Subsidence in the Santa Clara Valley California A Progress Report

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Poland and Green—SUBSIDENCE IN THE SANTA CLARA VALLEY, CALIF.—Geological Survey Water-Supply Paper 1619-C

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By J. F. POLAND *and* J. H. GREEN

CONTRIBUTIONS TO THE HYDROLOGY OF THE UNITED STATES

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CONTENTS

ILLUSTRATIONS

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SUBSIDENCE IN THE SANTA CLARA VALLEY, CALIFORNIA—A PROGRESS REPORT

By J. F. POLAND and J. H. GREEN

ABSTRACT

Subsidence of the land surface in the Santa Clara Valley, Santa Clara County, Calif., has been observed since 1933. A network covering the area of subsidence was first surveyed in the spring of 1934. That network was releveled seven times between November 1934 and April 1940, again in 1948 and 1954, and in part in 1956 and 1959, by the U.S. Coast and Geodetic Survey.

The releveling of the network in 1954 indicated that the land surface had subsided 7.75 feet at bench mark P 7 at San Jose. Subsidence near Sunnyvale from 1934 to 1954 was greater than at San Jose. The maximum subsidence from 1948 to 1954 occurred at San Jose and was on the order of 2.4 feet. By December 1959, total subsidence at bench mark P 7 since 1912 was 9.04 feet.

The area of land-surface subsidence extends southward about 25 miles from Redwood City to and beyond San Jose, has a maximum width of about 13 miles, and includes at least 230 square miles.

Plots of subsidence at individual bench marks compared to fluctuation in artesian pressure indicate that decline in artesian pressure is a major cause of subsidence. The rate of subsidence is generally in accord with the rate of fluctuation of artesian pressure. Subsidence virtually ceased during a period of increasing artesian pressure from 1937 to 1940, but resumed at an accelerated rate during a period of rapidly decreasing artesian pressure from 1944 to 1950.

INTRODUCTION

The Santa Clara Valley is a large structural trough that extends from Hollister to San Francisco, Calif. It is bounded on the southwest by the Santa Cruz Mountains and on the northeast by the Mount Hamilton Range (inset map, fig. 4). The San Andreas fault system is a few miles southwest of the valley plain and the Hayward fault borders the valley on the northeast.

Land subsidence occurs in the central reach of the valley in an area of intensive ground-water development. Discussion in this report is limited to this central reach of the valley, which extends southeastward about 30 miles from Redwood City and Niles to Coyote (fig. 4).

The purpose of this report is to present a brief summary of the subsidence that has occurred in the central part of the Santa Clara Valley, as defined by repeated leveling by the U.S. Coast and Geodetic Survey; to compare the subsidence with change in artesian pressure observed at the two principal centers of subsidence; and to draw preliminary conclusions concerning the principal cause of the subsidence.

GEOLOGY

A generalized geologic map of the central part of the Santa Clara Valley is shown on figure 4 and repeated on figures 5 and 6. This map was prepared chiefly from county geologic maps of the State of California Division of Mines (Davis and Jennings, 1954; Davis, 1955). The bedrock, shown as a single unit on the map, ranges in age from Jurassic to Pliocene and consists principally of consolidated sedimentary rocks but includes minor areas of metamorphic and igneous rock. Overlying this consolidated bedrock is the Santa Clara formation of Pliocene and Pleistocene age. Where exposed the Santa Clara consists of semiconsolidated conglomerate, sandstone, siltstone, and claystone. The conglomerate and sandstone are poorly sorted and have a fine-grained matrix; thus the formation has a low permeability and yields only small to moderate quantities of water to wells, rarely enough for irrigation purposes. Along the western margin of the valley the Santa Clara was warped and folded during the last uplift of the Santa Cruz Mountains. Beneath the valley the formation may be undisturbed and in part conformable with overlying beds.

Unconsolidated alluvial and bay deposits of clay, sand, and gravel overlie the Santa Clara formation and form the valley floor. As shown by well logs, the alluvial and bay deposits reach a thickness of 1,000 feet or more in the valley trough. However, the lower parts of these wells may be in the Santa Clara formation, which to date has not been differentiated from the overlying unconsolidated alluvium in drill holes.

The geology of the bedrock has been described in some detail in earlier reports (Davis and Jennings, 1954; Davis, 1955), and the geology of the water-yielding deposits has been described by Clark (1924), Tolman and Poland (1940), and the California State Water Resources Board (1955).

Geologic sections *A–A′* (fig. 1) and *B–B′* (fig. 2) show the general nature of the alluvial and bay deposits that underlie the valley floor. Fine-grained materials such as clay, silt, and sandy clay, which retard the vertical movement of confined ground water, constitute the major part of the valley fill. Sand and gravel occur in lesser amounts but are more abundant near the valley margins and in old stream channels. None of the deposits can be traced laterally for more than a short distance and possible correlations are not shown in figures 1 and 2.

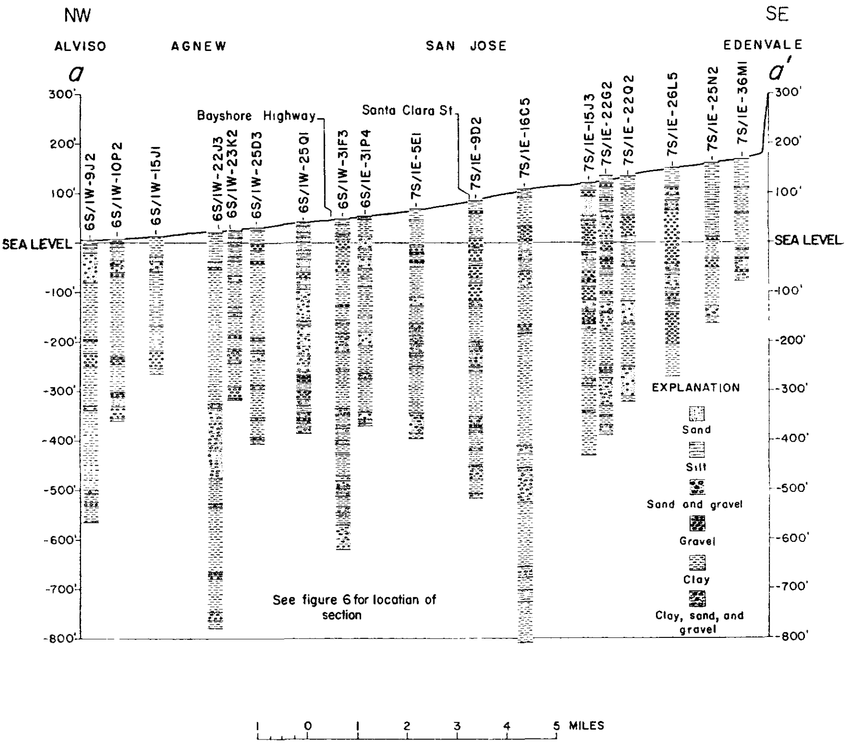

FIGURE 1.—Geologic section from Alviso to Edenvale.

Along section *A–A′* (fig. 1) the deposits become increasingly coarse grained from Alviso toward Edenvale. Gravel beds at the north end of the section, particularly in wells 6S/1W–9J2,[1] 10P2, and 15J1, probably are relatively recent deposits of the Guadalupe River (fig. 5). In the southern part of the section between San Jose and Edenvale, the coarse material most probably was deposited by Coyote Creek.

Beds logged as gravel at the west end of section *B–B′* (fig. 2) near Los Altos represent the subsurface extension of the Santa Clara formation. Between Alviso and Milpitas, the coarse materials are deposits of the Guadalupe River and Coyote Creek.

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

[1] The well-numbering system used shows the locations of wells according to the rectangular system for the subdivision of public land. That part of the number preceding the slash (as in 6S/1W–9J2) indicates the township (T. 6 S.); the number following the slash is the range (R. 1 W.); the digit following the hyphen is the section (sec. 9); and the letter following the section number indicates the 40-acre subdivision of the section according to the accompanying diagram. Within each 40-acre tract the wells are numbered serially, as indicated by the final digit.

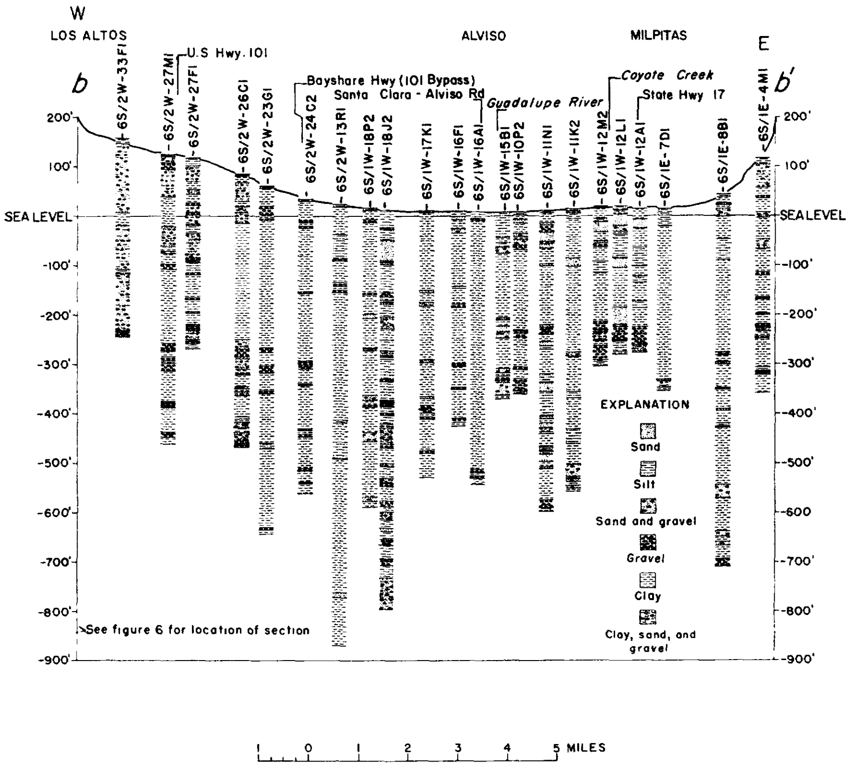

FIGURE 2.—Geologic section from Los Altos to Milpitas.

HISTORY OF LEVELING CONTROL

Interest in the subsidence of Santa Clara Valley first developed when the 1932 releveling of a 1912 first-order level line indicated that several feet of settlement had occurred in the San Jose area. More extensive releveling in 1933 confirmed the subsidence and indicated that it was continuing.

In order to determine the extent and magnitude of subsidence, the U.S. Coast and Geodetic Survey established an extensive level network in 1933 (fig. 3). The network was completely leveled for the first time in the spring of 1934; releveled 7 times from November 1934 to April 1940 (lines 1 and 2 were releveled 9 times in this period); once in 1948; and again in 1954.

As shown in figure 3, main level line 1 extends from Morgan Hill northwest to San Jose and north along the east side of San Francisco Bay to Hayward. Main line 2 extends along the west side of the bay from San Jose northwest to San Mateo. Three transverse lines (3, 18, and 9) extend southwest across the San Andreas fault and three (1, 4,

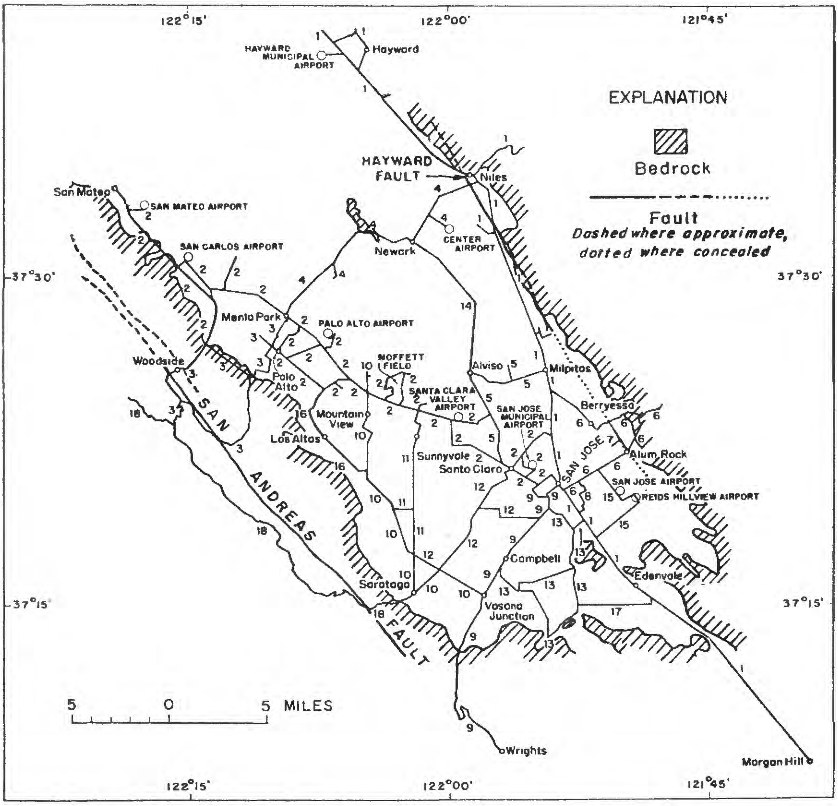

FIGURE 3.—Map showing network of level lines in the San Jose subsidence area, Santa Clara Valley, Calif. (Modified after U.S. Coast and Geodetic Survey.)

and 6) extend east across the Hayward fault. Additional cross lines bring the length of the level network in the area to about 190 miles.

The U.S. Coast and Geodetic Survey (1956) published a compilation of adjusted elevations for all bench marks in the level network. The elevations of certain bench marks at the valley margins were found to have remained stable (within the limit of accuracy of precise leveling) since they were established; these bench marks were assumed to be fixed, and elevations of the valley-floor bench marks were adjusted accordingly by the least-square method. The adjusted elevations were used in the preparation of this report.

MAGNITUDE AND DISTRIBUTION OF SUBSIDENCE

Figure 4 shows lines of equal subsidence from 1934 to 1954 superimposed on the simplified geologic map. The line of 0.1-foot subsidence partly encloses an area of at least 230 square miles, is open at

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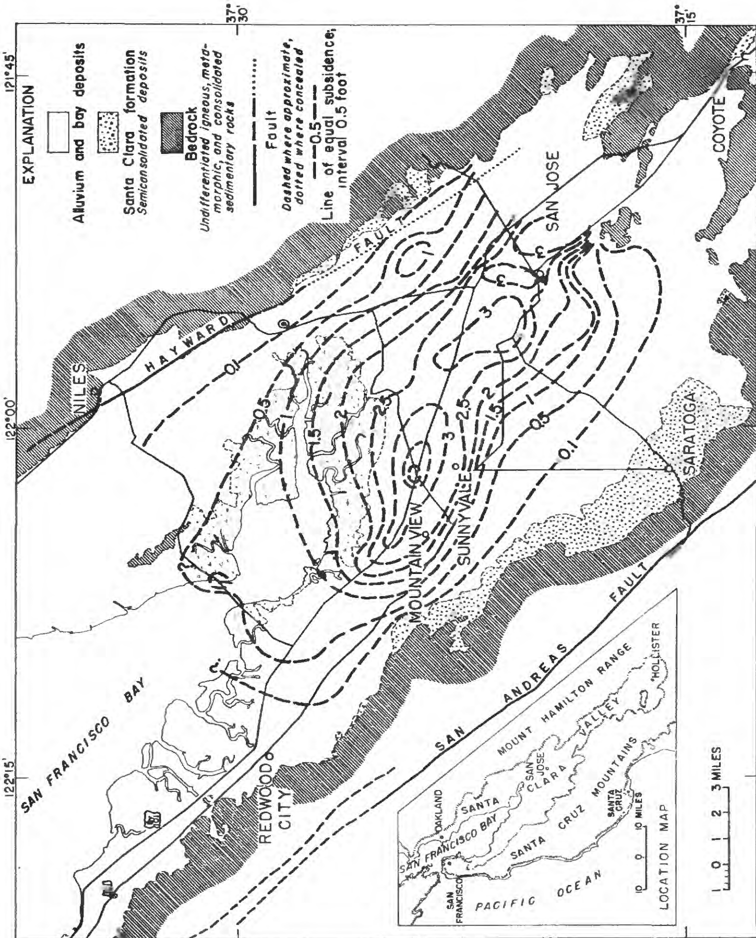

FIGURE 4.—Map of Santa Clara Valley, Calif., showing land subsidence, 1934–54.

both the north and the south ends, and would surround a still larger area if sufficient level control existed to permit closure. Control is not available to define the line of zero subsidence.

Maximum subsidence during the 20-year period was 4.06 feet at bench mark J 111 Reset near Sunnyvale at the intersection of the Alviso-Mountain View Road and the Bayshore Highway (figs. 7, 8). Subsidence in and around San Jose during the same period exceeded 3 feet in many places. At the southeast end of San Francisco Bay, the tidelands subsided as much as 2.5 feet.

The area of subsidence lies wholly within the area of valley fill and corresponds in general with the area of confined ground water as defined by the State (California State Water Resources Board, 1955, pl. 1). No subsidence has occurred in areas underlain exclusively by the Santa Clara formation, nor has any change in altitude of the land surface occurred across the San Andreas fault.

Figure 5 shows subsidence from the spring of 1948 to the summer of 1954. Subsidence in and near San Jose and near Sunnyvale exceeded 2 feet during the period. Maxium subsidence was 2.40 feet at bench mark E 886, about 2 miles north of downtown San Jose; the average rate of subsidence at this bench mark was 0.4 foot per year.

Figure 6 shows subsidence from 1940 to 1954 and the locations of various bench marks, wells, and cross sections which are discussed in this report. Subsidence in excess of 2.5 feet occurred in part of San Jose and in the area near Sunnyvale. The map differs only slightly from that of 1948–54 (fig. 5) because subsidence from 1940 to 1948 was small.

Figure 7 shows land-subsidence profiles *A–A′* from San Carlos to Coyote between 1912 and 1956. The May–July 1934 leveling was used as a reference line because leveling before that time is incomplete for the profile reach. Also, the 1934 leveling is the earliest included in all three of the profiles shown in figure 6. Subsidence before 1934 is shown above the 1934 reference base; subsidence after 1934 is shown below it.

Subsidence from 1912 to 1954 increased southeastward from about 0.1 foot at Redwood City to about 2.2 feet at Palo Alto, 6 feet at Sunnyvale, and 7.8 feet at San Jose. At a knob of bedrock (BM 152.36), 4 miles south of San Jose no subsidence occurred.

Maximum known subsidence prior to the spring of 1934 was 4.66 feet at bench mark P 7 in San Jose. From 1934 to 1954, maximum known subsidence was 4.06 feet at bench mark J 111 Reset in Sunnyvale. However, the maximum known subsidence from 1912 to 1959 was 9.04 feet at bench mark P 7 in San Jose.

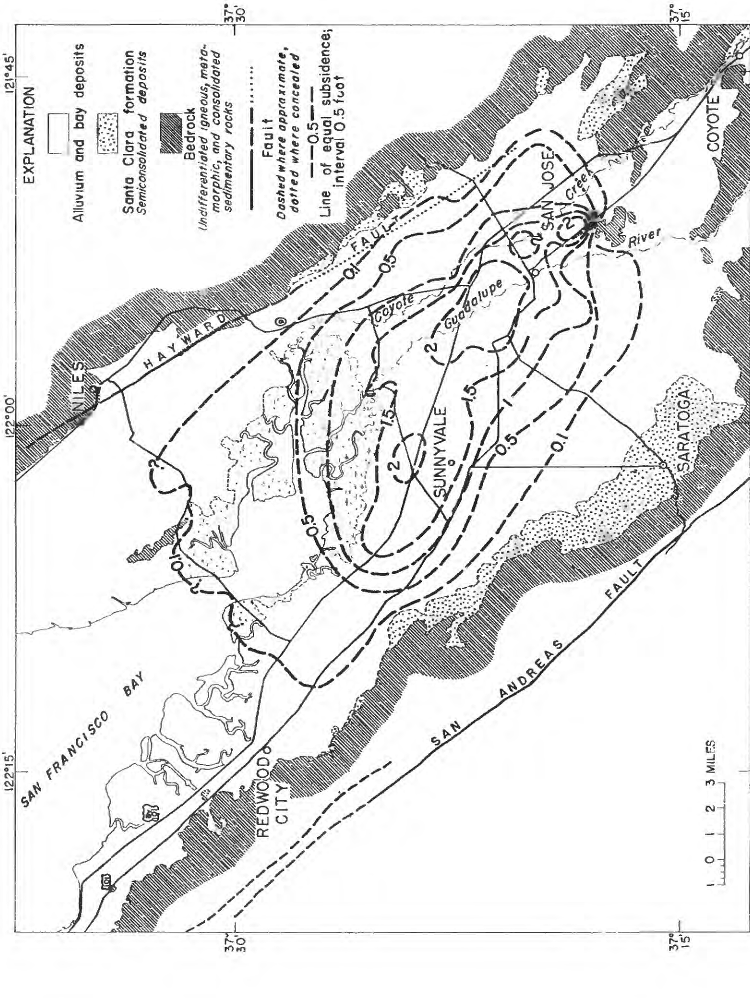

FIGURE 5.—Map of Santa Clara Valley, Calif., showing land subsidence, 1948–54.

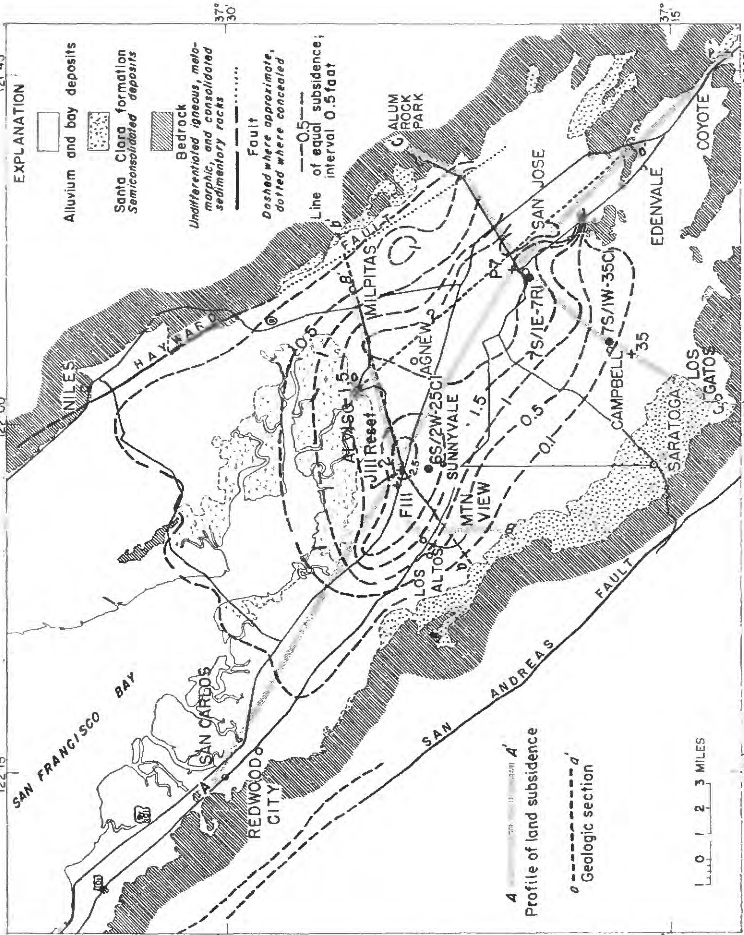

FIGURE 6.—Map of Santa Clara Valley, Calif., showing land subsidence, 1940–54.

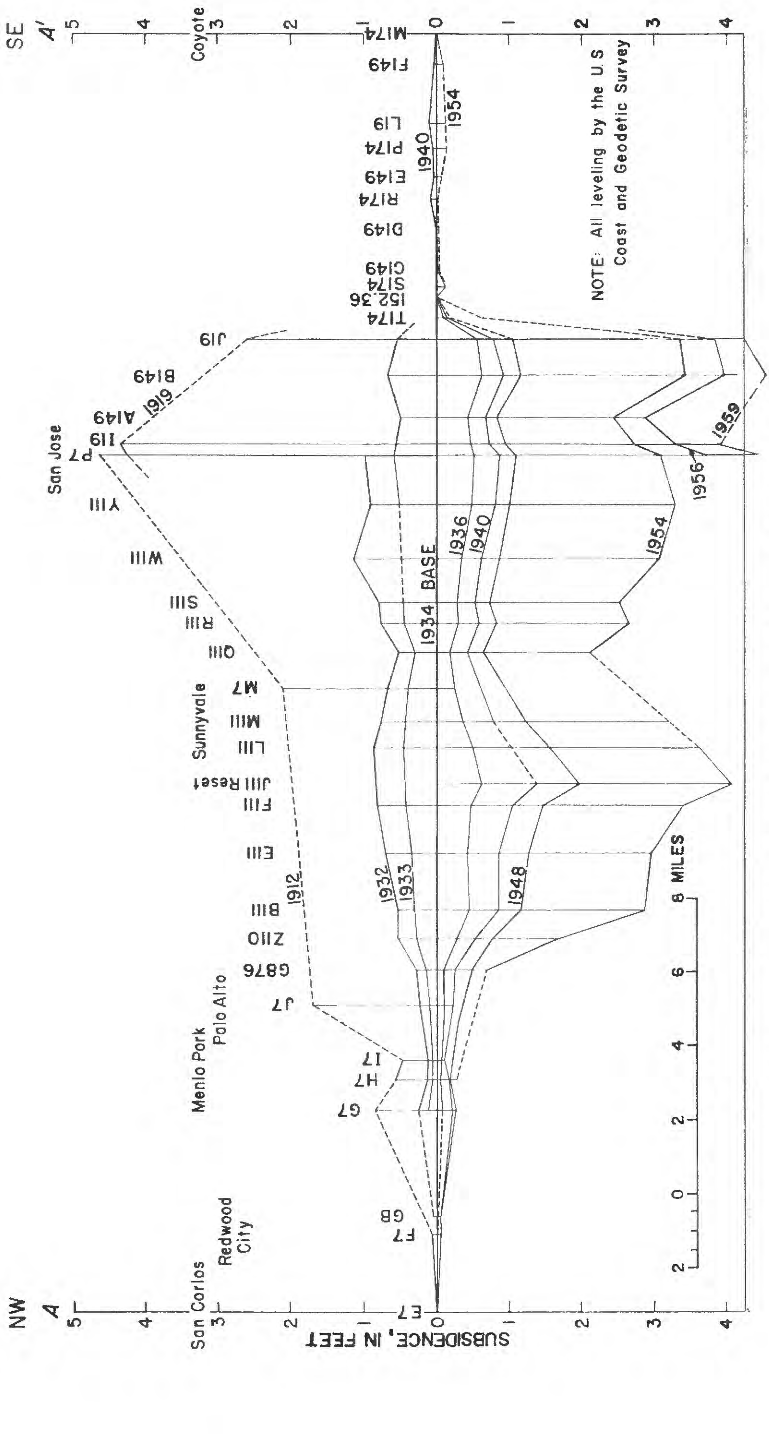

FIGURE 7.—Profiles of land subsidence, San Carlos to Coyote, Calif., 1912–59.

Figure 8 shows land-subsidence profiles *B–B′* from Mountain View to Milpitas between 1933 and 1954. Along the entire line, subsidence from 1948 to 1954 exceeded that from 1934 to 1948.

Apparent increases in altitude, such as that at bench mark Y 180, between 1937 and 1938, probably are due to adjustments of field-observed altitudes.

Figure 9 shows land-subsidence profiles *C–C′* from Los Gatos through San Jose to Alum Rock Park between 1934 and 1954. No appreciable subsidence occurred between Los Gatos and bench mark 35 (USGS). In this area the ground water is unconfined and coarse-grained deposits constitute about 75 percent of the underlying materials.

The edge of the area of artesian confinement, as shown in Bulletin 7 of the California State Water Resources Board (1955, pl. 1), lies approximately between bench marks T 176 and S 176 and marks the point at which subsidence increases sharply. Maximum subsidence along line *C–C′*, 3.49 feet, occurred at bench mark E 176 in San Jose. Along this line, as along profile *B–B′* (fig. 8), subsidence from 1948 to 1954 exceeded that from 1934 to 1948.

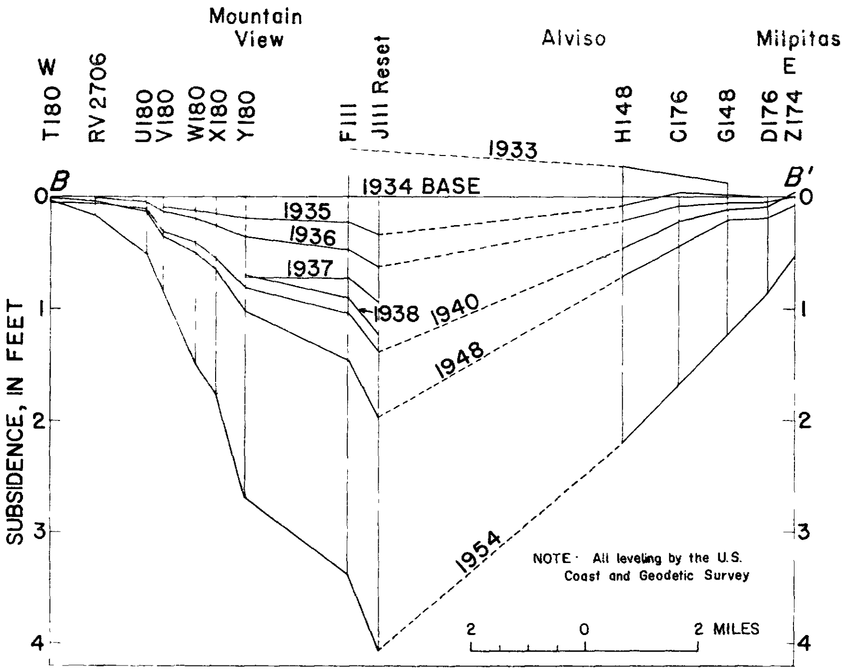

FIGURE 8.—Profiles of land subsidence, Mountain View to Milpitas, Calif., 1934–54.

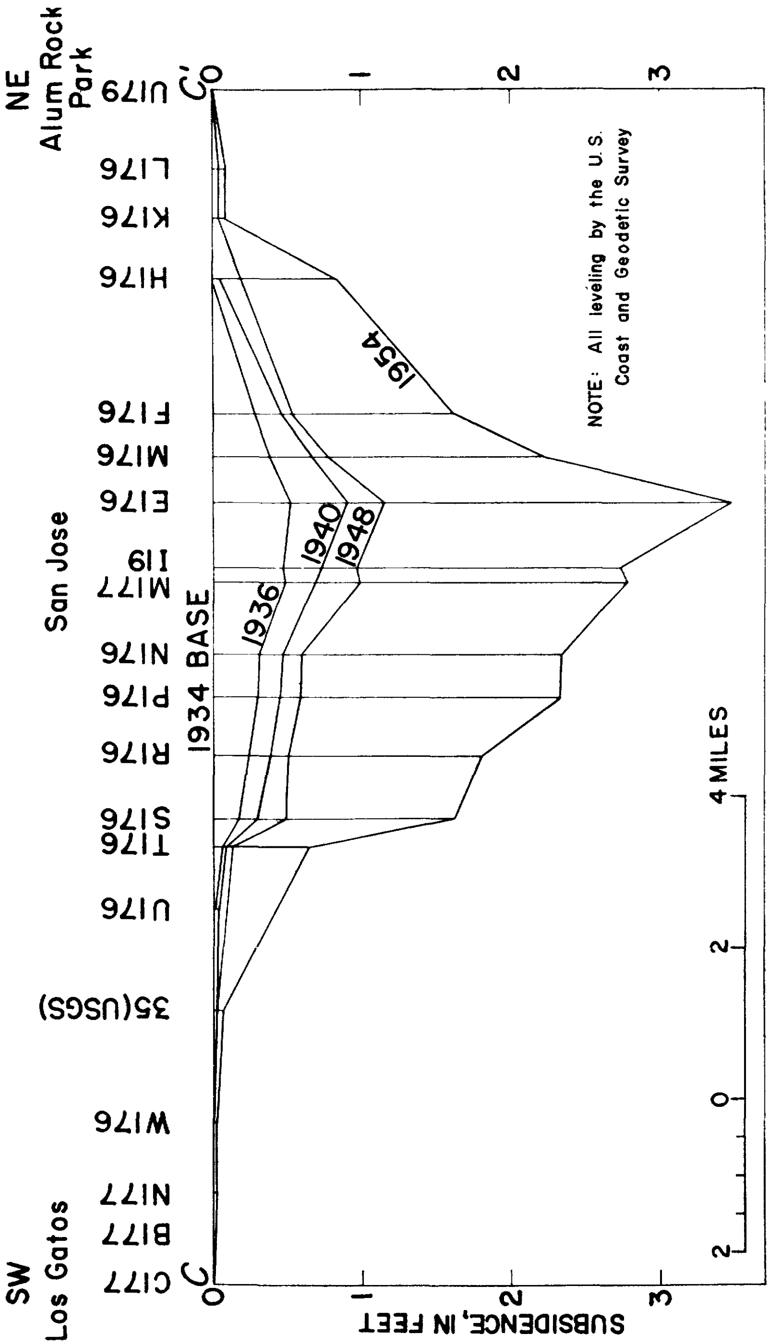

FIGURE 9.—Profiles of land subsidence, Los Gatos to Alum Rock Park, Calif., 1934–54.

Figure 10 shows the change in altitude at bench mark P 7 in San Jose and the change in artesian pressure at a nearby well. The artesian pressure head at well 7S/1E–7R1, which was above the land surface in 1915, declined 100 feet more or less continuously from 1916 to 1934, rose 74 feet to a peak in 1943, and then declined 95 feet by 1951. In 1958 the water level was about the same as in 1951. The water-level fluctuation in this well is reasonably representative of wells in the artesian area between San Jose and San Francisco Bay.

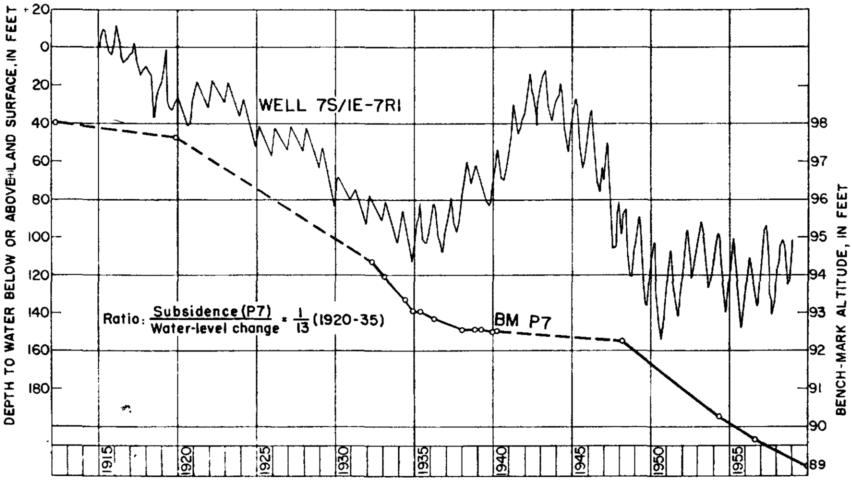

FIGURE 10.—Change in altitude at bench mark P 7 in San Jose and change in artesian pressure at nearby well.

Subsidence at bench mark P 7 was 0.39 foot from 1912 to 1919 and 4.56 feet from 1919 to November 1934, the first period of water-level decline. From November 1934 to November 1937 the rate of subsidence gradually decreased and from 1937 to 1940 there was a decrease of only 0.03 foot. The net was not leveled between 1940 and 1948; it is not known whether the land surface recovered in response to the water-level recovery. However, the trend from 1938 to 1940 suggests that recovery, if any, was small. The subsidence of 2.72 feet from 1948 to 1956 probably was a result of the rapid decline of artesian pressure from 1943 to 1951.

Subsidence was most rapid, averaging 0.5 foot a year, from April 1932 to November 1934. From 1948 to 1954 the average rate was 0.32 foot a year. The ratio of subsidence to artesian-pressure decline from 1920 to 1935, when both were occurring at nearly uniform rates, was about 1 to 13.

The close correlation between the subsidence plot and the hydrograph strongly suggests that subsidence of the land surface is caused by the decline in artesian pressure in the confined aquifers. If the hydrostatic pressure, which helps support the fine-grained clay and silt beds overlying the confined aquifers, decreases, the result is a like increase in effective stress (grain-to-grain load) on the aquifer skeleton. This effect is instantaneous in the coarse-grained permeable aquifers. However, permeability and head differential determine the rate at which water will escape from the fine-grained beds, and the rate of escape determines the rate of compaction. Therefore, compaction occurs more slowly in the fine-grained beds than in the coarse-grained beds.

The cessation of subsidence in 1938, when the artesian pressure had recovered to about 60 feet below the land surface, suggests that all compaction attributable to the net pressure decline from 1916 to 1938 had taken place. Ignoring possible land-surface recovery as a result of artesian pressure recovery, it would be expected that no additional subsidence would occur until the artesian pressure declined again below the 1938 level, at which time the effective stress due to overburden load would begin to exceed the preconsolidation condition. Such a decline occurred in 1947 and renewed subsidence probably began at that time.

Figure 11 shows the changes in altitude at two bench marks near Mountain View and the change in artesian pressure at a nearby well. The pattern of change in artesian pressure is similar to that at San

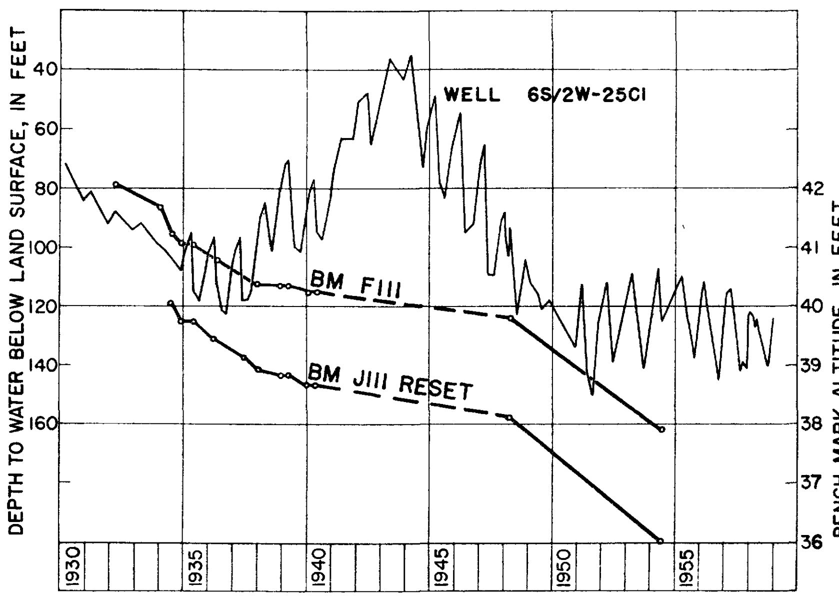

FIGURE 11.—Change in altitude at bench marks F 111 and J 111 Reset near Mountain View and change in artesian pressure at nearby well.

Jose, although the magnitude of the long-term fluctuation is less. Both bench marks subsided markedly from the beginning of record to the end of 1937 and again after 1948, each time presumably in response to the decline of artesian pressure. Neither bench mark had reached temporary stability by 1940, although the last two levelings of 1939–40 show little change.

Figure 12 shows the change in altitude at bench mark 35 (USGS) near Campbell, and the change in water level in a nearby well. Both bench mark and well are in the intake area where the ground water occurs under unconfined conditions and the alluvial deposits contain about 75 percent sand and gravel. Although clay beds are not numerous, the large annual water-level fluctuation suggests that the well taps confined deposits at depth. The long-term fluctuation of water level at Campbell is nearly the same as in the artesian area near San Jose and Sunnyvale. The plot of bench mark 35 (USGS), however, shows subsidence of only 0.06 foot from 1934 to 1954, indicating that a substantial decline of the water table may cause only a small amount of subsidence.

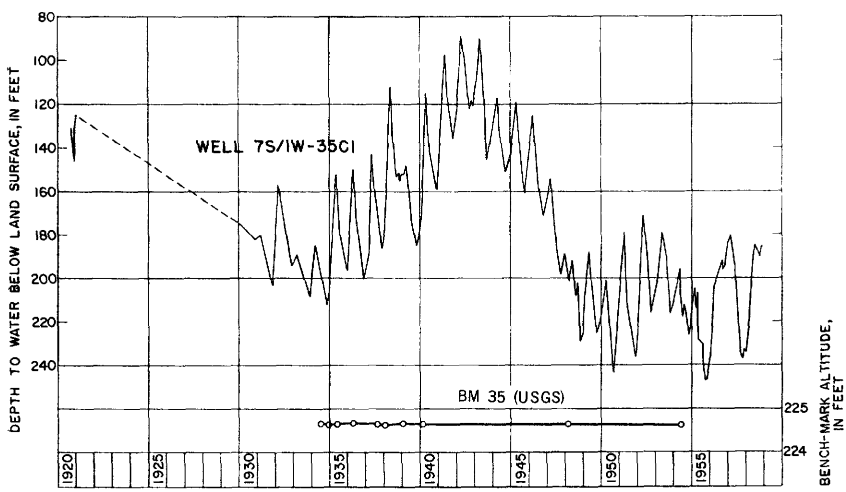

FIGURE 12.—Change in altitude at bench mark 35 (USGS) near Campbell and change in water level in nearby well.

CONCLUSIONS

From available evidenec it is concluded that decline of artesian pressure is the principal cause of land subsidence in the Santa Clara Valley. The area of intensive subsidence is limited to the area of confined water; subsidence is not appreciable in the area of unconfined water. Also, the rate of subsidence generally has corresponded with the rate of decline of artesian pressure; the ratio between the two was about 1 to 13 when the rates were relatively steady.

Tectonic movement may be a minor contributing cause of the subsidence. However, the level net is tied to consolidated bedrock at six widely spaced points around the valley margin, and these points remained stable from 1934 to 1954. Thus, there was no warping or displacement of any of the bedrock points relative to the others. For this reason it is concluded that tectonic movement could have occurred in only a minor amount, if at all.

The Geological Survey and the Coast and Geodetic Survey are continuing subsidence investigations. The Geological Survey has established bench marks at depth in nine wells, selected to span the vertical section of water-bearing sediments. The purpose of the installations is to determine whether compaction of the fresh-water-bearing deposits tapped by water wells is occurring and, if so, how much and at what depth intervals. The physical, hydrologic, and consolidation characteristics of the sediments being compacted are being tested in cores from holes drilled near Sunnyvale and in San Jose at the principal centers of subsidence.

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