HYDROGEOLOGY AND LAND SUBSIDENCE, GREAT CENTRAL VALLEY, CALIFORNIA *

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The first part of this paper describes the significant geomorphic features, presents a tentative correlation of the geologic units that constitute significant elements of the tremendous ground-water reservoir in the Great Central Valley, summarizes the post-Miocene geologic history, and describes briefly the ground-water conditions of the valley. It is a supplement to the more comprehensive companion paper by Otto Hackel on the geology of the valley from Late Jurassic time to the end of Pliocene marine deposition.

The second part of the paper describes the extent and magnitude of the land subsidence that is taking place in the San Joaquin Valley, caused chiefly by intensive pumping of ground water and the resulting decline in artesian head. Subsidence of the land surface is a critical aspect of the hydrogeology because it poses serious problems in construction and maintenance of engineering structures for water transport, especially large canals or aqueducts.

The first part of this paper is based largely on U.S. Geological Survey studies in the Sacramento Valley by Olmsted and Davis (1961), and in the San Joaquin Valley by Davis and others (1959 and 1964). The authors are also indebted to representatives of the Pacific Gas and Electric Company and the Sacramento Municipal Utility District for providing background data that facilitated estimates of ground-water withdrawal for irrigation use in 1964.

HYDROGEOLOGY

Geomorphology

The Central Valley constitutes a structural downwarp extending more than 400 miles from Redding on the north to the Tehachapi Mountains on the south; it has an average width of about 40 miles, and spans 15,000 sq. mi. or about one-tenth of the State. About the northern third of the valley is known as the Sacramento Valley and the southern two-thirds as the San Joaquin Valley. Drainage from the Sacramento Valley is southward through the Sacramento River to its confluence with the San Joaquin River, near Suisun Bay, and then westward through San Francisco Bay to the Pacific Ocean. The northern part of the San Joaquin Valley drains northward through the San Joaquin River but the southern part of the valley is a basin of interior drainage tributary to ephemeral lakes in the trough of the valley. These often nearly dry lake areas are known as Kern, Buena Vista, and Tulare Lake Beds.

The valley floor is divided, as shown on figure 1, into four geomorphic units: (1) dissected uplands, (2) low alluvial plains and fans, (3) river flood plains and channels, and (4) overflow lands and lake bottoms.

Dissected uplands fringe the valley along its mountain borders and are underlain principally by unconsolidated to semiconsolidated continental deposits of Pliocene and Pleistocene age which have been structurally deformed. Topographic expression of these uplands ranges from dissected hills with relief of several hundred feet to gently rolling lands where relief is only a few feet.

Low alluvial plains and fans that border the dissected uplands along their valleyward margins are generally flat to gently undulant and are underlain by undeformed to slightly deformed alluvial deposits of Pleistocene and Recent age.

The river flood plains and channels lie along the Sacramento, San Joaquin, and Kings Rivers in the axial parts of the valley and along the major streams on the eastern side of the valley. Those rivers that are incised below the general land surface have well-defined flood plains; but in the axial trough of the valley, the rivers are flanked by low-lying overflow lands and there the flood-plain and channel deposits are confined to the stream channel and to the natural levees that slope away from the river.

Overflow lands and lake bottoms include the historic beds of Kern, Buena Vista, and Tulare Lakes in the southern part of the valley, and also the lowlands adjacent to the natural levees of the major rivers. They are almost level and are underlain by lake and swamp deposits of Recent age.

Geologic Units

The deposits containing fresh ground water are principally unconsolidated continental deposits of Pliocene to Recent age that extend to depths ranging from less than a hundred to more than 3,500 feet. Locally, marine sediments contain fresh water and in other areas continental deposits contain saline water, but such conditions are of minor extent. Table 1 shows a tentative correlation of geologic units of hydrologic significance in the ground-water reservoir of the Central Valley and table 2 is a résumé of the post-Miocene

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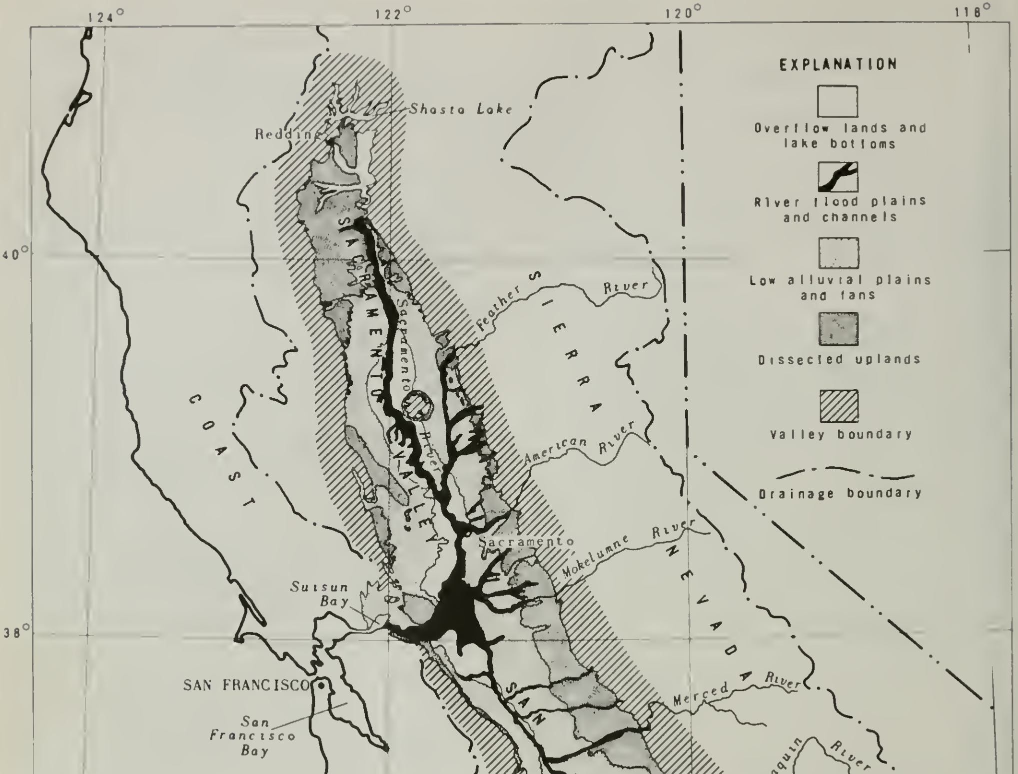


Figure 1. Geomorphic map of the Great Central Valley. Geomorphic units after Davis and others (1959, pl. 1) and Olmsted and Davis (1961, pl. 1).

CORRELATION CHART OF GEOLOGIC UNITS HYDROLOGICALLY SIGNIFICANT IN THE CENTRAL VALLEY, CALIFORNIA
(Estimated range in thickness indicated within parentheses)

	SACRAMENTO VALLEY (Olmsted and Davis, 1961)			SAN JOAQUIN VALLEY		
	West side	Northeast side	East side	Mokelumne area (Piper and others, 1939)	Stanislaus area (Davis and Hall, 1959)	West and south sides (Various authors)
RECENT	River, flood-basin, and alluvial-fan deposits (0-150+ ft)	River and alluvial-fan deposits (0 150+ ft)	River and flood-basin deposits (0-100 ft)	River-channel and flood-plain deposits (0-25 ft)	River-channel and flood-plain deposits (0 50 ft)	Alluvial-fan, flood-plain and flood-basin deposits (0-150+ ft)
PLEISTOCENE	Red Bluff Formation (0-50± ft)	Victor Formation and related deposits (0-100± ft) Fanglomerate from the Cascade Range (0-500+ ft)	Victor Formation (0-150+ ft) Laguna Formation and related continental deposits (0-1,000+ ft)	Victor Formation and related deposits (0-150 ft)	Modesto Fm of Davis and Hall, 1959 (50-100 ft) Riverbank Formation of Davis and Hall, 1959 (150-200 ft) Turlock Lake Fm of Davis and Hall, 1959 (350-850 ft)	Corcoran Clay Member b. $0.6(+)\times10^6$ years Tulare Formation (0-3,000 ft)
PLIOCENE	Tehama Formation (0-2,500+ ft) Nomlaki Tuff Member a. 3.3×10^6 years	Tuscan Formation (0-1,000+ ft)	Mehrten Formation and related volcanic rocks' (0-400 ft)	Laguna Formation (0-400 ft) Mehrten Formation (75-400 ft)	Mehrten Formation (800-1,200 ft)	San Joaquin Formation (0-1,800 ft) Etchegoin Formation (0-2,000 ft)
MIOCENE						

a. Evernden and others, 1964

b. Janda, R. J., 1965, p. 131

Table 1.

geologic history. Because of space limitations, the reader is referred to the cited references for information on the physical and water-bearing character of the individual geologic units listed in table 1.

The unconsolidated continental deposits consist chiefly of alluvium but in some areas include widespread lacustrine and marsh or estuarine sediments. These deposits constitute late Cenozoic fill in the structural trough, whose axis in the San Joaquin Valley lies west of the present topographic axis of the valley. Appreciable folding and minor faulting also has occurred; however, these structural features have had no significant barrier effect on ground-water movement.

Consolidated rocks form the boundaries beneath and on the flanks of the productive ground-water reservoir in the unconsolidated deposits. Only minor quantities of water occur in joints or fractures in the consolidated rocks in the Sierra Nevada, and the principal water supply to the valley—the stream runoff—passes over them.

Ground-Water Occurrence and Use

Ground water occurs under both confined (artesian) and unconfined (water table) conditions in the Central Valley. The degree of confinement varies widely because of the heterogeneity of the continental deposits. In the big alluvial fans on the east side of the San Joaquin Valley, the ground water is unconfined. The most extensive confined aquifer is the major aquifer system overlain by the Corcoran Clay Member of the Tulare Formation (table 1), which covers more than 5,000 square miles in the San Joaquin Valley.

Recharge to the ground-water reservoir is by infiltration of rainfall, infiltration from streams, canals, and ditches, by infiltration of excess irrigation water, and by underflow entering the valley from tributary stream canyons.

TABLE 2.—RESUME OF POST-MIOCENE GEOLOGIC HISTORY.

Epoch	Coast Ranges	Central Valley	Sierra Nevada
Pliocene	Folding and faulting on regional scale in late Pliocene time outlines present form of ranges. Northern part of central Coast Ranges undergoing subaerial erosion, concurrently with deposition of marine sediments in local basins in southern part of ranges during early and middle Pliocene time.	Deposition of marine sediments in southwestern part of valley during early and middle Pliocene time. Streams from Sierra Nevada depositing generally fine-grained alluvium on east side, including much coarse-grained volcanic detritus in early Pliocene time. All the valley was above sea level in late Pliocene time. Great thicknesses of continental deposits accumulating in downwarping basins along western and southern margins of valley. Extensive lake occupies western part of valley and present foothill area in late Pliocene time. Igneous activity pushed up an andesitic plug through Sacramento Valley sediments shattering or deforming them and forming the Sutter Buttes. Later rhyolitic domes and necks intruded the plug and around its periphery.	Relative structural stability, only minor crustal movement. Great volcanic activity; consequent streams erode volcanic deposits and move them toward the Central Valley.
Pleistocene	Major faulting and folding accentuates existing structures. Erosion of mountains with deposition in intermontane valleys.	Deposition of coarse alluvial deposits by streams draining Sierra Nevada contemporaneous with dissection of tilted older alluvial-fan deposits. Extensive lake in San Joaquin Valley deposits diatomaceous clay. Lowering of sea level and climatic changes during Pleistocene glaciations cause major rivers and tributaries to excavate trenches graded to lower base level or to mountain valley downcutting. Alluvial fans on east side tilted with Sierra Nevada block. Coast Range streams continue to build alluvial fans in downwarping area on west side of valley. Several lake clays of variable extent deposited in late Pleistocene time.	Several stages of glaciation in higher parts of range. Glacial scouring locally important in modifying land forms. Last major uplift of range along faults on eastern margin with additional westward tilting.
Recent	Subaerial erosion forms present topography. Minor structural movements continuing to present; many faults and folds still active; earthquakes frequent.	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 and south end of valley. Sediments generally finer grained than Pleistocene deposits. Trenches of major rivers and tributaries back-filled as sea level rises with retreat of continental glaciers.	Subaerial erosion. Glacially scoured features being modified by weathering, erosion, and deposition.

In the Sacramento Valley, water for irrigation, public supply, and industry is obtained primarily from surface-water sources, but in part from wells. These wells, in general, range in depth from 100 to about 500 feet, although some wells are as much as 1,000 feet deep. Most wells of large capacity are used for irrigation or for public supply; their yields range from 200 to 2,000 gpm (gallons per minute). Estimated withdrawal of ground water for irrigation in the Sacramento Valley during 1964 was on the order of 2,400,000 acre-feet. This represents an increase of 85 percent from the estimated withdrawal of about 1,300,000 acre-feet in 1950 (Olmsted and Davis, 1961, p. 8). The estimated total storage capacity of the deposits in the 20- to 200-foot depth range is about 33½ million acre-feet. However, the flood-basin deposits are fine-grained silt and clay, and thus are not usable for cyclic storage. Therefore, the total rechargeable storage capacity to a depth of 200 feet is about 28 million acre-feet.

Water levels in the Sacramento Valley have not been drawn down excessively by pumping. In most of the valley water levels have not declined as much as 100 feet, and in some areas levels have been raised by seepage from surface-water irrigation.

In the San Joaquin Valley, water for irrigation is supplied both from surface-water sources and from wells, but probably about 60 percent is from wells. Well water is the sole supply for half the irrigated land and a supplemental supply for another quarter. Furthermore, ground water supplies nearly all the municipal, industrial, and domestic needs.

Depths of water wells range widely, from 100 feet to 3,500 feet, depending either on the permeability of the deposits or on water-quality controls. For example, wells tapping the highly permeable alluvial-fan deposits derived from the Sierra Nevada granitic complex are relatively shallow. Accordingly, on the east side of the valley, from the Mokelumne River to the south edge of the Kings River fan, and within the Kern River fan, well depths range from 100 to 500 feet and the average depth is only about 250 feet. In contrast, on the central west side in western Fresno County, where the alluvial deposits of the Tulare Formation are derived chiefly from sandstone and shale detritus of Coast Range origin, and the shallower ground water is of poor quality, wells range in depth from 500 to 3,500 feet with the average depth being about 1,500 feet. At the south end of the valley, south of the Kern River fan, well depths range from 600 to 2,000 feet; the average is about 1,000 feet.

Yields of irrigation wells in the San Joaquin Valley also vary widely, ranging from 100 to more than 3,000 gpm, but most wells yield 500–1,500 gpm. Estimated storage capacity of the deposits in the depth interval from 10 to 200 feet is 93 million acre-feet. Locally the reservoir has been dewatered to a depth in excess of 350 feet.

Estimated withdrawal of ground water for irrigation in the San Joaquin Valley during 1964 was on the

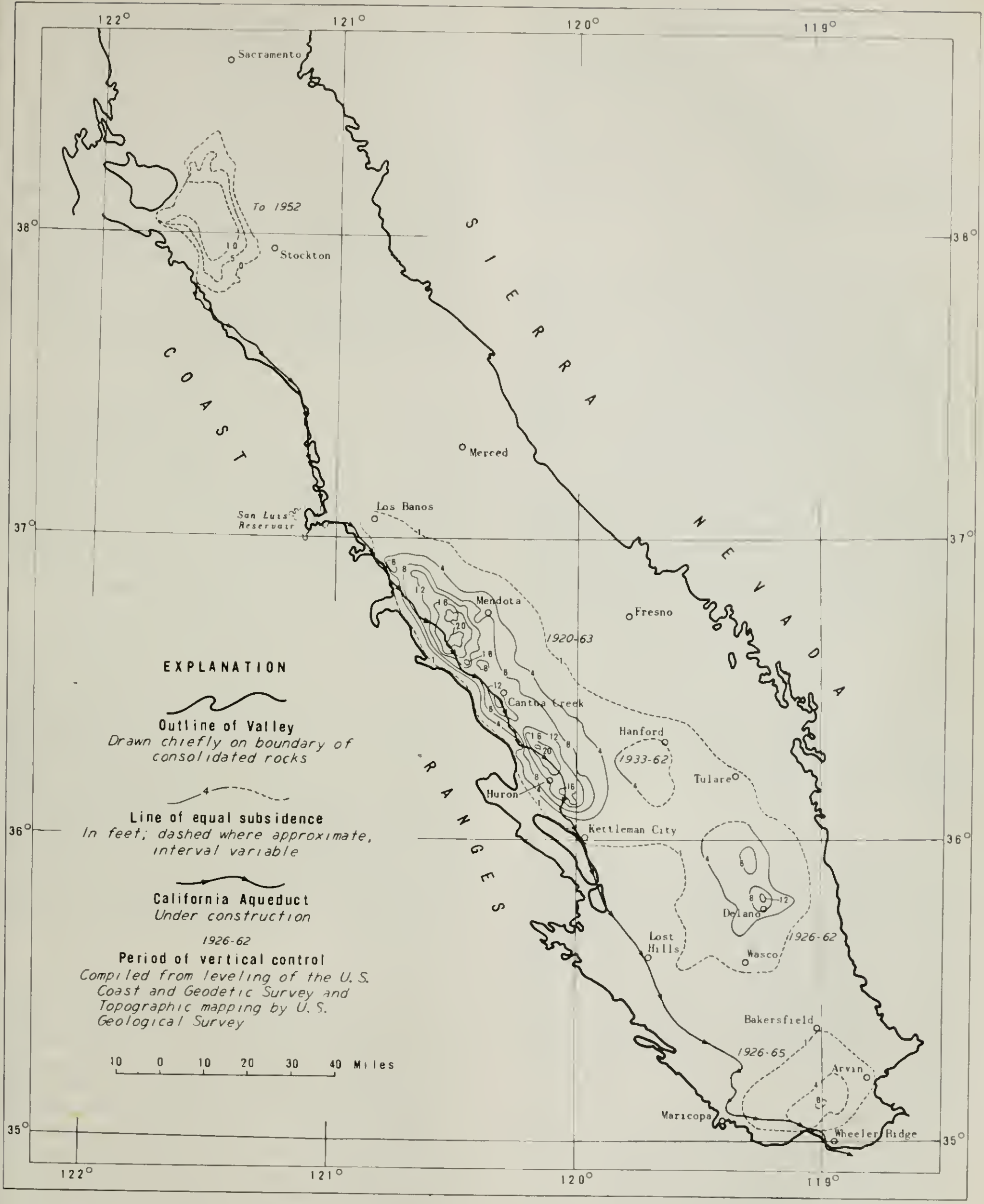


Figure 2. Areas of major land subsidence in the Great Central Valley.

order of 10,700,000 acre-feet, representing more than a threefold increase since 1940 when the draft was about 3 million acre-feet. This large withdrawal has caused substantial overdraft on the central west side and in much of the southern part of the Valley, where replenishment is small compared to withdrawal. As a result, water levels have declined 100 to more than 400 feet in the confined aquifer system in the Tulare Formation in western Fresno County and more than 300 feet in the same formation in Kern County south of the Kern River fan.

LAND SUBSIDENCE

In the great agricultural development of the Central Valley, man has caused major subsidence of the land surface in three extensive areas between Sacramento and the south end of the Valley. (See figure 2.) These three areas aggregate about 4,000 square miles, or roughly one-third of the valley lands south of Sacramento. Maximum subsidence ranges from 8 feet south of Bakersfield to 23 feet southeast of Los Banos. Nowhere else in the world has man produced such extensive subsidence of this magnitude.

The subsidence is of three types. In the lowlands of the Delta at the confluence of the Sacramento and San Joaquin Rivers, subsidence has been caused chiefly by the oxidation of peat lands accompanying drainage and cultivation. In the largest area, between Los Banos and Wasco, and at the south end of the valley between Arvin and Maricopa, most of the subsidence has been caused by lowering of the artesian head in confined aquifer systems, due to the intensive pumping of ground water. Locally, on the west and south flanks of the valley, a third type of subsidence has been caused by near-surface compaction of moisture-deficient alluvial-fan deposits above the water table, after initial wetting by percolating irrigation water. This third type of subsidence is of such local extent that it cannot be shown on figure 2.

Subsidence of the Delta

The organic soils or peat lands at the confluence of the Sacramento and San Joaquin River systems are highly productive agricultural lands. Drainage for cultivation began in 1850 and development continued for the next 70 years. The Delta is now a complex system of islands and channels, and prior to reclamation the islands were approximately at mean sea level. Levees were constructed around the islands at the time of their reclamation, and as the islands have subsided farther and farther below sea level the maintenance of levees and channels has been an increasingly difficult job.

The generalized lines of equal subsidence shown on figure 2 were constructed from topographic maps of the Geological Survey based on field surveys in 1952. The subsiding area covers about 450 square miles and more than one-third of the island area was 10 to 15 feet below sea level in 1952. The peat ranges in thickness from near zero to more than 40 feet.

Weir (1950) studied the subsidence in the Delta area for about 35 years, beginning in 1922. He found that subsidence on one island (Mildred Island) was 9.29 feet from 1922 to 1955, and was relatively uniform, averaging 0.28 foot per year. He concluded that the causes of the subsidence were: oxidation, compaction by tillage machinery, shrinkage by drying, burning, and wind erosion. Stephens and Johnson (1951) studied a similar peat subsidence in the Florida Everglades and concluded that the principal cause was oxidation due to action of aerobic bacteria above the water table. Hence, the primary cause of the Delta subsidence is the lowering of the water table by drainage in order to grow crops.

The sediments beneath the peat also have subsided to a much lesser degree, possibly because of extraction of gas and water from major local gas fields.

Near-Surface Subsidence

Locally on the west and south flanks of the San Joaquin Valley, near-surface alluvial-fan deposits above the water table have subsided in response to the first irrigation of the land. In the Los Banos-Kettleman City area, this near-surface subsidence or hydrocompaction encompasses two areas 4 to 6 miles wide and aggregating 22 miles in length along the west edge of the valley. Along the southwest flank of the valley between Lost Hills, Maricopa, and Wheeler Ridge, are four areas susceptible to near-surface subsidence; these aggregate at least 40 miles in length.

The deposits susceptible to hydrocompaction have been moisture deficient ever since their deposition. When water is applied to them the clay bond is weakened and the deposits compact (Bull, 1964). Subsidence of 5 to 10 feet is common and locally as much as 15 feet has been observed. This type of subsidence poses a serious problem in the construction and maintenance of large canals, irrigation distribution systems, pipelines, powerlines, highways, and buildings. The California Aqueduct (fig. 2), now under construction, passes through about 60 miles of these deposits between Los Banos and Wheeler Ridge. As a preventative measure the susceptible deposits along the Aqueduct alignment are being precompacted by prolonged basin-type wetting prior to the placing of the concrete lining.

Subsidence Due to Water-Level Lowering

The areas of significant land subsidence related to water-level lowering are in the San Joaquin Valley. The two areas of major extent are outlined on figure 2. The larger area extends about 145 miles southeast from Los Banos to Wasco, and includes about 3,300 square miles within the 1-foot subsidence line. The smaller area south of Bakersfield includes about 450 square miles. Together these areas cover about one-third of the San Joaquin Valley. The subsidence has been greatest at three centers. The center of maximum subsidence is 7 miles west of Mendota where 23 feet of subsidence has occurred (1963); the maximum rate of subsidence from 1959 to 1963 was about 1.5 feet per year. A second center is 2 miles north of Delano where 12 feet of subsidence has occurred, but subsidence has almost ceased there because of recovery of water levels. The third center, 18 miles south of Bakersfield, has subsided 8 feet.

These areas of land subsidence overlie confined aquifer systems, in which the artesian head has been drawn down everywhere more than 100 feet and as much as 400 feet locally north of Kettleman City. The area between Los Banos and Wasco is almost wholly underlain by the Corcoran Clay Member of the Tulare Formation which confines the underlying productive aquifer system that is also in the Tulare Formation.

The relationship of subsidence to head decline near the three centers of subsidence is illustrated by figures 3, 4, and 5. Figure 3 shows the nearly parallel trends of bench-mark subsidence and artesian-head decline from 1940 to 1963 at a site 8 miles southwest of Mendota. In this 22-year period, the bench mark subsided about 18.5 feet and the artesian head in nearby wells tapping the confined aquifer system decreased about 260 feet. The ratio of subsidence to head decline was approximately 1:20 from 1940 to 1950 and 1:10 from 1950 to 1963. This increase in the ratio with increasing drawdown of artesian head is characteristic of much of the subsiding area. It suggests a cumulative increase in delayed compaction of the fine-grained interbeds as head declines, due to slow adjustment of pore pressure.

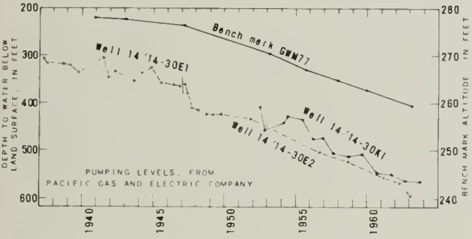


Figure 3. Subsidence and change in artesian head in an area 8 miles southwest of Mendota, Fresno County.

Five miles northeast of Delano, artesian head declined continuously from 1930 to 1951 (fig. 4) and then recovered rapidly as a result of delivery of surface water for irrigation from the Friant-Kern Canal, which brings water south from the San Joaquin River. Nearby bench marks showed a parallel subsidence into the early 1950's, after which the rate of subsidence decreased in response to the recovery of artesian head.

The relation of subsidence to artesian-head decline 21 miles south of Bakersfield (about 5 miles northwest of the town of Wheeler Ridge) is shown on figure 5. The water level declined from about 130 feet below the land surface in 1946 to 415 feet below in 1962, at an average rate of 18 feet per year. From 1947 to 1953 the rate of subsidence of nearby bench mark A-303 was 0.16 foot per year and during 1959–62 was 0.30 foot per year. At this site, therefore, the ratio of subsidence to artesian-head decline increased from 1:112 (1947–53) to 1:60 (1959–62).

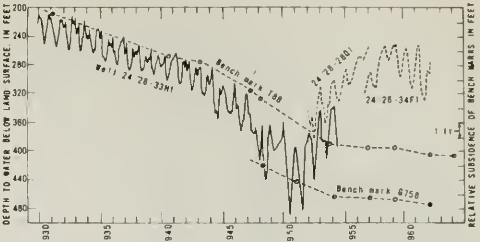


Figure 4. Subsidence and change in artesian head near Delano, Kern County.

To determine how much of the subsidence is caused by compaction of the deposits tapped by water wells, and to investigate the character of the response of the sediments to increasing effective stress (decreasing artesian head), the U.S. Geological Survey has established depth bench marks and operated compaction recorders in about 30 unused wells or cased core holes. The compaction-recorder installation (fig. 6) furnishes

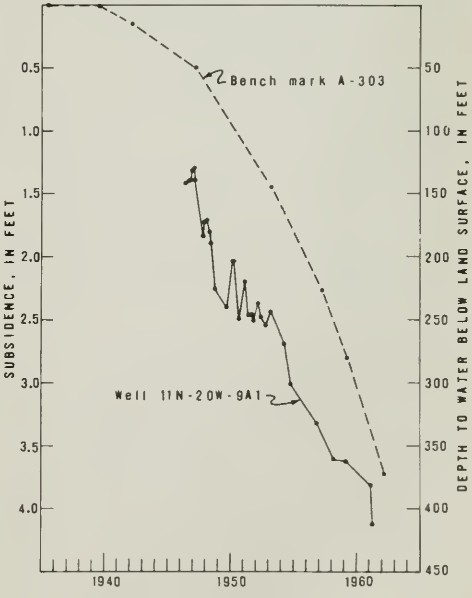


Figure 5. Subsidence and artesian-head decline, south of Bakersfield. After Lofgren (1963, fig. 47.3).

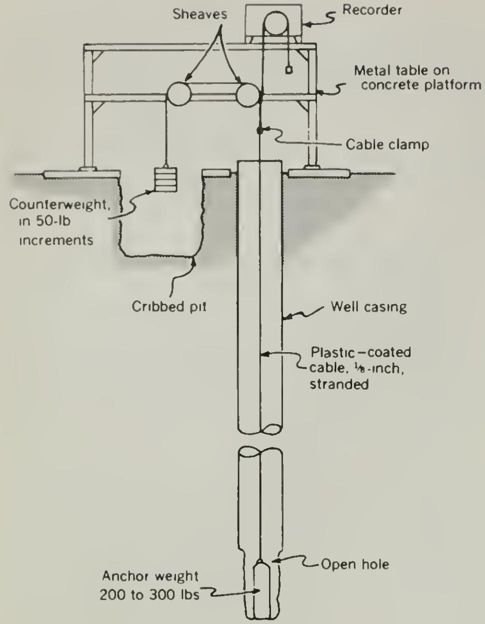


Figure 6. Diagram of typical compaction-recorder installation.

continuous measurement of compaction occurring between the land surface and the depth bench mark at the well bottom.

The first compaction recorder of this type was installed in a well 2,030 feet deep near Huron in 1955. Figure 7 shows the record of compaction from 1956 into 1960, the subsidence of nearby surface bench mark B 889 as determined by precise leveling of the U.S. Coast and Geodetic Survey, and the fluctuation of artesian head in a nearby well. During the 4.8 years of record shown, measured compaction of the aquifer system to a depth of 2,030 feet was 3.8 feet, the land subsided 4.6 feet, and artesian head declined about 40 feet. Thus, the measured compaction was 82 percent of the subsidence, indicating that 0.8 foot of compaction occurred below 2,030 feet, which is reasonable because nearby wells withdraw water from greater depths. The rate of compaction is variable, being greatest during periods of rapid decline in artesian head; recovery of head results in decrease or cessation of compaction. Such evidence, obtained here and at many other sites, indicates that the aquifer system is extremely sensitive to change in effective stress as defined by change in artesian head. At one site, increase of about 1 percent in effective stress (a 5-foot lowering of artesian head) caused noticeable compaction.

At a site near the town of Cantua Creek, a compaction recorder installed in a 2,000-foot well (N1) in 1958 recorded 7.43 feet of compaction by the end of 1964 (fig. 8). Two shallower installations registered

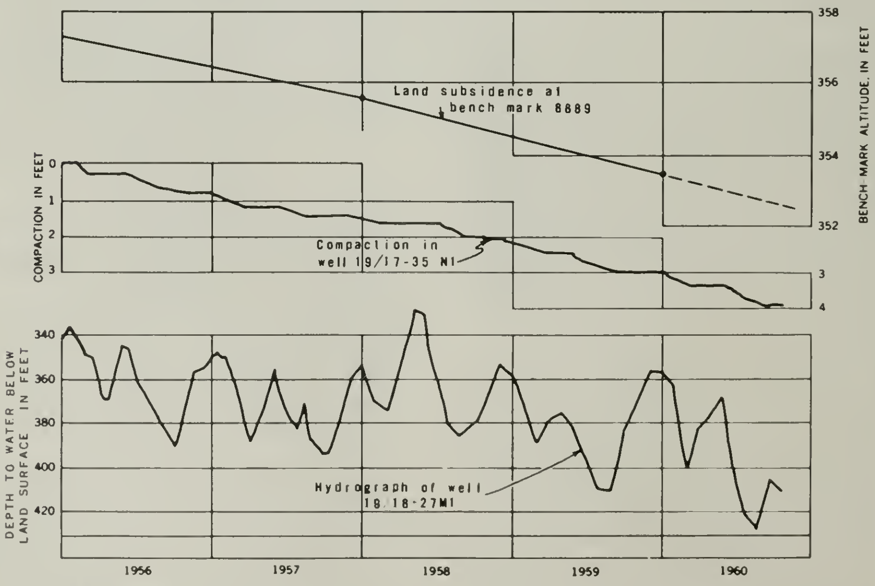
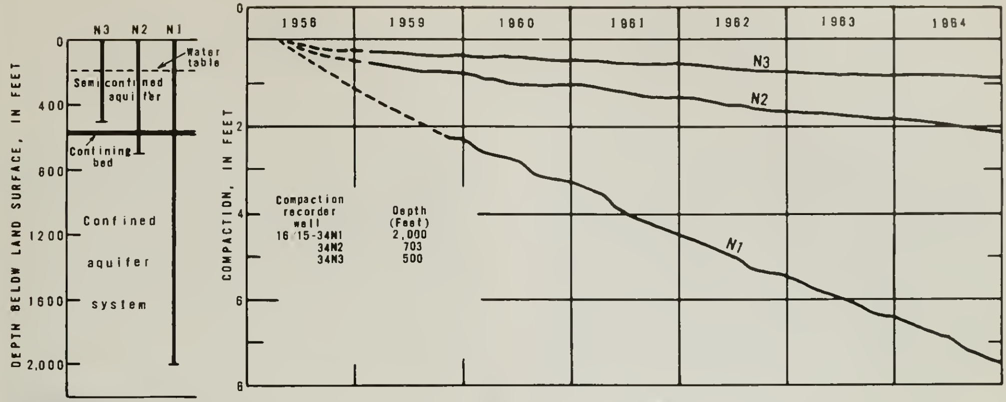


Figure 7. Measured subsidence, compaction, and water-level change, near Huron, Fresno County. After Lofgren (1961, fig. 24.2).



A. Relation of well depths to hydrologic units

B. Measured compaction

Figure 8. Compaction in three wells near Cantua Creek, Fresno County, during 1958–64.

0.89 foot (N3; 500 feet deep) and 2.10 feet (N2; 703 feet deep) of compaction during the same period. If the distribution of compaction in the interval between the bottoms of wells N3 and N2 was uniform, about 17 percent of the measured compaction occurred above the principal confining bed and 83 percent in the confined aquifer system. The measured compaction to 2,000 feet (well N1) from February 1960 to March 1963 was 3.37 feet; subsidence measured by leveling to surface bench marks in the same period was 3.45 feet. Thus, the measured compaction to this depth accounted for about 98 percent of total subsidence. It is noteworthy that the rate of compaction has been about constant throughout the year, even though the artesian head in an adjacent well fluctuates 60 feet or more seasonally. This suggests that at this site the residual excess pore pressure in the fine-grained interbeds is much greater than the annual fluctuation of head.

In conclusion, decrease in artesian head in compressible confined aquifer systems results in increased effective stress (grain-to-grain load) on the confined sediments and they compact, causing land subsidence. The magnitude of the subsidence is dependent on the magnitude of change in head and on the compaction characteristics and thickness of the sediments. The greater the number of clayey interbeds in the system, the greater is the compaction. Continuous measurements of compaction indicate rapid response to head change at most places in these subsiding areas. Subsidence can be slowed down or stopped by a rise in the artesian head sufficient to eliminate residual excess pore pressures. However, the compaction is almost entirely permanent. Recovery of water levels has not caused appreciable recovery of the land surface in any of the areas studied. This has been demonstrated on a broad scale in the Delano area.

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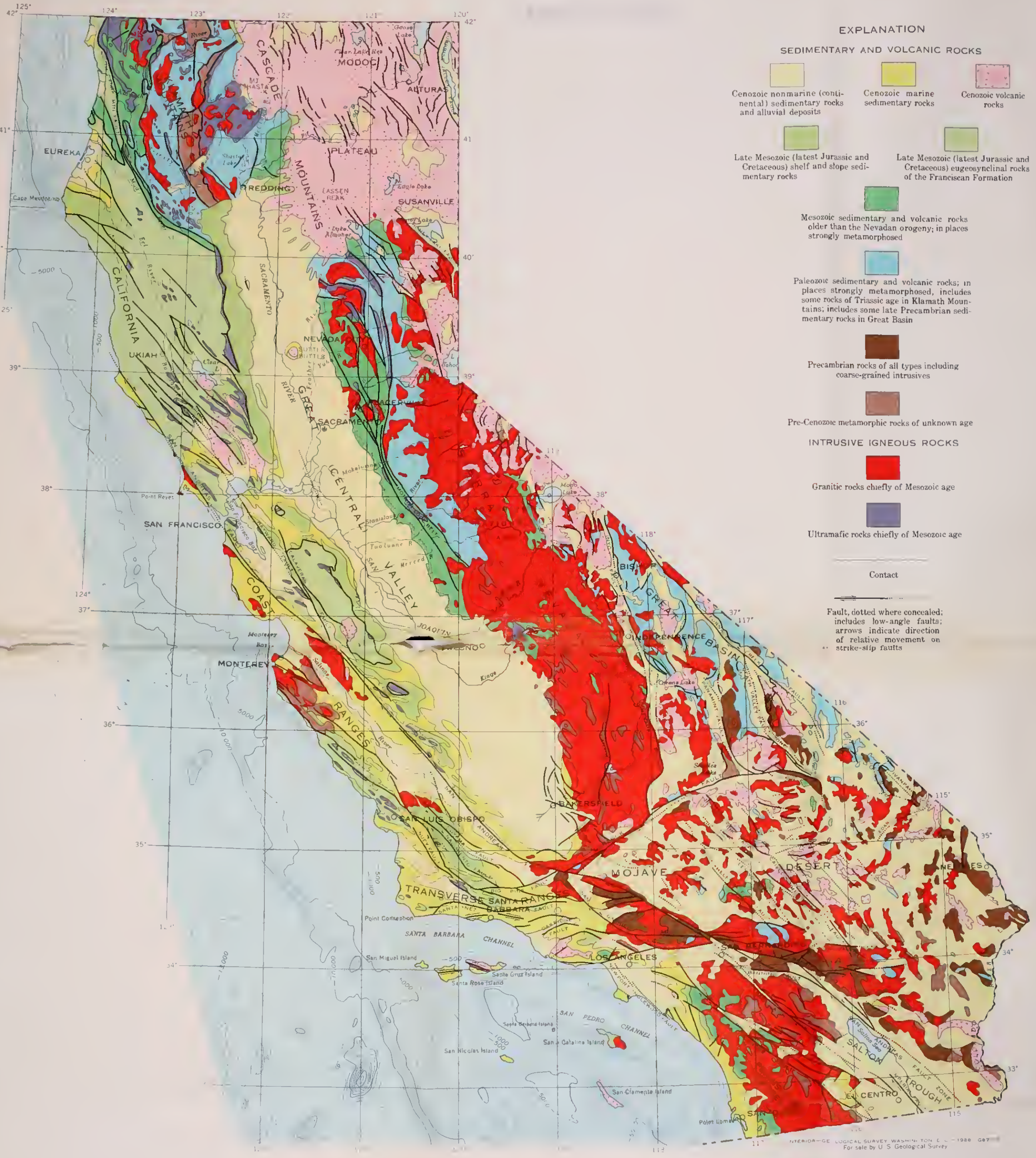
DEPARTMENT OF INTERIOR
UNITED STATES GEOLOGICAL SURVEY

MISCELLANEOUS GEOLOGICAL INVESTIGATIONS
MAP I-512



EXPLANATION

SEDIMENTARY AND VOLCANIC ROCKS

- 🟨 Cenozoic nonmarine (continental) sedimentary rocks and alluvial deposits
- 🟨 Cenozoic marine sedimentary rocks
- 🟪 Cenozoic volcanic rocks
- 🟩 Late Mesozoic (latest Jurassic and Cretaceous) shelf and slope sedimentary rocks
- 🟩 Late Mesozoic (latest Jurassic and Cretaceous) eugeosynclinal rocks of the Franciscan Formation
- 🟩 Mesozoic sedimentary and volcanic rocks older than the Nevadan orogeny; in places strongly metamorphosed
- 🟦 Paleozoic sedimentary and volcanic rocks; in places strongly metamorphosed, includes some rocks of Triassic age in Klamath Mountains; includes some late Precambrian sedimentary rocks in Great Basin
- 🟫 Precambrian rocks of all types including coarse-grained intrusives
- 🟫 Pre-Cenozoic metamorphic rocks of unknown age

INTRUSIVE IGNEOUS ROCKS

- 🟥 Granitic rocks chiefly of Mesozoic age
- 🟪 Ultramafic rocks chiefly of Mesozoic age

Contact

Fault, dotted where concealed; includes low-angle faults; arrows indicate direction of relative movement on strike-slip faults

INTERIOR—GEOLOGICAL SURVEY WASHINGTON D C —1966 G67
For sale by U S Geological Survey

GEOLOGIC MAP OF CALIFORNIA

COMPILED BY U.S. GEOLOGICAL SURVEY
AND CALIFORNIA DIVISION OF MINES AND GEOLOGY

SCALE 1 2 500 000
0 50 100 MILES
SUBMARINE CONTOUR INTERVALS 500 AND 1000 FEET DATUM IS SEA LEVEL

1966