wells were obtained by drilling into the confined aquifer system. Heavy withdrawals of ground water for irrigation between 1920 and 1930 caused a decline in water levels and wells ceased to flow. All ground-water discharge today (1959) is by pumping.

Water-level hydrographs and measurements show differences in seasonal fluctuations of water levels for the semiconfined and the confined aquifers. The confined aquifer system below the Corcoran Clay Member has deeper water levels and greater magnitude in the seasonal water-level fluctuations than in the semiconfined aquifer system. The hydrograph of well 23/23-33A1, Tube A-1 (fig. 22), shows water-level fluctuations below the Corcoran Clay Member. The annual water-level decline is 10 to 15 feet and seasonal fluctuations are about 50 feet. Following the wet winter of 1957-58, a reduction in pumping was followed by a water-level recovery.

Many of the wells penetrating below the Corcoran Clay Member are perforated both above the Corcoran in the semiconfined aquifer system and below the Corcoran in the confined aquifer system and indicate water levels that are a composite of both aquifer systems. For example wells 25/22-2E1 and 25/24-15H1, tube D-1 (figs. 28 and 22) are perforated both above and below the Corcoran. The water-level fluctuations in well 25/22-2E1, in an area of relatively little pumping, are similar to those in well 25/22-2E2 (fig. 28) and demonstrate the effect of confinement. The water level in well 25/24-15H1, tube D-1, near the southeastern boundary of the Corcoran, fluctuates as much as 110 feet per year and indicates the effect of pumping in the principal pumped zone and in the confined aquifer system below the Corcoran.

Water supplies of satisfactory quality might be developed more extensively from the confined water body in several areas: (1) between Alpaugh and Pixley; and (2) from the eastern part of T. 25 R. 21 to the vicinity of Pond. West of the trough of the valley and beneath Tulare Lake, water in the confined water body becomes saline in character. However because discharge exceeds recharge to the confined water body, further development will result in continued overdraft and increased rates of decline in water levels. Any large increase in pumpage from the aquifer also will extend its effect beyond the edge of the Corcoran Clay Member to lower water levels and cause further depletion of the ground water in storage in the principal pumped zone of the semiconfined aquifer system.

Confined Aquifers in Marine Rocks

Santa Margarita Formation of Diepenbrock (1933)

The Santa Margarita Formation of Diepenbrock (1933) has a sub-surface extent of approximately 800 square miles (fig. 20). One of the earliest wells to penetrate the Santa Margarita was drilled in the SW $\frac{1}{4}$ sec. 8, T. 25 S, R. 27 E. in 1954. In 1955, 13 more wells were drilled into the aquifer, and each succeeding year the number of wells pumping from this water body has increased. The largest yield reported to date (1959) is 1,950 gpm (gallons per minute). Static water-level measurements made before 1956 are available from wells penetrating the Santa Margarita but the general geology of the area suggests that hydraulic gradient until that time probably sloped to the west at less than 10 feet per mile. The static water-level measured by the Rag Gulch Mutual Water Co., for March 1956, ranged from 219 to 321 feet below land surface. Water-level contours, based on these few measurements, show that the hydraulic gradient ranged from less than 10 feet per mile to about 30 feet per mile (fig. 31). The depression immediately east of Richgrove probably resulted from pumping of wells 24/27-29P1 and 32K1, drilled in the spring of 1955.

The water levels in wells (figs. 31 and 32) declined annually an average of about 20 feet for the three years 1956 to 1959. Static water levels for March 1959 ranged from 276 to 382 feet below the land surface, and the water-level contours made from these measurements, show a maximum hydraulic gradient of about 30 feet per mile (fig. 32). An increase in the number of wells pumping from the aquifer since 1955 has resulted in an overall water-level decline and increase in hydraulic gradient; furthermore, this increase in gradient has become more widespread.

Because the Santa Margarita does not crop out at land surface, recharge must come from downward percolation of precipitation or stream runoff through deposits overlying the aquifer. Because the deposits overlying the Santa Margarita are fine grained, recharge probably is small and ground-water development of the formation, therefore, has been accompanied by a continuous decline of water levels, and most of the ground water pumped has been drawn from storage. All discharge from the aquifer results from pumping of wells in the Richgrove-Terra Bella area or from discharge into other deposits. In 1958, approximately 13,000 acre-feet was pumped from the Richgrove aquifer.

Possibilities for future development of the Santa Margarita Formation appear to be limited because of limited recharge to the water body. Further development of the aquifer, therefore, will result in a continuous decline of water levels. In addition, the usefulness of the aquifer decreases in an easterly direction because its thickness decreases, and in a westerly direction because the salinity increases and the permeability decreases.

Olcese Sand of Diepenbrock (1933)

The Olcese Sand of Diepenbrock (1933) underlies about 800 square miles along the east side of the Terra Bella-Lost Hills area (fig. 20). Lack of detailed data restricts discussion of the hydrology of the Olcese to a few general conclusions.

Only two water wells, one in sec. 30 and one in sec. 31, T. 24 S., R. 28 E., were known to pump from the Olcese in 1959. Depth to water in these wells in 1957 was 372 and 435 feet below land surface. Geologic surface and subsurface studies show that the Olcese does not crop out at the land surface. Because fine-grained deposits overlie the aquifer, recharge from deep infiltration of precipitation and surface-water runoff probably is small. Increased pumping will cause lowering of water levels and a depletion of the ground water in storage.

The physical character of the Olcese Sand based on examination of electric logs of oil-test wells probably is similar to that of the Santa Margarita. The Olcese is irregular in shape, not everywhere perfectly confined above and below, and composed of zones differing in permeability. Completely free movement in any direction may be impeded, and there is some movement of water through the confining clays above and below the aquifer. Also east of Richgrove the Santa Margarita Formation and Olcese Sand may be hydraulically interconnected.

A potential area for limited development of ground water lies west of R. 28 and north of T. 28. Northern and western boundaries have not been established, but the aquifer is known to underlie the area as far north as the town of Terra Bella. West of the town of Richgrove, water within the aquifer becomes increasingly saline, thus presenting a possible problem similar to that in the Santa Margarita.

WATER-USE PROBLEMS

Deficiency of supply, floods, conjunctive use of surface and ground water, and subsidence of the land surface are the principal problems directly related to the hydrology of the Terra Bella-Lost Hills area.

Deficiency of Supply

The greatest present and future water deficiencies in California are in the San Joaquin River and Tulare Lake basins in the San Joaquin Valley (California Dept. Water Resources, 1957, p. 119). Almost all available precipitation is consumed by evaporation, transpired by vegetation, or used to reduce the existing soil-moisture deficiencies. However, during periods of large runoff, some surface flow may be sufficient to provide seepage downward through stream beds to the ground-water bodies, but generally runoff is too small to provide recharge in significant amounts. Deficiency of the supply, therefore, has resulted in a substantial overdraft in the area.

Water requirements in the Terra Bella-Lost Hills area are being fulfilled by withdrawal from the ground-water reservoir and by importation of surface water from the San Joaquin and Kern Rivers via the Friant-Kern Canal of the U.S. Bureau of Reclamation and the canals of the Kern County Land Co. These supplies are inadequate to meet the present needs for water, however, and in areas not receiving imported water the withdrawal of ground water for irrigation greatly exceeds the amount being returned to the ground water by natural and artificial recharge. Ultimately, it is planned that the aqueduct of the proposed Feather River Project (California Dept. Water Resources, 1957, p. 142) will provide the additional water needed

Floods

Floods of the rivers and streams in the geologic past have transported into the San Joaquin Valley the materials that comprise the great thickness of the present valley fill. Agriculturally, man has found the valley-fill areas to be extremely productive, and accordingly many agricultural activities are adjacent to or on the flood plains of the streams. Thus crops and other property are exposed to the possibility of damage or destruction by flood.

Flooding in the Terra Bella-Lost Hills area occurs only during infrequent periods of heavy runoff from the principal streams. Flooding that does occur could be controlled adequately by constructing small reservoirs on Deer Creek, White River, and Poso Creek. Under the proposed California Water Plan, flood control on Deer Creek, White River, and Poso Creek would include construction of a relatively small reservoir on each stream (California Dept. Water Resources, 1957, p. 143). Excess flood waters of the Kern River and the aforementioned streams would be discharged into the proposed Sand Ridge Reservoir and would be impounded south of the natural sand ridge bordering Tulare Lake.

Conjunctive Use of Surface and Ground Water

Full utilization of water supplies potentially available for the Terra Bella-Lost Hills area will require conjunctive operation of surface-water supplies and underground storage capacity of the ground-water reservoir. Only regulation of surface reservoirs and conveyance systems and also the storage space available underground can provide the large volumes of water required over long periods of less than average precipitation. Conjunctive operation of imported water with its storage and distribution system and the ground-water reservoir will conserve the available ground-water supply by providing maximum recharge to the ground-water reservoir during periods of above average precipitation.

Two pertinent features of conjunctive operation must be considered: (1) ground water would be pumped when imported water is not available, and (2) excess imported water, when available, would be used to recharge the ground-water reservoir depleted by pumping during those months or years of water shortage when imported surface water is not available.

Artificial recharge may be defined as the deliberate or incidental introduction of water into the ground-water reservoir. The recharge may be accomplished by (1) water spreading, which includes diverting water into basins, ditches, or furrows; and (2) injection of water into wells. Water spreading is practical only in those areas underlain by permeable materials both at the surface and at depth while injection requires adequate permeability at depth. In addition water of suitable quality must be available both in the aquifer and for recharge.

Figure 21 differentiates those areas underlain by permeable to moderately permeable deposits from those underlain by relatively impermeable deposits. In general, the area underlain by the permeable deposits as shown on figure 21 corresponds to the areas (fig. 2) along the east side of the valley underlain by low alluvial plains and fans, and by river flood plains and channels. The areas underlain by relatively impermeable deposits correspond to low alluvial plains and fans along the east side of the valley, dissected uplands, and to overflow lands and lake bottoms.

Even though an area may be underlain by permeable deposits, artificial recharge through water spreading may be ineffective owing to changes in permeability encountered in the subsurface. Hardpan zones, which restrict downward movement of water, have been found within a few feet of the land surface in many parts of the area. Also throughout a large part of the area underlain by permeable deposits, fine-grained, poorly permeable deposits are encountered from about 150 to 300 feet below the land surface.

To determine potential sites for water spreading, drillers' logs of wells were examined to determine the depths to which the permeable deposits extend below land surface. Figure 10 shows that permeable deposits underlie a large part of the channel and alluvial fan of Poso Creek to a depth of about 100 feet in the vicinity of Fameso and to a depth of 200 feet about 6 miles northwest of Fameso. The absence of well logs precludes an estimate of the thickness of the permeable deposits in the channel of Poso Creek southeast of Fameso. South of Earlimart along the White River permeable deposits extend to a depth of about 100 feet and north of Terra Bella along the channel of Deer Creek they extend to at least 50 feet. The permeable deposits beneath the channel of Deer Creek may extend to depths greater than 50 feet; however, this cannot be determined from existing data because wells in this area do not exceed 50 feet in depth.

Insofar as known the only successful artificial recharge of substantial quantities of water in the Terra Bella-Lost Hills area has been by water spreading. Water spreading has been practiced since 1936, according to Kern County Land Co. records, in the vicinity of Wasco, Famoso, and Shafter at the sites shown in figure 10. During this period the annual quantities of water spread have ranged from 0 to approximately 95,000 acre-feet in 1958. This water is introduced through spreading basins and is the major source of artificial recharge to the ground-water bodies. This recharge is augmented by seepage from Calloway and Lerdo Canals (North Kern Water Storage District, 1960, p. 33).

Recharge by injecting water into wells has been practiced in a few isolated wells in the area. In these few instances it reportedly was difficult to maintain satisfactory rates of recharge. Contrasted to water spreading, far less water has been recharged into the ground-water reservoir by this method. No experiments using modern injection methods are known to have been conducted in the Terra Bella-Lost Hills area. In view of the successful use of injection methods elsewhere and the problems of water spreading imposed by local geology, any plan for artificial recharge should include study regarding the possibility of injecting large quantities of water into wells.

Because fine-grained, poorly permeable deposits generally are encountered from about 150 to 300 feet below land surface, the major part of the water recharged by water spreading goes to the shallow-water zone of the semiconfined water body. However, once underground the water probably moves through and around fine-grained deposits of low permeability and recharges the principal pumped zone of both the semiconfined water body and the confined water body beneath the Corcoran. The hydrology of the confined aquifers in marine rocks in the eastern part of the area is complex and the data are fragmentary. Consequently, it is not known to what extent and how rapidly recharge will effect those aquifers.

In addition to the problems of finding permeable deposits to recharge the quality of the water available for recharge and the quality of water in the aquifer must be considered. Replenishing an aquifer with water of a type different than the native ground water might cause chemical reactions resulting in a precipitate that would cement the deposits and cause a decrease in storage capacity. Also, where the ground-water quality is inferior that water would have to be flushed from the materials and (or) diluted with water of better quality to utilize most effectively the storage capacity of the deposits.

If a sufficient supply of imported water can be made available during periods of low demand, additional and substantial quantities of water probably could be recharged to the depleted ground-water reservoir. However, any contemplated site for water spreading should be examined carefully not only to determine whether the surface soils are permeable, but also to determine whether there are subsurface restrictions that might retard downward movement of water and whether there are water-quality problems. Therefore, as part of any program to select additional water-spreading sites, a test-drilling program should be included to determine more accurately, at proposed water-spreading sites, the extent, thickness, permeability, and changes of permeability with depth of the permeable deposits. In addition, where considerable differences of water quality exist between the native water and the recharge water, geochemical studies should be made to determine whether the waters are compatible.

Subsidence of the Land Surface

Subsidence of the land surface in the Terra Bella-Lost Hills area was first noted in 1935 by I. R. Althouse (Ingerson, 1941, p. 40-42) who called attention to the possibility of a definite land subsidence in the vicinity of Delano. Ingerson prepared a map for the period 1902-1940 which showed that subsidence had occurred in a 200-square-mile area between Famoso and Pixley; the map also showed that maximum subsidence of 5 feet had occurred in a small area 3 miles north of Delano. Subsequent studies by the Geological Survey indicate that for the period 1902-1954 the maximum subsidence has been 10.2 feet about 4 miles north of Delano.

From comparison of long-term hydrographs and subsidence graphs, Poland and Davis (1956, p. 287-291) concluded that land subsidence in the area east of Delano was closely associated with decline of water levels. Comparison of subsidence graphs and long-term hydrographs (Poland, Davis, Lofgren, and others, 1958) show that with importation of irrigation water through the Friant-Kern Canal beginning in 1951, water levels in the area east of Delano began to rise, and during the period 1954-57 the recovery of water levels had brought about a virtual cessation of subsidence.

Land subsidence is the result of compaction of unconsolidated alluvial and lacustrine and swamp deposits as ground-water levels are lowered by intensive pumping. The subsidence occurs in areas where there is intensive pumping from confined and semiconfined aquifer systems. Records indicate that compaction measured by recorders is directly related to decline in water levels. Iofgren (1961, p. 49) concluded that, " * * * Compaction of the unconsolidated deposits takes place as the artesian pressure decreases, thus transferring more of the overburden load to grain-to-grain contacts of the aquifer. The compaction is due chiefly to a nonelastic rearrangement of the grains of the deposit and results in a permanent decrease in volume. A small part of the compaction is elastic and samples tested in the laboratory for consolidation show minor rebound when unloaded. However, rebound or expansion of the aquifer system has not been observed in the field measurements."

Although importation of irrigation water via canals has resulted in rising water levels and virtual cessation of land subsidence in some areas, continued intensive pumping accompanied by compaction of the unconsolidated deposits persists in the area between Delano and Earlimart, and in the vicinity of Pixley. Maximum subsidence in these areas for the period 1930-59 has been about 9 feet.

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PART C

QUALITY OF WATER OF THE TERRA BELLA-LOST HILLS AREA,
SAN JOAQUIN VALLEY, CALIFORNIA

By E. J. McClelland and G. S. Hilton

ABSTRACT

The Terra Bella-Lost Hills area includes about 1,700 square miles in the southeastern part of the San Joaquin Valley. Drainage in this part of the San Joaquin Valley is tributary to Tulare Lake, a basin of interior drainage. Mild winters, long hot summers and little precipitation are typical of the area.

This report is the last of three reports covering geology, hydrology, and quality of water of the area. Chemical analyses of water samples are used to classify waters for irrigation use according to the sodium hazard, salinity hazard, and boron content.

Surface water is generally of good quality from intermittent streams in the area. Calcium bicarbonate water with less than 300 ppm dissolved solids is common to all surface waters except where degraded by waste water. The Poso Creek drainage receives water from oilfield waste disposal; analysis of water from the creek indicates it is sodium chloride in character with dissolved solids more than 1,000 ppm and with boron ranging from less than 1 to more than 3 ppm.

Ground-water quality in the Terra Bella-Lost Hills area varies laterally and vertically. A semiconfined aquifer system is identified in two zones; less than and greater than 300 feet below land surface. Water from wells less than 300 feet deep in the center of the area is satisfactory for irrigation use. In Tulare Lake bed shallow waters are reported of poor quality. Analysis of water from below 300 feet indicates good quality in the northern part of the area. In the central part of the area the semiconfined water below 300 feet is generally usable, but in the west there is evidence of poor quality water moving into the area from the west side of the San Joaquin Valley. Near the southern boundary in the vicinity of Highway 99 water from the south has a high salinity hazard and high nitrate content. To the west in the ridges and sloughs there is sodium chloride water with varying hazards, depending on dissolved solids concentration. In the western part of the area and south of Tulare Lake bed water from the semiconfined aquifer system on the west side of the San Joaquin Valley contain boron in quantities that are marginal to excessive for irrigation water.

One confined aquifer system and two confined aquifers in marine rocks are identified in the area. The water in the confined aquifer system below the Corcoran Clay Member of the Tulare Formation is of good quality for irrigation except in the west where water from the east and west sides of the valley probably are mixed. Water from the Santa Margarita Formation of Diepenbrock (1933), a confined aquifer in marine rocks is medium high salinity and high to very high sodium hazard irrigation water. Water of this quality is usable when properly treated but may become a problem over a long period of time. An interface between fresh water and salt water is identified from electric logs a short distance west of the town of Richgrove. The water from a second confined aquifer in marine rocks, the Olcese Sand of Diepenbrock (1933), has not been analyzed but it probably is similar to that in the Santa Margarita Formation.

The position of the base of the fresh water in the area, estimated from electric logs, is shown on the four geochemical sections. This interface slopes eastward from the trough of the valley and is probably continuous from beneath the Corcoran Clay Member into the semiconfined aquifer system.

Protection and maintenance of satisfactory water quality are among the present and future water problems in the area. Deficiency of supply has resulted in drilling deeper wells which must avoid intercepting water of unsatisfactory quality. Disposal of waste water must be controlled to prevent future degradation. The area is a closed system draining into Tulare Lake therefore drainage must be provided for removal of harmful salts in the sump area.

PURPOSE AND SCOPE OF THE INVESTIGATION

As part of the program of ground-water investigations in cooperation with the California Department of Water Resources, the U.S. Geological Survey, in July 1956, began a study of the Terra Bella-Lost Hills area to provide information pertinent to the solution of the principal water problems of the area. The principal water problems related to water use in the San Joaquin Valley are: (1) deficiency of supply, (2) floods, (3) how best to utilize surface and ground water conjunctively, (4) subsidence of land surface, and (5) protection and maintenance of water of good chemical quality. Of these, only flooding is not a critical problem in the Terra Bella-Lost Hills area.

The study of water-use problems in the Terra Bella-Lost Hills area is reported in three parts. The first part, Part A, Geology, describes the geologic units of the area, their water-bearing character, and the framework within which ground water occurs and moves. Geology is presented first because it is fundamental to an understanding of the problems that are related to the hydrology and chemical quality of ground water in the area.

The second part, Part B, Hydrology, is concerned with the hydrologic aspects of the investigation and hydrologic principles in general as they pertain to the source, occurrence, and movement of both surface and ground water in the area. These principles of hydrology are then related to the specific problems of deficiency of supply, floods, conjunctive use of surface and ground water and subsidence of land surface. This report, the third part, is concerned with the problems related to the protection and maintenance of water quality in the Terra Bella-Lost Hills area.

The investigation was begun under the supervision of G. F. Worts, Jr., and completed under the supervision of H. D. Wilson, Jr., successive district supervisors in charge of ground-water investigations of the Geological Survey in California. Fieldwork was done by G. S. Hilton, R. L. Klausning, R. H. Dale, and D. Blakely. Analysis of data and compilation of records were done by E. J. McClelland and G. S. Hilton.

WATER-QUALITY CLASSIFICATION

Concentration of dissolved solids in samples of water are determined by chemical analysis. The data from an analysis permits classification of the water for various uses according to established standards for domestic, agricultural and industrial uses. In the Terra Bella-Lost Hills area, classification of agricultural, and more specifically irrigation water, is of primary concern.

Following the usage of Piper and others (1953, p. 26) the terms describing the general chemical character of a water are used in particular senses, as in the following example: "(1) 'calcium bicarbonate' designates a water in which calcium amounts to 50 percent or more of the bases and bicarbonate to 50 percent or more of the acids, in chemical equivalents; (2) 'sodium calcium bicarbonate' designates a water in which sodium and calcium are first and second, respectively, in order of abundance among the bases but neither amounts to 50 percent of all the bases; and (3) 'sodium sulfate bicarbonate' designates a water in which sulfate and bicarbonate are first and second in order of abundance among the acids, as above."

In addition irrigation water is classified after Wilcox (1955, p. 9) and as shown by figure 33, as having low, medium, high, and very high salinity and alkali hazard. Electrical conductivity is used to determine salinity while sodium adsorption ratio (SAR) is used to show the sodium (alkali) hazard. The SAR expresses the relative proportion of sodium that can be adsorbed by soil when the water is used for irrigation. The analyses of water shown on figure 33 range from suitable for most crops and most soils to those which are not usually suitable for irrigation use. However, because of the empirical nature of the equations used to develop the method, the classification is not absolute and should be used for general guidance only (U.S. Geol. Survey, 1954, p. 12).

A third hazard, the occurrence of boron in toxic concentrations in some irrigation water, makes it necessary to consider also this element when assessing the quality of water. The following table by C. S. Schofield shows limits for boron concentration (Ham, 1959, p. 245). The behavior of any crop in relation to boron concentration will vary, depending on soil texture properties, climate, and plant physiological properties (California Dept. Water Resources, written communication, 1962), consequently the ranges of values given in table 7 cannot be considered as fixed limits.

Table 7.--Rating of irrigation water for various crops
on the basis of boron concentration in the water

Classes of water	Sensitive crops (ppm)	Semitolerant crops (ppm)	Tolerant crops (ppm)
Excellent	<0.33	<0.67	<1.00
Good	.33 to .67	.67 to 1.33	1.00 to 2.00
Permissible	.67 to 1.00	1.33 to 2.00	2.00 to 3.00
Doubtful	1.00 to 1.25	2.00 to 2.50	3.00 to 3.75
Unsuitable	>1.25	>2.50	>3.75

All three of the hazards described are present in some parts of the Terra Bella-Lost Hills area. Salinity represents a hazard due to the limited tolerance of crops to salt concentration in water used by the plants. This tolerance varies depending on the crop grown, local circumstances such as soil and climate, and on adequate drainage to remove harmful concentrations. The hazard can be reduced by careful crop selection, provision for drainage and by dilution with water of better quality. Adsorption by the soil of excessive quantities of sodium will reduce soil permeability tending to cause a hard crust to form at the surface. The sodium hazard can be controlled by treatment of the soil or water by applying a substance such as gypsum which increases the available calcium. Boron concentration represents a problem similar to the salinity hazard. This problem can be handled by crop selection, drainage, and dilution in the same manner as high salinity. Hem (1959, p. 246, 249) lists crops according to relative tolerance to boron and salinity as given in U.S. Department of Agriculture Handbook 60.

The character of the waters in selected samples are shown on figure 34. The results of analyses of samples are shown plotted as percent reacting values on diagrams with five radial coordinates (after Hem, 1959, p. 180). Each leg is measured in percentage, zero at the center to 100 at the outer end. The constituents determined by chemical analysis and calculated as percentage reacting values are plotted along the appropriate legs as indicated in the explanation on figure 34. The cations, calcium (Ca), magnesium (Mg), sodium (Na), and potassium (K) are plotted on the two legs extending upward from the center of the figures. The sum of the cations equals 100 percent. The anions, carbonate (CO_3), bicarbonate (HCO_3), sulfate (SO_4), chloride (Cl), fluoride (F), and nitrate (NO_3) are plotted on the three remaining legs and the sum of the anions equals 100 percent. Connecting lines were drawn between plotted values on adjacent legs of the diagrams forming shapes which symbolize the chemical character of the water analyzed.

All chemical analyses of water used in this investigation are tabulated in a mimeographed basic data report on file with the Geological Survey, Sacramento, Calif.

SURFACE WATER

The Terra Bella-Lost Hills area receives surface water from five streams along the east side of the valley and from the Kern River, south of the area. These streams, Deer Creek, White River, Rag Gulch, Pose Creek, and Little Creek which drains into Pose Creek, are all intermittent and water from the Kern River reaches the area in flood stage only. The quality of these waters generally is good where not degraded by the activities of man.

Surface waters are a limited source of recharge to ground-water bodies in the Terra Bella-Lost Hills area and have some effect on the quality of subsurface waters. This is shown by the analysis of water from well 24/28-21D2 in White River channel (figs. 34 and 35) which is similar to the analysis of White River water though higher in total solids. Over much of the area, as described in Part B (Hydrology) of this report, the hydrologic evidence indicates that a permeability restriction probably exists at a depth of 100 to 300 feet.

The quality of surface waters in the area generally is characteristic of surface waters on the east side of the San Joaquin Valley (Davis and others, 1959, p. 171) They are of the calcium bicarbonate type containing 150 to 300 ppm dissolved solids. Upon the classification of irrigation water of figure 33, the samples from Deer Creek, White River, and Rag Gulch are very low sodium hazard and low to medium salinity hazard waters. The outstanding exception to this pattern of quality is found in Poso and Little Creeks where waters upstream from nearby oilfields are of the characteristic east-side type but downstream from oilfield waste-water disposal these waters are strongly sodium chloride in character with dissolved solids of about 1,000 to 1,500 ppm. Waste waters from oilfield dumping in the vicinity constitute the base flow of Poso Creek during periods of no runoff. They are classified as very high sodium and high to very high salinity hazard waters and contain boron ranging from less than 1 to as much as 5.5 ppm. Information concerning oilfield waste-water in this vicinity is from reports of the Central Valley Regional Water Pollution Control Board No. 5, by Lorenz and Nicklen (1957), Nelson and Nicklen (1957), and Nelson and Pass (1957). No attempt was made to relate quality of water to changes in seasonal flow. This probably is important only in Poso and Little Creeks where variations in runoff combined with changes in waste water contributed may cause wide fluctuations in quality.

Unless waste waters in Poso and Little Creeks are treated to control the sodium hazard, they will tend to reduce soil permeabilities where they are applied to the ground. The salinity hazard and the effects of boron will be more apparent over a long period of time when salt concentrations will tend to increase in the soil where the water is applied and slow percolation will allow the waste waters to reach greater depths. Dilution with better quality water and provision of adequate drainage will aid in reducing the salinity hazard.

Deterioration of ground-water quality because of oilfield waste waters is suggested by the analysis of water from well 27/27-29J1 (fig. 34) which shows a calcium-sodium chloride water with 925 ppm dissolved solids. However, in the discussion of semiconfined water, the erratic chemical quality of ground water in this vicinity is pointed out and a single analysis cannot be accepted as positive evidence of degradation. Examination of the depth to a confining clay in Poso Creek channel indicates that shallow wells in the vicinity of the creek may be pumping from aquifers recharged directly by the creek. Additional analyses of water from wells less than 300 feet deep are not available to demonstrate whether degradation is moving westward. Analyses of deeper wells west of 27/27-29J1 show no evidence of waste-water recharge from Poso Creek.

Along the west side of the Terra Bella-Lost Hills area, Buena Vista Slough conducts overflow from the Kern River to Tulare Lake. Normally dry, the slough contains water only during years of very high runoff. Calcium-sodium bicarbonate waters with low dissolved solids and usually suitable for most irrigation uses characterize the overflow waters in the slough (Fellows and Morris, 1958 p. 36).

GROUND WATER

Ground water in the Terra Bella-Lost Hills area varies in quality both laterally and vertically. Selected analyses shown on figure 34 indicate lateral differences in chemical quality. Many of these analyses also are given on the geochemical sections (figs. 35 through 38) which show vertical and horizontal differences of chemical quality. These differences are in total dissolved solids and also in the relative concentrations of the individual constituents. The chemical characteristics of the water have been influenced by present and past surface waters in streams tributary to the area, variations in present and past climate, and by the rocks and sediments through which the water has moved.

All ground-water analyses on which this report is based are from wells which currently are used. Consequently, analyses are not available from water which is absolutely unsatisfactory for irrigation use and no specific areas or depth zones where such water is found can be indicated. A few samples were taken from abandoned wells but contamination from the surface, in the form of trash, bodies of small animals, or other debris, causes the analyses of the samples to be unreliable.

Semiconfined Aquifer System

The term semiconfined is applied to all ground water in the Terra Bella-Lost Hills area where distinct and extensive confining bed or beds cannot be determined. The semiconfined aquifer system is subdivided into two general zones, a shallow zone that extends from 0 to about 300 feet below land surface and a principal pumped zone below the shallow zone. The depth limitation is not exact and is based in general on an inferred zone of poorly permeable material presumably occurring at about 100 to 300 feet below land surface. The poorly permeable materials noted in the discussion of the shallow zone in Part B, Hydrology, are not shown conclusively by well logs. However differences in water levels and water quality suggest the existence of poorly permeable materials between the shallow and principal pumped zones of the semiconfined aquifer system.

Water from the Shallow Zone

The waters analyzed from wells perforated in the 0- to 300-foot depth zone show generally higher concentrations of dissolved solids than those from depths below 300 feet. Typical shallow zone water shown at U.S. Bureau of Reclamation test well 25/24-15H1 is calcium chloride-sulfate with more than 400 ppm dissolved solids (figs. 34 and 37). Because of the limited number of analyses, this depth group is shown only on figure 37. Davis (1959, p. 191) recognizes this zone and suggests that it originated as an evaporation brine in a local area of poor drainage. This water is good for most irrigation uses as it has low sodium and low to medium salinity hazards and low boron content.

To the northwest in Tulare Lake bed, waters from the shallow zone have been reported by residents as being of very poor quality. Mendenhall (1916, p. 105) indicates that this problem is caused by the alternating periods of evaporation and flooding which produced deposits of highly saline material. Locally very few wells tap this depth zone but the California Department of Water Resources, San Joaquin Valley Investigation (in progress) has drilled test wells 20 feet deep in Tulare Lake bed which show shallow ground waters with as much as 14,400 ppm sodium and 11,100 ppm chloride (California Dept. Water Resources, written communication, 1962).

On Semitropic Ridge, damaging deposits of calcium carbonate have accumulated on pump parts and casings of wells. The location and composition of the water from one of these wells, 27/23-16R1, is shown on figure 34. Carbonate deposition is apparently related to depth as these deposits tend to occur in wells that take at least part of their water from depths less than 200 feet below land surface. Several exceptions have been noted in wells not perforated above 200 feet. However, water from the shallow depth zone may migrate to the perforated interval via the gravel pack in some of the wells with deeper perforations.

This deposition may be related to carbon dioxide released from ground water when the well is pumped (Hem, 1959, p. 71). The problem might be controlled by perforating below 200 feet and cementing the well above the perforations to prevent ground-water movement through the gravel pack.

Water from the Principal Pumped Zone

Semiconfined water from wells perforated below 200 to 300 feet is generally of good quality in the Terra Bella-Lost Hills area. This water is commonly of the sodium bicarbonate type with less than 300 ppm dissolved solids and is satisfactory for most uses. Surface water from the east side of the San Joaquin Valley is characteristically calcium bicarbonate. This is the most probable source of the sodium bicarbonate water in the semiconfined aquifer system. The alteration in cation content from predominantly calcium to predominantly sodium is attributed to the process of cation exchange. In this process calcium and magnesium ions in solution replace adsorbed sodium on the exchange material (Hem, 1959, p. 221). Ample quantities of exchangeable sodium are available in the heterogeneous sands and clays through which the water must move from the east towards the trough of the valley. Sodium concentrations tend to increase with the distance from the recharge area of a given aquifer system and the depth of the water below land surface.

Chemical quality of the semiconfined aquifer system is outlined along each line of geochemical cross section. Some analyses shown on figure 34 are not included on the cross sections where the projected analysis would cause distortion in the section or where they are not essential to the section. The cross sections intercept and show all of the identified units of distinctive chemical quality.

Geochemical section A-A'.--In the northern part of the area figure 35, geochemical section A-A', shows the characteristic sodium bicarbonate water in the semiconfined aquifer system. In the east a slightly higher relative concentration of calcium in some analyses may be due to the proximity to intake areas and the fact that the water has not traveled as far through the sources of sodium as waters farther west. The eastern part of the section corresponds to a high nitrate zone outlined in the vicinity of Ducor on figure 39. The nitrate concentrations observed range from 20 ppm in 23/28-30KI to 72 ppm in 23/27-21KI. Locally this area has been subject to intensive citrus cultivation starting in the early 1900's and the nitrate concentrations are probably attributable to the continued use of fertilizers. This degradation of ground water is of no concern when the water is used for irrigation, but should be considered if the water is used for domestic supply. Hem (1959, p. 239) refers to a tentative limit of 44 ppm nitrate in a potable water supply for infants.

At the western end of section A-A' in water from the semiconfined aquifer system above the Corcoran Clay Member of the Tulare Formation, the dissolved solids concentration is about 400 ppm, the chemical character remains sodium bicarbonate type. All the semiconfined water shown along this line of section is suitable for most irrigation uses; sodium and salinity hazards are low to medium.

Geochemical section B-B'.--Semiconfined waters shown on figure 36, geochemical section B-B', are of more varied character than those of section A-A' though the sodium bicarbonate type is still common, and all are suitable for most irrigation uses. The eastern end of section B-B' is in the dissected uplands where the water is of highly variable quality (fig. 34). Wells in this locality even where in close proximity may penetrate lithologically different parts of the geologic section which could explain the erratic results of water analyses. Waters at the east end of the section show an increase in sulfate content compared to waters to the west and the dissolved solids are greater than 300 ppm.

Between wells 24/25-21L1 and 24/26-32L1 northeast of Delano analyses indicate increased relative concentration of calcium similar to that found near the eastern end of section A-A'. This locality also shows high nitrate concentrations (fig. 39) the highest being found in well 32L1 (76 ppm). Most of the other wells in the vicinity are near or below the suggested 44 ppm nitrate limit for domestic use.

In the western part of the section analysis of water from well 24/22-35N1 indicates a zone of sodium bicarbonate water above the Corcoran Clay Member. Water in this zone has more than 300 ppm dissolved solids and correlates with similar water shown at the western end of section A-A'. All the water from the semiconfined aquifer system shown on this section is satisfactory for most irrigation use, though treatment of the soil or water may be required where the sodium content is excessive.

Geochemical section C-C'.--Figure 37, geochemical section C-C', shows sodium chloride-sulfate water with more than 500 ppm dissolved solids in the dissected uplands in the east. Correlations between geochemical sections along the east side have not been made south of section A-A' because of the water-quality variation from one well to the next as noted in the discussion of section B-B'.

In the central part of the area beneath the shallow water zone is the sodium bicarbonate water containing less than 300 ppm dissolved solids which is found throughout much of the area.

At the western end of section C-C', chemical analysis of water from well 26/21-14H2 shows sodium chloride-sulfate water with nearly 3,000 ppm dissolved solids. A series of five analyses of water from this well in the period from 1954 through 1956 show an increase from about 2,650 ppm to about 3,000 ppm in dissolved solids with no significant change in the relative concentrations of the various constituents. There is no east-side source that would provide water of such poor quality nor is there any apparent source of degradation from the east. In T. 25 S. and T. 26 S., R. 21 E., Davis (1959, pl. 28) indicates on his geochemical section h-h', sodium sulfate, sulfate-chloride, and chloride waters with 2,000 to 7,000 ppm dissolved solids. This well and others located to the south are near the trough of the valley where waters from the east and west sides of the valley meet and mix.

High boron concentrations are also indicated in this area in figure 39. Boron is, in varying degrees, injurious to crops and unless good drainage is provided, waters with excessive boron concentrations cannot be used. Throughout most of this report area, boron concentrations are quite low, but in the trough of the valley higher boron concentration is found associated with the water entering from the west.

Water in the semiconfined aquifer system shown along section C-C' generally is acceptable for irrigation use. In the east the sodium and salinity hazards range up to high but both generally are low to medium and boron content is low. The water sample from well 26/21-14B2 is classed as high sodium hazard and very high salinity hazard and boron content is acceptable only for use on crops which have high boron tolerance. Crop selection for boron and salt tolerance and suitable treatment for the high sodium content will be required if this water is used extensively. South and west of 14B2 the same problems are amplified by even higher concentrations of dissolved solids (Hanson and Nicklen, 1956, p. 4), and west of the area of this report, water of similar quality was noted by Wood and Davis (1959, pl. 5).

Geochemical section D-D'.--Near the southern boundary of the Terra Bella-Lost Hills area figure 38 (geochemical section D-D') shows more varied water quality than any other part of the area. A zone of variable water quality, as previously noted in the discussions of sections E-B' and C-C', underlies the dissected uplands at the eastern end of the section. Sodium and salinity hazards range from medium to very high.

Adjacent to the dissected uplands and east of Highway 99 there is a zone of calcium chloride water having about 1,400 ppm dissolved solids and immediately west of Highway 99 calcium sulfate water having more than 400 ppm dissolved solids. The sodium hazard is low in this locality, but the salinity hazard is medium to high. Nitrate concentrations range up to 148 ppm at well 28/26-3C1 in the same zone. These concentrations of nitrate may be influenced by organic matter indicated in several well logs in the vicinity or by agricultural fertilization. Water movement is northward in this locality as shown on the water-level contour map (fig. 25), indicating a possible source of the high chloride and sulfate waters to the south. Determination of the source of these waters will depend on the results of a ground-water investigation in the Kern River fan area, now in progress.

Sodium bicarbonate waters with less than 300 ppm dissolved solids, common to much of the area, are found from the east side of R. 24 E. to Semitropic Ridge. The water-level contour map mentioned above indicates possibly a separate hydrologic unit extending west from the western edge of Semitropic Ridge and including Jerry Slough and Buena Vista Slough. This unit is present as a separate chemical quality unit that extends west from Semitropic Ridge and includes Buttonwillow Ridge. Waters in the ridge and slough setting are the sodium chloride type with more than 500 ppm dissolved solids. Although the chemical character of the waters is quite similar, the total dissolved solids is variable, ranging up to about 2,300 ppm near the confluence of Jerry and Buena Vista Sloughs (fig. 34). West-side waters are probably the source for the waters in this vicinity and the variations in quality may be due to flushing by ground water moving northward along the Kern River channel. Water from well 28/23-11E2 probably represents flushing by Kern River water in the southern part of Jerry Slough.

Boron concentrations in excess of 2 ppm are found along the west side of the valley trough. This zone as shown on figure 39 is correlated with boron to the north and is probably found in waters reaching the area from the west side of the San Joaquin Valley. On Semitropic Ridge and in Jerry Slough the ground-water analyses indicate a low sodium hazard and low to high salinity hazard. The analyses from wells on Buttonwillow Ridge and Buena Vista Slough show medium to high sodium hazard and high to very high salinity hazard. Near the confluence of Jerry and Buena Vista Sloughs sodium hazard is high to very high and salinity hazard is very high. Treatment to reduce the sodium hazard is required to prevent damage to soil permeability. Salt tolerant crops may permit the use of water that has a high salinity hazard. Unless adequate provision is made for dilution with water of better quality and for drainage, salt concentrations may eventually increase to unusable limits.

Confined Aquifer System

The confined aquifer system beneath the Corcoran Clay Member of the Tulare Formation contains water, as indicated on geochemical sections A-A', B-B', and C-C', (figs. 35-37) that is of the sodium bicarbonate type, less than 300 ppm dissolved solids, similar to that in the semiconfined aquifer system to the east. The semiconfined aquifer system undoubtedly is the source of the water having these characteristics. Each of the three cross sections indicates a zone in the west where the confined waters are of much poorer quality. This zone probably represents mixed water from the east and west sides of the San Joaquin Valley and shows a sodium chloride or chloride-sulfate character with dissolved solids ranging from about 700 ppm to about 2,400 ppm (figs. 35-38).

Most of the water below the Corcoran Clay Member is of usable quality for irrigation. Waters in the west are classed as having high to very high salinity hazard and medium to high sodium hazard. (figs. 35-57). Boron concentration does not exceed 0.8 ppm in any of the analyses available, therefore the water is within permissible limits for boron sensitive crops. The sodium hazard can be altered by suitable treatment of the water and (or) soil but the salinity hazard accentuates the need for dilution with water of better quality and for provision of adequate drainage.

Confined Aquifers in Marine Rocks

Water confined in rocks of the Santa Margarita Formation is uniformly sodium chloride in character with dissolved solids concentrations greater than 300 ppm and generally less than 500 ppa. A short distance west of the town of Richgrove an interface between fresh and saline water is indicated by electric logs of oil-test wells. Future development of the Richgrove aquifer will be restricted west of this interface.

Sedimentary rocks comprising the Santa Margarita Formation are largely marine in origin and probably contained salty water when deposited. Fresh water found east of the interface at present is attributed to partial flushing by fresh water at some time subsequent to deposition of the aquifer. East of the interface the water is classed as having medium to high salinity hazard and high to very high sodium hazard. In spite of this water classification approximately 30 irrigation wells have been developed in the aquifer since 1954. The sodium hazard is dealt with by treatment of water and (or) soil and as long as this procedure is used, the hazard is not apparent, though the salinity hazard is increased by the treatment. Effects of the salinity hazard are more difficult to predict. As dissolved solids concentrations are not prohibitively high, the salinity hazard will probably be apparent only on long-term basis.

Water confined in the Olcese Sand beneath the Santa Margarita Formation of Diepenbrock (1933) (figs. 35, 37, and 20) represents a potential source of ground water but is little developed at the present time. Water quality is estimated to be similar to that in the Santa Margarita Formation on the basis of electric logs from oil-test wells that penetrate both aquifers.

Fresh Water-Salt Water Relationships

Each of the four geochemical sections (figs. 35 through 38) show the approximate position of the base of the fresh water, sloping eastward from the trough of the valley. This position is estimated from electric logs of oil-test wells. The points at which the depth was estimated are often far apart and estimates of water-quality changes were not certain. The base of the fresh water is probably continuous from the semiconfined waters to the confined waters beneath the Corcoran Clay Member of the Tulare Formation.

No analyses are available for water from the Santa Margarita Formation or Olcese Sand west of the base of the fresh water (figs. 37 and 20). The water to the west is estimated from electric logs to be very high in dissolved solids, probably in excess of usable concentrations.

WATER-QUALITY PROBLEMS

Protection and maintenance of satisfactory water quality are among the present and future problems facing water users in the Terra Bella-Lost Hills area. Deleterious effects on the quality of water may result from deficiencies in surface- and ground-water supplies, injudicious disposal of waste waters, and lack of adequate drainage for removal of harmful salts or pollutants.

Deficiencies in surface- and ground-water supplies have influenced the quality of available ground water in the Terra Bella-Lost Hills area. Irrigation with surface and ground water leaches substances from the soil through which the water percolates. When waters containing excessive concentrations of these substances reach and mix with the ground-water body, they contribute to its gradual degradation. In the area, changes of quality with time have not been consistently demonstrated; some individual wells show short-term trends indicating that such changes may be occurring. Deficiency of supply results in the drilling of deeper wells in an effort to reach previously untapped sources of ground water. If deeper wells intercept waters of unsatisfactory quality, any communication between bodies of water along the well core or casing will permit mixing due either to head differences or to pumping effects. Most of the existing wells do not approach the depth where electric logs indicate water of very poor quality. Development of the Santa Margarita Formation will probably be restricted by the presence of brackish or salty waters west of Richgrove.

Injudicious disposal of waste waters of undesirable quality can cause degradation of ground waters. In the Terra Bella-Lost Hills area, dumping of oilfield waste water constitutes a real and potential problem along Poso Creek. Only limited evidence of contamination is found at present, though in time the problem may become evident over a larger area. This problem is not widespread and is under the supervision of the Central Valley Regional Water Pollution Control Board (No. 5). Surface drainage of irrigation water is also part of the disposal problem as water, repeatedly applied for irrigation, is degraded by each reuse until it acquires an unsatisfactory quality. The solution of this problem ultimately is related to providing a supply adequate to dilute and drainage to flush the undesirable salts out of the area.

The drainage in the Terra Bella-Lost Hills area is a closed system tributary to Tulare Lake. In a closed system, lack of adequate drainage for removal of harmful salts or pollutants is a direct cause of degradation of ground water in the sump area. Sump conditions in Tulare Lake have resulted in the development of alkaline soils and a shallow groundwater body of such poor quality that wells tapping this source are very scarce. This problem might be alleviated by providing adequate drainage to prevent the accumulation of harmful concentrations of salts.

The California Water Plan proposes to provide adequate drainage for removal of the harmful salts and pollutants by constructing a waste conduit (California Dept. Water Resources, 1957, p. 119). This conduit will extend along the trough of the valley from the vicinity of Buena Vista Lake to the saline water channels near the combined deltas of the Sacramento and San Joaquin Rivers.

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EXPLANATION



Sierra Nevada



Dissected uplands



Low alluvial plains and fans



River flood plains and channels



Overflow lands and lake bottoms

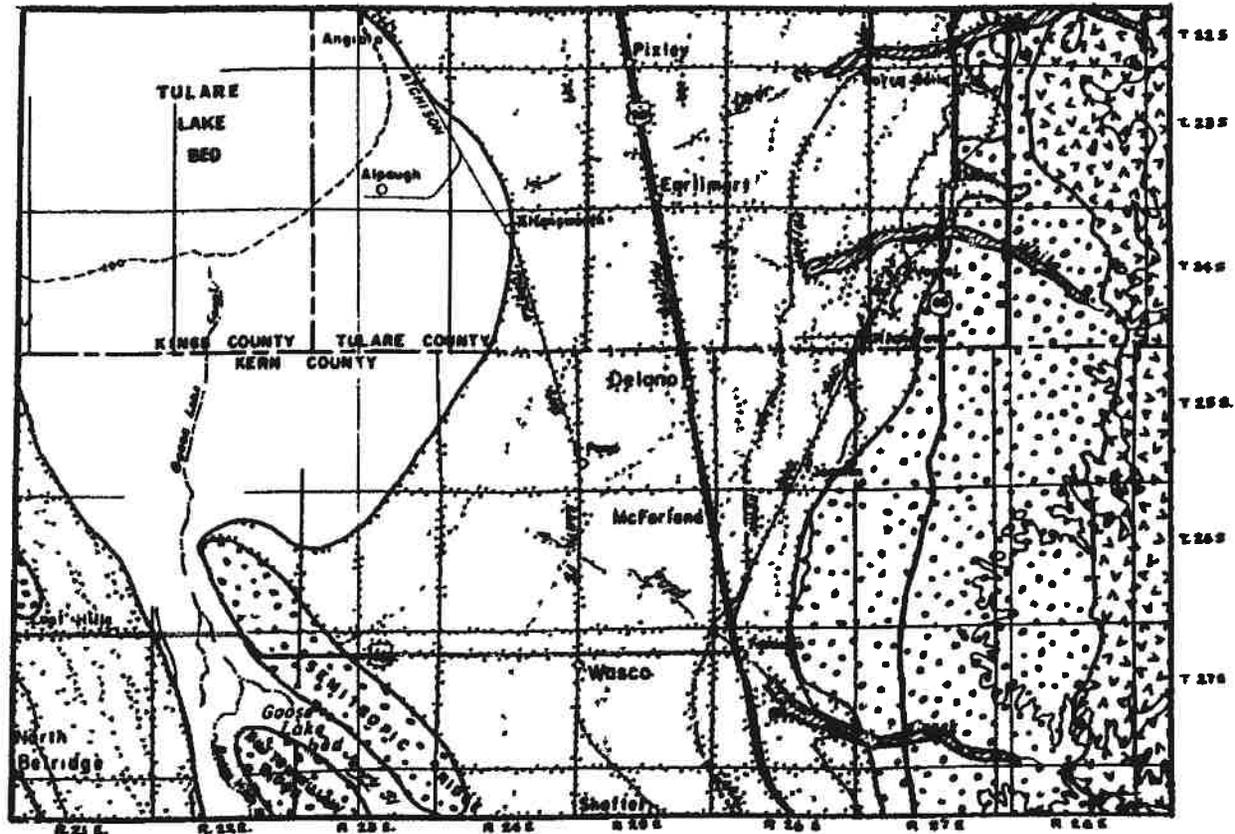


FIGURE 2.— MAP OF THE TERRA BELLA - LOST HILLS AREA, CALIFORNIA, SHOWING GEOMORPHIC UNITS

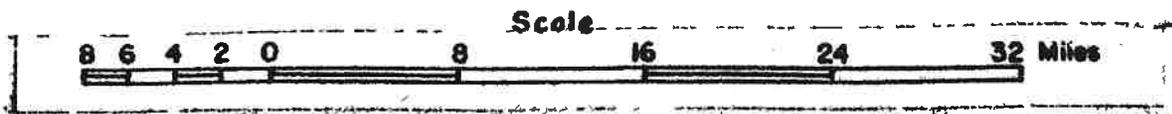


Figure 2

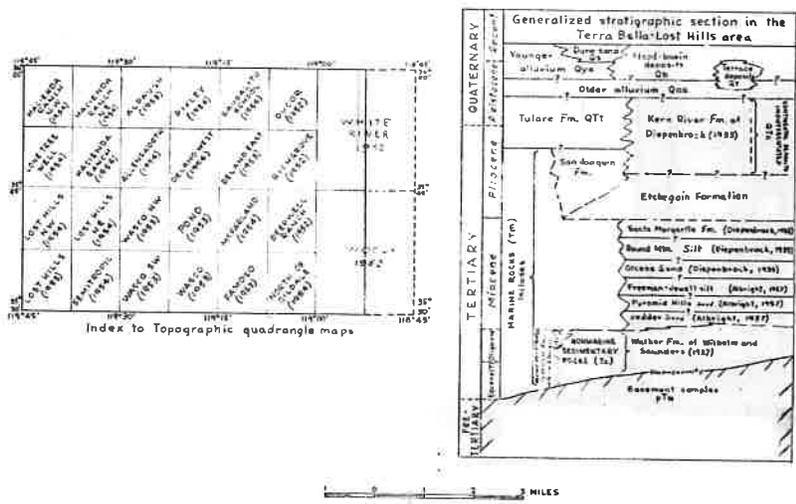
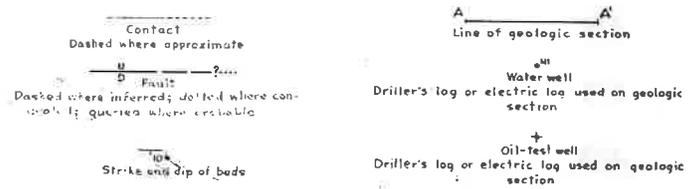
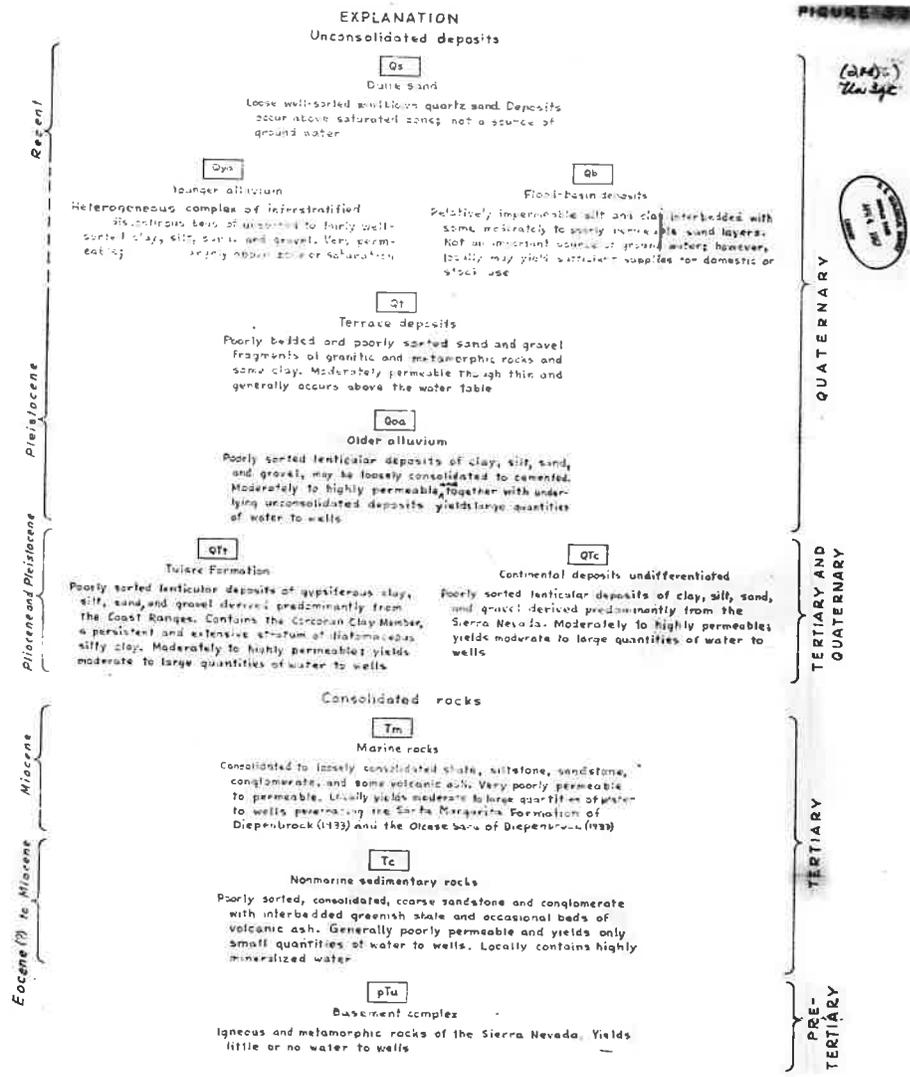


FIGURE 3. MAP OF THE TERRA BELLA-LOST HILLS AREA SHOWING GEOLOGY AND WELLS

Geology by G.S. Hilton and R.L. Klausung, 1960

Poorly bedded and poorly sorted sand and gravel. Fragments of granitic and metamorphic rocks and some clay. Moderately permeable though thin and generally occurs above the water table

Qoa

Older alluvium

Poorly sorted lenticular deposits of clay, silt, sand, and gravel, may be loosely consolidated to cemented. Moderately to highly permeable, together with underlying unconsolidated deposits yields large quantities of water to wells

QTt

Tulare Formation

Poorly sorted lenticular deposits of gypsiferous clay, silt, sand, and gravel derived predominantly from the Coast Ranges. Contains the Corcoran Clay Member, a persistent and extensive stratum of diatomaceous silty clay. Moderately to highly permeable; yields moderate to large quantities of water to wells

QTc

Continental deposits undifferentiated

Poorly sorted lenticular deposits of clay, silt, sand, and gravel derived predominantly from the Sierra Nevada. Moderately to highly permeable; yields moderate to large quantities of water to wells

Consolidated rocks

Tm

Marine rocks

Consolidated to loosely consolidated shale, siltstone, sandstone, conglomerate, and some volcanic ash. Very poorly permeable to permeable. Locally yields moderate to large quantities of water to wells penetrating the Santa Margarita Formation of Diepenbrock (1933) and the Ocese Sand of Diepenbrock (1933)

Tc

Nonmarine sedimentary rocks

Poorly sorted, consolidated, coarse sandstone and conglomerate with interbedded greenish shale and occasional beds of volcanic ash. Generally poorly permeable and yields only small quantities of water to wells. Locally contains highly mineralized water

pTu

Basement complex

Igneous and metamorphic rocks of the Sierra Nevada. Yields little or no water to wells

Pleistocene
Pliocene and Pleistocene
Miocene
Eocene (?) to Miocene

QUATERNARY
TERTIARY AND QUATERNARY
TERTIARY
PRE-TERTIARY

Contact
Dashed where approximate

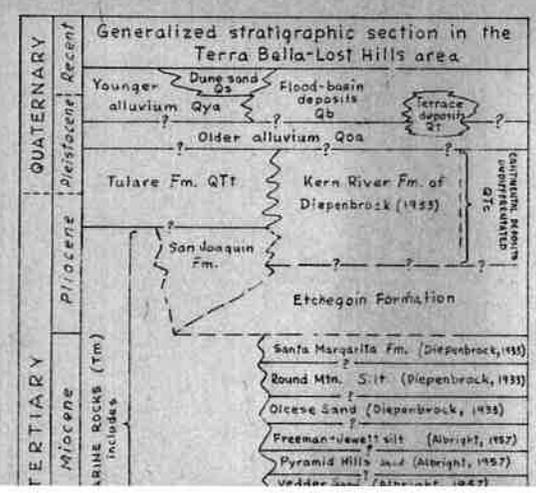
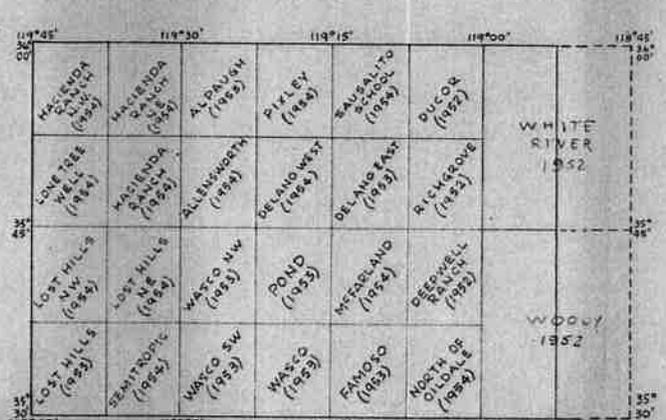
U
D Fault
Dashed where inferred; dotted where concealed; queried where probable

10
Strike and dip of beds

A A'
Line of geologic section

Water well
Driller's log or electric log used on geologic section

Oil-test well
Driller's log or electric log used on geologic section



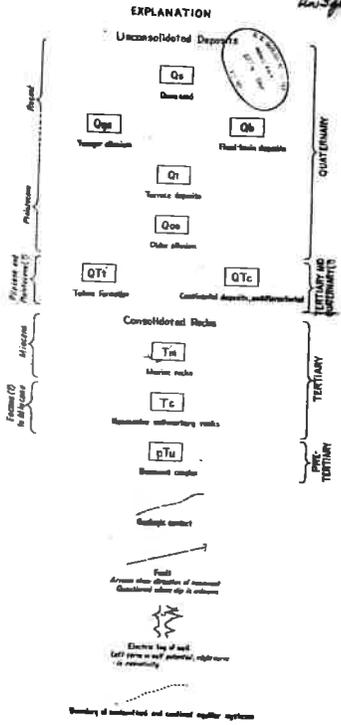
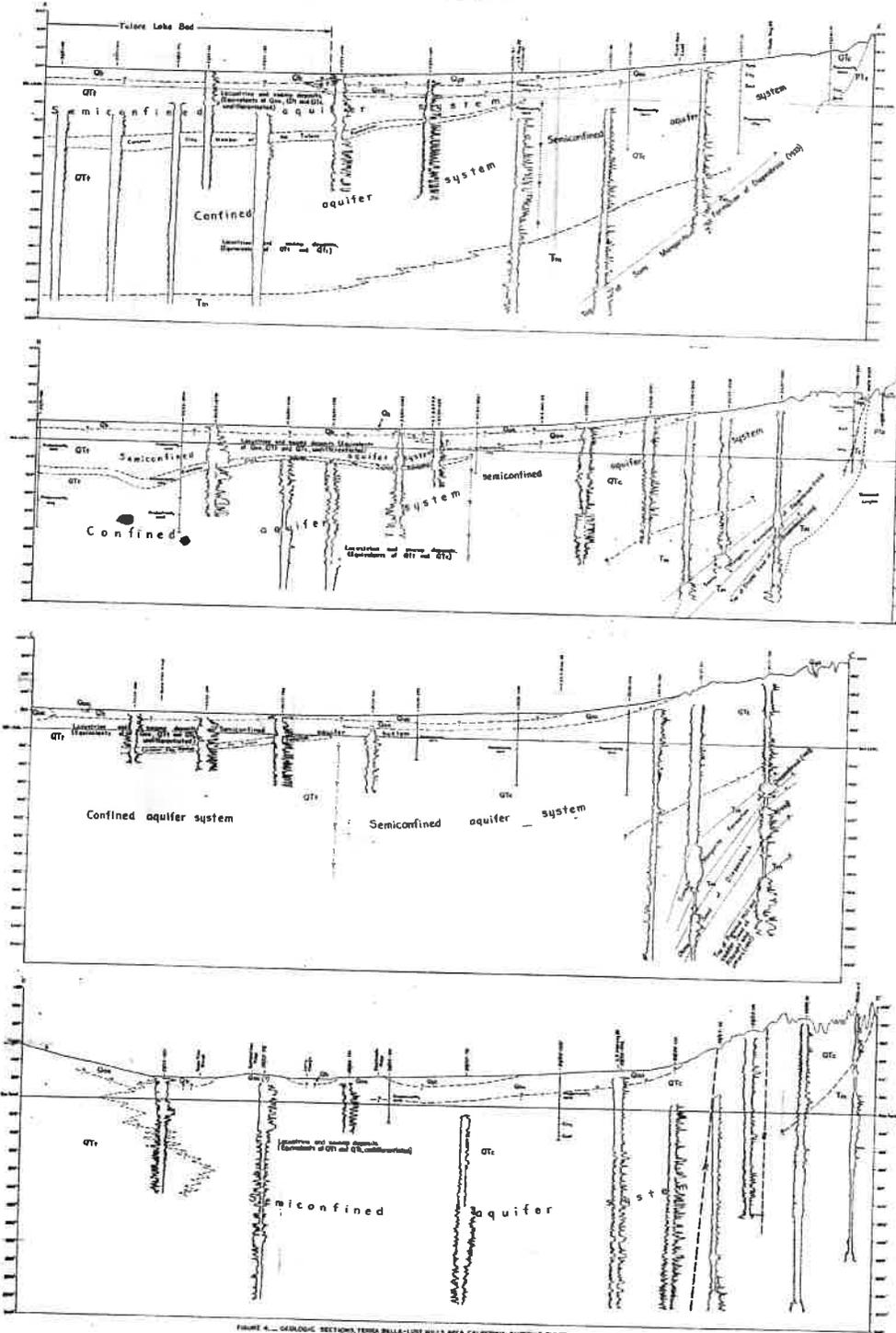
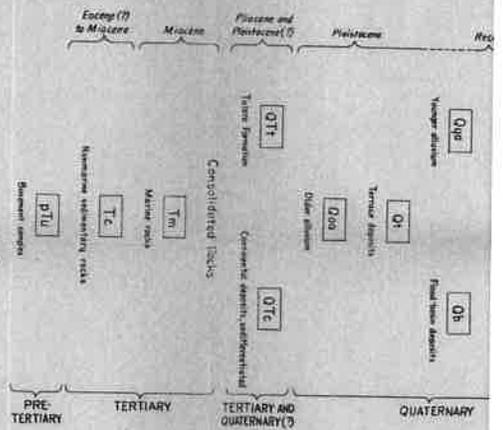
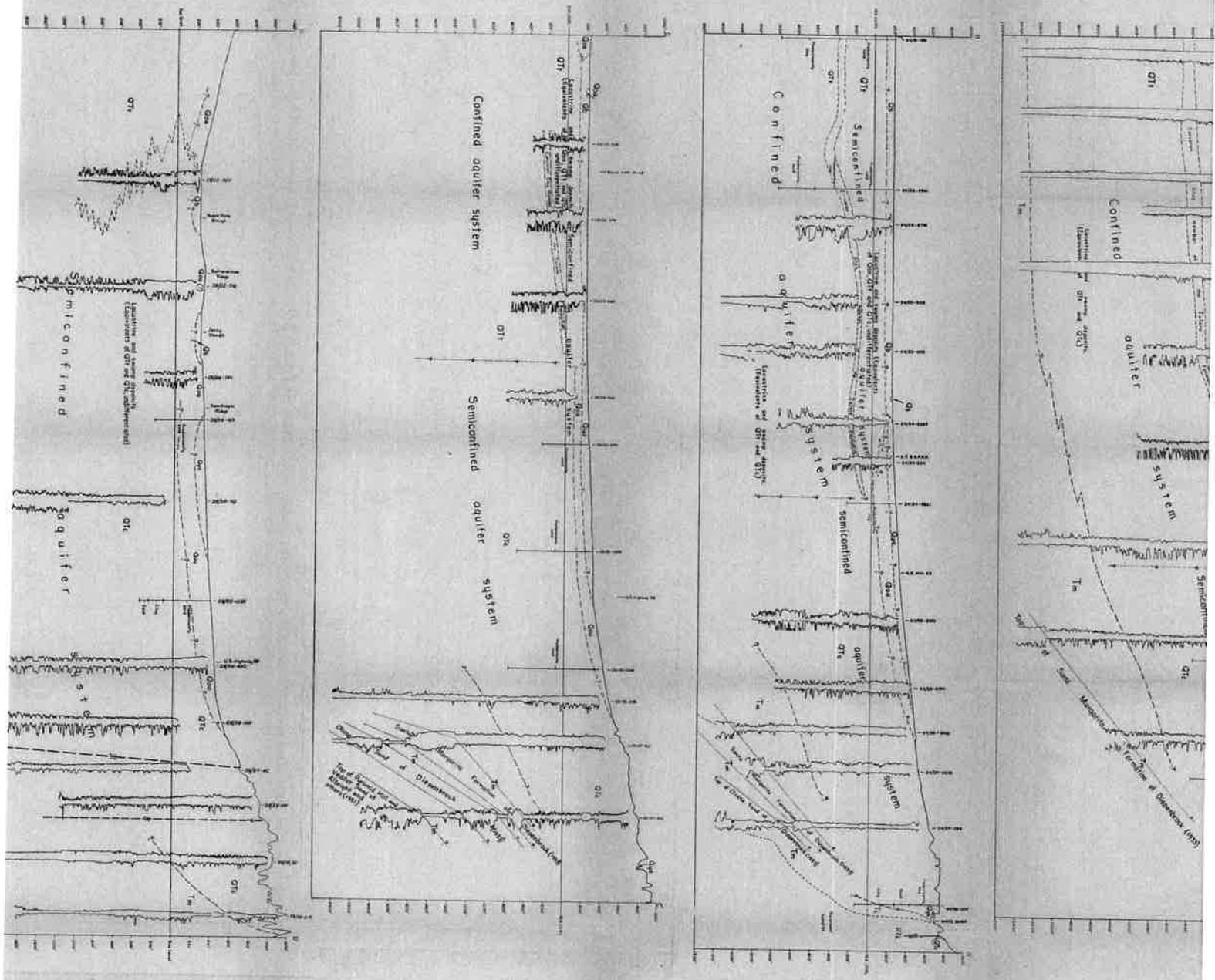


FIGURE 4. GEOLOGIC SECTIONS, FERRA BELLA-LIST HILLS AREA, CALIFORNIA, SHOWING ELECTRIC LOGS OF SELECTED WELLS



Legend for geological features:

- Fault:** Indicated by a line with a wavy pattern.
- Geologic contact:** Indicated by a line with a wavy pattern.
- Disconformity:** Indicated by a dashed line with a wavy pattern.
- Consolidated rocks:** Indicated by a solid line.
- Unconsolidated rocks:** Indicated by a dashed line.
- Major faults:** Indicated by a thick solid line.
- Minor faults:** Indicated by a thin solid line.
- Discontinuity:** Indicated by a wavy line.
- Disconformity:** Indicated by a dashed line with a wavy pattern.
- Geologic contact:** Indicated by a line with a wavy pattern.

Geological cross-sections showing different aquifer systems: Confined aquifer system, Semiconfined aquifer system, and others. The figure includes a geological time scale and a legend for geological features.

6347 FIGURE 5

EXPLANATION

Structure contour
 Drawn on top of Santa Margarita Formation of Diepenbrock (1933). Dashed where inferred. Contour interval 200 feet; datum is mean sea level.

Approximate position of interface between fresh and saline water. Saline water west of interface.

Electric log control point

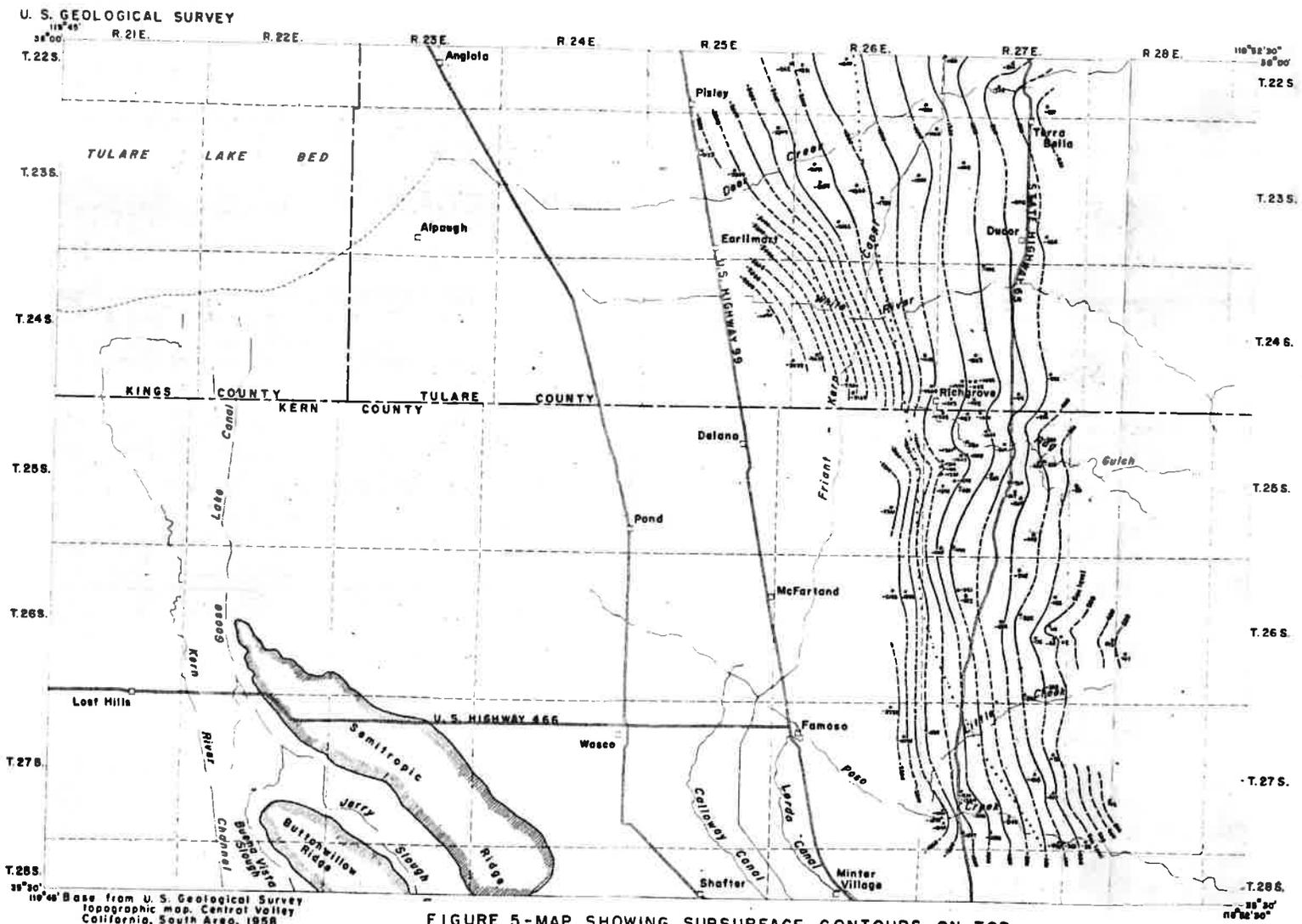


FIGURE 5.-MAP SHOWING SUBSURFACE CONTOURS ON TOP OF THE SANTA MARGARITA FORMATION OF DIEPENBROCK(1933)



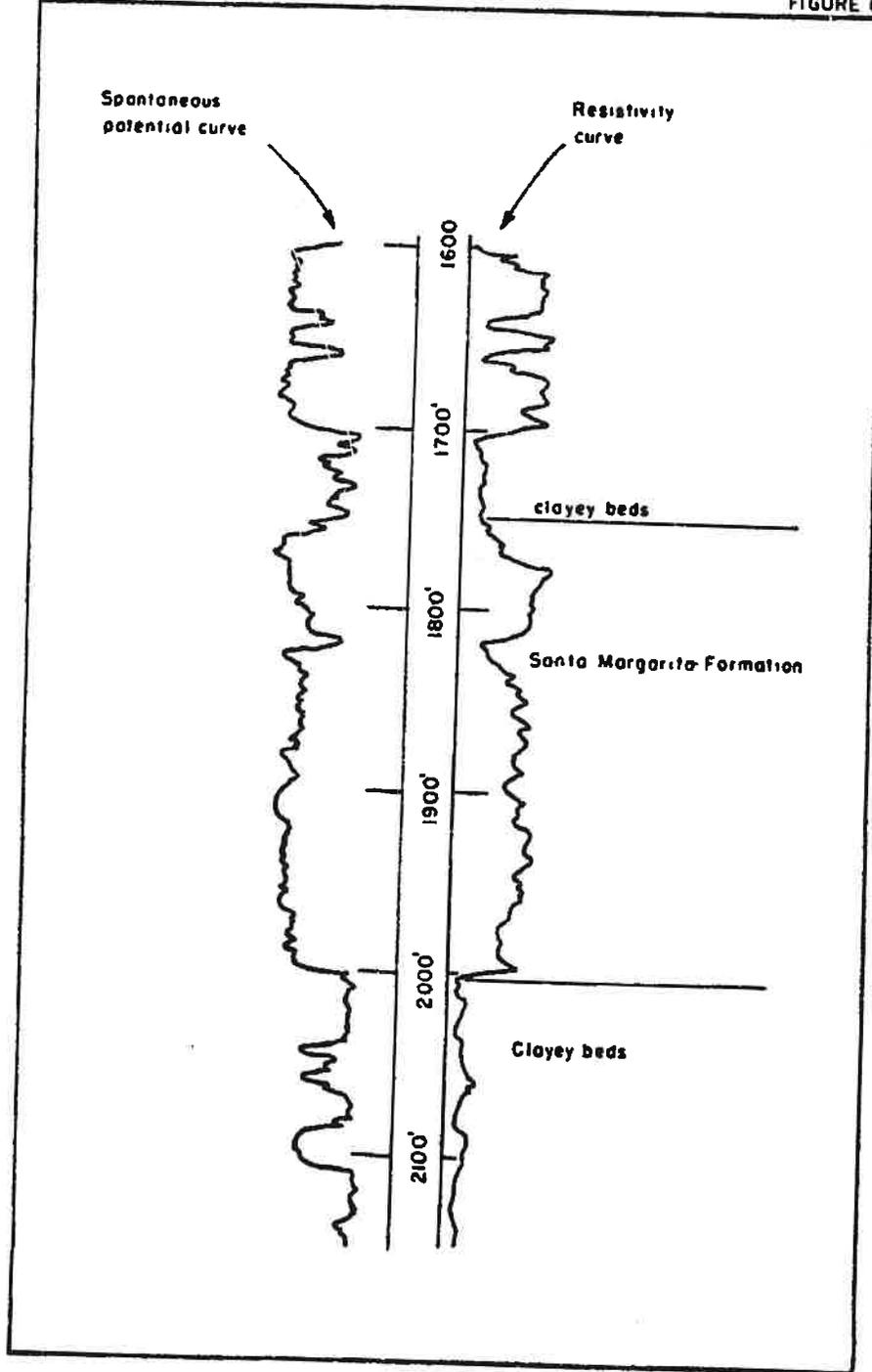
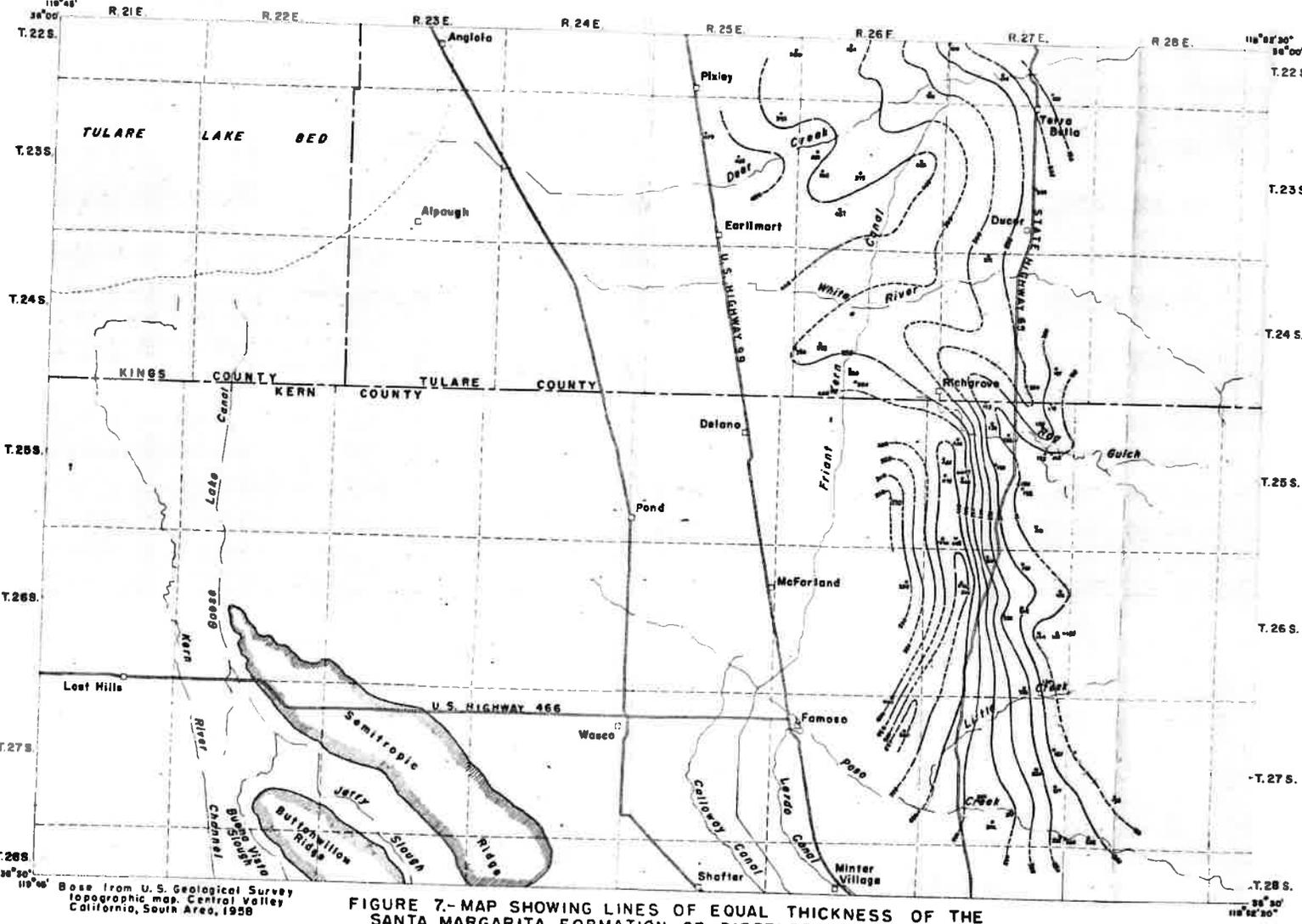


FIGURE 6 REPRESENTATIVE ELECTRIC LOG OF THE SANTA MARGARITA FORMATION OF DIEPENBROCK (1933)

U S GEOLOGICAL SURVEY



6347

FIGURE 7

EXPLANATION

Isopach line
 Connects points of equal
 thickness. Dashed where
 inferred. Contour interval
 50 feet.

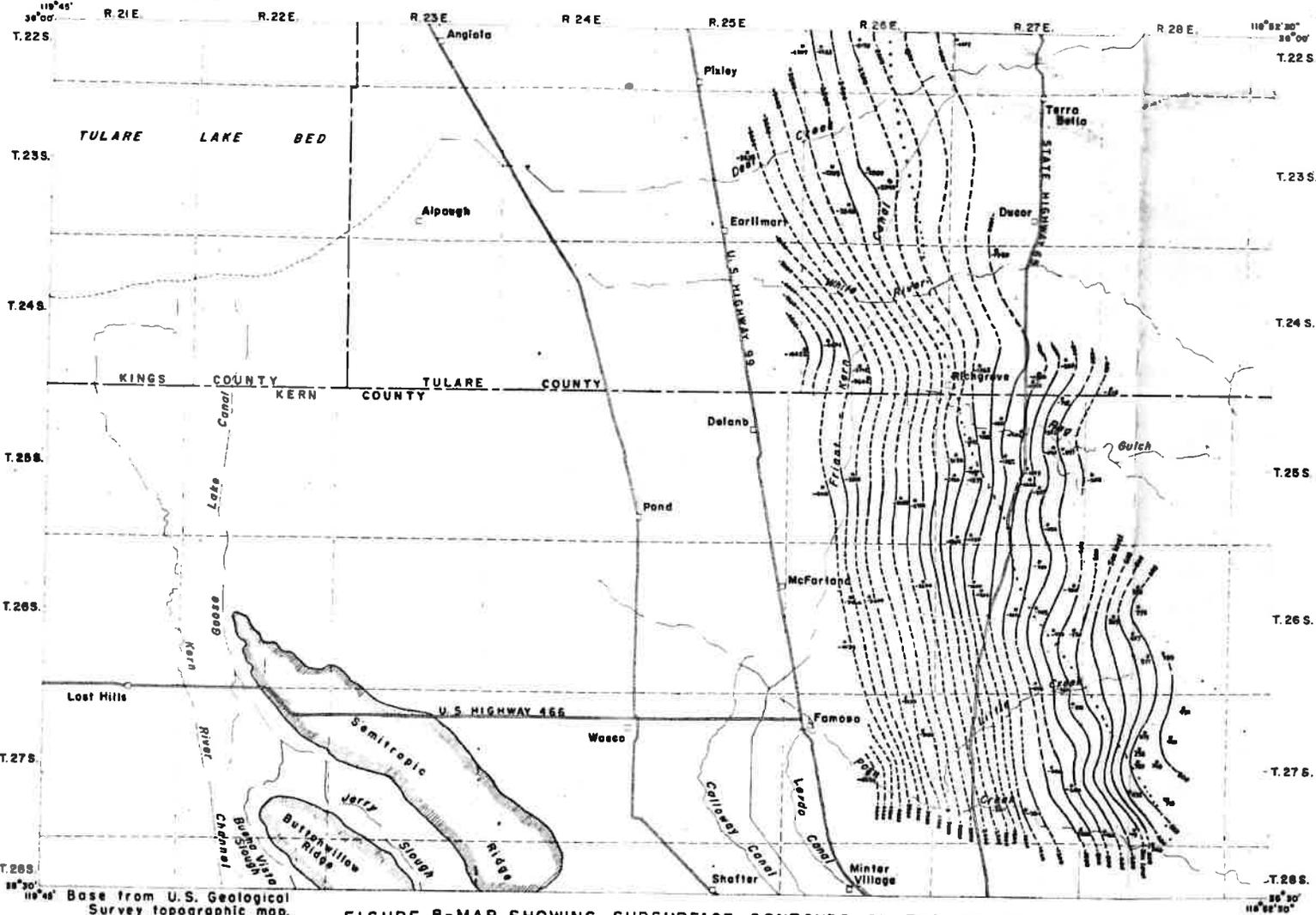
Electric log control point

Base from U.S. Geological Survey
 topographic map, Central Valley
 California, South Area, 1958

FIGURE 7.- MAP SHOWING LINES OF EQUAL THICKNESS OF THE
 SANTA MARGARITA FORMATION OF DIEPENBROCK (1933)



U. S. GEOLOGICAL SURVEY



Base from U. S. Geological Survey topographic map, Central Valley California, South Area, 1958

FIGURE 8.-MAP SHOWING SUBSURFACE CONTOURS ON TOP OF THE OLCESE SAND OF DIEPENBROCK(1933)



6347 FIGURE 8

EXPLANATION

- Structure contour
Drawn on top of Olcese sand.
Dashed where inferred.
Contour interval 200 feet;
datum is mean sea level
- Approximate position of interface between fresh and salt water. Saline water west of interface.
- Electric tag control point

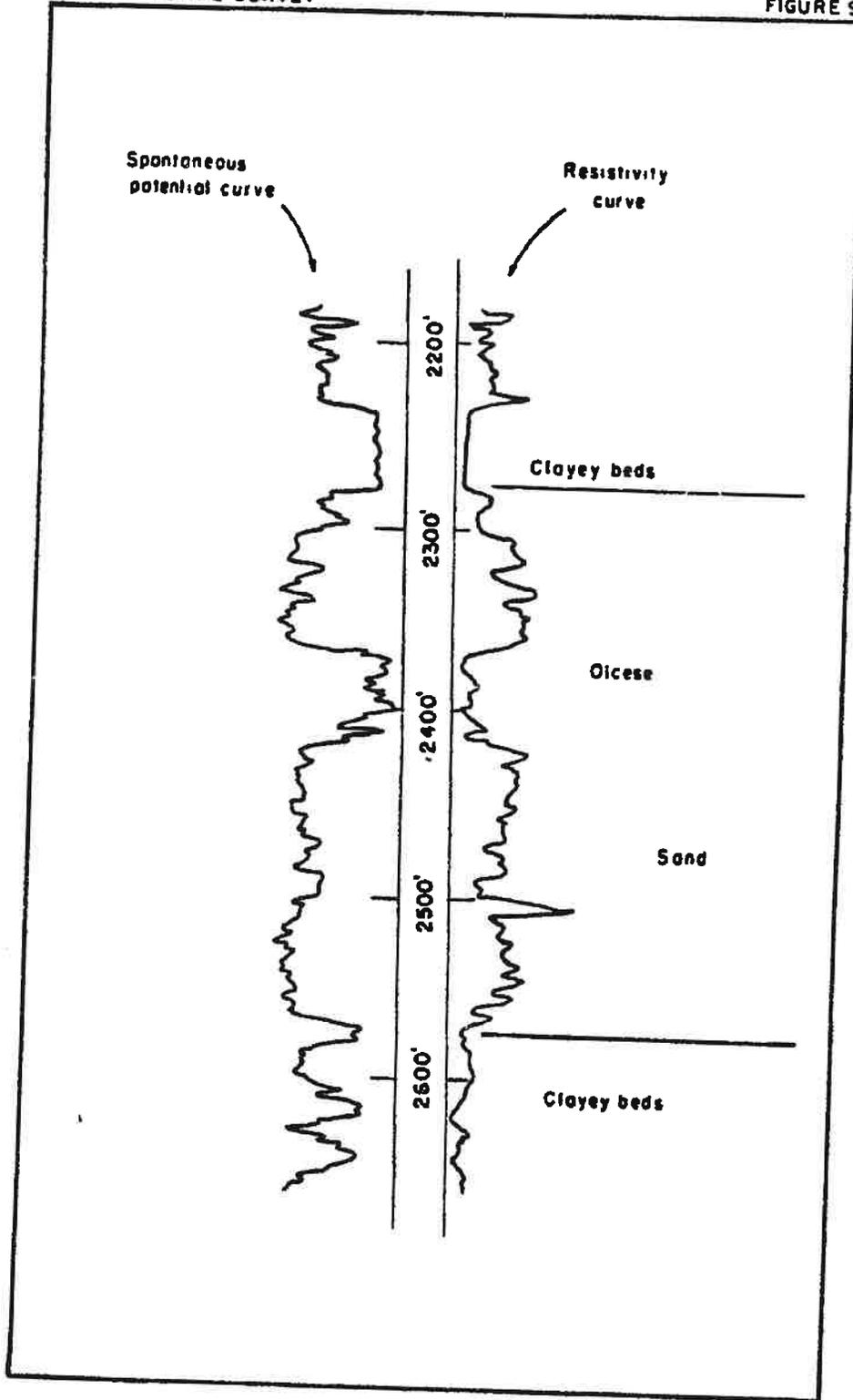
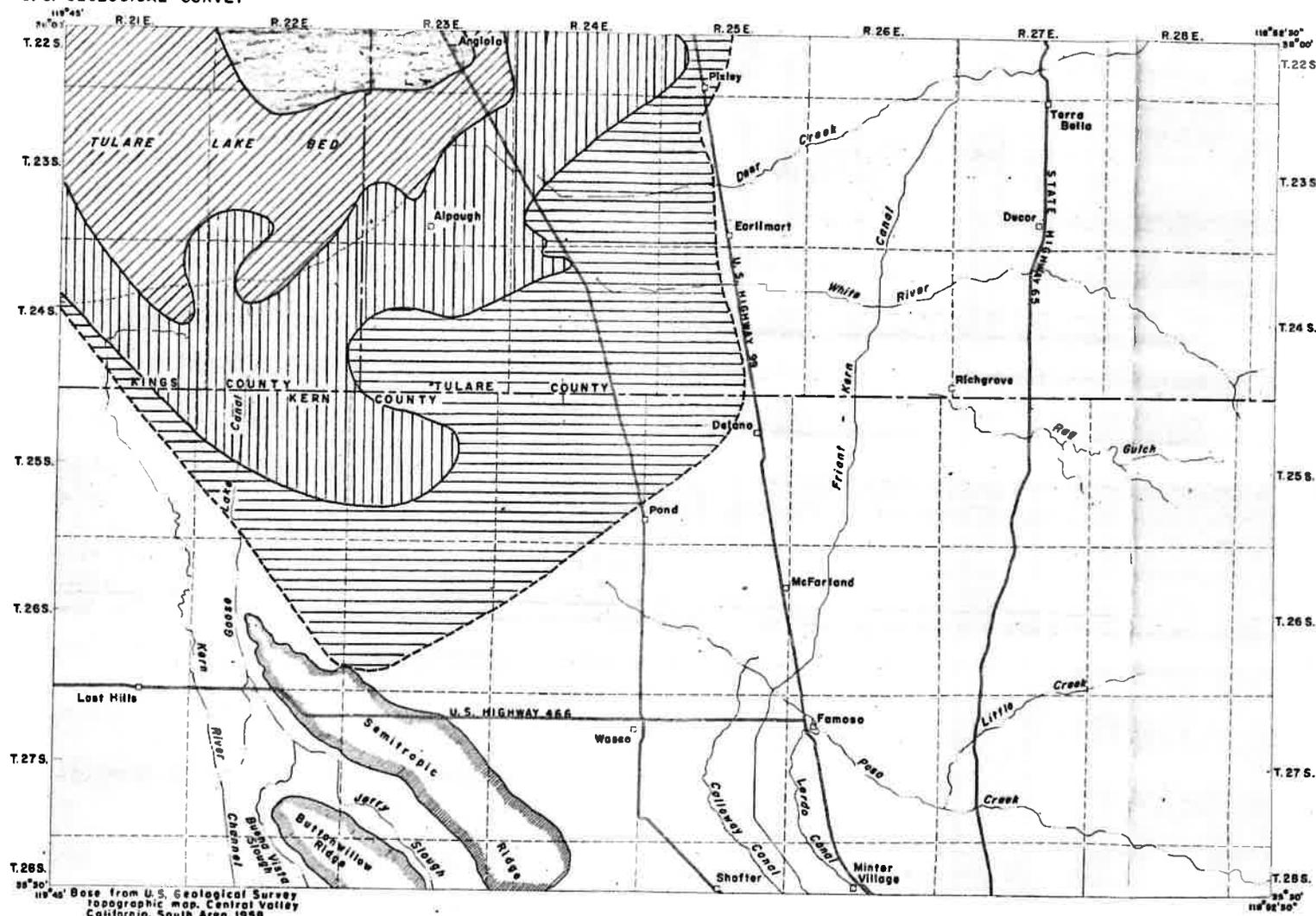


FIGURE 9 - REPRESENTATIVE ELECTRIC LOG OF THE OLCESE SAND OF DIFPENBROCK (1933)

U. S. GEOLOGICAL SURVEY



Base from U. S. Geological Survey
topographic map, Central Valley
California, South Area, 1958

FIGURE 10.- MAP SHOWING EXTENT AND APPROXIMATE THICKNESS OF THE CORCORAN CLAY MEMBER OF THE TULARE FORMATION



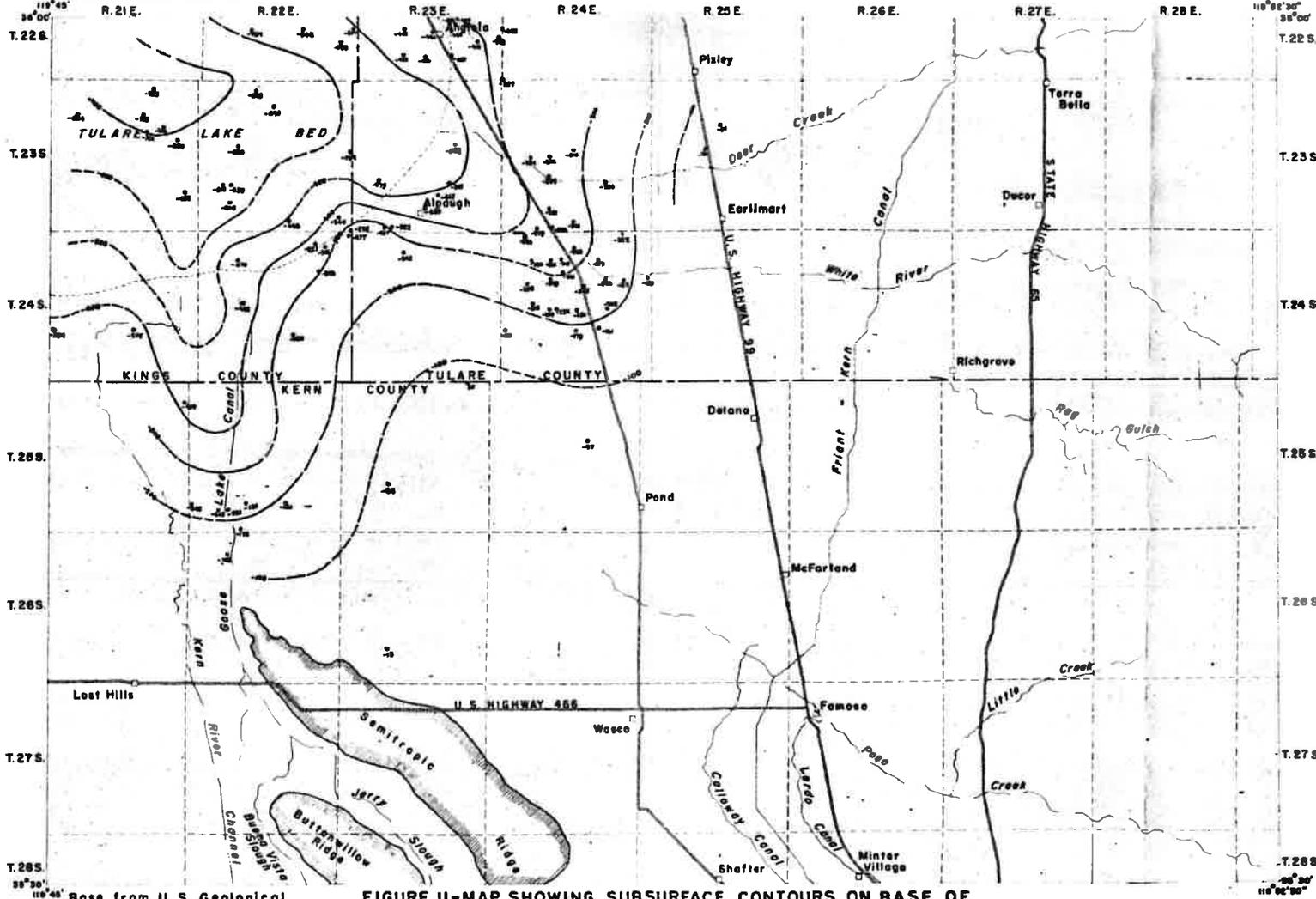
FIGURE 10

6347

EXPLANATION

-  0-60 feet
-  60-120 feet
-  120-160 feet
-  Greater than 160 feet
-  Approximate boundary of the Corcoran Clay Member

U.S. GEOLOGICAL SURVEY



Base from U.S. Geological Survey topographic map, Central Valley, California South Area, 1958

FIGURE II—MAP SHOWING SUBSURFACE CONTOURS ON BASE OF CORCORAN CLAY MEMBER OF TULARE FORMATION



63-47 FIGURE II

EXPLANATION

-  Structure contour
Drawn on base of Corcoran Clay Member. Dashed where inferred. Contour interval 100 ft; datum is mean sea level.
-  Drillers log control point
-  Electric log control point

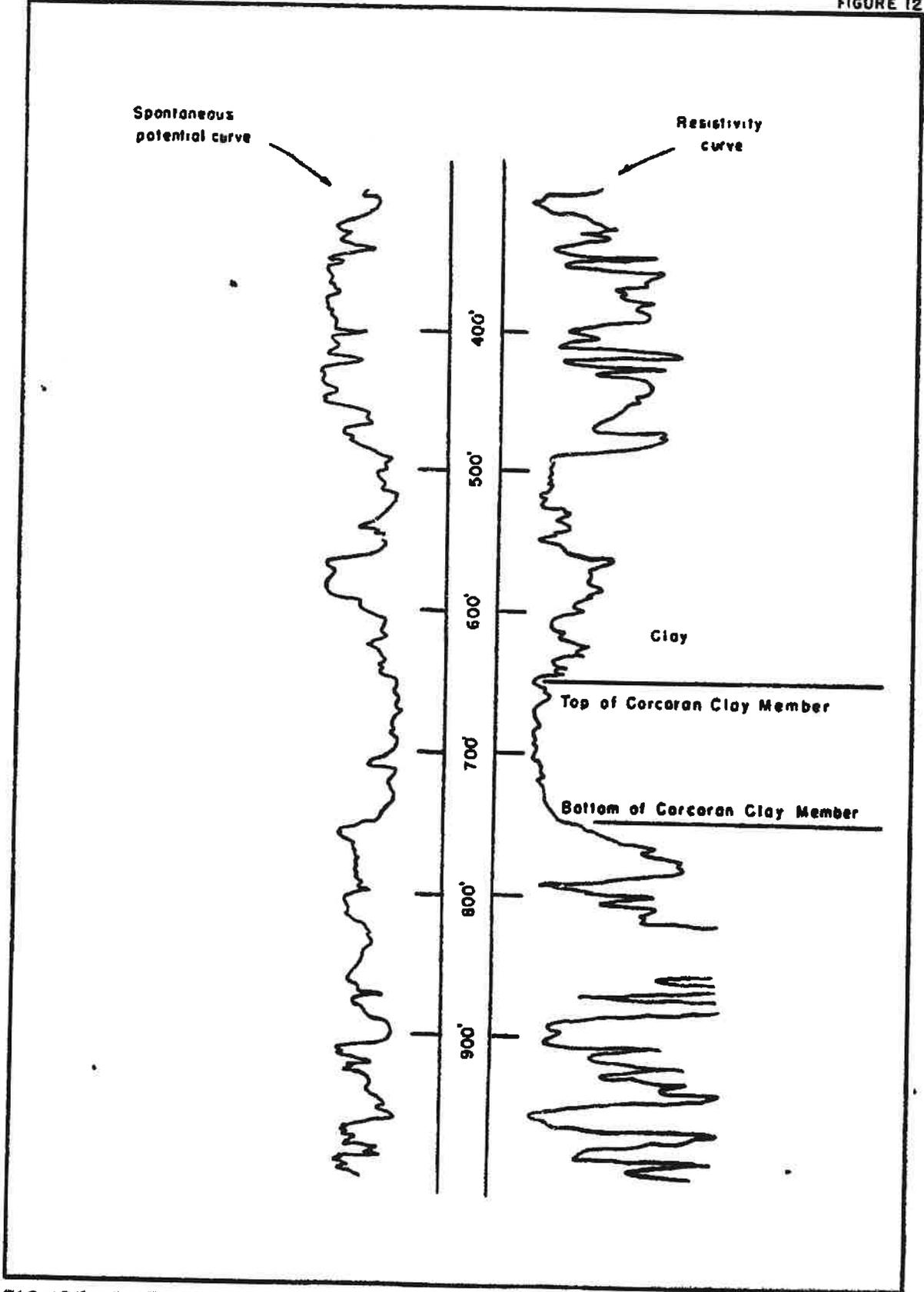


FIGURE 12.-REPRESENTATIVE ELECTRIC LOG OF THE CORCORAN CLAY MEMBER OF THE TULARE FORMATION

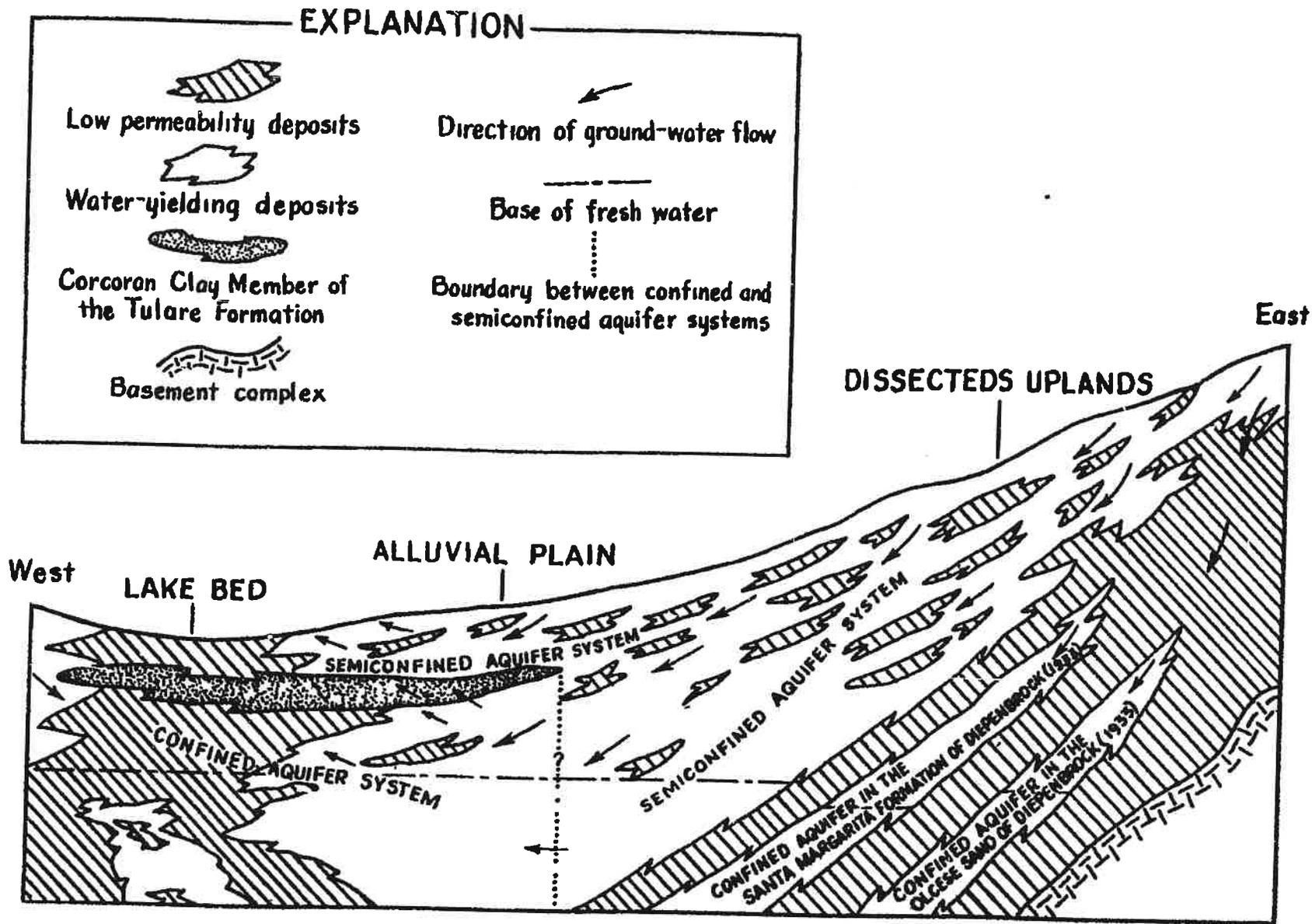


Figure 13. Diagrammatic section showing the ground-water reservoir

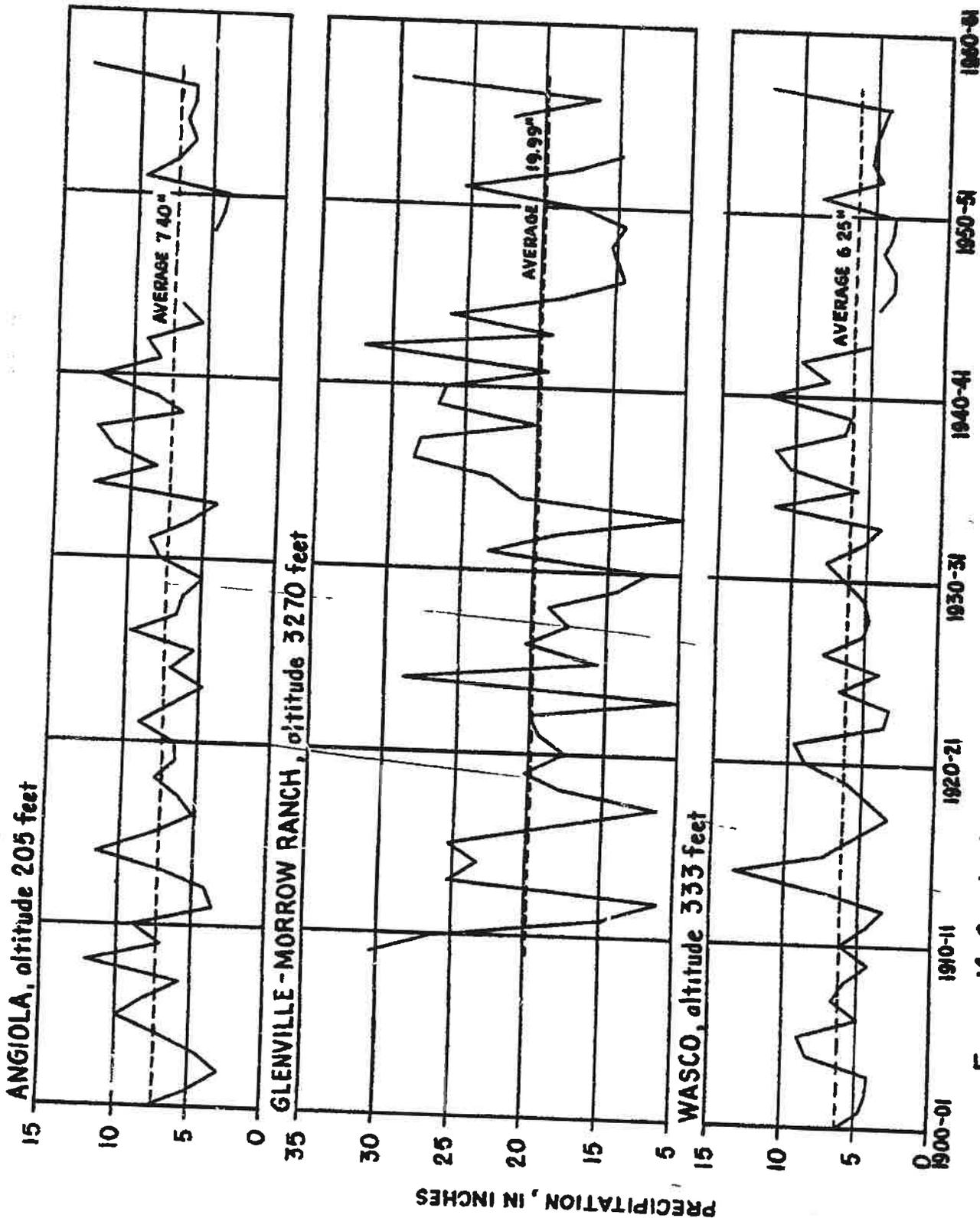


Figure 14 Graph showing precipitation at three stations in or near the Terra Bella - Lost Hills area, California

FIGURE 15

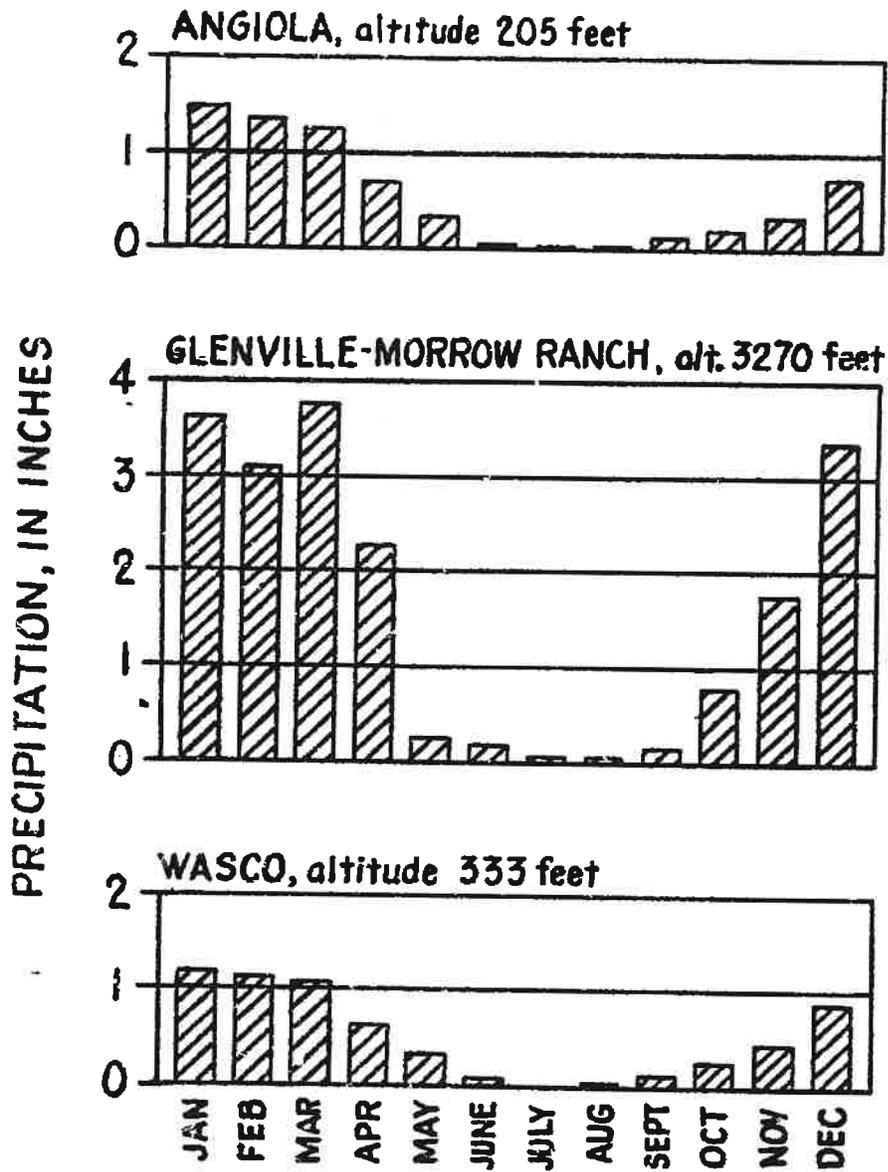


Figure 15. Graph showing average monthly precipitation at three stations in or near the Terra Bella - Lost Hills area, California

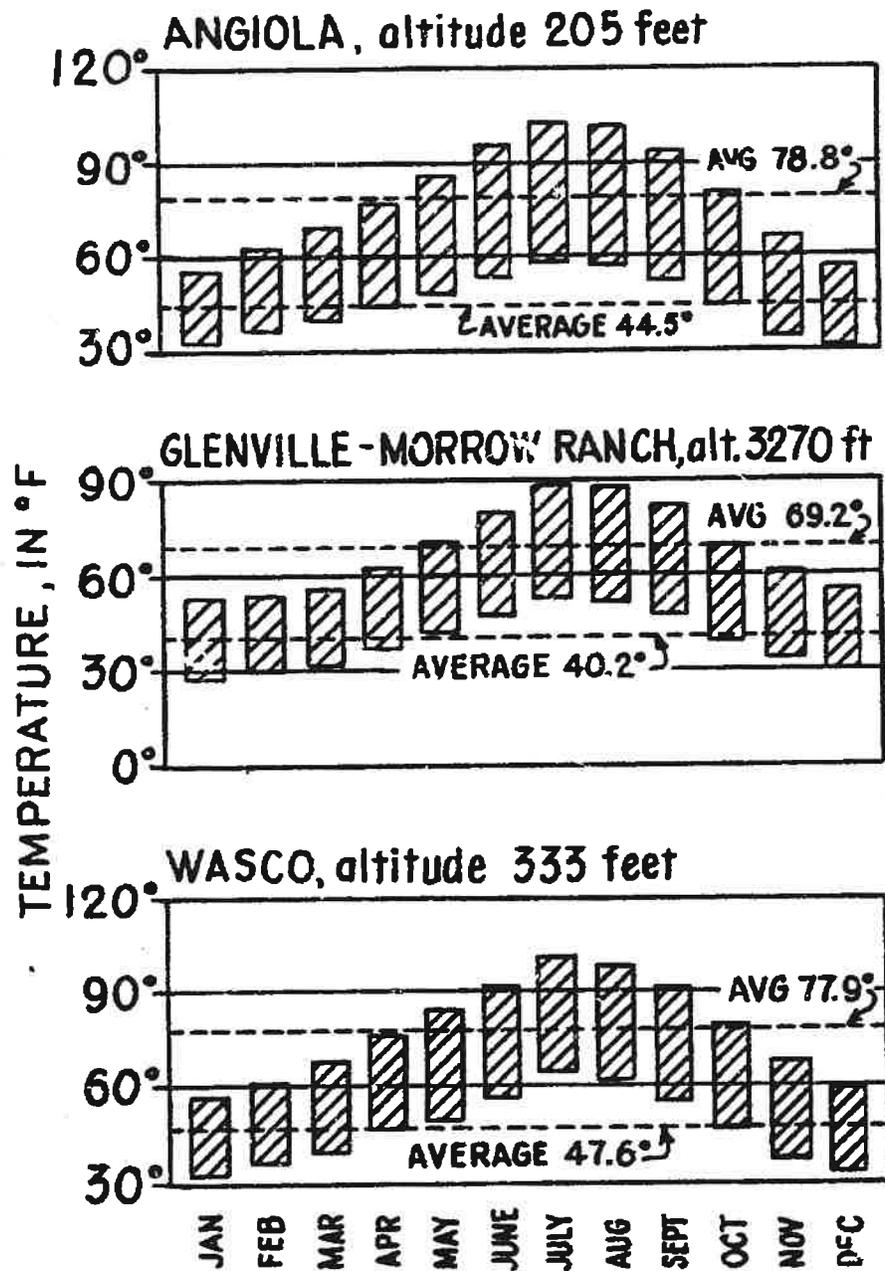


Figure 16. Graph showing maximum and minimum average temperature at three stations in or near the Terra Bella-Lost Hills area, California

FIGURE 17

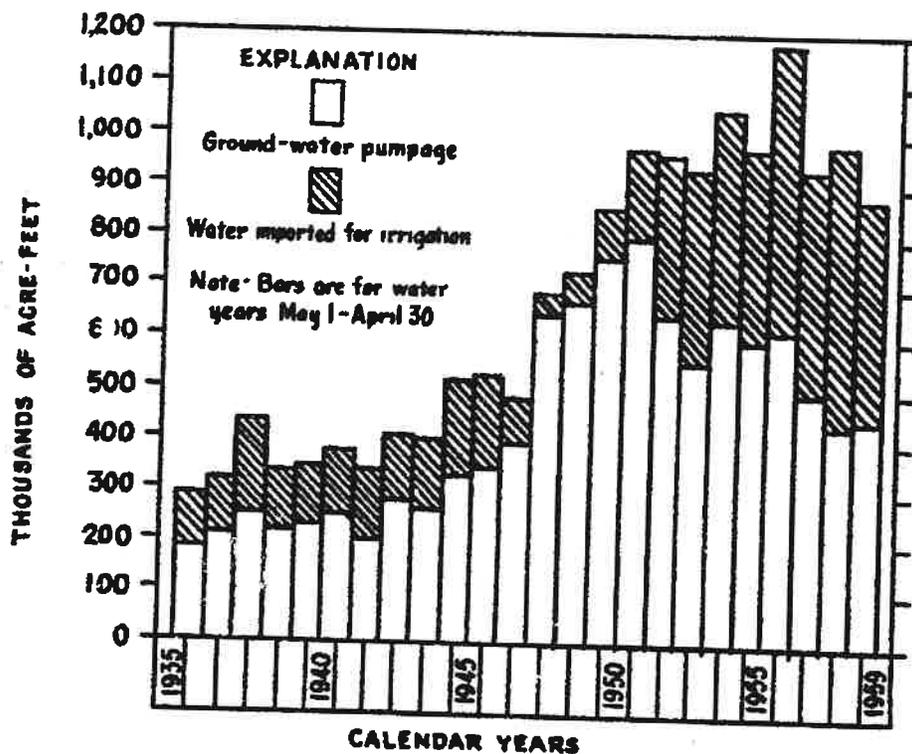
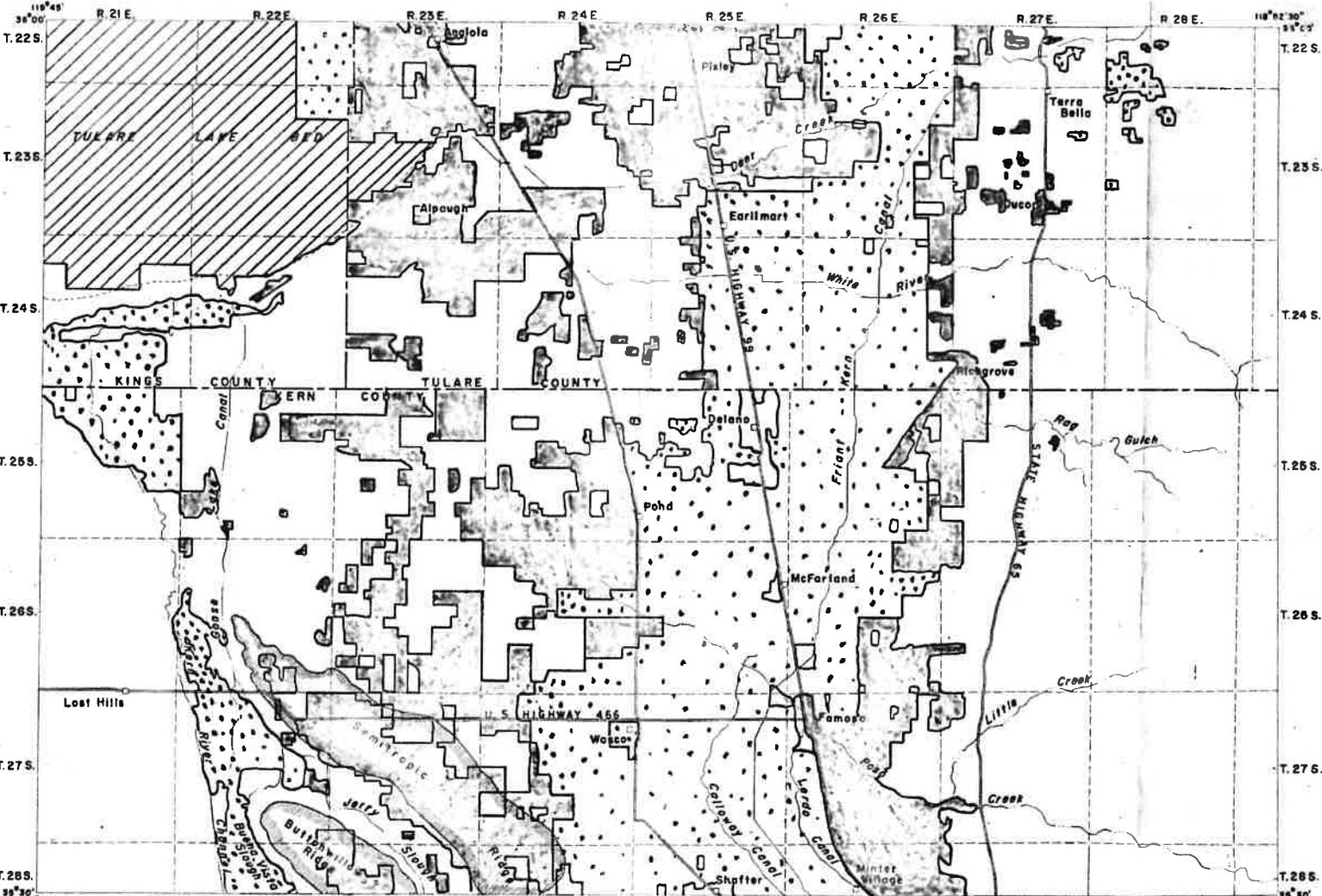


Figure 17 Graph showing estimated ground-water pumpage and water imported for irrigation, 1935-59, Terra Bella-Lost Hills area, Calif.

U.S. GEOLOGICAL SURVEY



Base from U.S. Geological Survey
 topographic map, Central Valley Calif.,
 South Area, 1958

**FIGURE-18 MAP SHOWING IRRIGATED ACREAGE,
 1958, AND SOURCES OF WATER**



63-47 **FIGURE 18**

EXPLANATION

-  Irrigated by surface water
-  Irrigated by ground water
-  Irrigated by surface and ground water

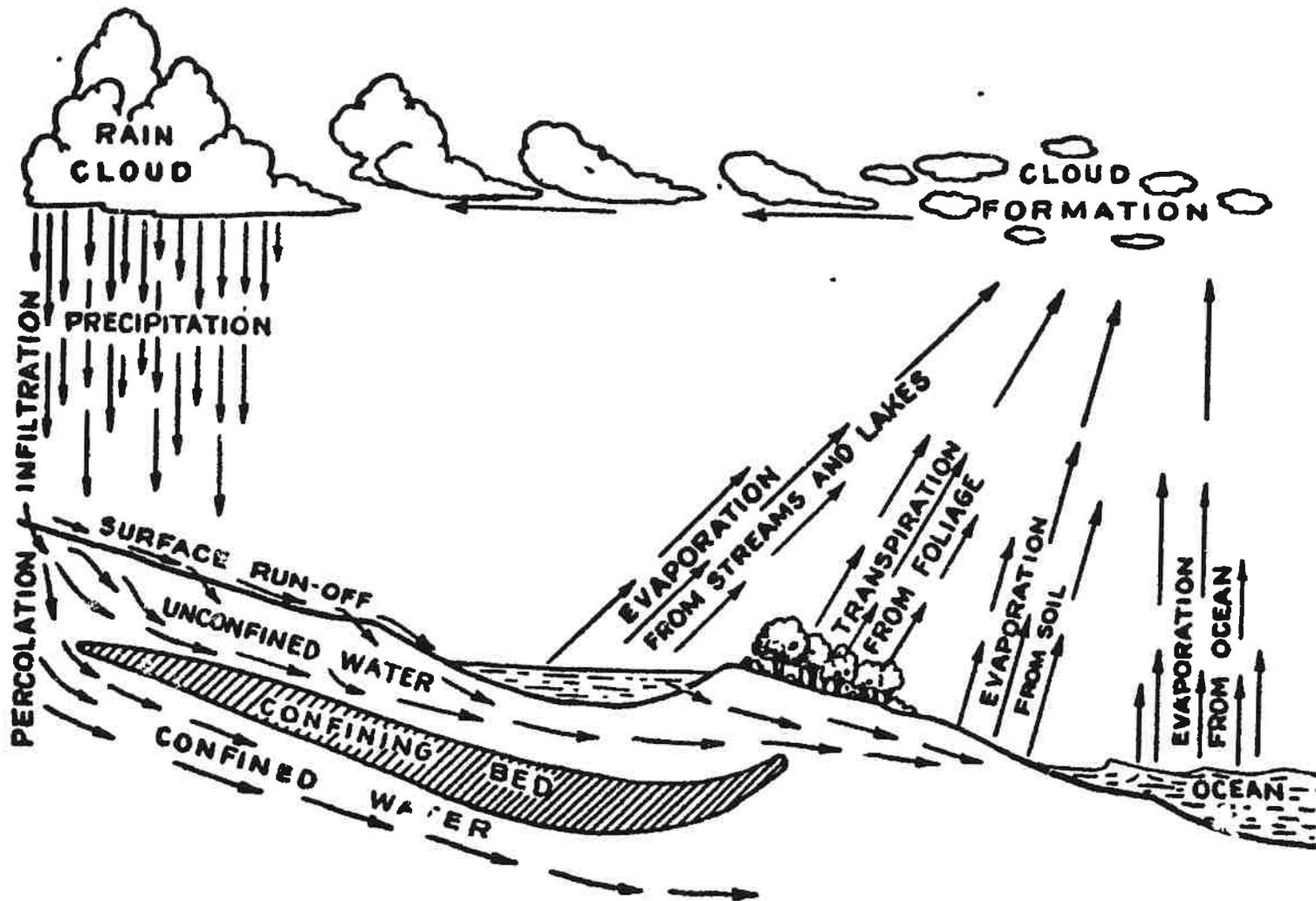
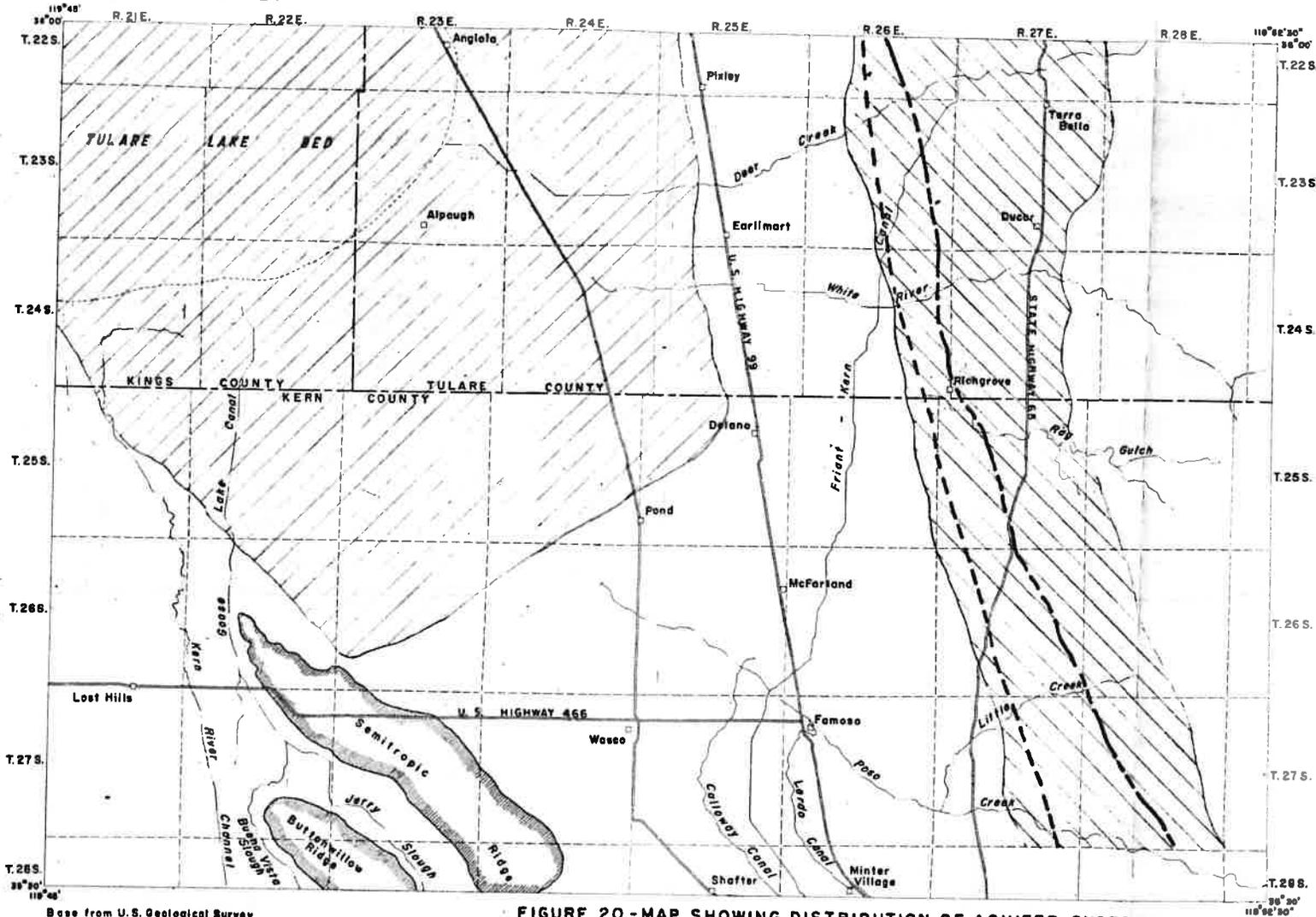


Figure 19. The Hydrologic Cycle

FIGURE 19

U. S. GEOLOGICAL SURVEY

63477 FIGURE 20



- EXPLANATION**
-  Area underlain by the semiconfined aquifer system
 -  Approximate area underlain by the semiconfined aquifer system and the confined aquifer system below the Corcoran Clay Member of Tulare Formation
 -  Approximate area underlain by the semiconfined aquifer system and the confined aquifers in the Santa Margarita Formation and Olcese Sand of Diepenbrock, (1933)
 -  Approximate western limit of the fresh water in the Santa Margarita Formation of Diepenbrock (1933)
 -  Approximate western limit of the fresh water in the Olcese Sand of Diepenbrock (1933)

Base from U. S. Geological Survey topographic map, Central Valley California, South Area, 1958

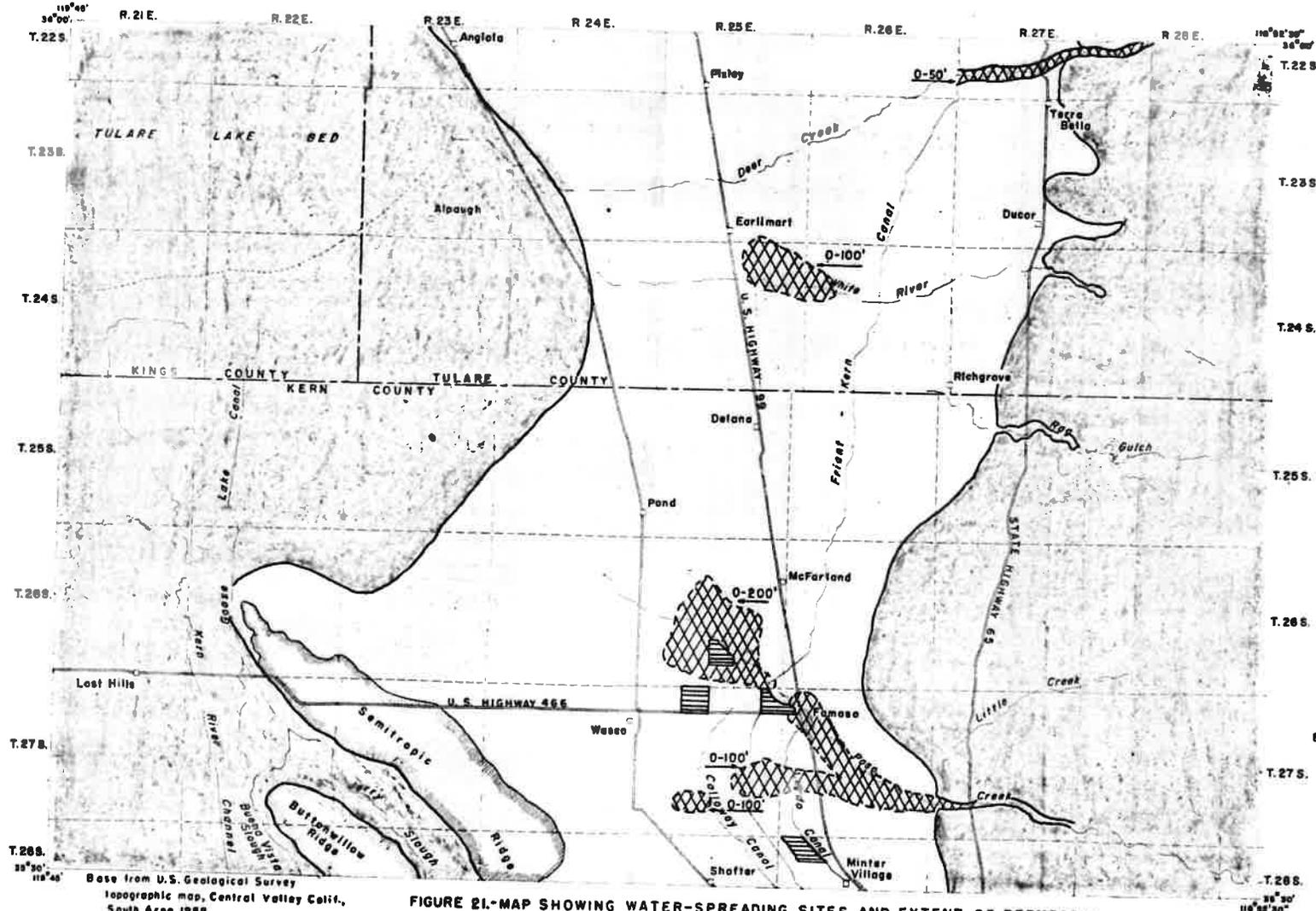
FIGURE 20.-MAP SHOWING DISTRIBUTION OF AQUIFER SYSTEMS AND CONFINED AQUIFERS IN MARINE ROCKS



U.S. GEOLOGICAL SURVEY

63-47

FIGURE 21



EXPLANATION



T.23 S. Area underlain by highly permeable deposits. Depth indicated in feet below land surface



T.24 S. Area underlain by permeable to moderately permeable deposits.



T.25 S. Area underlain by poorly permeable deposits.



T.27 S. Existing water-spreading sites

Base from U.S. Geological Survey topographic map, Central Valley Calif., South Area, 1958

FIGURE 21.-MAP SHOWING WATER-SPREADING SITES AND EXTENT OF PERMEABLE MATERIALS FROM LAND SURFACE TO DEPTH OF 200 FEET



63-47 FIGURE 22

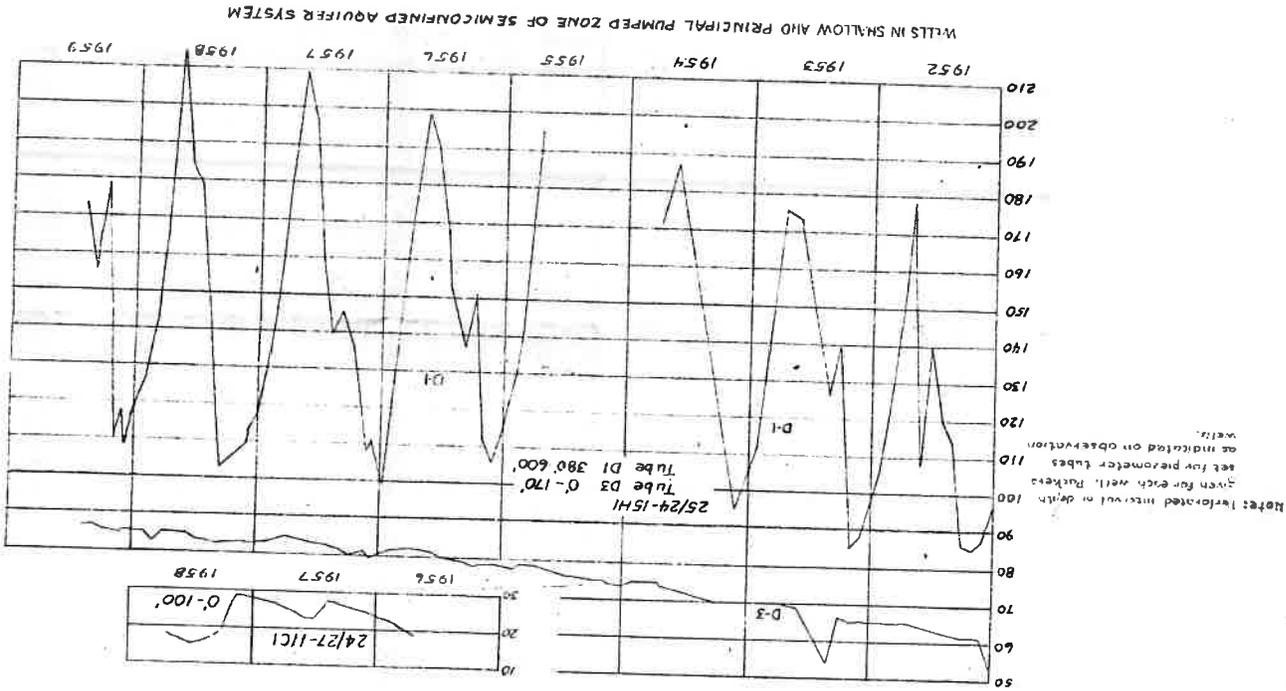
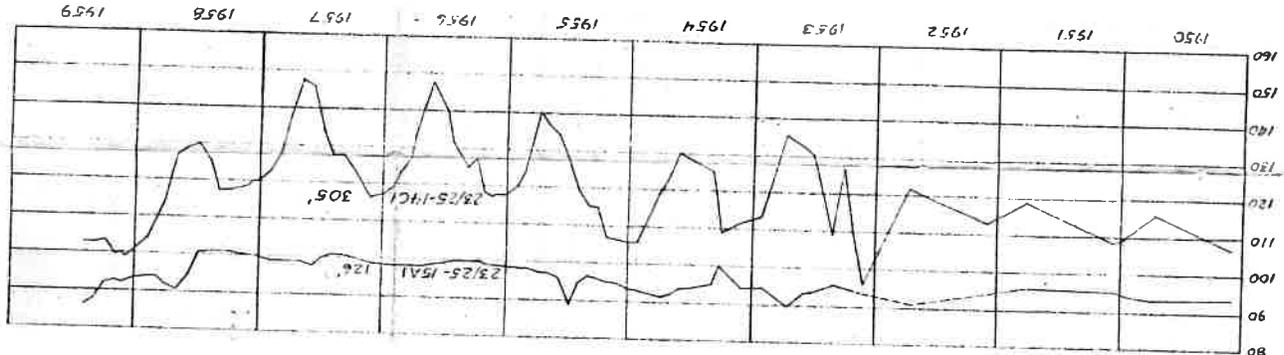
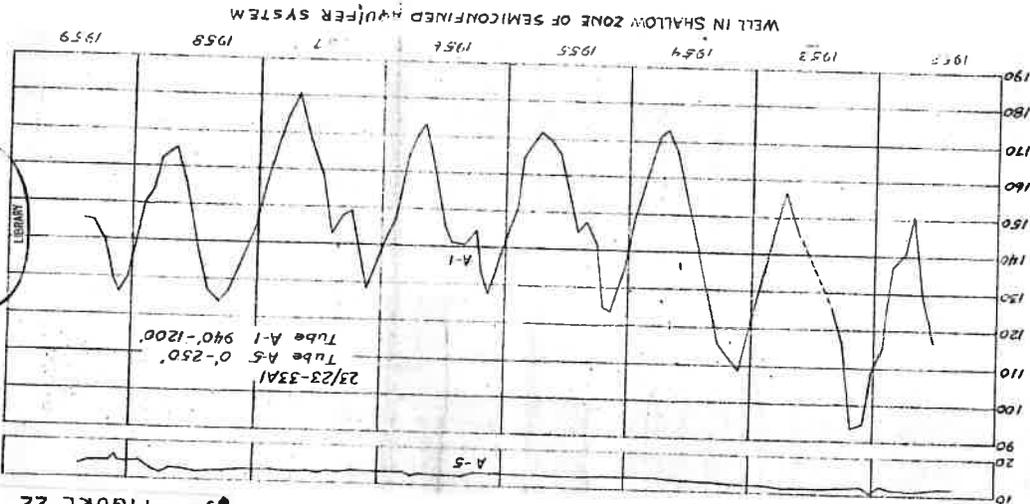


FIGURE 22. HYDROGRAPHS OF PAIRED SHALLOW AND DEEP WELLS

DEPTH TO WATER, IN FEET BELOW LAND-SURFACE DATUM

U. S. GEOLOGICAL SURVEY
MONROE PARK
APR 4 1967

(200)
Wm. J. G. T.

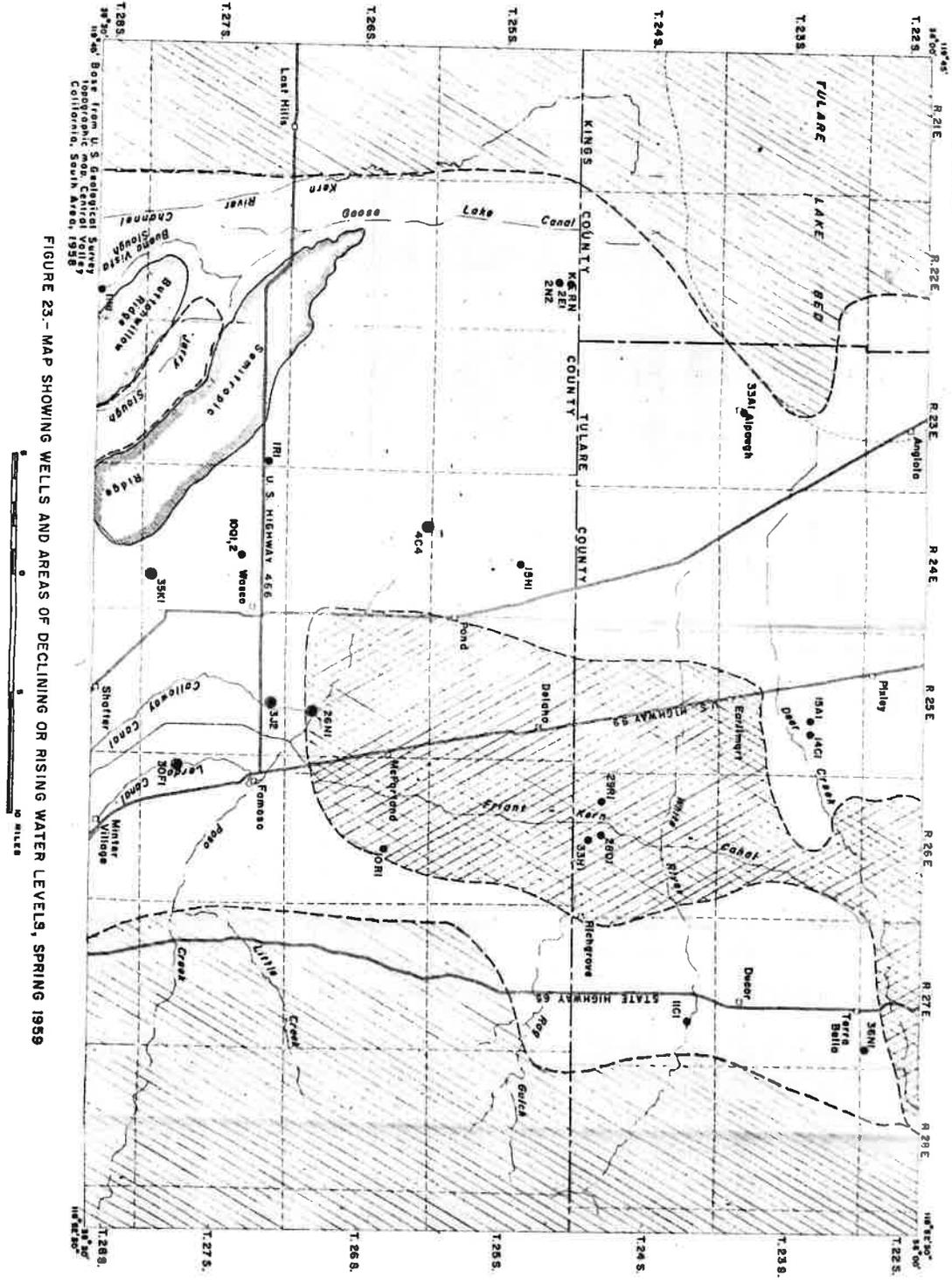


FIGURE 23.- MAP SHOWING WELLS AND AREAS OF DECLINING OR RISING WATER LEVELS, SPRING 1959

Scale: 1 inch = 10 miles

FIGURE 23
63-47

EXPLANATION

-  Area of rising or nearly-stationary water levels
-  Area of declining water levels
-  Area of few irrigation or domestic wells
-  Well
-  Site of aquifer test

Hydrograph in report

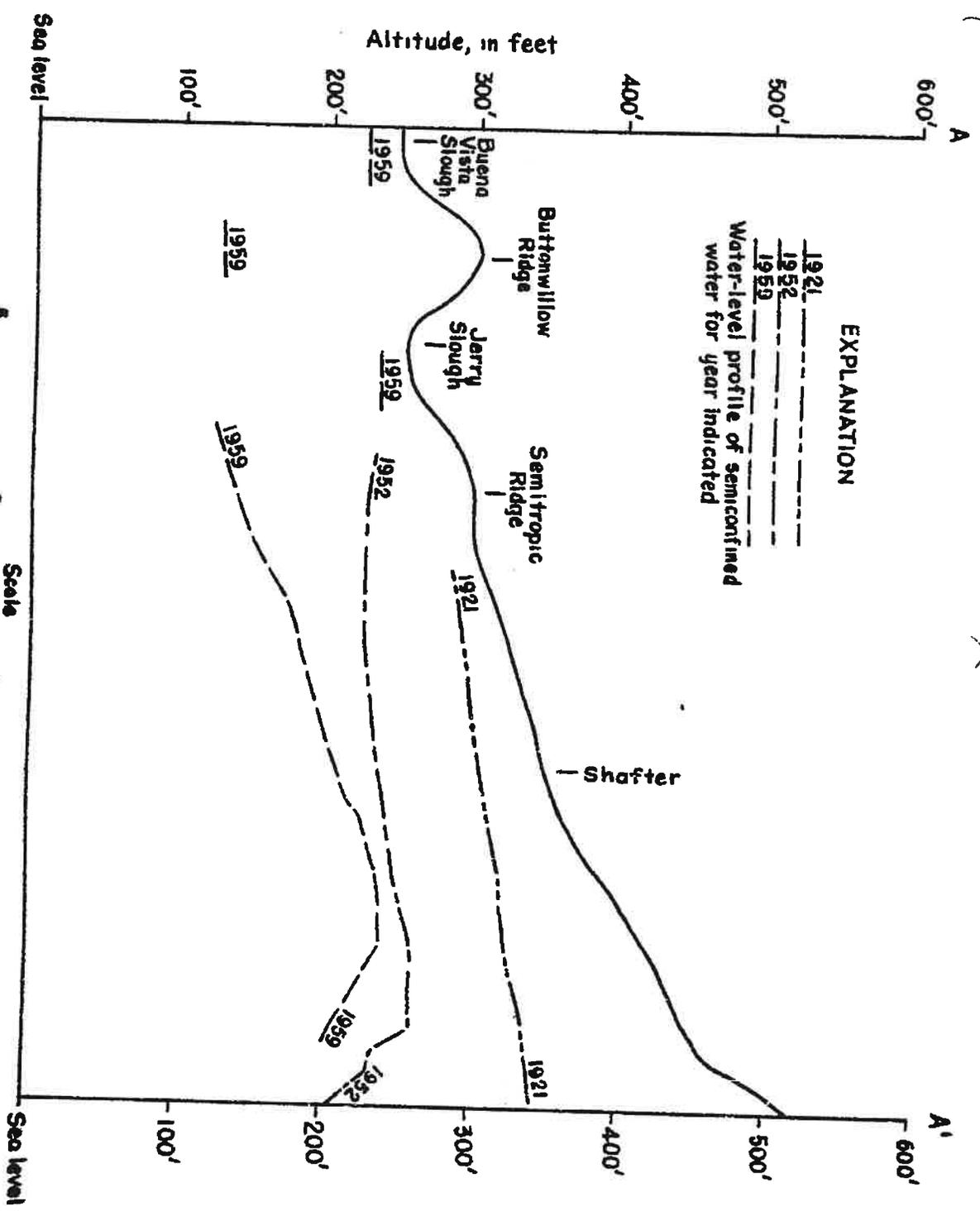


FIGURE 24. — DIAGRAM SHOWING WATER-LEVEL PROFILES ALONG SECTION A-A' IN THE TERRA BELLA-LOST HILLS AREA, CALIFORNIA

FIGURE 25

63-471

EXPLANATION

- 200 ———— Water-level contour
- Draw on top of principal pumped zone of semi-confined aquifer system
- - - - - Dashed water table
- Contour interval 25 feet; datum is mean sea level
- Line of water-level profile
- Well location
- Number indicates altitude of water surface in the well

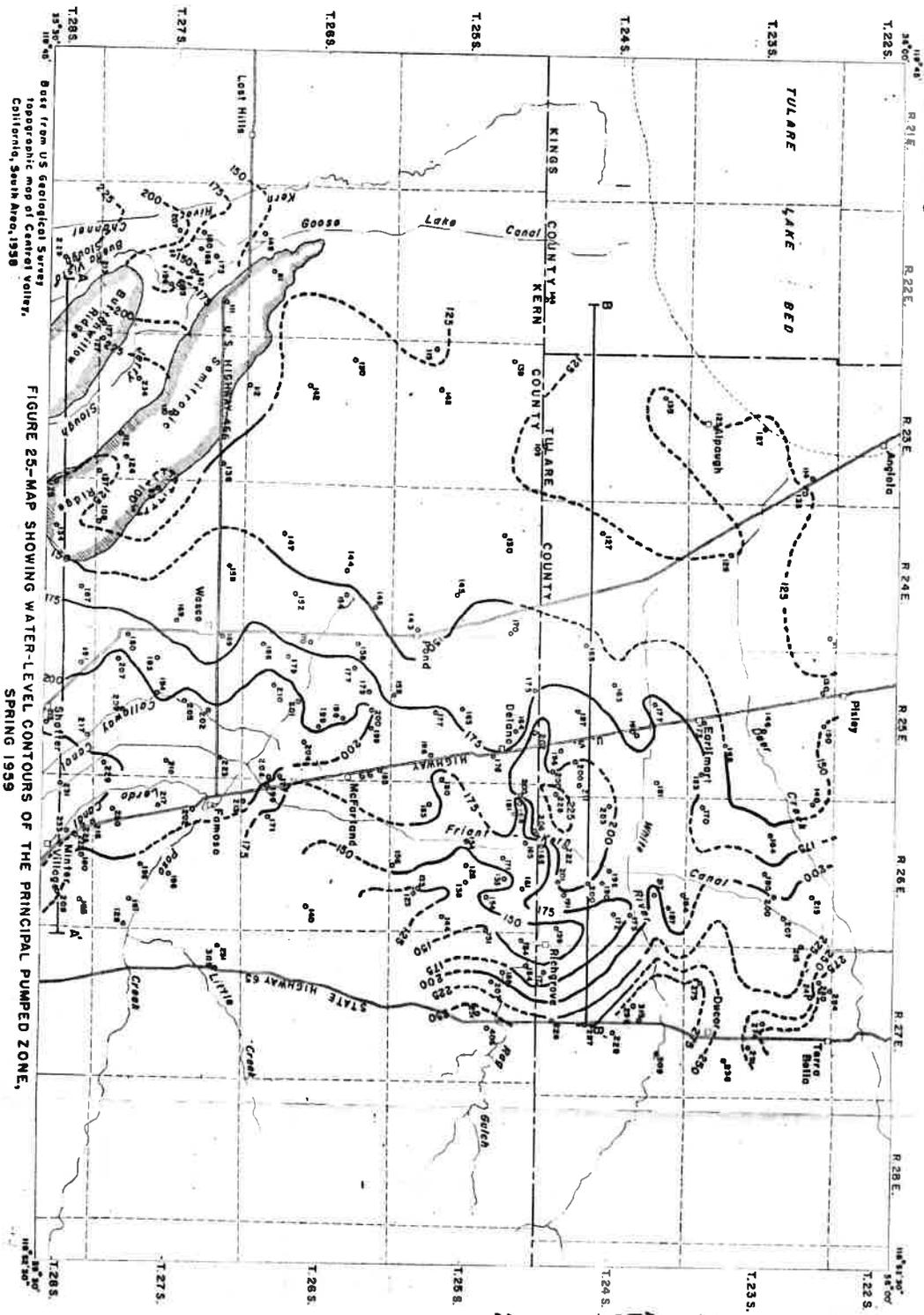


FIGURE 25—MAP SHOWING WATER-LEVEL CONTOURS OF THE PRINCIPAL PUMPED ZONE, SPRING 1959

Best from US Geological Survey topographic map of Central Valley, California, Sheet Area, 1938

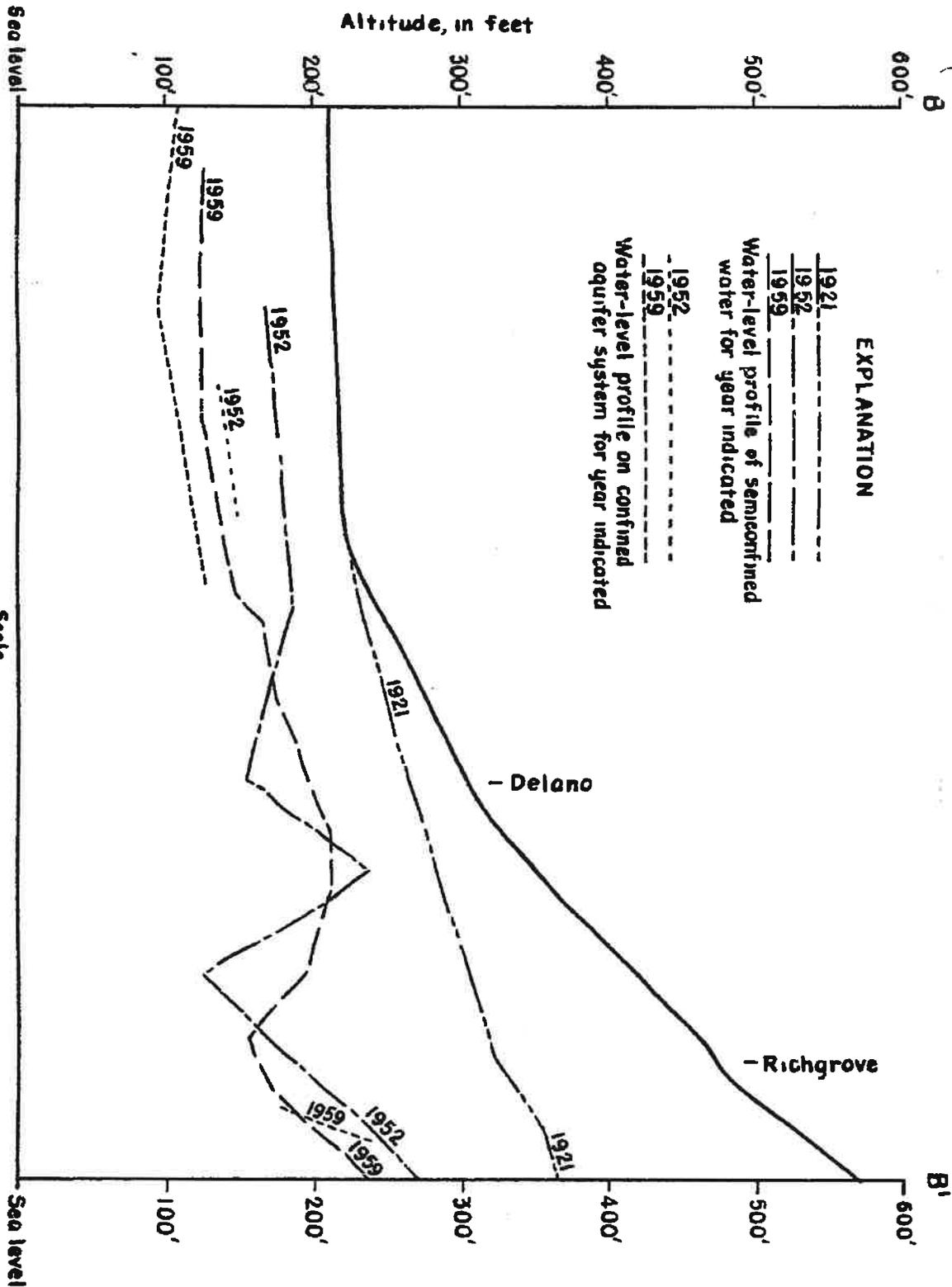


FIGURE 26. -- DIAGRAM SHOWING WATER-LEVEL PROFILES ALONG SECTION B-B' IN THE TERRA BELLA-LOST HILLS AREA, CALIFORNIA

FIGURE 27

63-47

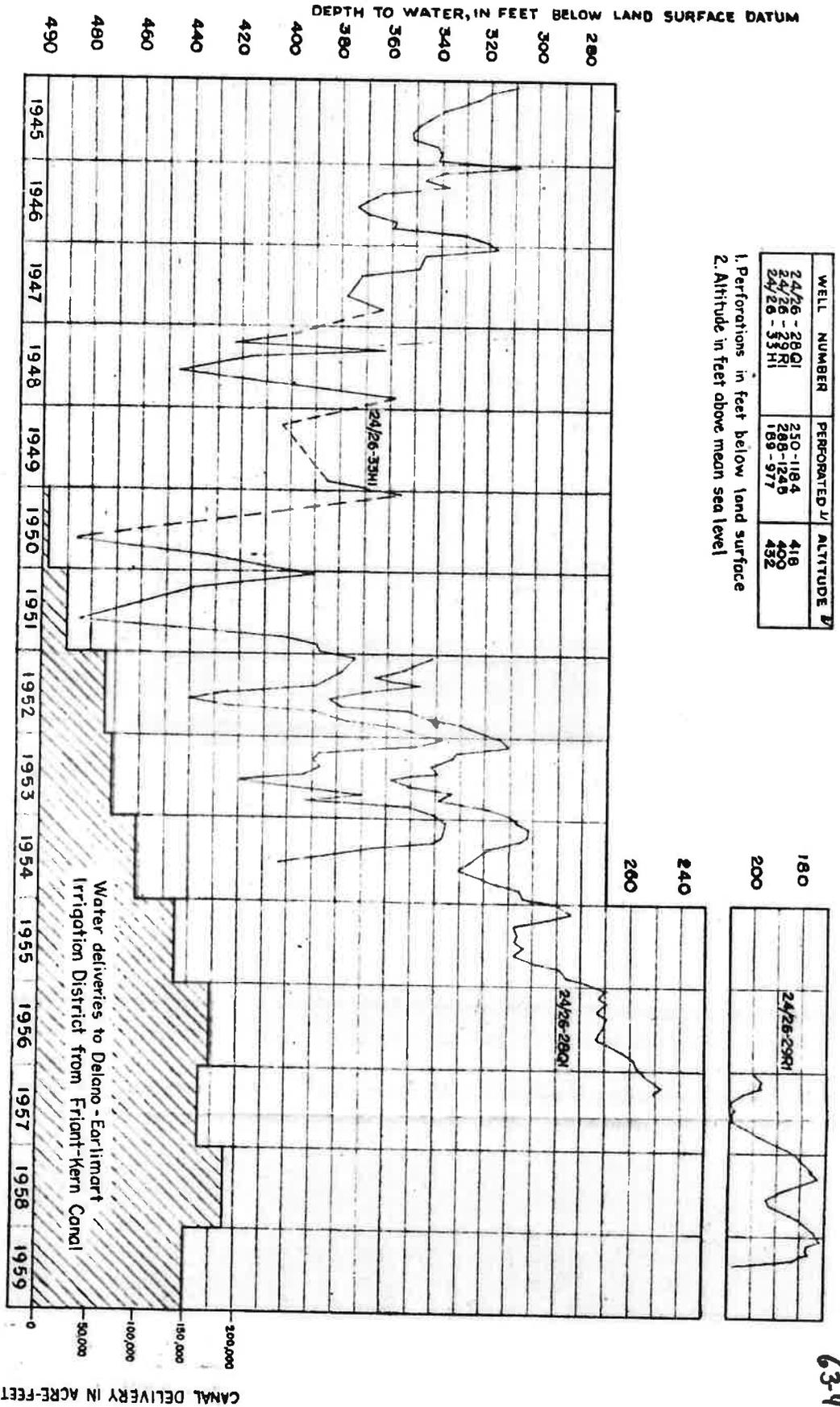


FIGURE 27. HYDROGRAPHS OF WELLS 24/26-28Q1, 29R1, AND 33H1 AND WATER DELIVERIES TO DELANO-EARLIMART IRRIGATION DISTRICT FROM FRIANT-KERN CANAL

DEPTH TO WATER, IN FEET BELOW LAND SURFACE DATUM

FIGURE 28 - HYDROGRAPHS OF WELLS 22/27-36N1, 25/22-2N2 AND 2E1, 26/26-10R1, 27/23-1R1, AND 28/22-11N1

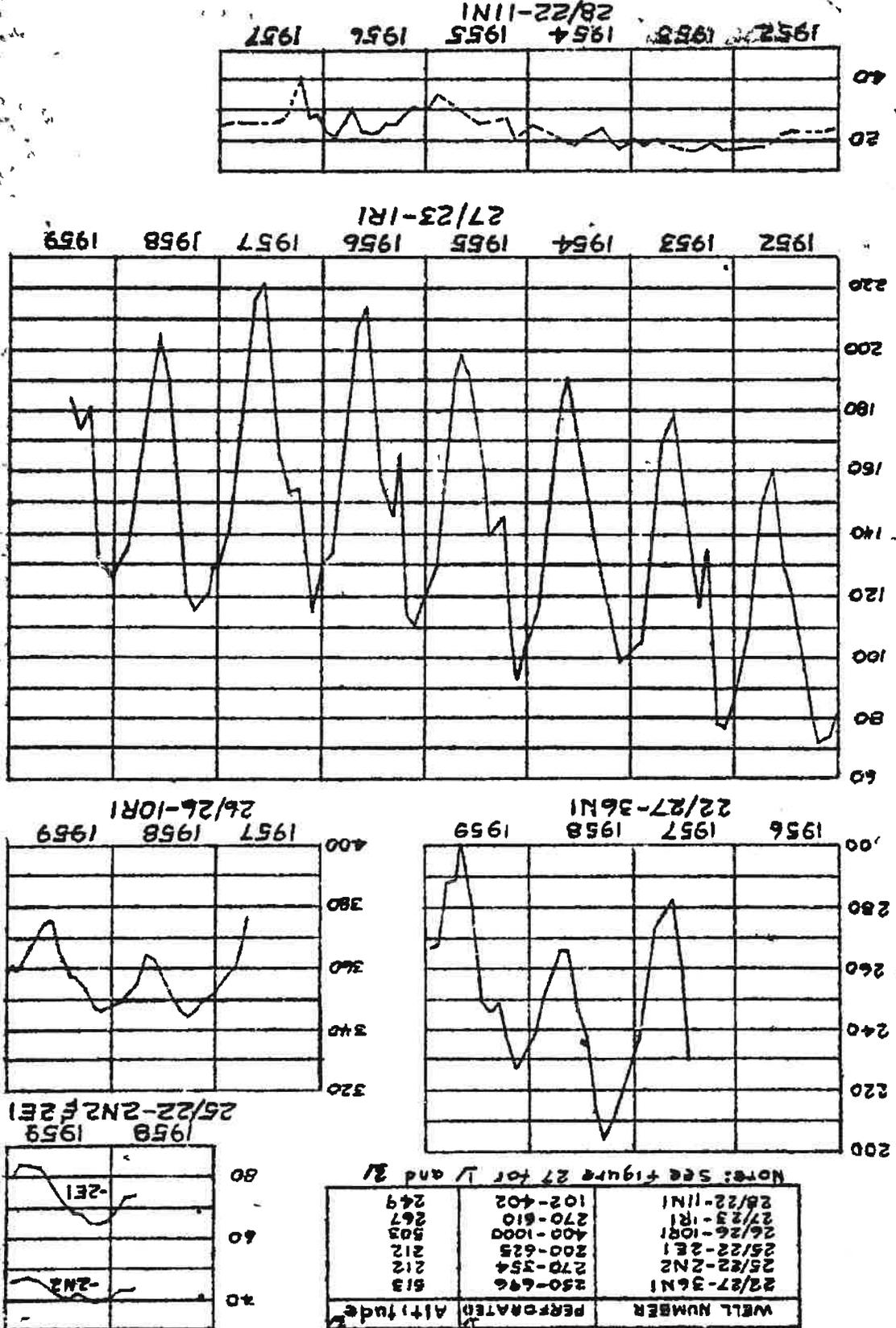
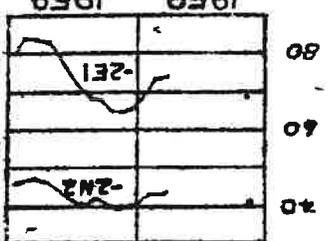


FIGURE 29



Note: See figure 27 for T and 31

WELL NUMBER	PERFORATED ALTITUDE	DATE
22/27-36N1	250-696	22/27-36N1
25/22-2N2	270-354	25/22-2N2
26/26-10R1	200-625	26/26-10R1
27/23-1R1	400-1000	27/23-1R1
28/22-11N1	102-402	28/22-11N1

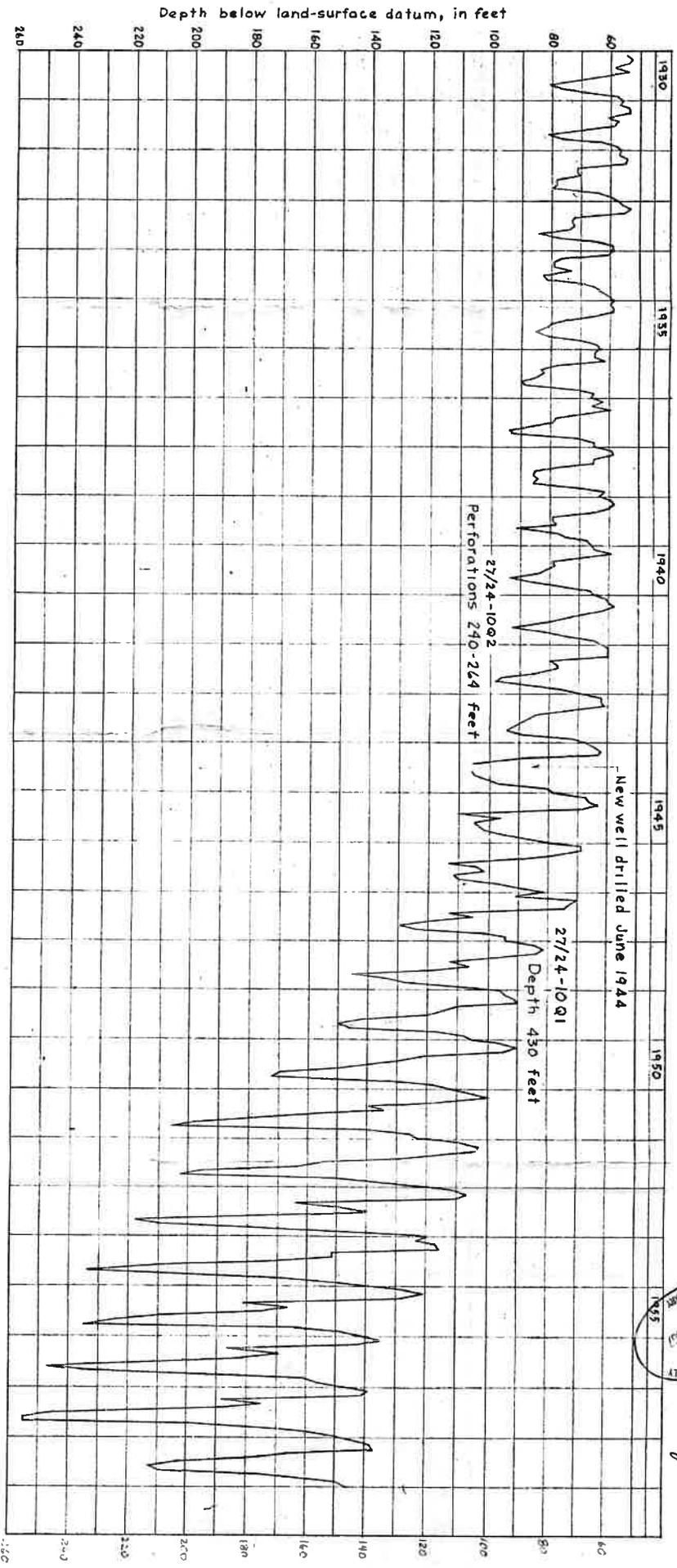
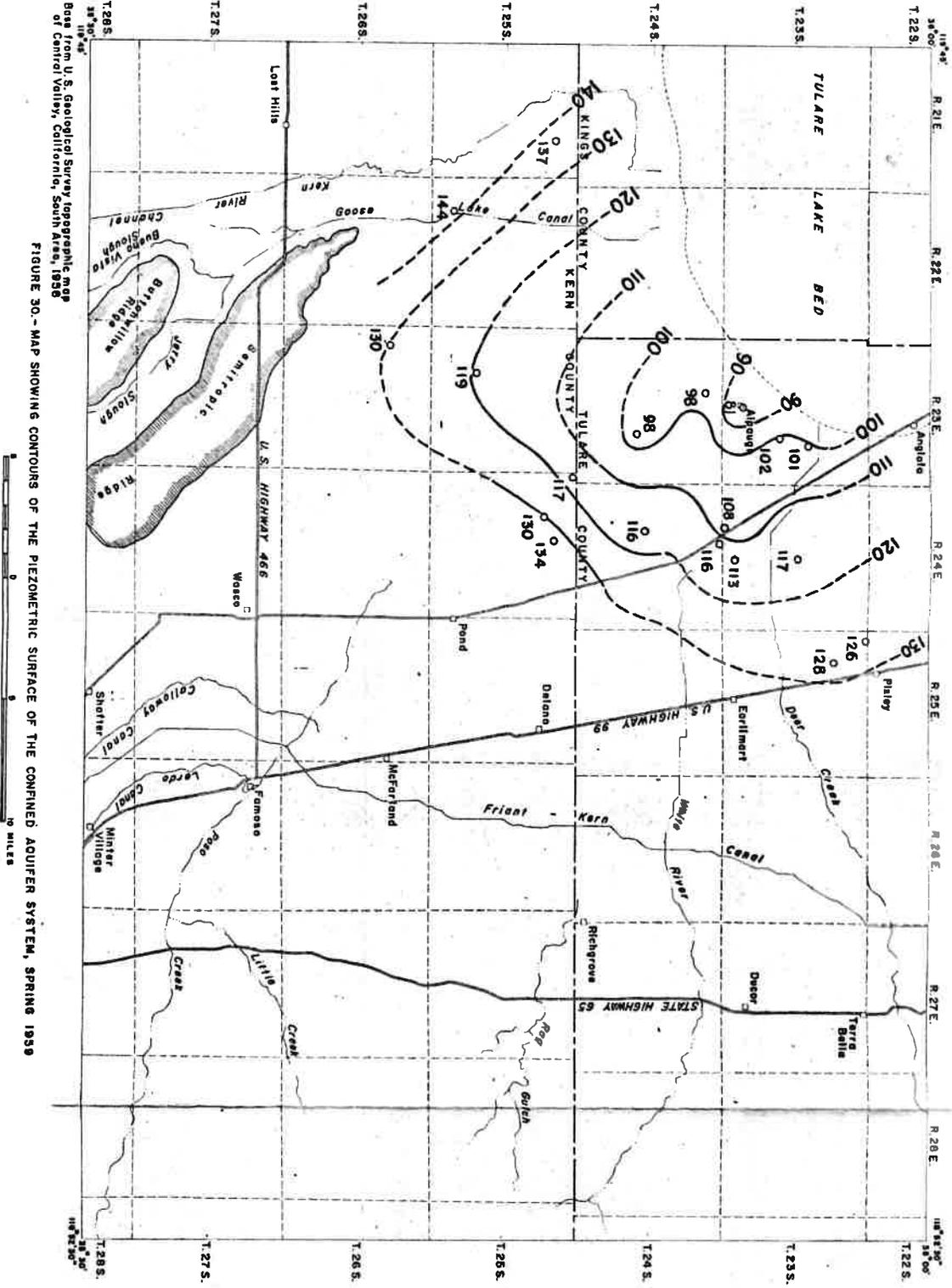


FIGURE 29. HYDROGRAPH OF WELLS 27/24-1001 AND 1002

FIGURE 29
 (2/23)
 Wm Jgc
 63-47



EXPLANATION

- 120
- Well
- Number indicates altitude of water surface in well
- Piezometric line
- Shows the surface to which water will rise in wells. Dashed where intervals; contour interval 20 feet; datum is mean sea level

FIGURE 30.-MAP SHOWING CONTOURS OF THE PIEZOMETRIC SURFACE OF THE CONFINED AQUIFER SYSTEM, SPRING 1939

Base from U. S. Geological Survey topographic map of Central Valley, California, South Area, 1938

EXPLANATION

— Piezometric line
 - - - - - Shows the surface to which water will rise in wells.
 Dashed where inferred,
 contour interval 10 feet;
 datum is mean sea level

Well
 ○ 30P1
 ○ 150

Upper number identifies the well and lower number indicates altitude of piezometric surface

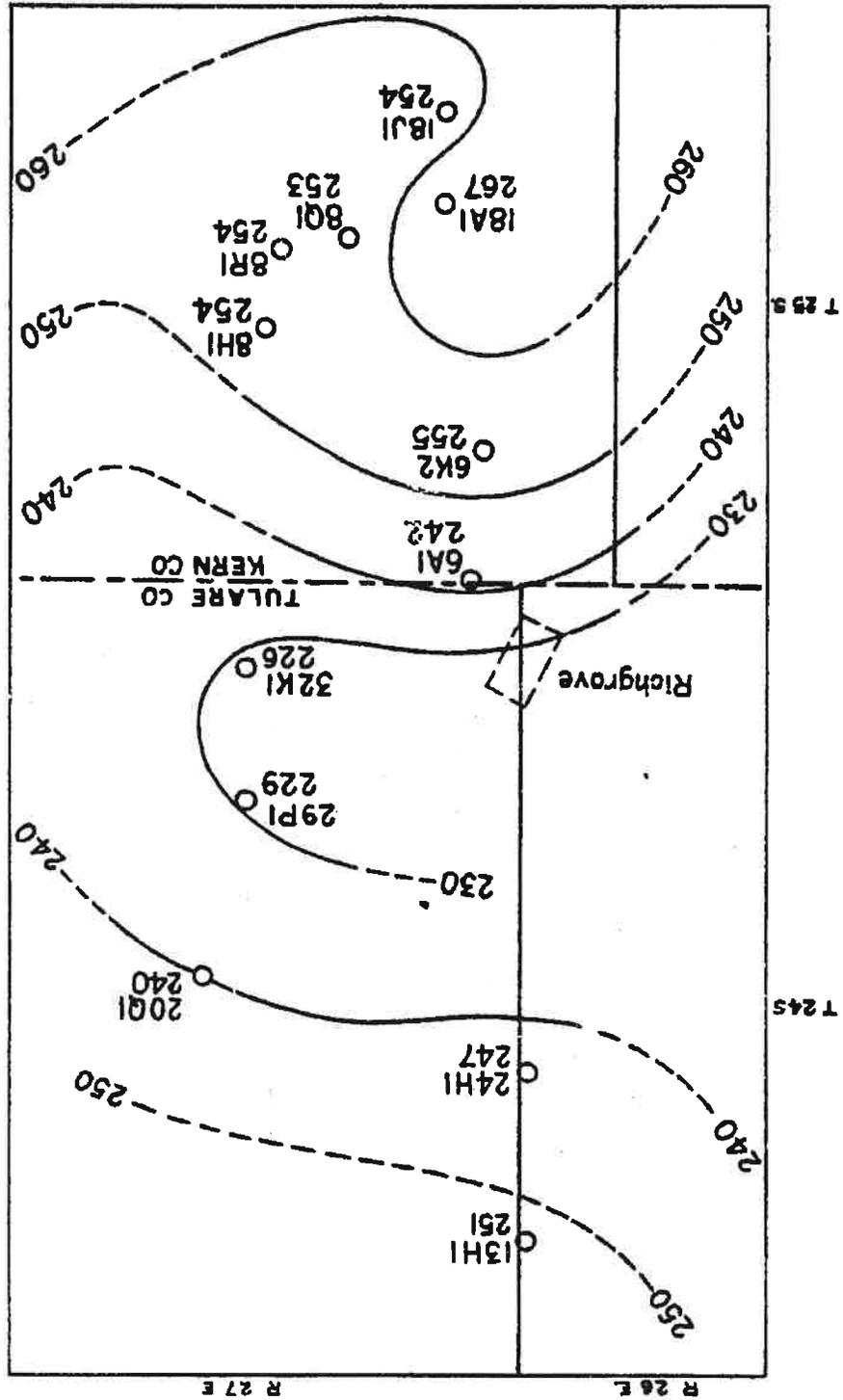


FIGURE 31. MAP SHOWING CONTOURS OF THE PIEZOMETRIC SURFACE OF THE SANTA MARGARITA FORMATION OF DIAPENBROCK (1933), SPRING 1956



EXPLANATION

— 150 —
Piezometric line
Shows the surface to which
water will rise in wells.
Dashed where inferred;
contour interval 10 feet;
datum is mean sea level.

Well
30P1
150

Upper number identifies the
well and lower number
indicates altitude of
piezometric surface

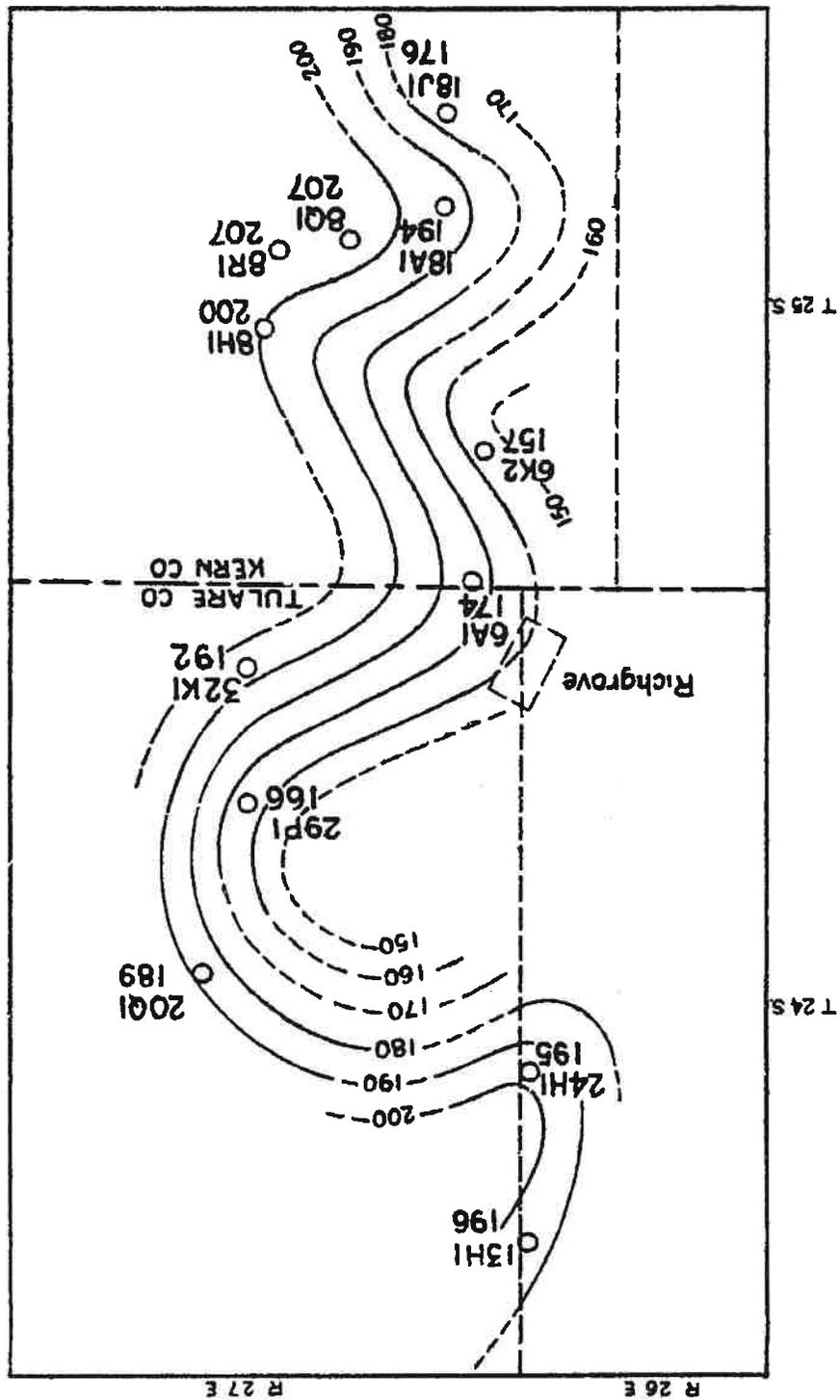
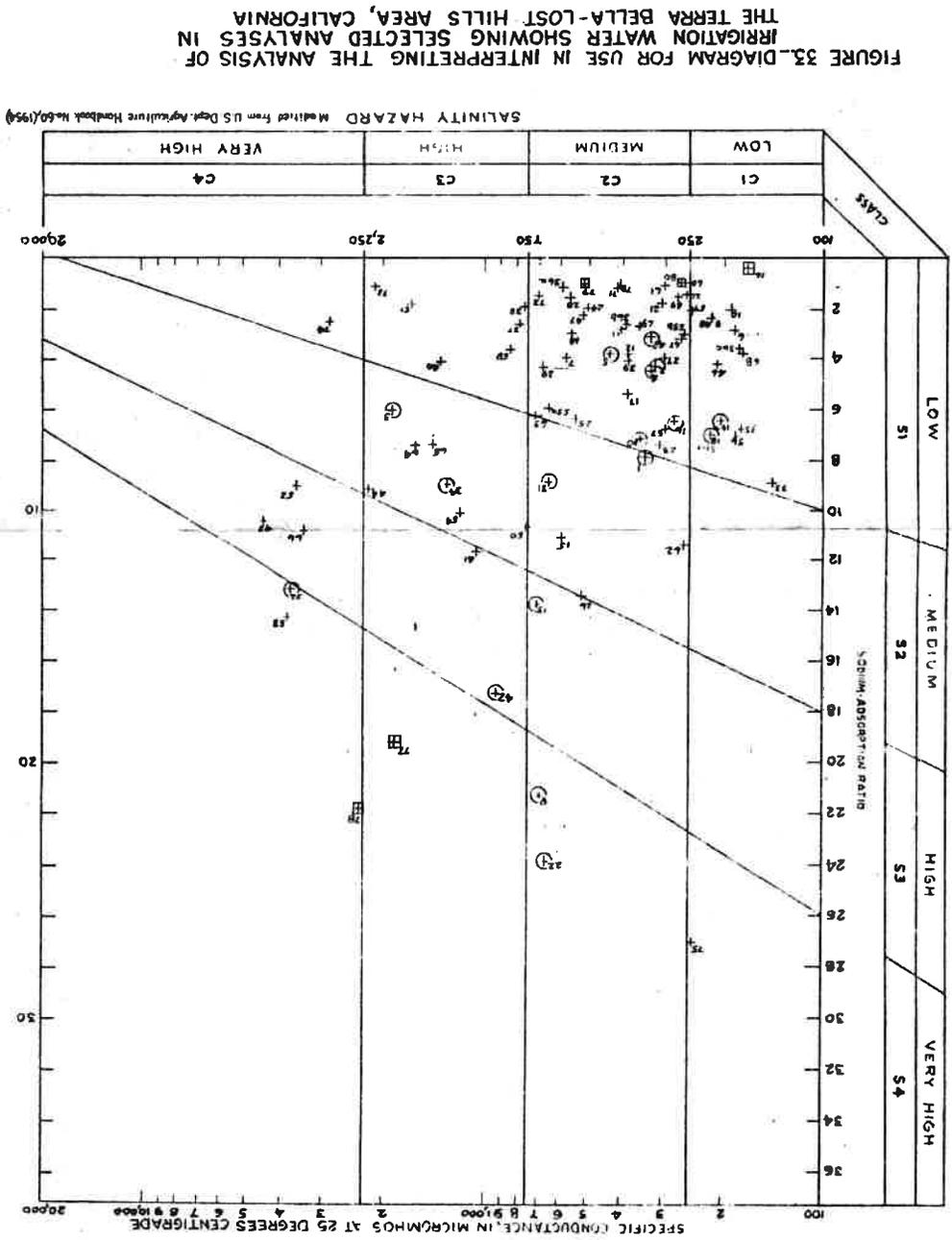


FIGURE 32. MAP SHOWING CONTOURS OF THE PIEZOMETRIC SURFACE OF THE SANTA MARGARITA FORMATION OF DIEPENBROCK (1933), SPRING 1959



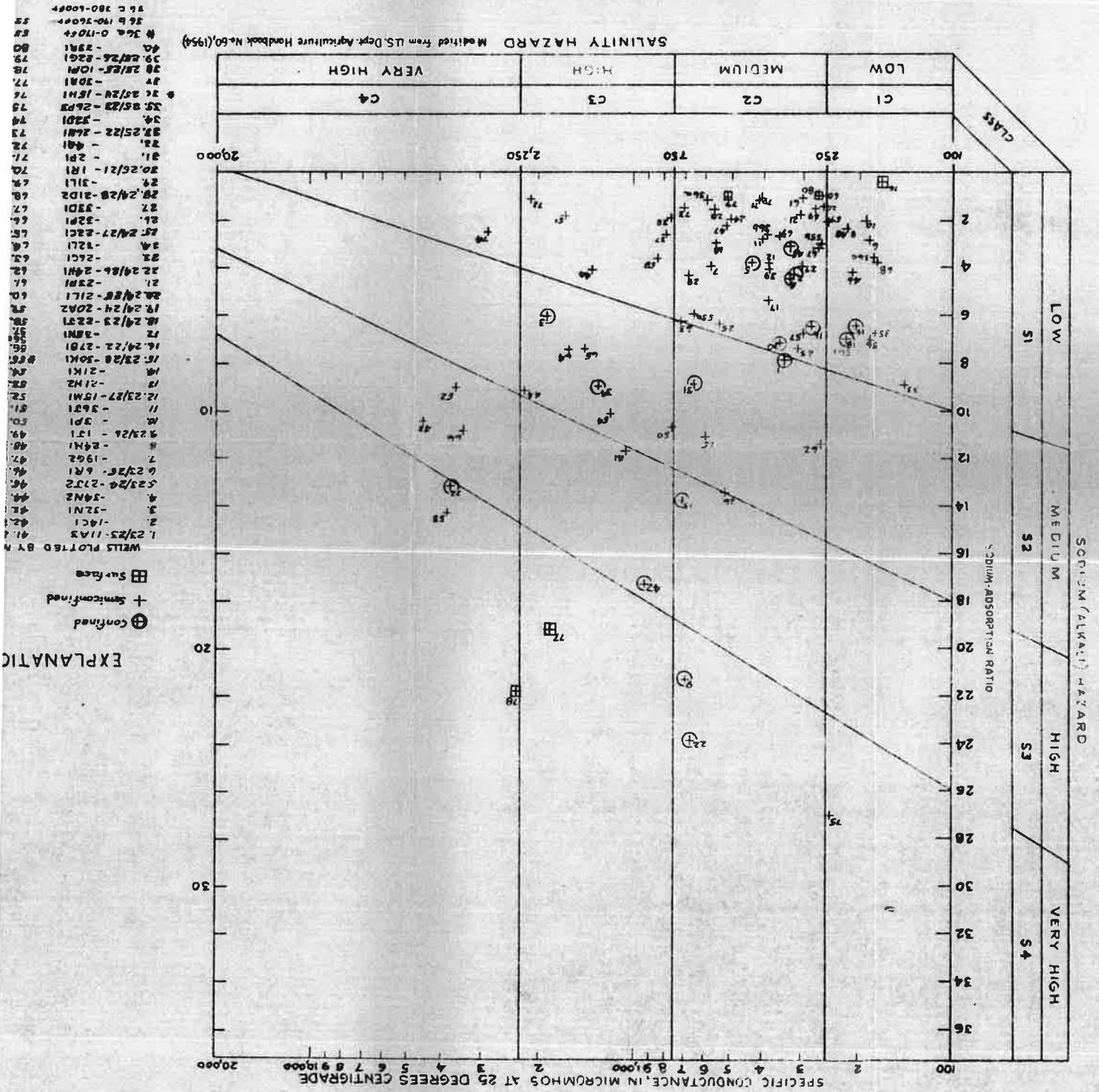


FIGURE 33. DIAGRAM FOR USE IN INTERPRETING THE ANALYSIS OF IRRIGATION WATER SHOWING SELECTED ANALYSES IN THE TERRA BELLA-LOST HILLS AREA, CALIFORNIA

Accompanying text is shelved in the back units under the same classification as this map.

U.S. GEOLOGICAL SURVEY
 WATER RESOURCES DIVISION
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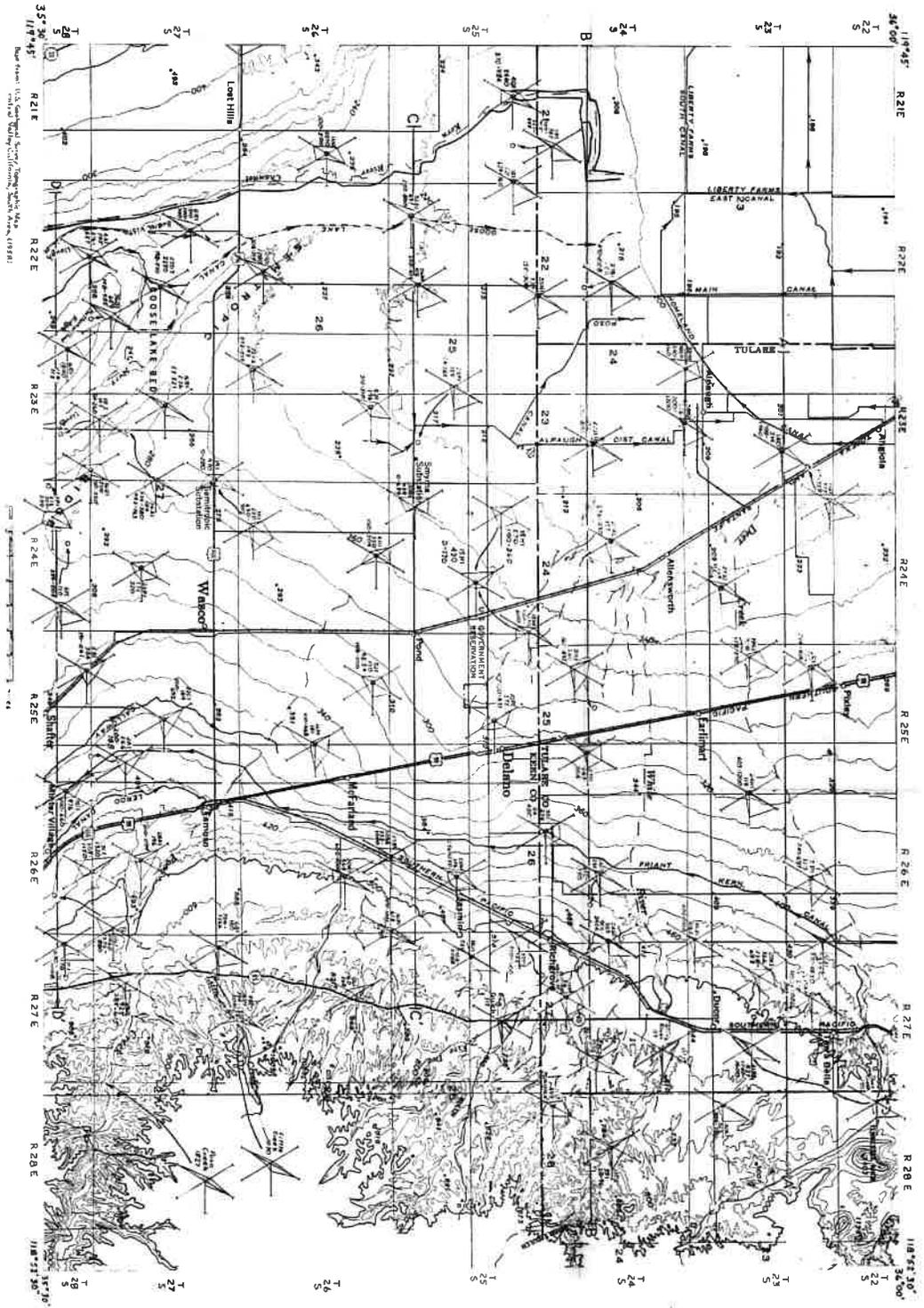


FIGURE 34.-MAP SHOWING SELECTED CHEMICAL ANALYSES OF SURFACE AND GROUND WATERS, TERRA BELLA-LOST HILLS AREA, CALIFORNIA

E. J. Mc Clelland, M.S.I.



FIGURE 34

Handwritten notes:
 10/15/64
 E. J. Mc Clelland

EXPLANATION-

Well

Chemical analysis

Ground water analysis

Surface water analysis

Line of geological section

EXPLANATION

Diagram of chemical analysis

The analytical results in percentage (weight volume) are shown from the center of the diagram. The numbers outside the diagram indicate the number of samples analyzed.

(Well number in parentheses)

(Number in brackets)

(Number in circles)

(Number in squares)

(Number in triangles)

(Number in diamonds)

(Number in hexagons)

(Number in octagons)

(Number in stars)

(Number in circles)

(Number in squares)

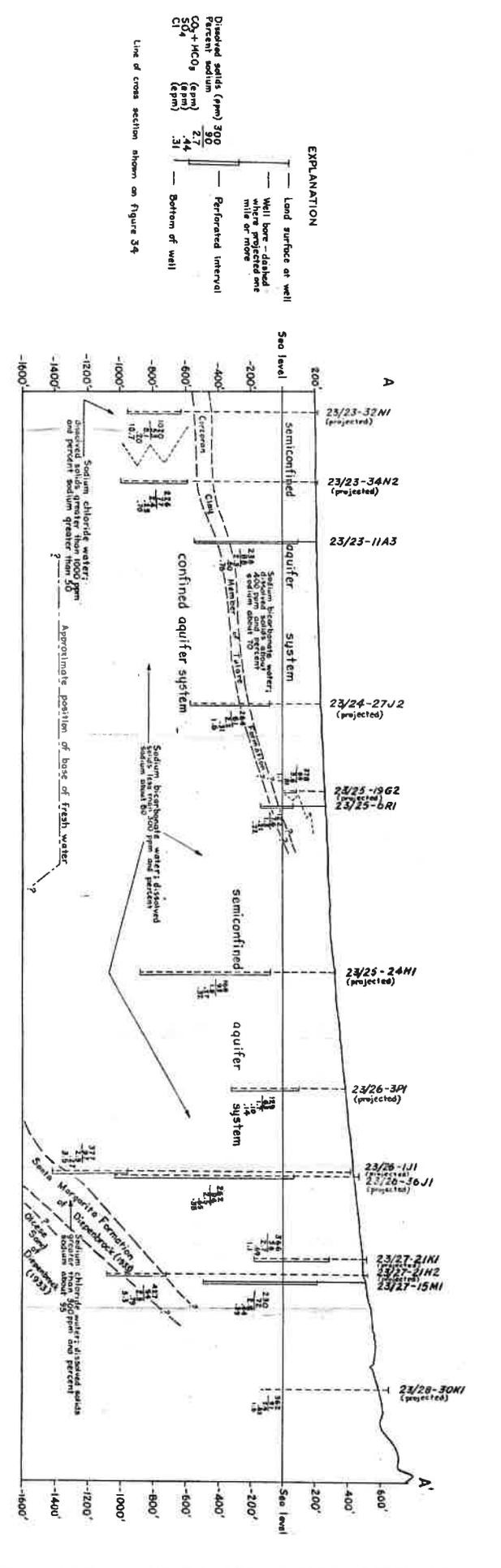
(Number in triangles)

(Number in diamonds)

(Number in hexagons)

(Number in octagons)

(Number in stars)



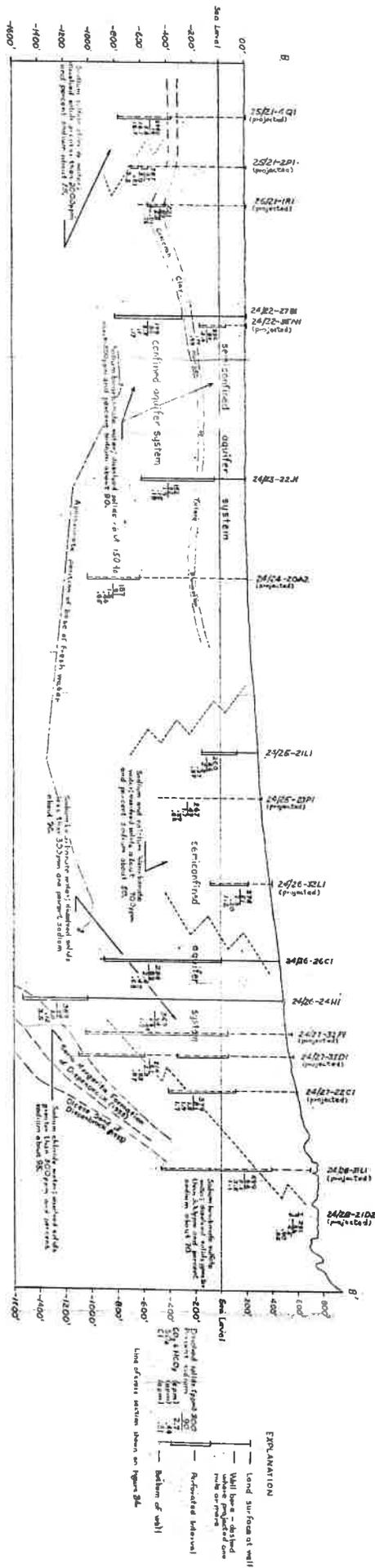


FIGURE 36. GEOCHEMICAL SECTION B-B' IN THE TERRA BELLA - LOST HILLS AREA, CALIFORNIA

Vertical scale 25 times horizontal scale

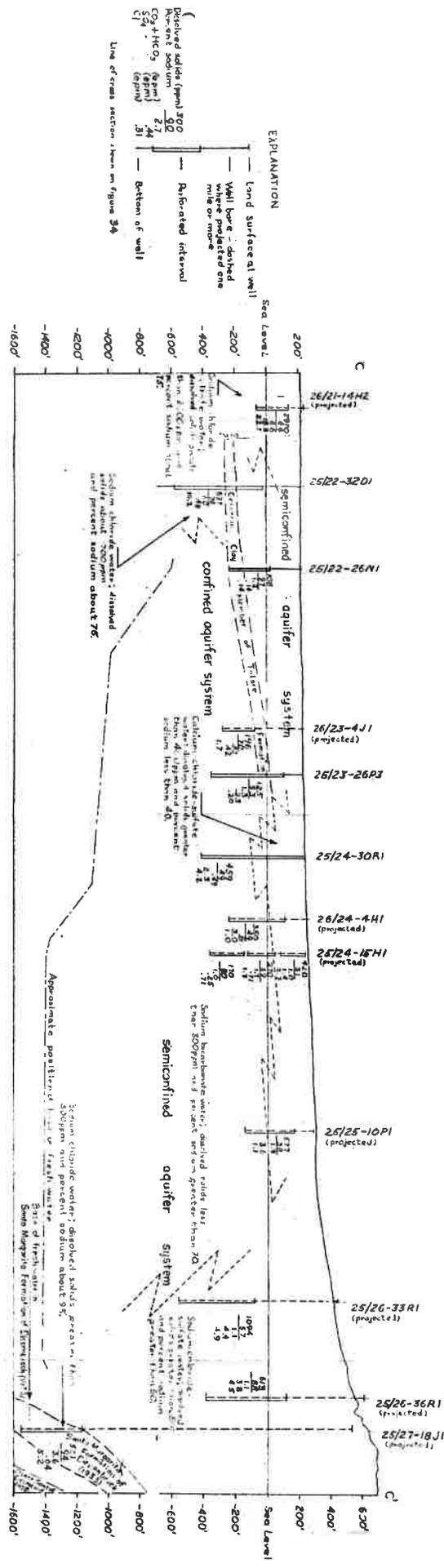


FIGURE 37. GEOCHEMICAL SECTION C-C' IN THE TERRA BELLA-LOST HILLS AREA, CALIFORNIA

Vertical scale 26 times horizontal scale

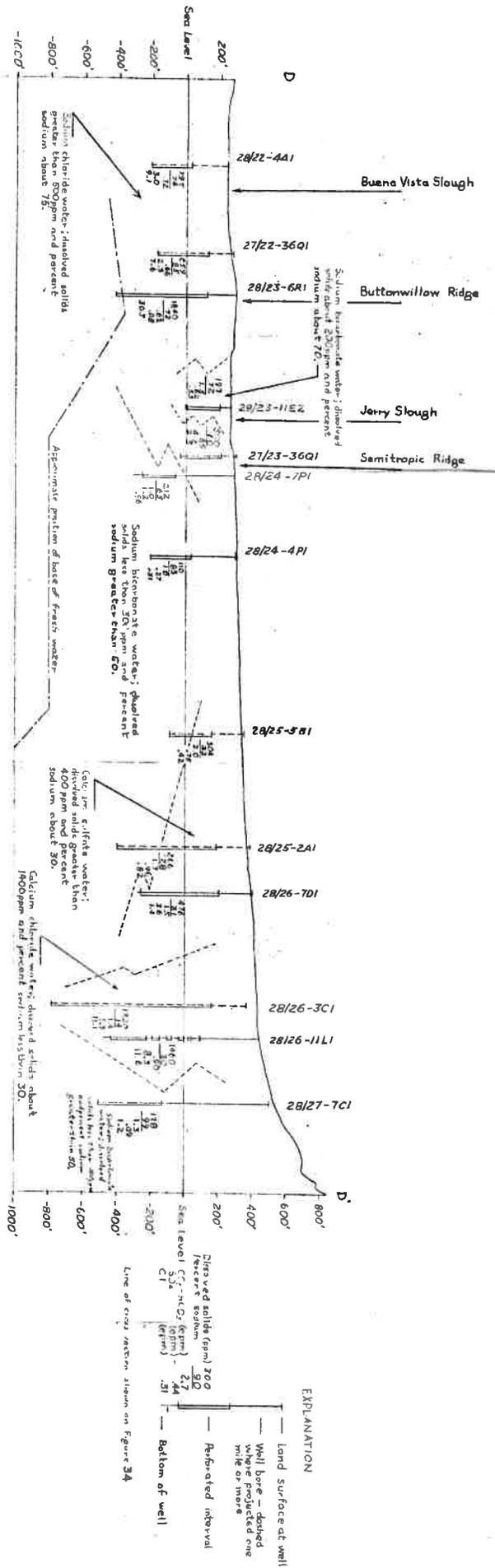


FIGURE 38.—GEOCHEMICAL SECTION D-D' IN THE TERRA BELLA-LOST HILLS AREA, CALIFORNIA

Vertical scale 2 1/2 times horizontal scale

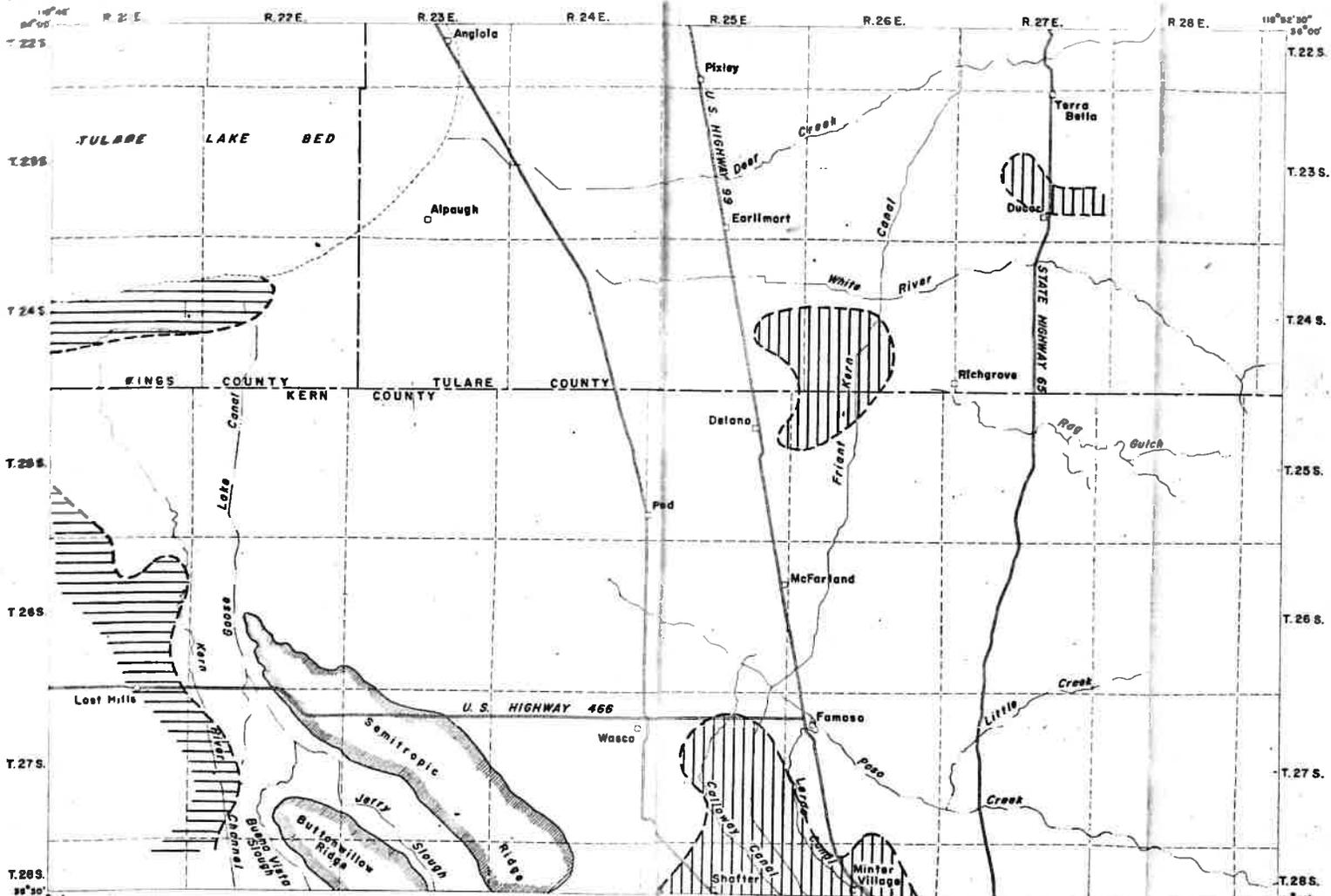
EXPLANATION

- land surface at well
- Well base—depth water produced one mile or more
- Reformed interval
- Bottom of well

Disolved solids (ppm) 200 (Ca⁺⁺-Mg⁺⁺) 200 (Ca⁺⁺-Mg⁺⁺-Cl) 2.7 (ppm) .51

Figure 38
13-47

U.S. GEOLOGICAL SURVEY



Base from U.S. Geological Survey topographic map of Central Valley, California, South Area, 1958

FIGURE 39.- MAP SHOWING HIGH BORON AND NITRATE CONCENTRATIONS IN THE TERRA BELLA-LOST HILLS AREA, CALIFORNIA



6347 FIGURE 39

EXPLANATION

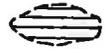
-  Boron concentration in excess of 2.0 ppm; found in wells perforated above the Corcoran Clay Member of the Tulare Formation
-  Nitrate concentration in excess of 40 ppm

Table 1.--Geologic history of the San Joaquin Valley and bordering mountains
(Adapted from Davis and others, 1959, p. 38-39.)

63-47

Epoch	Coast Ranges	San Joaquin Valley	Sierra Nevada
Recent	Subaerial erosion forms present topography. Minor structural movements continuing to present time.	Deposition of stream-channel, alluvial-fan, overflow, and lacustrine deposits contemporaneous with mild dissection of tilted alluvial fans on east side of valley. Deposition of broad coalescing alluvial fans on west side of valley.	Subaerial erosion at high altitude.
Pleistocene	Major faulting and folding developed present relief and form of existing structures reflected by Lost Hills, Buttonwillow Ridge, and Semitropic Ridge, and probably eastern area of dissected uplands.	Deposition of coarse alluvial deposits by streams draining Sierra Nevada contemporaneous with dissection of tilted older alluvial-fan deposits. Alluvial fans on east side tilted with Sierra block.	Several stages of glaciation in higher parts of range. Last major uplift of range along faults on eastern margin with additional westward tilting of Sierra block.
Pliocene	Folding and faulting on regional scale in late Pliocene outlines present form of ranges.	Extensive lake occupied western part of valley for a time in late Pliocene. Most of the valley was above sea level in late Pliocene. Streams from Sierra Nevada deposited generally fine-grained siltstone on the east side, including coarse-grained volcanic detritus.	Relative structural stability.

Table 1.--Geologic history of the San Joaquin Valley and bordering mountains--Continued

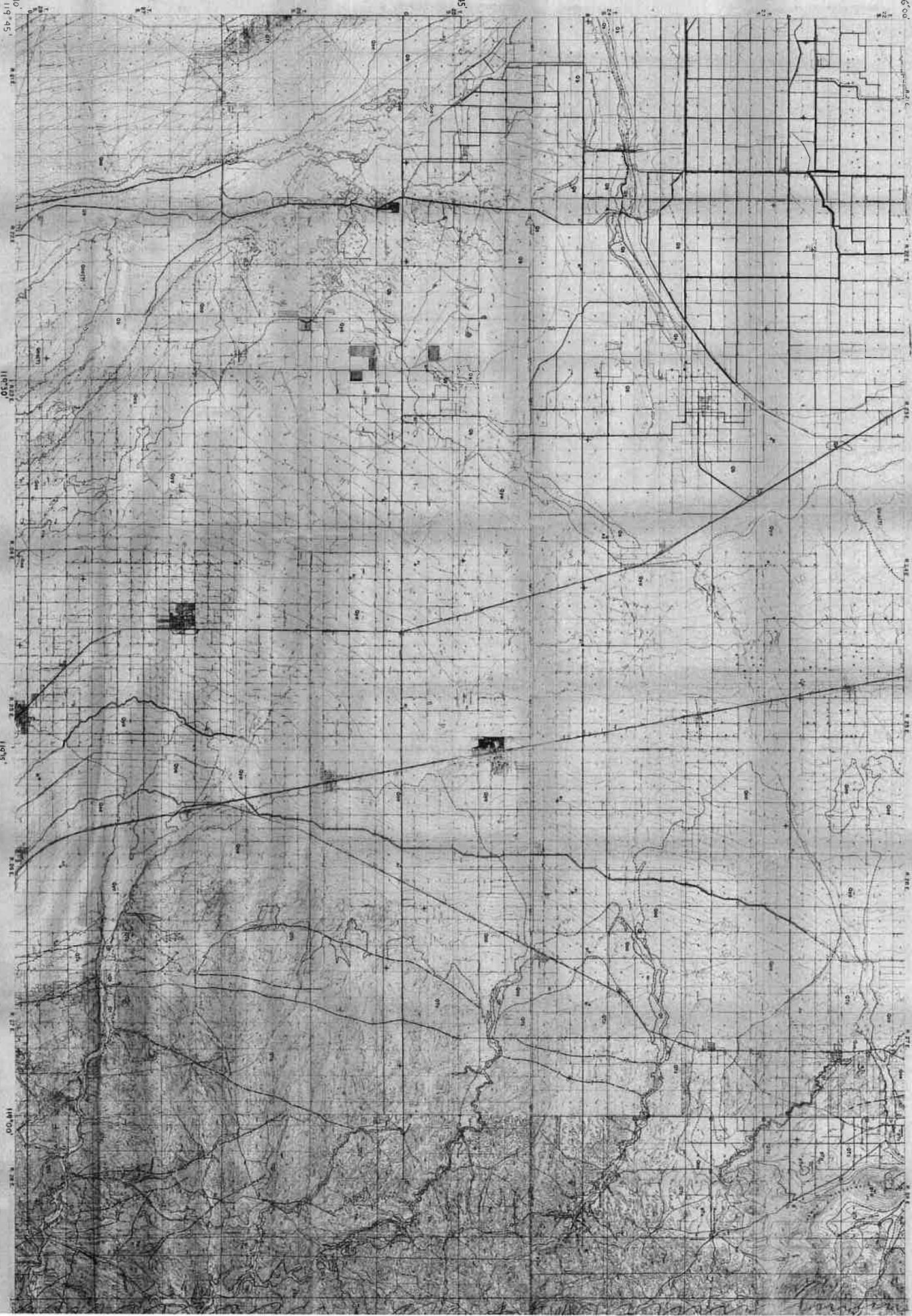
Epoch	Coast Ranges	San Joaquin Valley	Sierra Nevada
Miocene	General trend of present structural and topographic features was established.	Deposition of continental and marine sediments in southeastern part of valley contemporaneous with marine sedimentation in central and western areas. Valley largely above sea level during early Miocene.	Uplift along faults on eastern border elevated range several thousand feet.
Oligocene	Most of ranges above sea level.	Continental deposition in southeastern part of valley.	Erosion continued.
Eocene	Marine deposition along east flank.	Shallow sea occupied most of valley area, shore locally encroached on Sierra and Coast Ranges; streams from Sierra deposited nonmarine clay, quartzose sand, and gravel along eastern border of valley.	Moderate uplift of change in base level caused dissection of weathered rocks.
Pliocene	Sedimentation practically uninterrupted along eastern flank of present Coast Ranges.	Deposition of marine sediments in northwestern part of valley.	Erosion continued.
Late Cretaceous	Shallow-water marine sediments deposited in sinking geosyncline.	Deposition of clastic sediments in shallow sea occupying the northern and western parts of present valley. Downwarping kept pace with deposition.	Erosion uncovered granitic rock over broad areas. Rocks of Paleozoic and early Mesozoic age folded and intruded by igneous rocks of granitic composition.

63-07

Table 3.--Stratigraphy and water-bearing character of the marine sedimentary rocks of Tertiary age

Geologic unit	Lithologic character and thickness	Importance as a source of water
<p>Richegoin Formation named for exposure in vicinity of Richegoin Ranch, 20 miles northeast of Coalinga, Calif. (Anderson, 1905). In the oilfields on the east side of the San Joaquin Valley the marine siltstone and claystone immediately overlying the Chauc Formation of Pliocene age is designated as the Richegoin Formation.</p>	<p>Occurs only in the subsurface and consists of clayey micaceous siltstone and claystone with lenses of well-sorted fine silty to medium grained sand (Diepenbrock, 1933, p. 13). In the Jasmín Oilfield, southeast of Richgrove, Calif., the Richegoin Formation is about 500 feet thick (Park and Weddle, 1959).</p>	<p>Claystone and siltstone are poorly permeable but lenses of well-sorted sand may contribute small amounts of water to wells.</p>
<p>Santa Margarita Formation named for exposures at Santa Margarita, San Luis Obispo, Calif. In the oilfields of the east side of the San Joaquin Valley, marine sand immediately underlying Pliocene and Pleistocene continental deposits, are designated as the Santa Margarita Formation (Diepenbrock, 1933, p. 13).</p>	<p>Occurs only in the subsurface and consists of fairly well-sorted to well-sorted gray sand. In the Jasmín oilfield, southeast of Richgrove, it is 150 feet thick; the thickness ranges from 0 to 600 feet.</p>	<p>Extensively utilized in the Richgrove area.</p>
<p>Mount Mountain Silt of Diepenbrock (1933, p. 14-16).</p>	<p>Crops out only near Poso Creek. In Mount Poso oilfield it consists of 220 feet of gray and brown siltstone, including a 50-foot bed of diatomite 70 feet below top and 57 feet of gray silty sand 3 feet above base. The thickness ranges from 0 to 220 feet.</p>	<p>Poorly permeable and not used as a source of water.</p>
<p>Oleace Sand of Diepenbrock (1933, p. 14).</p>	<p>Crops out only near Poso Creek. Mainly unconsolidated medium- to coarse-grained gray sand, contains occasional pebble and siltstone beds. In the Jasmín oilfield, southeast of Richgrove, the unit is approximately 650 feet thick (Kretzinger and Nelson, 1957, p. 6); it ranges from 0 to 650 feet in thickness.</p>	<p>Moderately permeable to permeable; potentially a source of water in the area east of Richgrove.</p>
<p>Presman-Lewett Silt of Albright and others (1957, p. 13).</p>	<p>Hard compact sandy siltstone and silty sand; silty in upper portion. In Mount Poso oilfield the unit is approximately 1,100 feet thick; thickness ranges from 0 to 1,100 feet.</p>	<p>Probably not important as a potential source of water.</p>
<p>Greenland Hill and Vedder Sands of Albright and others (1957, p. 13)</p>	<p>Consists of gray sand, olive brown, very clayey, black pebbles at base. Lower sand, alternating fine-grained marine sand and nonmarine rough gritty sand and gravel. Combined thickness ranges from 0 to approximately 340 feet.</p>	<p>Little information available. At present is not used as a source of water, but may be a potential source for a limited area east of Richgrove.</p>

(24)



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119 30

119 15

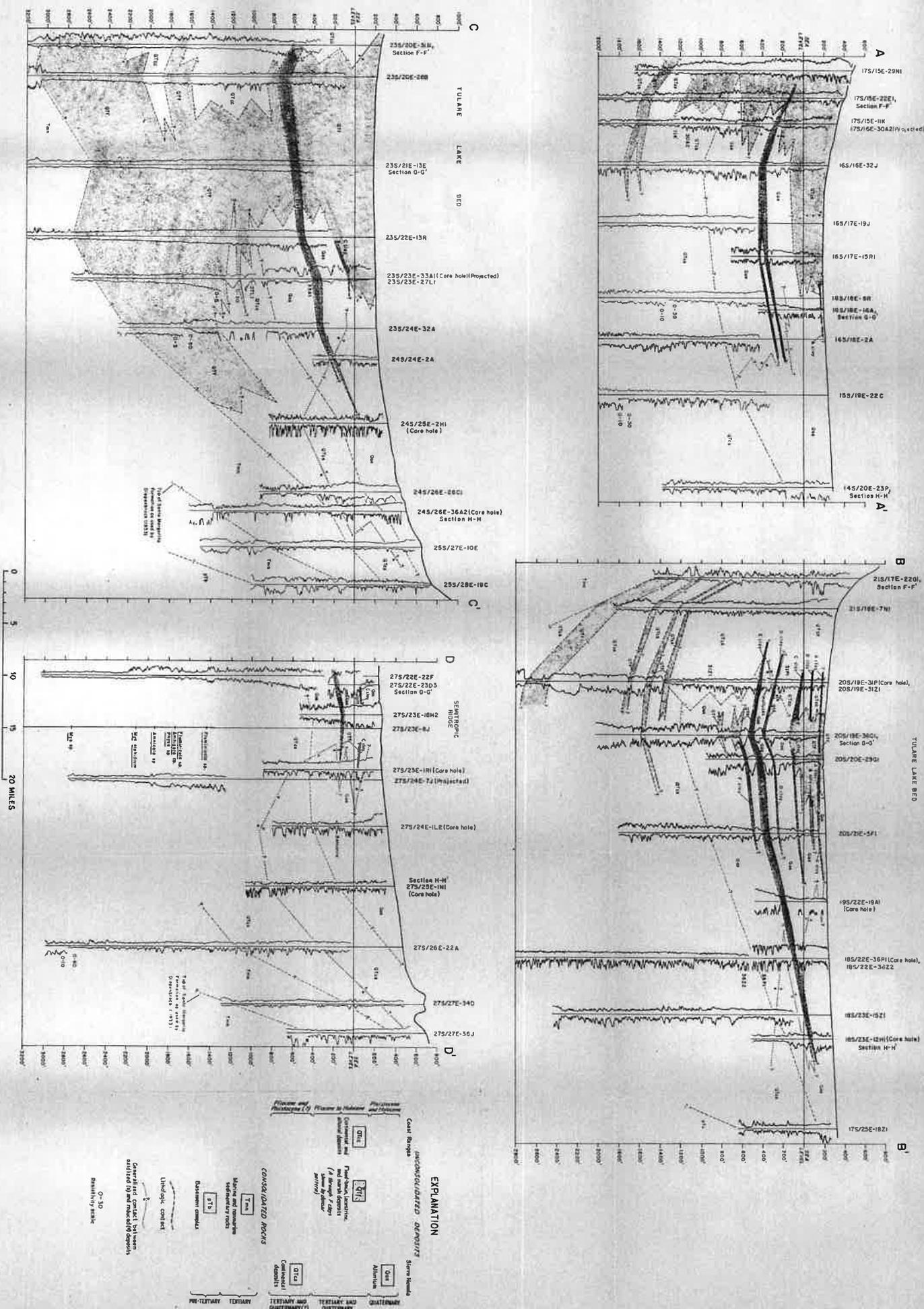
119 00

1800
1810
1820
1830
1840
1850
1860
1870
1880
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000

TERRA DELLA

Scale 1:50,000
Vertical Datum
Horizontal Datum

GEOLOGIC SECTIONS A-A', B-B', C-C', AND D-D', SOUTHERN PART OF SAN JOAQUIN VALLEY, CALIFORNIA



EXPLANATION

Geologic Symbols:

- Q:** Quaternary
- T:** Tertiary
- C:** Cretaceous
- J:** Jurassic
- T:** Triassic
- P:** Permian
- C:** Carboniferous
- D:** Devonian
- S:** Silurian
- O:** Ordovician
- F:** Frasnian
- G:** Givetian
- S:** Silurian
- D:** Devonian
- F:** Frasnian
- G:** Givetian

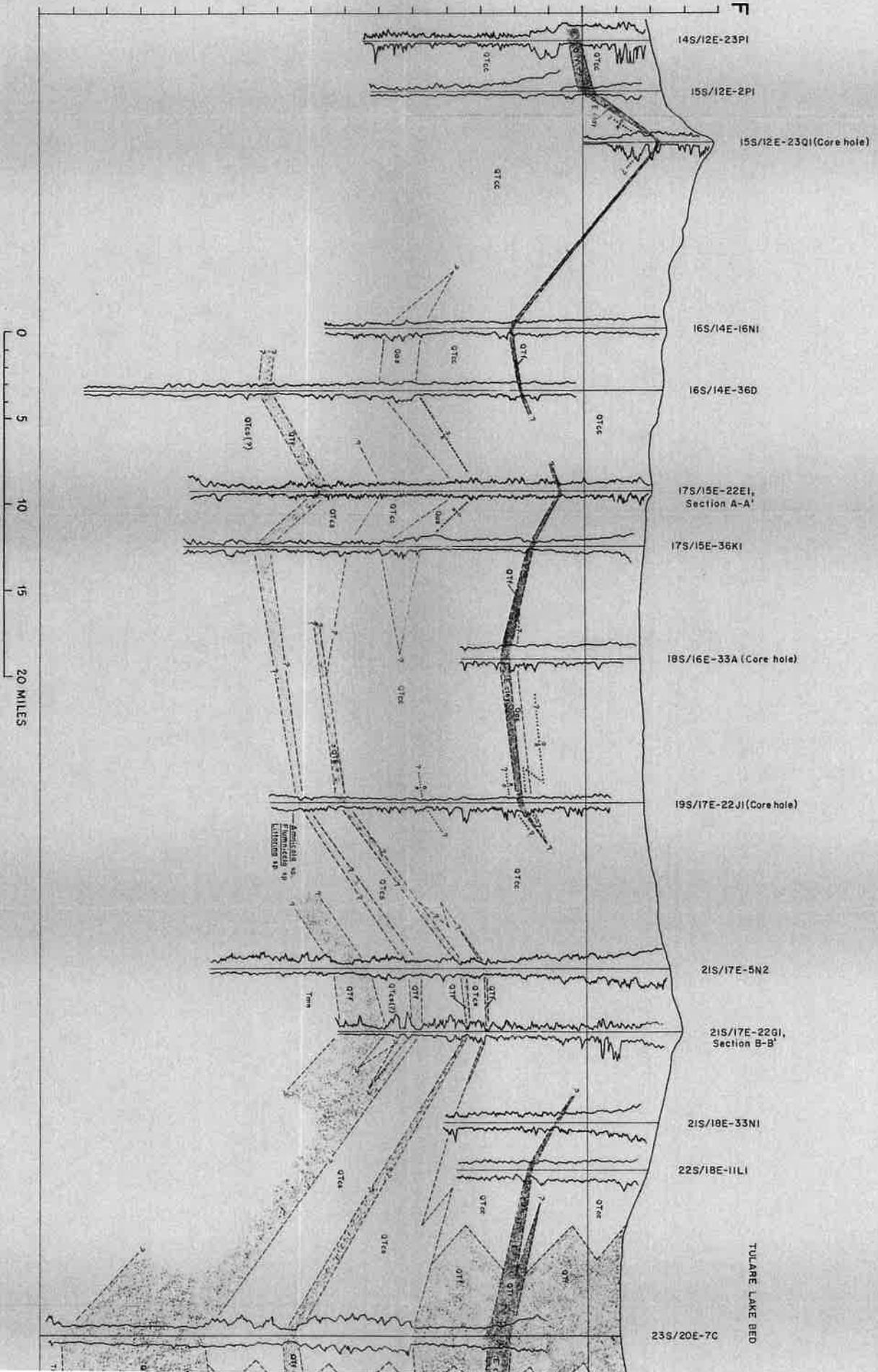
Geologic Features:

- Q:** Quaternary
- T:** Tertiary
- C:** Cretaceous
- J:** Jurassic
- T:** Triassic
- P:** Permian
- C:** Carboniferous
- D:** Devonian
- S:** Silurian
- O:** Ordovician
- F:** Frasnian
- G:** Givetian

Geologic Features:

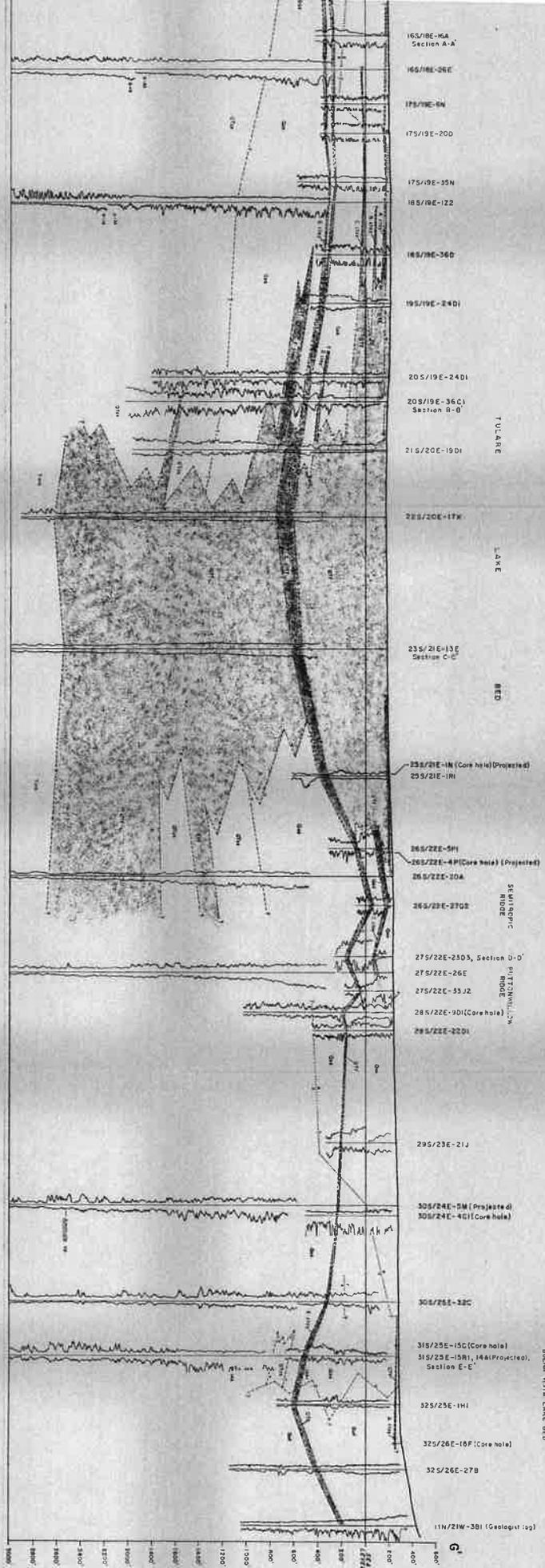
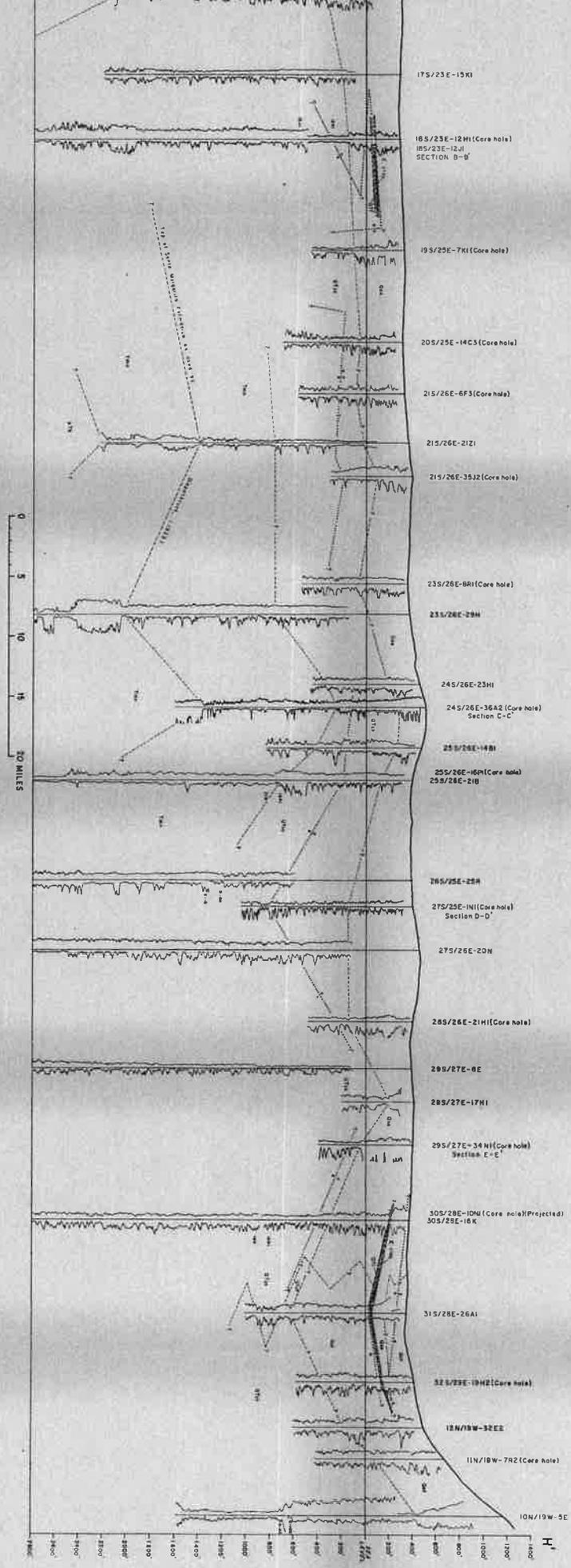
- Q:** Quaternary
- T:** Tertiary
- C:** Cretaceous
- J:** Jurassic
- T:** Triassic
- P:** Permian
- C:** Carboniferous
- D:** Devonian
- S:** Silurian
- O:** Ordovician
- F:** Frasnian
- G:** Givetian

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GEOLOGIC SECTIONS E-E' AND F-F', SOUTHERN PART OF SAN JOAQUIN VALLEY, CALIFORNIA

GEOLOGIC SECTIONS G-G' AND H-H' SOUTHERN PART OF SAN JOAQUIN VALLEY, CALIFORNIA



Prepared in cooperation with CALIFORNIA DEPARTMENT OF WATER RESOURCES

BROWN WITH LANE BRD

Shaded and Hatched (1) Please to Historic Photographs and Reports

MAP OF THE SOUTHERN PART OF THE SAN JOAQUIN VALLEY, CALIFORNIA, SHOWING STRUCTURE AND EXTENT OF THE CLAY

Compiled from U.S.G.S. maps
in which the clay is shown
in white or light gray
This is a new edition

Alignment of geologic section

Wells, canals, or other lines
of 1/2 inch

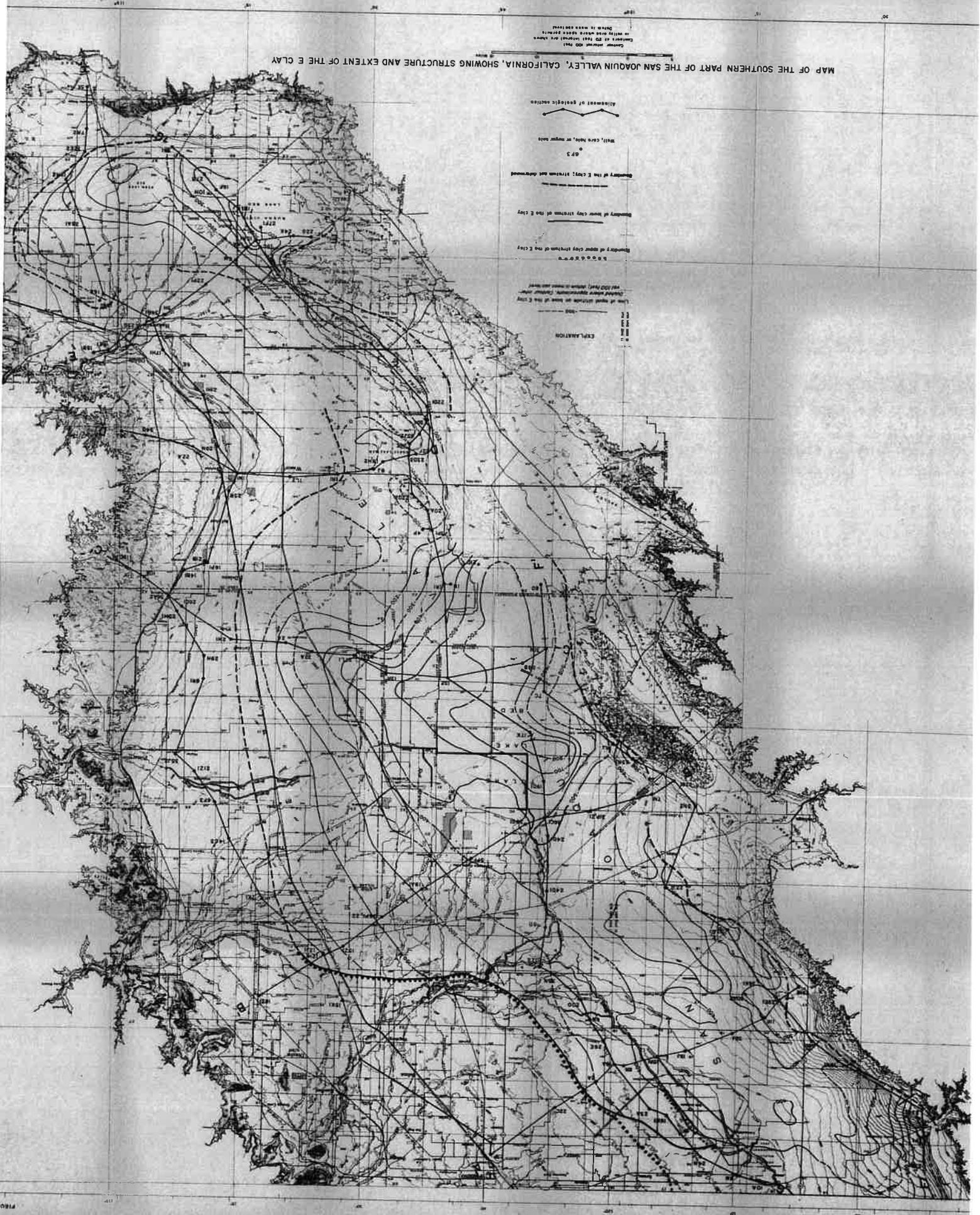
Boundary of the E. clay; stream and drainage

Boundary of lower clay stream of the E. clay

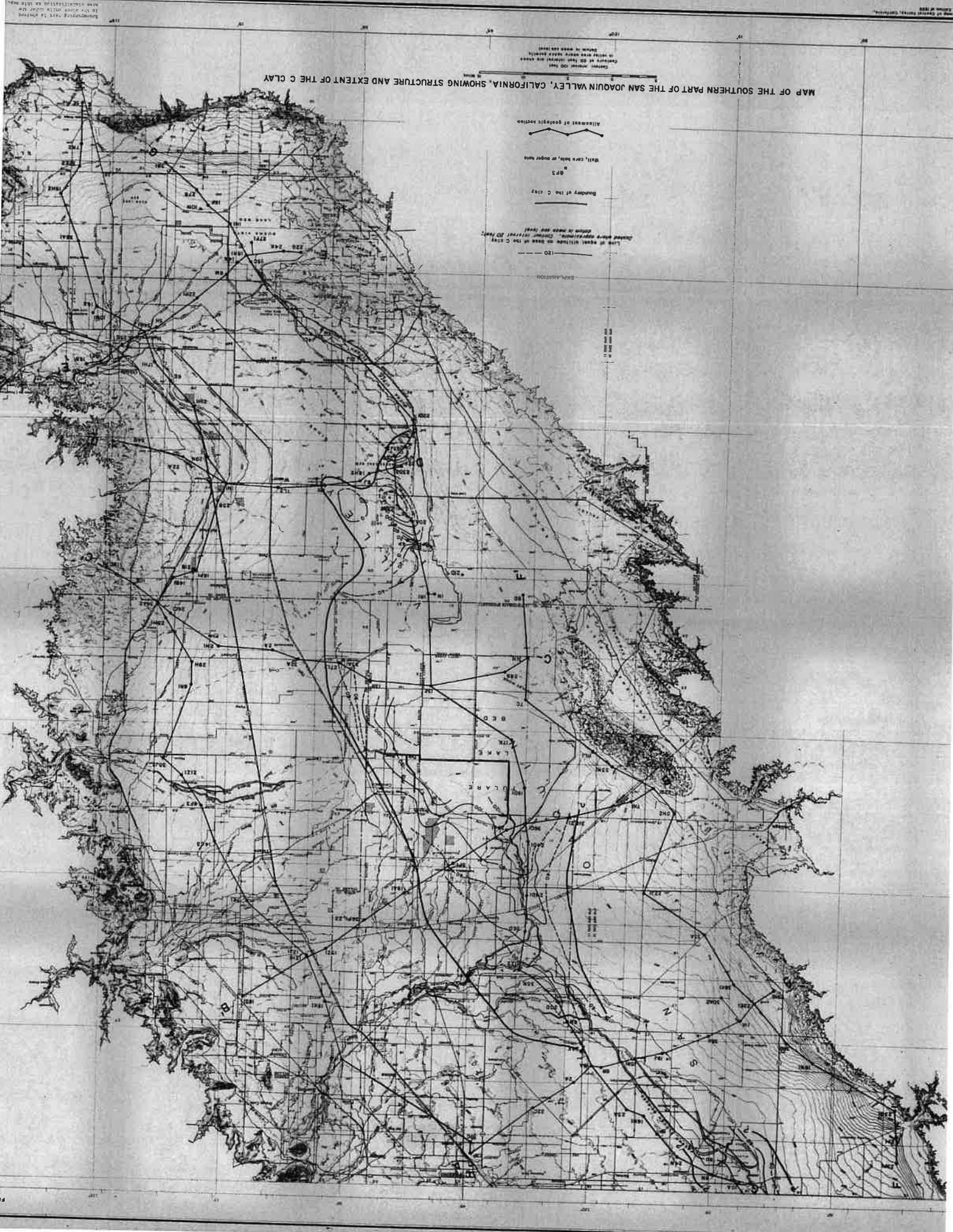
Boundary of upper clay stream of the E. clay

Line of equal altitude on base of the E. clay
Contour interval, 100 feet

EXPLANATION

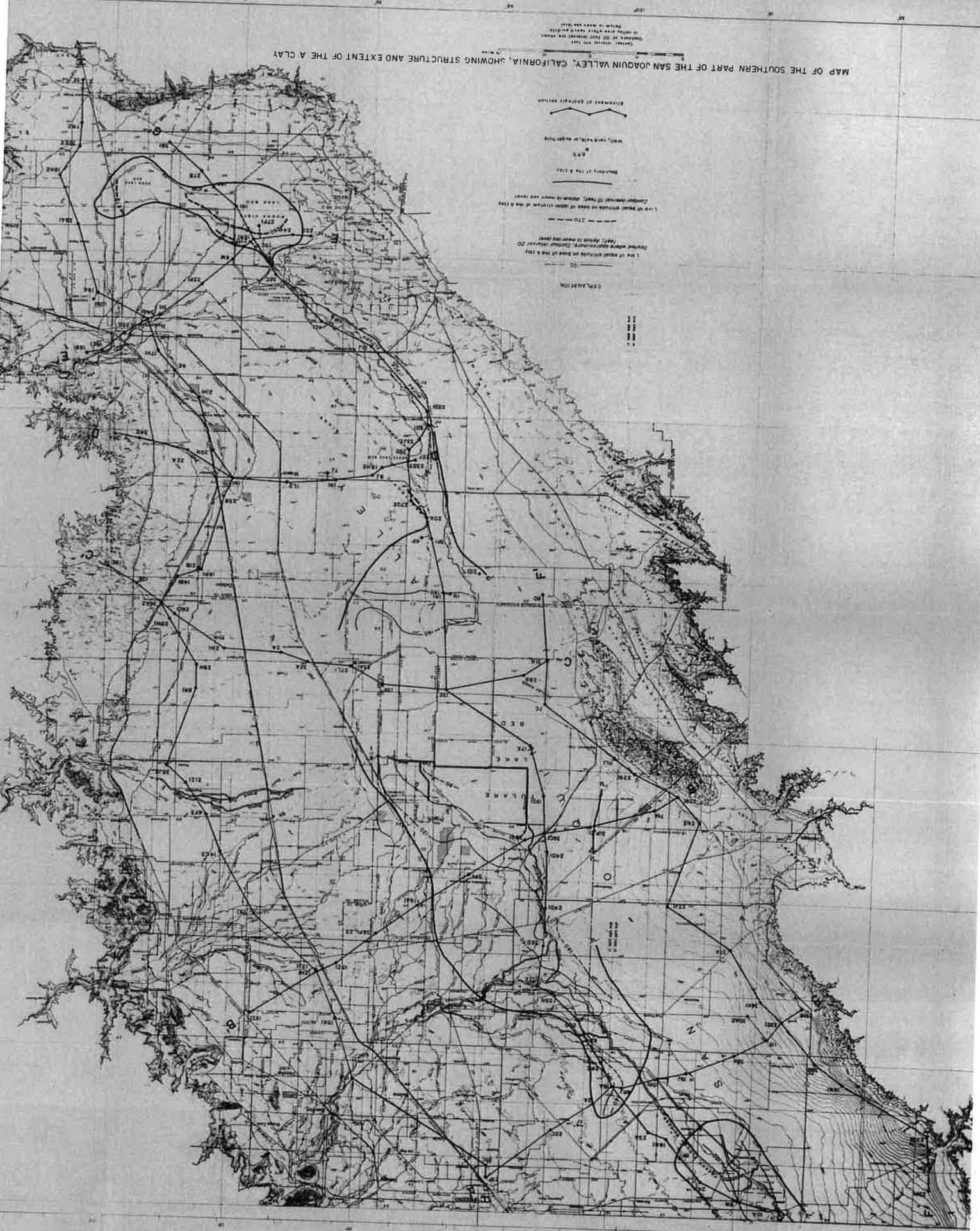


MAP OF THE SOUTHERN PART OF THE SAN JOAQUIN VALLEY, CALIFORNIA, SHOWING STRUCTURE AND EXTENT OF THE C CLAY



Reproduced from the report of the U.S. Geological Survey, California, showing structure and extent of the C clay.

U.S. Geological Survey, California, showing structure and extent of the C clay.



MAP OF THE SOUTHERN PART OF THE SAN JOAQUIN VALLEY, CALIFORNIA, SHOWING STRUCTURE AND EXTENT OF THE A CLAY

Line of great thickness on base of the clay
 Derived from the *San Joaquin River*, 20
 miles north of Hanford, California
 Line of great thickness on base of the clay
 Derived from the *San Joaquin River*, 20
 miles north of Hanford, California
 Boundary of the clay
 Wells, springs, or other thin
 Alignment of geologic section

10
 20
 30
 40
 50
 60
 70
 80
 90
 100

CALIFORNIA

