Geologic Features and Ground-Water Storage Capacity of the Sacramento Valley California

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By F. H. Olmsted and G. H. Davis

ABSTRACT

The Sacramento Valley constitutes the northern and smaller arm of the Central Valley of California. It is about 150 miles long by about 30 miles wide; and its area is about 5,000 square miles. The Sacramento Valley is drained by the Sacramento River, the largest in California, which rises west of Mount Shasta and flows southward to join the San Joaquin River near Suisun Bay and discharges through San Francisco Bay to the Pacific. Most of the valley floor is suitable for growing crops, and under irrigation the land is highly productive.

The Sacramento Valley is underlain by sediments transported from the surrounding mountains by the Sacramento River and its tributaries. The floor of the valley slopes southward from about 300 feet above sea level at the north end near Red Bluff to sea level at Suisun Bay. The Sutter Buttes, which are erosional remnants of an old volcano rise to 2,132 feet above sea level near the center of the valley. The valley floor is not a featureless plain but is characterized by various types of topography, which have been assigned to four principal groups: 1, low hills and dissected alluvial uplands; 2, low alluvial plains and fans; 3, flood plains and natural levees; and 4, flood basins; a fifth and relatively minor group consists of the tidal islands of the Sacramento-San Joaquin Delta, which are south of the principal area of investigation.

The rocks that underlie the Sacramento Valley and the bordering mountains range from crystalline rocks of Paleozoic and Mesozoic age to unconsolidated alluvium of Recent age. These rocks have been subdivided into 20 geologic units which may be assigned to 2 broad categories: rocks that yield little water and rocks that yield water freely. The rocks of the first category are chiefly marine sedimentary rocks of Late Jurassic, Cretaceous, and early Tertiary age and a basement complex of pre-Tertiary crystalline rocks. The rocks of the second category consist predominantly of nonmarine valley-filling sediments of late Tertiary and Quaternary age, which constitute the principal ground-water reservoir in the Sacramento Valley.

The rocks that yield little or no water includes the following geologic units: 1, Basement complex of the Sierra Nevada (pre-Tertiary); 2, Shasta series (Lower Cretaceous); 3, Chico formation (Upper Cretaceous); 4, Paleocene series; 5, Eocene series (in part, water yielding); 6, basalt (Tertiary); 7, sedimentary rocks of volcanic origin on the west side of the Sacramento Valley (Tertiary, in part water yielding); 8, intrusive rhyolite and andesite and vent tuff of the Sutter Buttes (Pliocene); and 9, tuff-breccia of the Sutter Buttes (Pliocene, in part water yielding).

The rocks that yield water freely, comprises the following geologic units: 1, Volcanic rocks from the Sierra Nevada (Eocene to Pliocene; in part yield

little or no water); 2, Tuscan formation (Pliocene; in part yield little or no water); 3, Tehama formation (Pliocene); 4, Tehama formation and related continental sediments, undifferentiated (Pliocene and Pleistocene); 5, Laguna formation and related continental sediments (Pliocene and Pleistocene); 6, fanglomerate from the Cascade Range (Pleistocene); 7, Red Bluff formation (Pleistocene); 8, Victor formation and related deposits (Pleistocene); 9, alluvial-fan deposits (Pleistocene and Recent); 10, river deposits (Recent); and 11, flood-basin deposits (Recent).

The volcanic rocks from the Sierra Nevada consist chiefly of andesitic and rhyolitic detritus. Most of these volcanic rocks are fragmental and were deposited either as mudflows or by streams. Their permeability is extremely variable, the poorly consolidated sandstone and conglomerate strata locally yield water copiously to wells, but the interbedded fine-grained and cemented strata are virtually impermeable and act as confining layers.

The Tuscan formation, which occurs in the northeastern part of the valley, consists of fragmental andesitic and basaltic material ranging from fine-grained tuff and clay to volcanic breccia of mudflow origin. The Nomlaki tuff member, which is in the basal part of both the Tuscan and the Tehama formations, is a useful stratigraphic marker in the northern part of the Sacramento Valley. The Tuscan formation is moderately permeable, except for beds of tuff and breccia that locally act as confining layers beneath the valley.

The Tehama formation consists of somewhat compacted to locally cemented fluviatile sediments derived from the Coast Ranges. It interfingers with the Tuscan formation in the northern part of the Sacramento Valley and probably in part with the Laguna formation and related continental sediments in the southern part of the valley. The Tehama formation is one of the most important sources of ground water in the valley, although the average permeability of the formation is somewhat less than that of the overlying alluvial-fan deposits.

The geologic unit identified as the Tehama formation and related continental sediments, undifferentiated, which was mapped south of Cache Creek and between Cortina Creek and the South Fork of Willow Creek, comprises the Tehama formation, the Red Bluff(?) formation, post-Red Bluff stream-terrace deposits, and the so-called Cortina member of the Tehama formation as used by the geologists of the U.S. Bureau of Reclamation. Its general water-bearing character is similar to that of the Tehama formation.

The geologic unit identified as the Laguna formation and related continental sediments comprises the Laguna formation, the Arroyo Seco gravel, and gravel deposits of uncertain age in the Mokelumne area, and unnamed equivalents of these formations north of the Mokelumne area. The Laguna formation and its northern equivalents consist chiefly of somewhat consolidated silt, sand, and clay; the overlying gravel deposits for the most part are unsorted and are relatively thin. At most places the unit is only moderately permeable, and generally it does not yield water as readily as the overlying Victor formation and related deposits or the underlying volcanic rocks from the Sierra Nevada.

The fanglomerate from the Cascade Range consists almost entirely of volcanic detritus derived from the Tuscan formation. The beds are locally indurated, and the unit is similar to the Tuscan formation in general water-bearing character.

The Red Bluff formation is a poorly-sorted gravel that has a distinctly reddish silty or sandy matrix. It lies on an erosion surface cut on the Tehama formation and older rocks and, at least in part, probably is equivalent in age to the fanglomerate from the Cascade Range and the Arroyo Seco gravel. The Red Bluff is largely above the zone of saturation in the outcrop areas; its subsurface extent and character are not well known.

The Victor formation and related deposits are an extremely heterogeneous assemblage of lenticular bodies of silt, sand, gravel, and clay. The unit comprises the Victor formation in the Mokelumne area and deposits of equivalent age (late Pleistocene) to the north. It probably interfingers with the lower part of the alluvial-fan deposits on the west side of the Sacramento Valley. The Victor formation and related deposits are moderately to highly permeable at most places, but the saturated part generally is too thin to support wells producing more than 1,000 gpm (gallons per minute).

The alluvial-fan deposits were deposited along the west side of the Sacramento Valley and around the Sutter Buttes; and on the alluvial fans of Big Chico, Little Chico, and Butte Creeks on the east side of the valley. The deposits are heterogeneous and range from clay and silt to coarse sand and gravel. The alluvial-fan deposits of Putah, Cache, and Stony Creeks include some of the most permeable sand and gravel in the valley, but well yields are small where silt and clay predominate.

The river deposits consist predominantly of well-sorted sand, gravel, and silt along the channels, flood plains, and natural levees of the major streams in the Sacramento Valley. The deposits are moderately to highly permeable, but they are not tapped extensively by wells, because surface-water supplies are available at most places where they are present.

The basin deposits are largely silt and clay deposited in the flood basins during floods on the major streams. They grade laterally into the river deposits and into the younger alluvial-fan deposits. The basin deposits are generally of low permeability, and few irrigation wells derive appreciable quantities of water from them.

The Sacramento Valley occupies the northern part of the Great Valley structural trough, a downwarped basin of deposition filled with sedimentary materials, which range in age from Cretaceous to Recent. To the east is the Sierra Nevada, a mountain range formed by a block tilted upward on the east and dipping westward beneath the Central Valley almost to the flanks of the Coast Ranges. West of the Sacramento Valley the Coast Ranges are a complexly folded and faulted mountain mass nearly parallel to the Sierra Nevada. The sedimentary rocks of the eastern part of the Coast Ranges were deformed in several stages into steep folds and local thrust faults. The compressive forces from the west that caused this deformation may have tilted the relatively rigid Sierra Nevada block by forcing its western part below its position of isostatic equilibrium. The sedimentary rocks of late Tertiary and Quaternary age along the western border of the valley are deformed by several folds and faults of the Coast Range type. Such structures occur in the Corning Ridge, Dunnigan Hills, Plainfield Ridge, Potrero Hills, Kirby Hill, and Montezuma Hills.

The structural trough of the Sacramento Valley is asymmetrical; the deepest part of the basin lies west of the present axis of the valley. The valley sediments thin eastward and overlap the crystalline rocks of the Sierra Nevada block. The Cretaceous and lower Tertiary marine sedimentary rocks extend westward into the Coast Ranges where they are deformed by folds and faults. The valley fill may be more than 20,000 feet thick along the southwestern margin of the valley. The northern part of the valley has been uplifted on a regional scale, and several structural features are superimposed on the regional uplift. Among these are the Chico monocline, Red Bluff arch, Corning Ridge, and Orland Buttes. The Chico monocline, which deforms the volcanic rocks (Tuscan formation) of the southwestern part of the Cascade Range, accounts for the straight northeastern border of the Sacramento Valley north of Chico.

Data on yields of 2,783 wells of large capacity are summarized for 21 areas in the valley. The data summarized include, average well discharge in gallons per minute (gpm); average specific capacity in gallons per minute per foot of drawdown (gpm per ft); average depth in feet of logged irrigation wells; and average yield factor for saturated thickness (specific capacity divided by the saturated thickness in feet and multiplied by 100).

Average well discharges for the 21 areas range from 250 gpm in the North Sacramento–Fair Oaks area to 1,690 gpm in the Colusa area. Average specific capacities range from 21 gpm per foot in the North Sacramento–Fair Oaks area to 106 gpm per foot in the Woodland area. Average well depths range from 120 feet in the highly productive Cache Creek area to 494 feet in the Williams area. The average yield factors for saturated thickness afford an approximate measure of the areal variations in permeability of the deposits throughout the valley, and they correspond to the geologic features of the valley in general. The highest yield factors are found in some of the areas on the west side of the valley where wells draw water from permeable alluvial-fan deposits of the larger streams draining the Coast Ranges. The highest average yield factor is 97, in the Cache Creek area where highly permeable clean gravel extends to a maximum depth of 150 feet. The lowest average yield factor is 7, in the North Sacramento–Fair Oaks area on the east side of the valley. However, in the Williams area, on the west side of the valley, where fine-grained deposits predominate, the average yield factor is only 8.

For the purpose of estimating ground-water storage capacity the Sacramento Valley was divided, on the basis of physiography, soils, and lithologic character of the deposits to a depth of 200 feet, into 4 storage groups which in turn were subdivided into a total of 29 storage units. The storage capacity was estimated for three depth zones: 20 to 50 feet, 50 to 100 feet, and 100 to 200 feet below the land surface. In order to estimate the storage capacity of the water-bearing deposits, the writers classified the materials in the drillers' logs in five groups to which selected specific yields were assigned. Briefly, the storage capacity was estimated by multiplying the total volume of materials in a given depth zone of a given storage unit by a weighted average specific yield.

The four storage groups into which the valley deposits were divided are river flood-plain and channel deposits (group A); low alluvial-plain and alluvial-fan deposits (group B); dissected alluvial deposits (group C); and basin deposits (group D).

Group A includes 5 storage units with a total storage capacity of about 10 million acre-feet in the depth range 20 to 200 feet below the land surface—about 30 percent of the valley's total. Group B comprises 11 storage units with a storage capacity of about 13 million acre-feet in the depth range 20 to 200 feet below the land surface—about 39 percent of the valley's total. Group C comprises 8 storage units with a storage capacity of nearly 5 million acre-feet in the depth range 20 to 200 feet below the land surface—about 15 percent of the valley's total. Five storage units are included in group D; the total storage capacity in the 20- to 200-foot depth range is nearly 5½ million acre-feet, or 16 percent of the total for the Sacramento Valley.

The total ground-water storage capacity of the deposits in all 4 storage groups in the 20- to 200-foot depth range is about 33½ million acre-feet. However, because the basin deposits, group D, are fine grained and are in large part unusable, the storage capacity, excluding these deposits, is reduced to a total of about 28 million acre-feet.

INTRODUCTION

PURPOSE AND SCOPE OF THE INVESTIGATION

In March 1948 a cooperative agreement was made by the Geological Survey, United States Department of the Interior, and the Division of Water Resources, Department of Public Works, State of California, (now the Department of Water Resources), providing for an investigation of the ground-water resources of ground-water basins in California, with special reference to geologic features. The first activity of the Geological Survey under the cooperative agreement was to investigate the geologic features and to estimate the total ground-water storage capacity of the near-surface water-bearing deposits in the Sacramento Valley. The total ground-water storage capacity is the volume of water that would drain by gravity from the material underlying the designated ground-water storage areas if the regional water level were lowered from 20 feet below the land surface to a depth of 200 feet. As of 1948 this valley had a known surplus of water—that is, there was more surface and ground water jointly available than was being used or would be needed in the valley in the future. The State desired to know the order of magnitude of the ground-water storage to assist in estimating the magnitude of the surplus.

The investigation reported herein included reconnaissance geologic mapping of the water-bearing deposits and the subjacent rocks with respect to their physical and hydrologic character, thickness, distribution, and structural features. In addition the investigation included estimating the total ground-water storage capacity of the water-bearing deposits between 20 and 200 feet below the land surface. No attempt was made to estimate the usable storage capacity. Usable storage capacity is a volume of water equivalent to the specific yield of deposits that can be shown to be economically capable of being dewatered during periods of deficient surface supply and of being resaturated, either naturally or artificially, during periods of excess surface supply. Obviously the deposits must contain usable water, which may be defined as water whose quality is satisfactory for irrigation and which occurs in sufficient quantity in the underground reservoir to be available without uneconomic drawdown or reduction in well yield. An accurate appraisal of usable storage capacity of the Sacramento Valley would require a detailed geologic and hydrologic study beyond the scope of the present investigation. However, the work accomplished to date is a necessary first step in an estimate of usable storage capacity. Accordingly, there would be no duplication of effort if an estimate of usable storage capacity should be undertaken in the future.

The fieldwork done by the Geological Survey consisted of collecting about 6,000 well logs and determining locations in the field of about 3,200 of the wells for which the logs were collected. Because of the desire of the State for rapid completion of the estimates of storage capacity, no information about each well other than its location was obtained, except in Solano and southern Yolo Counties where the Geological Survey concurrently was conducting a more detailed hydrologic and geologic investigation.

In addition to locating wells for which logs were collected, the field investigation included reconnaissance geologic mapping of the eastern margin of the Sacramento Valley and, subsequently, of detailed mapping of parts of Solano and southern Yolo Counties as part of the separate investigation in that area.

The total ground-water storage capacity in the Sacramento Valley between 20 and 200 feet below the land surface was summarized in a brief report by the Geological Survey which was published in 1951 as appendix D in Bulletin 1 of the California State Water Resources Board. The present report gives the same data in greater detail and with slight revisions and describes the geologic features of the valley.

The collection of data, locating wells in the field, and geologic mapping reported herein was done mainly during 1948 and 1949, and most of the work of analyzing data and preparations of the report was done in 1949 and 1950. Because work was proceeding concurrently on a comprehensive investigation of various aspects of the water resources of the part of Solano County in the Sacramento Valley, reported by Thomasson, Olmsted, and LeRoux in Water-Supply Paper 1464, completion of this report on the entire valley was delayed to permit incorporation of information collected in the Solano County study. Thus, for the most part, conditions reported are as of about 1950, rather than the date of publication; however, new developments in geologic thinking regarding the Sacramento Valley have been incorporated in this report insofar as practicable.

The investigation was made under the immediate direction of J. F. Poland, who at the time was district geologist in charge of ground-water investigations in California. Fred Kunkel and W. J. Hiltgen, of the Geological Survey, assisted in the fieldwork and office computations.

LOCATION OF AREA

The Sacramento Valley is in north-central California, about midway between the west coast and the Nevada border. The valley is bounded on the west by the Coast Ranges, on the northeast by the

Cascade Range, and on the east by the Sierra Nevada. To the south the Sacramento Valley merges almost imperceptibly with the San Joaquin Valley; together they form the Central Valley, the largest and most important agricultural region in the State.

The area investigated is shown on the geologic map (pl. 2), on the map showing the ground-water storage units (fig. 4), and in a general way on plate 1 and figure 2. It comprises the Sacramento Valley and fringes on the surrounding mountains and is within the area delimited by 38°00′ and 40°30′ north latitude and 121°00′ and 122°30′ west longitude. The valley floor extends from Red Bluff, on the north, southward beyond Sacramento, the State capital, to the Cosumnes River on the southeast, to the northern edge of the Sacramento-San Joaquin delta on the south, and to the northern edge of the Montezuma Hills on the southwest.

DEVELOPMENT OF GROUND WATER

Although the Spanish settlers of southern California practiced irrigation on a limited scale in the Spanish period, extensive cultivation of crops and irrigation did not begin in the Sacramento Valley until the great influx of population to the gold-mining districts in the 1850's created a local demand for foodstuffs. Earlier settlers of the valley were interested primarily in cattle grazing, although Capt. John Sutter is reported to have raised wheat commercially as early as 1843 (Bryan, 1923, p. 1). Garden plots may have been irrigated earlier, but the first irrigation on a commercial scale began with the construction of the Moore ditch in 1856 to divert water from Cache Creek about 8 miles upstream from the vicinity of Woodland (Chandler, 1901, p. 22). The development of irrigated agriculture proceeded slowly until the severe drought of 1864, after which many new irrigation diversions were made. By 1880 some 13,400 acres was under irrigation in the Sacramento Valley, according to a report of the State engineer of that date (California Division Water Resources, 1931, p. 97).

Wells were used for domestic and stock-watering supplies from the time of the earliest settlements, but, owing to the lack of efficient pumps and power plants, wells were not used for irrigation until 1879. In that year a well 18 inches in diameter and 24 feet in depth was drilled on the Blowers Ranch near Woodland (Chandler, 1901, p. 25). The success of this well encouraged further drilling, and Chandler (1901) listed 24 irrigation wells in the Woodland district in 1900.

Adams (1913, p. 21), reporting on irrigation development as of 1912, listed about 76,500 acres irrigated in the Sacramento Valley, exclusive of the delta islands. Bryan (1923, p. 5) in his discussion of ground-water development of the Sacramento Valley as of 1913 and 1914 reported that 1,664 irrigation wells irrigated about 49,000 acres.

High commodity prices during World War I encouraged further irrigation of new lands, so that Bryan (1923, p. 4) reported that 473,000 acres was irrigated in 1919, although this total may include land in the delta area not included in the 76,500-acre total of 1912. Development continued during the 1920's, and by 1929 (California Division Water Resources, 1931, p. 38) 550,000 acres was irrigated in the Sacramento Valley, exclusive of the delta area, including about 203,000 acres irrigated with ground water.

Little new land was placed under irrigation during the depression years of the 1930's, but high commodity prices during World War II and the postwar period through 1950 brought about further development, so that surveys of irrigated areas carried out in the period 1946–50 (California State Water Resources Board, 1955, table 104) report almost 750,000 acres irrigated. Recent estimates by the California Department of Water Resources indicate that 351,000 acres was irrigated by ground water in 1950; this requires an average annual pumping draft of 1,287,000 acre-feet.

ACKNOWLEDGMENTS

The Sacramento Valley has been studied either in whole or in part by several investigators since 1900. The data and reports, both published and unpublished, that were used as references in the present investigation are cited in the text and are given in the section "References cited," at the end of the report. Bryan's report (1923) on the geology and ground-water resources of the Sacramento Valley was a particularly important source of data and may, in a sense, be considered a predecessor of the present report, although Bryan's paper included a discussion of the hydrologic features of the valley—a subject not studied in the present investigation.

Several agencies and companies and many individuals supplied invaluable assistance and data to the Geological Survey in the present investigation. The California Department of Water Resources, in addition to providing a part of the funds used in the study, supplied about 700 well logs, including locations of wells, in Sutter and Yuba Counties, furnished many other important data, and assisted in many ways. The U.S. Bureau of Reclamation supplied about 900 well logs and many miscellaneous data and provided a geologic map of the west side of the valley; this map was used as a source of most of the geology of the foothill belt between Stony and Cortina Creeks shown on plate 2. The Standard Oil Co. of California also furnished geologic maps used as source material along the west side of the

valley, and several oil companies supplied electric logs of gas and gas-test wells used in subsurface correlation.

The description of the geology of the Sutter (formerly Marysville) Buttes was adopted from a report by H. R. Johnson (1943) in California Division of Mines Bulletin 118. Geologic boundaries of most of the deposits of late Quaternary age in the valley were interpreted from soils maps and reports of the U.S. Department of Agriculture and the University of California. Several dozen water-well drillers furnished logs of most of the wells used in the storage study and also in the interpretation of the geology of the near-surface deposits. Well logs were supplied also by many small agencies and landowners. The Pacific Gas and Electric Co. and the Sacramento Municipal Utility District supplied invaluable water-well pump-test data which were used to evaluate the water-yielding characteristics of the deposits throughout the valley.

WELL-NUMBERING SYSTEM

The well-numbering system used in California by the Geological Survey shows the locations of wells according to the rectangular system for the subdivision of public land. For example, in the number 11/4E–21H1, which was assigned to a well about 15 miles north of Sacramento, the part of the number preceding the bar indicates the township (T. 11 N.); the number and letter between the bar and the hyphen, the range (R. 4 E.); the digits between the hyphen and the letter, the section (sec. 21); and the letter (fig. 1) following

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

FIGURE 1.—Well-numbering system.

the section number, the 40-acre subdivision of the section, as shown in the accompanying diagram. Within each 40-acre tract the wells are numbered serially, as indicated by the final digit of the number. Thus, well 11/4E–21H1 is the first well to be listed in the SE¼NE¼ sec. 21, T. 11 N., R. 4 E.

As all the Sacramento Valley is north of the Mount Diablo base line, the foregoing abbreviation of township and range is sufficient. Parts of the valley are in old Mexican land grants and have never been public land; for these the rectangular system of subdivision has been projected for reference purposes only.

GEOLOGY

GEOMORPHOLOGY

GENERAL FEATURES

The region discussed in this report covers a large part of north-central California and includes the northern part of the Central Valley and bordering parts of three other geomorphic provinces: the Sierra Nevada on the east, the Cascade Range on the northeast, and the northern Coast Ranges on the west (pl. 1; fig. 2).

The northern part of the Central Valley, or Great Valley, is named the Sacramento Valley after the river flowing through it. Although the Great Valley province, as usually defined, extends as far north as Redding (see Jenkins, 1943a), the Sacramento Valley proper, as it has been defined by Bryan (1923), extends from Red Bluff, about 30 miles south of Redding, to the mouth of the Sacramento River at Suisun Bay, a distance of 150 miles by airline and about 240 miles by river. The valley area between Red Bluff and Redding is separated from the main Sacramento Valley by an uplifted area underlain by volcanic rocks through which the Sacramento River flows in a series of entrenched loops. The width of the Sacramento Valley ranges from 30 to 45 miles in the central and southern parts but narrows to 5 miles at the northern end. The area of the valley is approximately 5,000 square miles, or 3 million acres; the total area of the Sacramento River drainage basin is 26,548 square miles (California State Water Resources Bd., 1951, p. 309).

The Sacramento River, largest in California, rises west of Mount Shasta in Northern California and flows southward to the junction with the Pit River, which flows in from the east, at Shasta Reservoir, 42 miles by airline north of Red Bluff. The river enters the Sacramento Valley at the lower end of Iron Canyon, about 5 miles northeast of Red Bluff, then flows southward to join the San Joaquin River in the delta east of Suisun Bay.

The Feather River, the other principal stream in the Sacramento Valley, enters the valley from the east at Oroville, about 70 miles south-southeast of Red Bluff, and then flows southward 50 miles by airline to its junction with the Sacramento River. The Feather River intercepts the drainage from the Sierra Nevada to the east throughout this 50-mile reach. Honcut Creek, the Yuba River, and the Bear River are the principal tributaries of the Feather River. The American River, which joins the Sacramento River at Sacramento, about 15 miles by airline south-southeast of the mouth of the Feather River, is the southernmost tributary from the east.

The western tributaries of the Sacramento River, head in the northern Coast Ranges and are not large in comparison with the eastern streams. Stony, Cache, and Putah Creeks, are the only sizable streams south of Red Bluff.

The Sacramento Valley is underlain by sedimentary material brought in from the adjacent uplands by the Sacramento River and its tributaries. The valley floor slopes southward from an altitude of nearly 300 feet at the north end to sea level at Suisun Bay. The Sutter Buttes, a circular mass of erosional remnants of an old volcano about 10 miles in diameter, rise to a maximum altitude of 2,132 feet near the center of the valley.

The valley floor, although seemingly flat on superficial examination, is not a featureless plain but is characterized by various types of topography which for the purpose of this report have been grouped into 16 geomorphic units. These various topographic features are not everywhere readily apparent to the eye and are best studied with the aid of a topographic map having a 5- or 10-foot contour interval. The geomorphic features of the valley and bordering mountains are discussed in some detail in the following pages. Plate 1 is a geomorphic map of the valley and shows the location and extent of the geomorphic subdivisions discussed in the text. In addition, four cross sections normal to the valley axis illustrate some of the geomorphic features. Place names referred to in the text generally are found on the geologic map of the Sacramento Valley (pl. 2).

MOUNTAINOUS REGION EAST OF THE SACRAMENTO VALLEY

SIERRA NEVADA

The mountainous region east and northeast of the Sacramento Valley includes parts of two geomorphic provinces—the Cascade Range and the Sierra Nevada (geomorphic units 14 and 15, respectively, on pl. 1). The boundary between these two provinces is at the southeast edge of the fragmental volcanic rocks of Pliocene age known as the Tuscan formation. The Sierra Nevada extends southward from this boundary, which approximates the northern limit of the Feather River drainage, to Tehachapi Pass, a distance of about 390 miles by airline. The width of the range is 40 to 75 miles, and the trend of the long axis is approximately north-northwest, or parallel with the Central Valley.

The Sierra Nevada has been described as a single block of the earth's crust which has been uplifted along fractures along its eastern margin and tilted westward (Lindgren, 1911; Matthes, 1930; Piper and others, 1939). Hudson (1951) questions this view, however, stating that present stream grades along the Tertiary channel of the Yuba River, displacement of some of the volcanic rocks of Tertiary age, and other evidence indicate warping and block faulting within the Sierra Nevada block.

The interstream divides of the northern Sierra Nevada are generally of accordant height, and they descend westward at slopes of 1°20' to 2°00', or from 120 to 180 feet per mile. However, the buried surface of the hard, crystalline rocks of the Sierra Nevada block has a somewhat steeper slope farther west beneath the sediments of the Sacramento Valley. (See pl. 3.) The interstream divides are capped by fragmental volcanic rocks and are probably the dissected remnants of a once nearly continuous volcanic plain formed during the late part of the Tertiary period. The summit altitudes in the northern Sierra Nevada decline northward from about 10,000 feet near Lake Tahoe, about 80 miles east of Marysville, to between 7,000 and 8,500 feet near Lake Almanor, about 60 miles east of Red Bluff.

The inclination of the western surface of the northern Sierra Nevada is the result of intermittent tilting and upwarping that have taken place since before the formation of the volcanic surface. Nearly half the tilt has resulted from faulting along the eastern margin of the range during the Pleistocene epoch (Matthes, 1930, p. 29).

Several peaks and ridges rise above the old volcanic surface and were probably never covered by the volcanic rocks. Such ridges border the valley between the Feather and Yuba Rivers near the valley margin east of Sacramento.

The streams in the northern Sierra Nevada are at most places consequent on the volcanic surface of late Tertiary age, although locally they are controlled by bedrock structure. The prevolcanic stream deposits were buried by the volcanic rocks and now in part are preserved beneath the ridge caps and on the upland surfaces. The gentle topography that developed before the period of volcanism has been locally exhumed in the areas between the present canyons where the volcanic cover has been stripped off only recently in geologic time. This gentle topography is often referred to as an Eocene erosion surface, because it was probably developed by the end of that epoch.

The history of the Sierra Nevada block is closely related to the geomorphic history of the eastern part of the Sacramento Valley. The relief and angle of tilt of the western slope of the Sierra block in part have controlled the grain size of the sediments deposited in the valley. Marine invasions of the Sacramento Valley region may have been closely related to Sierran orogenic episodes.

CASCADE RANGE

The Cascade Range (geomorphic unit 14 on pl. 1) extends from near the United States-Canadian border to the northern end of the Sierra Nevada in California. However, only that part of the range adjacent to the Sacramento Valley is discussed in this report.

The southwestern part of the Cascade Range province, which borders the northeastern part of the Sacramento Valley from 13 miles southeast of Chico to near Red Bluff, is underlain by the gently southwestward dipping fragmental volcanic rocks of the Tuscan formation. The volcanic rocks of the Tuscan formation form a blanket about 1,000 feet thick over older sedimentary deposits and crystalline bedrock that may be a northern continuation of the Sierra Nevada block. (See pl. 3.)

The surface of the Tuscan formation now is much eroded. Southwestward-flowing consequent streams have cut deep, narrow canyons through the layered volcanic rocks and in places have exposed the older rocks beneath. The sides of the canyons are characterized by alternating cliffs and slopes caused by the unequal resistance to erosion and mass wasting of the different strata. As seen from the air, this alternation produces an effect similar to unequally spaced contours on a map.

The streams that cross the southern part of the exposed Tuscan formation do not trend in the direction of steepest regional slope, which is about S. 60° W., but flow about S. 10° W. On entering the valley, however, the courses of such streams as Pine, Rock, Big Chico, and Butte Creeks shift westward to a direction more nearly in accord with the regional slope. The reason for the anomalous direction of the stream courses is not known, but it is possibly due to joint or fault trends in the volcanic rocks.

The dip slope of the surface of the Tuscan formation averages about 2½°, or 200 feet per mile, to the east of the valley but becomes steeper adjacent to the Sacramento Valley, where the beds have been folded into a monocline. The monocline is most pronounced east of Red Bluff, where the flexure dips 10° to 20° southwestward toward the valley. In this area the mountain front is abrupt and straight and resembles a fault scarp. West of the flexure, beneath the valley sediments, the dip flattens. The monocline becomes less distinct to the south, in the vicinity of Chico. South of Chico long ridges of volcanic rocks extend westward into the valley as tongues, and the dip of the Tuscan formation does not increase materially adjacent to the valley.

The northern end of the Sacramento Volley is delimited by a group of folds along which the Tuscan formation has been elevated, isolating Cottonwood Valley south of Redding from the Sacramento Valley. The Sacramento River flows through the uplifted area in a series of large loops and has cut canyons in the volcanic rocks.

PLAINS AND FOOTHILL REGION ON THE EAST SIDE OF THE SACRAMENTO VALLEY

DISSECTED ALLUVIAL UPLANDS WEST OF THE SIERRA NEVADA

The dissected alluvial uplands west of the Sierra Nevada (geomorphic unit 11 on pl. 1) extend along the east side of the Sacramento Valley from Dry Creek, north of Oroville, to the southern edge of the mapped area, a distance of about 115 miles, and beyond. The width of the belt averages about 5 miles but is as much as 16 miles in the southeastern part of the valley.

The dissected alluvial uplands consist of low hills and gently rolling country merging with the foothills of the Sierra Nevada on the east and with the low plains of the eastern Sacramento Valley on the west. The land-surface altitudes range from 50 to 135 feet on the west to as much as 400 feet on the eastern margin.

The geologic units underlying the uplands are the Laguna formation and related continental sediments (most of the area), volcanic rocks from the Sierra Nevada (east of Marysville and south of the Consumnes River), and undifferentiated sedimentary rocks (Eocene). In general, the dissected alluvial uplands approximate or coincide with Bryan's red lands (Bryan, 1923, pl. 3).

From the surface form and areal distribution of the alluvial uplands, it is apparent that the underlying materials have been uplifted and are being eroded. Rounded knolls and ridges separated by minor intermittent streams are typical. The local relief at most places is 25 to 50 feet, but the Recent flood plains of the American, Yuba, and Feather Rivers lie as much as 200 feet below the upland surface at the eastern margin of the valley.

Between Dry Creek (Butte County) and the Feather River near Oroville, the alluvial uplands are sharply bounded on the east by Table Mountain, a conspicuous group of flat-topped hills capped by a basalt flow. West of Table Mountain, the Campbell Hills (see pl. 2) and two smaller hills 2 miles to the north are capped by the same basalt flow and rise 100 to 350 feet above the dissected upland surface.

From Oroville south to the Yuba River, the alluvial uplands lie in two parallel belts: one about 1 to 2 miles wide adjacent to the Sierra foothills and the other a series of disconnected hills about 1 to 2 miles farther west, separated from the first by a strip of low plains.

Near Oroville the Feather River has trenched the dissected alluvial uplands, so that the flood plain is 30 to 200 feet below the general upland level. Several distinct terraces can be distinguished above the Feather River flood plain; part of the town of Oroville is built on one of them.

Farther south, between Oroville and the Yuba River, the alluvial uplands are bounded rather sharply on the east by northward-trending ridges of altered diabase of the Sierra Nevada basement complex. Relatively thick gravel deposits lie east of the diabase ridges, but the topography formed on these deposits is more typical of the Sierra Nevada foothills than of the alluvial uplands.

Just north of the Yuba River, the Trainer Hills 8 miles northeast of Marysville, whose summits are as much as 100 feet above the surrounding low plains, are the most rugged and conspicuous outliers of the alluvial uplands on the east side of the valley.

Immediately south of the Yuba River, the alluvial uplands are in large part underlain by the volcanic rocks from the Sierra Nevada. There the boundary with the Sierra foothills is vague, except for that with a prominent hill of altered diabase immediately south of the Yuba River. Scattered small hills, rising as much as 45 feet above the low plains lie west of the main upland belt.

A triangular area of alluvial uplands extends as far west as Wheatland between the flood plains of the Bear River on the south and Dry Creek on the north. The bluffs at the edges of this area are abrupt and as much as 50 feet high. The summit altitudes decline from 230 feet at the eastern margin to about 90 feet at Wheatland—a west-southwestward slope of about 30 feet per mile. In contrast, the adjacent Bear River flood plain slopes 10 feet per mile in the same distance.

From Bear River to Coon Creek, 4 miles north of Lincoln, the alluvial uplands are moderately rugged, and a few hills rise 75 to 100 feet above the adjacent low plains and the Bear River flood plain. The topographic break with the low plains to the west is generally abrupt. By contrast, in the Lincoln area the uplands are relatively undissected and merge gradually with the low plains.

From Auburn Ravine, just south of Lincoln, to the American River, the alluvial uplands are bounded on the east by the westward-sloping volcanic ridges of the Sierra Nevada foothills and on the west by the low plains. The boundary with the low plains generally is vague, but the change in topography at the west edge of the volcanic area is abrupt. The typical topography in this region is rolling, although the soils are not gravelly as they generally are elsewhere.

Southwest of Folsom, the American River has eroded an area of the alluvial uplands ranging in width from less than a mile at Folsom to nearly 4 miles east of Sacramento. The river has been cutting laterally northward in late Quaternary time, and the bluff forming the north bank of the river is precipitous. Near Folsom the bluff is more than 125 feet high, but the height declines southwestward, and the bluff is less than 25 feet high at the west edge of the alluvial upland.

The upland surface south of the American River consists of three terraces, evidently formed by the American River and now somewhat dissected. The highest one corresponds to the Arroyo Seco pediment to the south (Piper and others, 1939). The terraces differ rather uniformly in altitude by about 25 to 30 feet and are underlain by coarse gravelly deposits. East of Elk Grove the west-southwestward slope of the Arroyo Seco pediment is between 10 and 20 feet per mile (Piper, and others, 1939, p. 21). This is less than the average for the pediment and is considerably less than the average for the dissected upland belt as a whole, which is about 20 to 30 feet per mile.

DISSECTED ALLUVIAL UPLANDS WEST OF THE CASCADE RANGE

The dissected alluvial uplands west of the Cascade Range (geomorphic unit *12* on pl. 1) extend from about 5 miles northeast of Red Bluff southeasterly to the vicinity of Chico. The upland belt trends north-northwest and is about 40 miles long and as much as 8 miles wide.

The alluvial uplands show forms characteristic of alluvial fans, but they are deeply trenched by the present streams draining the Cascade Range to the east. In the northern area near Red Bluff, the dissected fans merge with the younger alluvial fans and flood plains on the west. In the central part, between the Rio de los Berrendos land grant and Singer Creek, the Sacramento River at some time in the past has cut a steep bluff as much as 50 feet high along the western margin of the fans. South of Singer Creek the dissected fans again merge gradually with the younger alluvial fans and plains on the south and west.

Narrow gorges have been cut near the apexes of the old fans by the larger streams from the east. The lower part of the fans are not deeply trenched but are cut by numerous small stream courses that have developed on the surface of the fans.

The geologic unit underlying the dissected alluvial uplands is the fanglomerate from the Cascade Range, and the geologic and geomorphic boundaries coincide.

The average slope of the fan surfaces is about 50 feet per mile, and the rough and stony character of the land precludes its extensive use for agriculture, except for grazing.

LOW ALLUVIAL PLAINS AND FANS WEST OF THE SIERRA NEVADA

The low alluvial plains and fans west of the Sierra Nevada (geomorphic unit 7 on pl. 1) lie on the east side of the Sacramento Valley and extend about 125 miles from near Big Chico Creek to the southern boundary of the mapped area. The dissected alluvial uplands west of the Sierra Nevada lie to the east, and the natural levees of the Sacramento River, the flood basins, and the delta of the Sacramento and San Joaquin lie to the west. The width of the belt ranges from about 2 miles near Chico at the north end to more than 16 miles near Marysville.

Topographically, the low alluvial plains are nearly flat to slightly dissected where they merge with the dissected alluvial uplands on the east. The altitudes range from sea level on the southwestern margin adjacent to the delta to as much as 200 feet at the northeastern margin. The average westward slope of the land surface is 5 to 10 feet per mile, but it is greater on the east and less near the western margin.

In the Mokelumne area Piper and others (1939) used the term "Victor plain" for the low alluvial plains. The Victor plain was described as coalesced alluvial fans built up by the Mokelumne River and smaller streams from the Sierra Nevada. The plain is 12 to 16 miles wide and rises eastward at a rate of 5 to 8 feet per mile. The underlying geologic unit is the Victor formation. North of the Mokelumne area the low alluvial plains and fans are underlain principally by deposits equivalent to the Victor formation.

Unlike the low plains on the west side of the valley, little or no deposition is taking place on most of the low alluvial plains west of the Sierra Nevada. A condition approaching equilibrium has been reached, and many of the soils underlying this belt have mature profiles containing hardpan.

In general, the surface drainage throughout the low alluvial plains is west or southwest, normal to the trend of the Sierra Nevada. A notable exception, however, is the Feather River, which traverses the low plains from north to south, oblique to the general slope. The Feather River intercepts the drainage from the Sierra Nevada for 50 miles south of Oroville. West of the Feather River, a narrow strip of the low alluvial plains, generally less than 1 mile and at no place more than 2 miles wide, drains eastward and is tributary to the river.

North and east of Sutter Buttes, the surface of the low alluvial plains is nearly flat and is like a segment of a saucer with the rim side on the east and north. South of Chico the slope of the western part of the unit is slightly west of south; farther to the southeast the direction of slope changes gradually to west near Gridley. The average slope of the land surface is 3 to 4 feet per mile throughout this area—somewhat less than the average for the low alluvial plains as a whole.

North of the Yuba River and east of the Feather River, the low alluvial plains are dissected slightly and extend eastward beyond outliers of the dissected alluvial uplands, such as the Trainer Hills 8 miles northeast of Marysville. Just north of the Yuba River the land surface slopes about 6 feet per mile southwestward.

South of the Sutter Buttes and west of the Feather River, the low alluvial plains are nearly flat and slope southwestward toward the Sutter Basin at 3 feet per mile or less. Some of the natural drainage from the Gridley area passes east of the Buttes and into the Sutter Basin.

The westward slope and the degree of dissection of the low alluvial plains and fans increase southward from the Yuba River. The boundary with the dissected alluvial uplands to the east becomes increasingly vague in that direction, and immediately north of the American River the transition from the dissected uplands to the only slightly less dissected low alluvial plains and fans is gradual. The average westerly slope of the plains just south of the Bear River is about 6 feet per mile; northeast of Sacramento it is nearly 11 feet per mile.

South of the American River the low alluvial plains are considerably less dissected than to the north. The low plains south of the river extend eastward to Folsom and actually are a terrace or group of low terraces above the present flood plain of the American. This surface is topographically continuous with the Victor plain described in the Mokelumne area to the south (Piper and others, 1939).

LOW ALLUVIAL PLAINS AND FANS WEST OF THE CASCADE RANGE

The low alluvial plains and fans west of the Cascade Range (geomorphic unit *8* on pl. 1) lie between the present flood plain of the Sacramento River and the dissected alluvial fans west of the Cascade Range. Their extent from Red Bluff to the southern edge of the socalled Chico alluvial fan is about 45 miles; the width is as much as 10 miles in the southern part near Chico but is only 1 to 3 miles in the northern part.

The broader southern area includes the alluvial fans of Big Chico, Little Chico, and Butte Creeks and extends northward to Singer

Creek. The alluvial fan built by Big Chico, Little Chico, and Butte Creeks, and often referred to as the Chico alluvial fans, is rather unusual in that it is perhaps the only large fan being built up at the present on the east side of the Sacramento Valley. The slope of the land surface of the Chico fan averages about 13 feet per mile compared to 3 to 4 feet per mile or less for the low alluvial plains immediately to the south. Typically, the slopes of alluvial fans are steeper near the apex. At low flow, Big Chico Creek and the other creeks occupy shallow gravel-floored channels in the fan, but during floods the creeks overflow their banks in the lower reaches and have changed their courses in Recent geologic time.

From Big Chico Creek to Singer Creek, the streams are relatively small and have not built up well-defined fans. This area consists of a southwestward-sloping low alluvial plain bordered on the northeast by the old dissected alluvial fans west of the Cascade Range and on the southwest by the flood plain of the Sacramento River.

From Singer Creek northward, the low alluvial plains and fans include three principal types of topography: the broad gravel-floored plains that extend into the dissected uplands to the northeast, small alluvial fans deposited at the western ends of these gravelly plains, and in the area chiefly north of Mill Creek, old terraces cut by the Sacramento River. In places the boundary between the low-plains unit and the flood plain of the Sacramento River is distinct and marked by a bluff several feet high, but throughout most of the reach from Red Bluff to Singer Creek, the transition is rather gradual.

FLOOD PLAINS

The flood plains on the east side of the Sacramento Valley (geomorphic unit *5* on pl. 1) occur as discontinuous strips along the streams emerging from the Sierra Nevada between Honcut Creek on the north and the Mokelumne River on the south. Topographically they lie below the adjacent low alluvial plains and fans and dissected alluvial uplands, and they have been flooded periodically in historic time. The underlying stratigraphic unit is river deposits (pl. 2).

The flood plain of Honcut Creek extends roughly west from the Sierra Nevada foothills to the Feather River flood plain, a distance of 7 miles. The flood plains of the two main forks of Honcut Creek unite about 2 miles west of the main flank of the Sierra, but the channels themselves join 4 miles farther west after following the approximate northern and southern edges of the flood plain. The width of the main flood plain decreases westward from about 2 miles to about a quarter of a mile at the junction with the Feather River flood plain.

The Yuba River flood plain is a broad southwestward-trending strip having a somewhat obscure southern edge. The food plain extends about 3 miles east of the edge of the exposures of the bedrock of the Sierra Nevada. The original channel of the Yuba River was obscured completely by the effects of hydraulic mining in the 1870's and 1880's. In 1850 the Yuba was a clear stream flowing on a gravel bottom about 20 feet below the low plains at Marysville (Lindgren, 1911). At present the Yuba occupies a raised channelway 1 to 3 miles wide which locally stands 10 feet or more above the adjacent plains. Several tributaries of the Yuba River, especially those entering from the north, were dammed by the channel fill and were diverted toward the Marysville area where the excess water resulted in a troublesome drainage problem. Hydraulic mining was supposedly terminated by court order in 1884, but some mining continued later (Gilbert, 1917). Several thousand acres of the Yuba River flood plain upstream from Marysville has been excavated by gold dredges, producing a terrain characterized by parallel ridges of coarse gravel.

The Bear River has a history similar to that of the Yuba. As a result of hydraulic mining, its flood plain no longer presents its natural appearance. The Bear River, like the Yuba, occupies a raised channelway enclosed between artificial levees. A comparison of its present flood plain with that of Dry Creek, a tributary entering from the north, suggests that an average of about 15 feet of fill was deposited by the Bear River.

The flood plain of Dry Creek and the Bear River join just west of Wheatland, where their combined width is nearly 4 miles. At the junction with the Feather River flood plain 6 miles farther west, the Bear River flood plain has narrowed to about half a mile. The average altitude of the Bear River flood plain decreases from 130 feet at the edge of the Sierra Nevada to 45 feet at the junction with the Feather River flood plain—an average gradient of 7 feet per mile. The average gradient of the Yuba River flood plain is also about 7 feet per mile west of the edge of the Sierra Nevada.

Several smaller streams trend parallel to the Yuba and Bear Rivers and normal to the Sierra block. These minor streams drain the western border of the Sierra Nevada and discharge into the Feather River or its tributaries. The flood plains of these streams generally are narrow and discontinuous but are fertile agricultural land where wide enough to cultivate.

Between the Bear and American Rivers, a group of westward- or west-southwestward-trending small streams carry the runoff from the Sierra Nevada foothills. Most of these streams have small, narrow flood plains along parts of their courses, but only the flood plains of

Dry and Arcade Creeks, which are the most extensive, are shown on the geomorphic map (pl. 1).

The flood plain of the American River extends generally west-southwestward from Folsom to Sacramento. The part of the flood plain from Folsom to Fair Oaks, about 6 miles by airline downstream from Folsom, is narrow. Downstream from Fair Oaks the flood plain widens to about 1 to 1.5 miles. The flood plain is bounded along its northern edge by a steep bluff about 125 feet high at Folsom, but the height of the bluff decreases to less than 10 feet near Sacramento. The southern edge also is abrupt, but the bluff is lower, and the adjacent surface is a terrace produced by the American River before it constructed the present flood plain.

The present channel of the American River is only 20 feet below its flood plain, and artificial levees have been constructed on both sides of the river for several miles east of Sacramento. In 1950 the river overflowed its banks and levees and flooded the adjacent plain and causing widespread damage. A large part of the city of Sacramento is built on the broad area where the alluvial plains of the American and Sacramento Rivers meet.

South of the American River are the well-defined flood plains of the Cosumnes River, Dry Creek, and the Mokelumne River. These streams unite at the eastern edge of the delta of the Sacramento and San Joaquin Rivers about 12 miles northwest of Lodi. The Cosumnes River flood plain, which averages about 1 mile in width, is nearly straight and trends southwesterly from the junction of Deer Creek, about 12 miles northeast of Elk Grove, to the delta. The Dry Creek flood plain is narrower than that of the Cosumnes River and has an eastward trend. The flood plain of the Mokelumne River is not as wide or straight as that of the Cosumnes but is equally well defined. The river flows in a somewhat sinuous inner channel as much as 30 feet deep, but under natural conditions it would inundate much of the flood plain (Piper and others, 1939, p. 19).

The Cosumnes River, Dry Creek, and Mokelumne River flood plains lie below the Victor plain and rise eastward at a flatter gradient.

CENTRAL SACRAMENTO VALLEY

SACRAMENTO RIVER FLOOD PLAINS AND NATURAL LEVEES

The Sacramento River flood plains and natural levees (unit 3 on pl. 1) extend from Red Bluff on the north to the northern end of the delta of the Sacramento and San Joaquin Rivers at Clarksburg, about 12 miles south of Sacramento. The distance from Red Bluff to the mouth of the river at Collinsville is about 240 miles along the river channel, 165 miles along the general course of the river, and about 150 miles by airline. The distance from Red Bluff to Clarksburg is about 200 miles along the river channel.

The belt of flood plains and levees, or "river lands," ranges in width from less than 1 mile to nearly 10 miles but averages less than 3 miles. The river follows the approximate centerline of the valley for most of its course, but between Colusa and the mouth of the Feather River, it swings westward to within 7 miles of the edge of the Dunnigan Hills.

From Red Bluff to the mouth, the average grade of the river is 1 foot per mile. The average annual runoff of the river and its tributaries for the 40-year period 1903–04 through 1942–43 was 21,750,000 acre-feet (U.S. Bur. Reclamation, 1949b, p. 100).

For convenience, the reach of the river south of Red Bluff, exclusive of the delta, may be divided into four smaller reaches, which are discussed below, as follows: Red Bluff to Hamilton City, Hamilton City to Colusa, Colusa to the mouth of the Feather River at Verona, Verona to Clarksburg.

From Red Bluff to Hamilton City, the distance along the channel is 42.5 miles; the airline distance is 33 miles. The altitude of the river surface at Red Bluff is 240 feet; near Hamilton City, it is 125 feet. The descent, therefore, is about 2.7 feet per mile. This reach is unusual in that the river channel is flanked by a well-defined flood plain which is incised below the adjoining land surface on both sides, but south of Hamilton City it flows between natural levees that are as high or higher than the adjacent lands. The flood plain north of Hamilton City is several feet lower than the adjoining lands and the channel bed lies 10 to 20 feet below the level of the flood plain. The flood plain is 1 to 4 miles wide and is characterized by sinuous abandoned channels and sloughs. The present channel ranges in width from 100 yards to half a mile, and small islands and sand bars are numerous. According to Bryan (1923, p. 34), topography of this type is associated with a relatively steep, narrow flood plain and with the coarse type of material the river transports in this reach.

From Hamilton City to Colusa the general course of the river changes from the south-southeast below Red Bluff to nearly due south. The distance along the channel is 53 miles, the altitude of the river surface at Colusa (taken from the Colusa quadrangle, scale 1:31,680) is 40 feet; hence, the average grade is 1.6 feet per mile. The air line distance from Hamilton City to Colusa is 36 miles. The river course is very sinuous in this reach and is marked by bends and meanders where the direction may change more than 180° in 2 miles or less. Oxbow lakes or abandoned meanders are a characteristic feature, and the river course has changed markedly in historic time. The channel proper averages 600 to 3,000 feet in width throughout this reach. The natural levees, which have formed during time of overflow, are not as high or conspicuous here as south of Colusa. The levees form a strip of land 3 to 5 miles wide lying between the low alluvial plains and fans on both sides of the valley from Hamilton City to a point about 8 miles south, and between the Colusa Basin and the Butte Creek lowland area farther south. East of the river in the northern part of the Butte Creek lowland a group of distributary channels parallel to the main stream carry overflow waters from the Sacramento into the lowland area. Referring to these channels, Bryan (1923, p. 35) stated:

> They appear to be due to overflows from the river in the vicinity of Hamilton and Chico Landing, which starting as broad sheets of water, tend gradually to collect in separate channels and thus to pursue their way into Butte Basin. The balance between erosion and deposition in these channels is so even that no natural levees are formed.

On the west side of the river, distributary channel ridges extend into the Colusa Basin. Because these ridges are distinct from the basin, they are included in the Sacramento River flood plains and natural levees geomorphic unit.

South of Colusa the river again takes a south-southeastward course. The distance along the channel from Colusa to Verona is 63.5 miles, and the average descent is about 0.4 foot per mile; the air line distance is 36 miles. The river follows a sinuous course, but meanders and oxbow lakes are not so common in this reach as north of Colusa. The channel is narrow and averages 150 to 600 feet in width, and the natural levees are well defined.

The natural levees of the Sacramento River are broader than artificial levees and dikes, and slopes away from the river are concave upward and relatively gentle. The riverward slopes of the levees are steep, and the surface of the river may be as high or higher than the land surface of the flood basins beyond the levees. In effect, the river is flowing along a broad upraised trench flanked on either side by poorly drained low-lying flood basins.

About 5 to 10 miles south of Colusa, natural levees widen, especially east of the river. West of the river, Sycamore Slough and several other channel ridges extend southwestward into the Colusa Basin. One of the more conspicuous ridges, Sycamore Slough nearly bisects the basin. Colegrove Point is a particularly well-defined channel ridge that extends northeastward into the Sutter Basin, about 12 miles by air line northwest of Verona. These subsidiary channel ridges have formed from breaks in natural levees where flood waters repeatedly have flowed into the basins.

South of Verona at the mouth of the Feather River, the aspect of the Sacramento River changes completely, and the course of the river consists of broad, gentle bends and relatively long straight reaches. The channel averages 600 to 1,200 feet in width, and bars and islands are uncommon. The natural levees are well defined and are generally narrower than those upstream; the belt of river lands averages about 2 miles in width. The distance along the channel from Verona to Clarksburg is 37.5 miles, and the average descent is less than 0.3 foot per mile. Before the days of hydraulic mining, tidal effects were observed along the Feather River as far as Marysville (Bryan, 1923, p. 36), but since that time, tidal effects have been recorded no farther upstream than a little north of Sacramento.

FEATHER RIVER FLOOD PLAINS AND NATURAL LEVEES

The Feather River, the principal tributary of the Sacramento River, leaves the Sierra Nevada foothills at Oroville. It follows a southwesterly course for about 6 miles to a point where it turns sharply south to its junction with the Sacramento River near Verona. Several west-southwestward-flowing tributaries, including the Yuba River, join the Feather before it reaches the Sacramento River. However, the geomorphic unit identified as Feather River flood plains and natural levees (unit 4 on pl. 1) does not include these tributary streams.

Upstream from Marysville the Feather River flood plain is 1 to 2 miles wide and lies 10 to 15 feet below the adjoining low plains. The river pursues a meandering course on its flood plain, and oxbow lakes and abandoned channels are common features, indicating frequent changes in course—a normal condition for a river of moderate gradient.

South of Marysville the regimen of the Feather River has been so changed by human activities that the flood plain no longer possesses its original form. Historically the Feather River was a deep clear stream flowing in a narrow channel; the river now occupies a broad channelway as much as a mile wide that is choked with sand and gravel contributed by the Yuba and Bear Rivers. This channel aggradation is a direct result of hydraulic mining in the Sierra Nevada. At Marysville as much as 15 feet of fill has been attributed to hydraulic-mining debris (Gilbert, 1917). The river lies on a ridge which slopes toward the adjacent low plains on both sides. Many lakes, some long and narrow and others somewhat circular, exist within the levees.

In the 7-mile reach upstream from its junction with the Sacramento River, the Feather River occupies a channel ridge similar to that of the Sacramento River. The prominent natural levees slope a mile or more toward flood basins on either side. Well-formed channel ridges of flood distributaries extend laterally toward the flood basins, and bends and abandoned channels are noticeably absent, suggesting long-continued channel stability.

The average grade of the Feather River from Honcut Creek to Marysville is 1.4 feet per mile and from Marysville to the Sacramento River is 1.1 feet per mile.

FLOOD BASINS

The flood basins (geomorphic unit 1 on pl. 1) are low, nearly flat, poorly drained lands on both sides of the Sacramento River between the natural levees and the low alluvial plains on the east and west sides of the valley. There are five more or less distinct basins: Butte Creek lowland, Sutter Basin, and American Basin east of the river, and Colusa and Yolo Basins west of the river (pl. 2).

The flood basins are related in origin to the natural levees; the levees form in effect a raised channelway for the Sacramento River, so that when the river overflows its banks the excess water accumulates in the lower lying basins as broad, shallow temporary lakes. The downstream reach of the Feather River also contributes flood waters to the American and Sutter Basins. In recent years the construction of levees along the major streams, and of floodwater bypasses through the Sutter and Yolo Basins has greatly limited the large-scale flooding of the basins.

The Colusa Basin extends from the southeastern edge of the Stony Creek alluvial fan to the old Cache Creek channel ridge at Knights Landing—a distance of about 60 miles. The width ranges from as much as 9 miles south of Colusa to about 3 miles near Knights Landing. The basin is bordered on the northwest, west, and south by the low alluvial plains and fans, and on the east by the natural levees of the Sacramento River. The land surface is nearly flat, sloping from an altitude of 100 feet at the north to about 25 feet near the south end. Numerous small depressions are a characteristic feature of the basin north of Colusa. Farther south, low channel ridges of distributaries of the Sacramento River extend into the basin and nearly divide it in half at Sycamore Slough, about 6 miles south of Colusa. The basin is underlain by the geologic unit termed "basin deposits." (See pl. 2.) However, the basin deposits extend farther west than the gradational boundary of the basin shown on the geomorphic map (pl. 1). Actually, soils and topography characteristic of the basins extend several miles west of the geomorphic boundary in the northern half of the basin, but the slope of the land surface in this western strip is several feet per mile eastward and is continuous with the slope of the low plains to the westward. Therefore, these lands have been included in the low alluvial plains geomorphic unit.

The Butte Creek lowland lies east of the Sacramento River and extends from the Chico alluvial fan on the north to Butte Slough, between the Sacramento River and the Sutter Buttes, on the south. The length is about 30 miles; the width ranges from about 3 miles at each end to 9 miles in the central part. The lowland is bordered on the north by the Chico alluvial fan, on the east by the low alluvial plains and fans west of the Sierra Nevada, on the south by the alluvial fans of Sutter Buttes, and on the west by the natural levees of the Sacramento River. The land surface is not so flat as the other flood basins but slopes from an altitude of 115 feet at the north end to 50 feet at the Butte Slough outlet, or about 2 feet per mile. The poor drainage and heavy soils, however, are typical of the flood basins.

Flood waters of Butte Creek and Little Chico Creek enter the Butte Creek lowland, as do the flood waters from the Sacramento River. Numerous small distributaries from these streams extend through the lowland, forming small channels about 5 to 6 feet deep. (See pl. 4.) Flood waters drain slowly around the west side of the Sutter Buttes into the Sutter Basin through Butte Slough. The Butte Slough swamp land at the southern end is the only part of the Butte Creek lowland underlain by deposits classified as basin deposits on the geologic map (pl. 2). The materials underlying the lowland area west of Butte Creek have been classified as river deposits, and those underlying the area east of Butte Creek as Victor formation and related deposits.

The Sutter Basin extends from the Sutter Buttes on the north to the junction of the Sacramento and Feather Rivers on the south—a distance of about 28 miles. It lies between the natural levees of the Sacramento River and the Feather River.

The Yolo Basin extends from an old channel ridge of Cache Creek on the north to the Montezuma Hills on the south. It is bordered on the west by low alluvial plains and fans and on the east by the natural levees of the Sacramento River. A small, nearly enclosed basin lies north of the main basin, between the old channel ridge of Cache Creek near Knights Landing and the present ridge 4 miles south. The length of the Yolo Basin is about 42 miles; the width ranges from 3 to 8 miles.

Topographically, the Yolo Basin is a flat, low area from which flood waters drain southward very slowly under natural conditions. As in the other basins, the typical soils are heavy clay and clay adobe; these support a natural growth of tules in the swampy areas. The land-surface altitude is about 20 feet at the north end and slopes to nearly sea level at the south end—an average gradient of about 0.5 foot per mile. The area now is traversed from north to south by the Yolo By-Pass. In addition to receiving flood waters from the Sacramento River, the Yolo Basin is sometimes partly flooded by Cache and Putah Creeks from the west.

The American Basin, smallest of the basins, extends from about 6 miles north of the junction of the Feather and Sacramento Rivers to the junction of the American and Sacramento Rivers—a distance of about 20 miles. The width ranges from 2 to 7 miles. The basin is bordered on the east by low alluvial plains and fans west of the Sierra Nevada; and the basin on the west is bordered by natural levees of the Feather and Sacramento Rivers.

The American Basin has greater local relief than the other basins. It is pock marked with small mounds, depressions, and irregularly shaped elevated areas, which are underlain by remnants of the older alluvial material (Victor formation and related deposits) of the low plains to the east that have not been buried completely by Recent basin deposits. To the northeast the transition from basin to low-plains topography is fairly gradual, but south of the boundary of Sutter and Sacramento Counties a rather well-defined low escarpment marks the eastern boundary of the basin. The land surface slopes from an altitude of 25 feet at the north end to 12 feet at the south end—an average gradient of about 0.6 foot per mile. Since achievement of the effective control of the floodwaters of the Feather and Sacramento Rivers, this land is seldom flooded and is now devoted to farming.

SUTTER BUTTES

The Sutter Buttes (geomorphic unit 16 on pl. 1), which are erosional remnants of an old volcano probably formed during Pliocene time, lie between the Feather and Sacramento Rivers near the center of the valley. The outline of the buttes is an almost perfect circle, 10 miles in diameter.

Geomorphically, the buttes may be divided conveniently into three concentric zones of strikingly different topography: the central core, the saddles and low areas surrounding the central core, and an outermost ring of tuff-breccia slopes.

The central core is a roughly circular area 3 to 4 miles in diameter dominated by a cluster of sharp, steep-sided volcanic peaks. These peaks are principally erosional remnants of a laccolith. Three of the most prominent peaks and their altitudes are South Butte—2,117 feet, West Butte—1,681 feet, and North Butte—1,863 feet. A few detached necks rise above the low, saddle area outside of the main central core.

The saddles, low hills, and ridges surrounding the central core form a ring-shaped area between the central core and the tuff-breccia slopes. This topography is best developed on the south and west sides and is nearly missing on the northeast. The belt averages 1 mile in width on the south and west. The area is underlain by sedimentary rocks of Teritary and Late Cretaceous age that were pushed up and fractured when the core was emplaced. Generally, the topography consists of rounded knolls and ridges which owe their form to the lithology and structure of the underlying rocks. Altitudes in the belt range from 200 to 500 feet.

The tuff-breccia slopes form the outermost ring of the buttes. The ring is 2 to 3 miles wide and consists of dissected slopes, some areas of which have been isolated by erosion and are surrounded by alluvium. The inward slopes are relatively steep; the outward slopes are much gentler, averaging 5° or less. The outward slopes are trenched by ravines which have in places cut deeply into the original constructional surface of the tuff-breccia. The altitudes range from about 500 to 800 feet at the tops of the slopes and 50 to 100 feet at the foot of the slopes. If the slopes of the original surface, which is concave upward, were projected inward and upward, the restored altitude of the cone would be about 5,000 feet.

ALLUVIAL FANS OF SUTTER BUTTES

Beyond the outcrops of tuff-breccia, the Sutter Buttes are encircled by a ring of coalescing alluvial fans (geomorphic unit 9 on pl. 1) which average about three-fourths of a mile in width and have been formed by deposition from the numerous small streams draining the hills. The alluvium extends inward along the larger drainages where the streams have cut down through the tuff-breccia; and in places the alluvium completely surrounds hills of tuff-breccia. The largest alluvial fans have been built by the streams having the largest drainage areas, such as the stream draining the area northwest of Sutter City. On the east side of the buttes, the fans are very small; on the west they are relatively large. The alluvium on the north side of the buttes extends as narrow tongues between steep-sided ridges of tuff-breccia.

PLAINS AND FOOTHILL REGION ON THE WEST SIDE OF THE SACRAMENTO VALLEY

LOW ALLUVIAL PLAINS AND FANS

The low alluvial plains and fans on the west side of the valley (geomorphic unit 6, pl. 1) form a belt extending from the vicinity of Corning to the Montezuma Hills—a distance of about 125 miles—and ranging in width from 18 miles near Woodland to as little as 2 miles east of the Dunnigan Hills, 15 miles north of Woodland. The underlying geologic unit is the alluvial-fan deposits of late Pleistocene to Recent age.

In the Corning area on the north, the low plains and fans form an irregular area between the adjacent dissected uplands and low hills. Thomas Creek forms the approximate boundary between the plains and the dissected uplands to the north, and two hilly areas, known locally as the Corning Ridge, border the low plains to the east, except for two narrow gaps where the plains extend eastward to the flood plain of the Sacramento River. From the south edge of Corning Ridge just east of Corning to the boundary of Glenn and Tehama Counties, the low plains are bounded on the west by the gravelly surfaced uplands and on the east by the Sacramento River flood plain. The land surface of the low plains in the Corning area ranges from an altitude of 175 feet to 325 feet.

South of the boundary between Glenn and Tehama Counties lies a broad eastward and southeastward-sloping alluvial fan built by Stony Creek. The apex of the fan is about 5 miles northwest of Orland, and the approximate southern limit is near Willows. The fan is bounded on the east by the flood plain of the Sacramento River, on the southeast by the Colusa Basin, and on the north and west by a group of low hills underlain by uplifted and dissected sediments of the Tehama formation. The east-west width of the fan is about 15 miles; the north-south extent is about 20 miles. The fan surface slopes from an altitude of about 350 feet at the apex to 100 feet at the edge of the Colusa Basin. The average southeasterly slope is about 12.5 feet per mile, but the gradient is steeper near the apex and flatter near the periphery.

The fan surface is not perfectly smooth but is cut by several incised drainage courses lying 1 to 5 feet below the general land surface. Most of these drainage lines are south of the present channel of Stony Creek, which enters the Sacramento River south of Hamilton City. These are abandoned channels of Stony Creek.

South of the Stony Creek fan, the low-plains belt narrows to an average width of less than 10 miles. The streams crossing this area are small and intermittent and have built small, poorly defined coalescing fans. From Willows to Williams the low hills to the west are underlain by the Tehama formation and give way southward to low parallel ridges underlain by northward-trending Cretaceous sedimentary rocks flanked on the valley side by discontinuous exposures of the Tehama formation and related continental sediments. The small streams draining this region include, from north to south, Willow Creek, Logan Creek, Hunters Creek, Funks Creek, Stone Corral Creek, Lurline Creek, Freshwater Creek, and Salt Creek. Land surface ranges in altitude from about 150 to 175 feet at the edge of the foothills of the Coast Ranges to between 50 and 80 feet at the edge of the Colusa Basin. Soils in the eastern part of this belt are heavy clays characteristic of the flood basins and the underlying sendiments are mapped as basin deposits (pl. 2).

From Williams south to Woodland the low-plains belt lies between the northwestward-trending Dunnigan and Rumsey Hills and the Colusa Basin. The width of this belt ranges from about 10 miles at the north and near Williams to 2 miles at Dunnigan, 3 miles south of the boundary of Colusa and Yolo Counties. The northeasterly slope of the land surface, which is a series of small alluvial fans, is relatively steep, being as much as 50 feet per mile. Near the southern end of this area, an old channel ridge of Cache Creek extends northeastward from the southern edge of the Dunnigan Hills west of Woodland to Knights Landing on the Sacramento River. This channel ridge is a prominent feature, rising gradually from 15 to 20 feet above the adjacent plains and separating the Colusa Basin from the Yolo Basin to the south.

South of Cache Creek the Dunnigan Hills give way to a group of low disconnected hills known variously as Plainfield Ridge sometimes called Fairfield Knolls. Southwest of the southern end of the Dunnigan Hills, a low-plains reentrant extends 7 to 8 miles north of Cache Creek. This area, which is bounded on the west by the Rumsey Hills, is known as Hungry Hollow. Hungry Hollow is topographically continuous with the plain to the south, east of Plainfield Ridge. East of Plainfield Ridge, between Cache and Putah Creeks, the low plains slope fairly uniformly eastward about 7 feet per mile to the Yolo Basin. West of Plainfield Ridge, the slope steepens and averages about 16 feet per mile to the foot of the low hills north of Winters.

From Putah Creek to the north edge of the Montezuma Hills, the slope of the low plains changes from east to southeast. This area, which is about 20 miles north-south by 15 miles east-west, is traversed by numerous small channel ridges trending southeastward toward the southern part of Yolo Basin. Most of the channels are incised 2 to 10 feet into their channel ridges, but Putah Creek has cut a channel as much as 40 feet deep in its present channel ridge. A large part of this downcutting has occurred in historic time as a result of manmade changes in the stream course and reclamation of part of Yolo Basin. The plain slopes from Winters southeast to the edge of the Yolo Basin at an average gradient of a little more than 6 feet per mile.

LOW HILLS AND DISSECTED UPLANDS

On the west, low hills and dissected uplands (geomorphic unit 10 on pl. 1) flank the Sacramento Valley from Red Bluff to the Montezuma Hills. North of Willows the uplands belt is as much as 18 miles wide, but from Willows south to the northern end of the Rumsey

Hills west of Williams the Coast Ranges extend almost to the valley floor. From Williams to Woodland the Dunnigan Hills and northern end of the Rumsey Hills trend approximately southeast for about 37 miles. The Dunnigan Hills, which parallel the Rumsey Hills from the boundary between Yolo and Colusa Counties southeast to near Woodland, extend several miles into the valley. South of the Dunnigan Hills a group of isolated low hills (Plainfield Ridge) continues southward to Putah Creek. Farther west, a strip of low hills, averaging about 5 miles wide, extends along the east flank of the Coast Ranges from north of Cache Creek to Vacaville. West of Rio Vista and north of the mouth of the Sacramento River, the Montezuma Hills form an isolated, roughly circular area about 10 miles across.

The degree of relief and surface form of the hills and uplands are in large measure a reflection of the structure in the underlying sediments. In general, the Pliocene and Pleistocene sediments dip more steeply on the west side of the Sacramento Valley than on the east side, and the hills are higher and more severely dissected. Where the sediments have been folded into anticlines, such as at the Dunnigan Hills and Corning Ridge, the topography reflects the structure. Instead of merging rather gradually with the low plains of the valley, as do many of the uplands on the east side, most of the west-side hills rise abruptly from the alluvial fans and plains.

In Tehama County the dissected uplands from a broad belt sloping from altitudes of about 1,000 feet on the west to between 225 and 275 feet near Corning and the Sacramento River flood plain on the east. The underlying Pliocene and Pleistocene sediments dip gently eastward 2° or 3°. The western part of the belt is underlain by predominantly fine-grained sediments of the Tehama formation of Pliocene age, but farther east the coarse gravelly deposits of the Red Bluff formation of Pleistocene age lie at the land surface. The drainage is eastward, and the stream courses divide the area into long, narrow interstream ridges. Thomes Creek is the largest stream, and its flood plain, which averages about 1 mile in width, extends across the entire belt from the outcrops of Cretaceous rocks in the Coast Ranges to the Sacramento River flood plain about 4 miles northeast of Corning.

From the boundary between the Glenn and Tehama Counties to west of Willows, the upland belt narrows, and the easterly slopes steepen. Between Stony and Willow Creeks the drainage pattern is roughly radial, the northern streams near Stony Creek trend northeast and the southern streams trend southeast. From this pattern and from the altitudes of interstream slopes, an old, much dissected alluvial fan, possibly of a Pliocene Stony Creek, may be recognized. Orland Buttes, a northward trending discontinuous ridge underlain by basalt, rise about 500 feet above the general upland level, about 8 miles west of Orland.

From Salt Creek west of Williams to Cache Creek near Woodland, the low hills have a general southeast trend, and the valley border is straight and abrupt. The northern Rumsey Hills in large part are underlain by eastward-dipping sediments of the Tehama formation, but gravel-capped terraces border the valley at several places.

South of the boundary between Colusa and Yolo counties the Dunnigan Hills extend farther east than do the Rumsey Hills to the north; they jut out in to the valley several miles near Woodland. The Dunnigan Hills, like the northern Rumsey Hills, are rather severely dissected, but the summits are rounded and rise to nearly the same height. The summits decline from an average altitude of 400 feet at the north end to about 200 to 250 feet near the south end of the hills. The northeastern margin of the hills is remarkably abrupt and straight. This was thought by Bryan (1923) to indicate a fault, but conclusive evidence for this is lacking. The Pliocene and Pleistocene sediments underlying the Dunnigan Hills have been folded into a gentle anticline with an axis trending about S. 40° E.

South of Cache Creek, the Plainfield Ridge, a series of low knolls rising 10 to 50 feet above the low plains may be a continuation of the Dunnigan Hills anticline. The ridge is actually two groups of knolls separated by a gap of low plains about 3 miles wide. The northern group of knolls has a southerly alinement; the southern group trends more nearly southeastward. Plainfield Ridge is terminated at Putah Creek, and to the south the expanse of low plains is unbroken from the Yolo Basin to the low hills on the flank of the Coast Ranges.

The southern part of the Rumsey Hills is flanked on the east by a strip of gravel-capped terraces that have been classified as dissected uplands. Immediately north of Cache Creek several stream-cut terraces can be recognized. Similar terraces also are prominent along the larger streams on the east side of the valley. Bryan discussed these terraces at some length, offering two principal hypotheses to explain their origin—a diastrophic hypothesis and a climatic hypothesis. He states the two hypotheses as follows (1923, p. 21):

The origin of the terraces is probably to be explained by one of the following two hypotheses: (1) That the terraces are due to stream erosion and lateral planation accompanied by incidental deposition during a series of earth movements which deformed the borders of the valley—this may be called the diastrophic hypothesis; (2) that the terraces are due to fluctuations in the ratio of sediment to volume of water, caused by changes in climate during the period of dissection of the older alluvium that followed the uplift—this may be called the climate hypothesis.

The belt of low hills south of Cache Creek averages about 5 miles in width but narrows to less than a mile where Putah Creek has cut a broad plain across the belt near Winters. The hills end abruptly about a mile north of Vacaville. The altitude ranges from 100 to 225 feet along the eastern foot of the hills as much as 500 feet at the western margin of the belt. Several small streams drain eastward across the hills, and are flanked by narrow flood plains from as far west as the Coast Ranges geomorphic unit. Many of the interstream ridges are broad, gently eastward-sloping terracelike surfaces that appear to be dip slopes on the more resistant beds of the Tehama formation.

The Montezuma Hills are a much dissected uplifted block of soft alluvial deposits of late Teritary or Quarternary age. Along the southwestern, southern, and southeastern margins of the hills are a series of straight bluffs that are unusually steep, when one considers the soft character of the deposits. The Sacramento River flows along the base of the bluffs from Rio Vista to its mouth. Although the hills are severely dissected, the summits are of approximately accordant height, and the restored surface slopes northward from altitudes of 200 to 300 feet in the southwest to from 25 to 50 feet where the hills merge with the low plains on the north.

COAST RANGES

The northern Coast Ranges (geomorphic unit 13 on pl. 1) adjacent to the Sacramento Valley consist of a series of parallel ridges and intervening valleys trending slightly west of north. From Stony Creek to the south, these strike ridges, developed on steeply eastward-dipping sandstone beds of Cretaceous age, average 1,500 to 2,500 feet in altitude. The drainage has a trellis pattern in which the streams follow the strike valleys for considerable distances and then cut eastward across the ridges through narrow gaps.

North of Willows the Coast Ranges are flanked on the east by a belt of low hills underlain by sediments of the Tehama formation, and from Willows to Williams, the northward-trending ridges of Cretaceous rocks are separated from the low alluvial plains and fans on the west side of the Sacramento Valley by a narrow discontinuous strip of dissected slopes underlain by the Tehama formation and related continental sediments. Here the easternmost ridges are low and relatively gentle and rise only 50 to 150 feet above the alluvial plain.

From Williams to Cache Creek the numerous ridges and valleys give way to a more rugged terrain in which a few higher ridges trending a little west of north are flanked on the east by the northwestward-trending Dunnigan Hills and northern part of the Rumsey

Hills. The southern part of the Rumsey Hills are topographically a part of the Coast Ranges, being the expression of a faulted anticline affecting Upper Cretaceous sedimentary rocks, with the Tehama formation on the flanks. Capay Valley is a long, narrow synclinal valley east of the Rumsey Hills. Cache Creek flows south-southeastward down the valley and then turns and flows through a narrow canyon through the southern tip of the Rumsey Hills.

From west of Capay Valley a high, rugged ridge extends southward to near Fairfield, north of Suisun Bay. South of the bend where Cache Creek turns eastward and flows toward Sacramento Valley, this ridge is bordered on the east by low hills. Although the summit altitudes average 2,500 to 3,000 feet, Putah Creek has cut a deep canyon across the ridge from Berryessa Valley, now occupied by Lake Berryessa, on the west side to the Sacramento Valley near Winters. Steeply eastward-dipping sandstone and shale beds of Cretaceous age are well exposed along the canyon. It is not known whether Putah Creek is a superposed or antecedent stream.

South of Putah Creek a ridge called the Vaca Mountains reaches an altitude of 2,819 feet at Mount Vaca and then decreases in height southward. Vaca Valley and Pleasants Valley are strike valleys between the Vaca Mountains and the English Hills to the east. The highest point in the English Hills is Putnam Peak, a basalt-capped hill, 1,224 feet in altitude. Between Vacaville and the Montezuma Hills, the altitude of parallel south-southeastward-trending elongate hills decreases toward the southeast and the hills nearly buried by the alluvium.

GEOLOGIC UNITS

SUMMARY OF STRATIGRAPHY

The rocks in the Sacramento Valley and the adjacent hills and mountains range in kind from crystalline rocks of Paleozoic and Mesozoic age to unconsolidated alluvium of Recent age. These rocks are herein divided into 19 partly overlapping geologic or stratigraphic units. Their areal extent is shown on plate 2 and their subsurface distribution and character, on plates 3 and 4. Their lithologic and water-bearing character are summarized in table 1.

TABLE 1.—*Geologic units of the Sacramento Valley*

System	Series	Geologic unit (pl. 2)	Thickness (feet)	General character	Water-bearing character
		Flood-basin deposits	0–100(?)	Largely silt and clay deposited in flood basins during flood stages of the Sacramento River, Feather River, and other large streams.	Generally of low permeability. High production rates are obtained locally from wells in the flood basins, but most of this water is yielded by sediments underlying the basin deposits of Recent age. Sutter Basin contains water of poor quality at all depths.
	Recent	River deposits	0–100(?)	Sand, gravel, silt, and minor amounts of clay along the channels, flood plains, and natural levees of the Sacramento and Feather Rivers, the major streams along the east side of the valley, Cache Creek between Rumsey Hills and Dunnigan Hills, and Putah Creek west of Winters.	Moderately to highly permeable, but availability of surface-water supplies has limited well development in most areas underlain by river deposits.
Quaternary		Alluvial-fan deposits	0–150+	Heterogeneous fluviatile sediments ranging from clay and silt to coarse sand and gravel. Deposited on alluvial fans along west side of valley and around Sutter Buttes, and on alluvial fans of Chico, Little Chico, and Butte Creeks on east side of valley.	Permeability extremely variable from place to place. Deposits of Putah, Cache, and Stony Creeks include tongues, lenses, and sheets of some of the most permeable sand and gravel in the valley, but well yields are small in many areas where silt and clay greatly predominate.
		Victor formation and related deposits	0–150+	Heterogeneous assemblage of silt, sand, gravel, and clay, deposited during the latest Pleistocene by streams draining the Sierra Nevada and Cascade Range. Deposits are extremely lenticular and vary widely in lithology. Includes the Victor formation in the Mokelumne area (Piper and others, 1939) and deposits of equivalent age to the north.	At most places moderately permeable throughout. Some sand and gravel lenses highly permeable. Overall permeability generally higher than that of the underlying Laguna and other formations, but the saturated thickness at most places is insufficient to support wells producing more than 1,000 g.p.m.
	Pleistocene	Red Bluff formation	0–50±	Poorly sorted pebble and small-cobble gravel having a distinctly reddish silty or sandy matrix. Lies on an erosion surface cut on the Tehama formation and older rocks.	Largely above zone of saturation in the outcrop areas. Locally may contain small bodies of perched water of little economic significance. Subsurface extent and character not well known.
		Fanglomerate from the Cascade Range	0–500+	Sand, gravel, and silt consisting almost entirely of volcanic detritus derived from the Tuscan formation. The beds are well indurated locally.	Moderately permeable in the vicinity of Chico; similar to the Tuscan formation in general water-bearing character.

TABLE 1.—*Geologic units of the Sacramento Valley*—Continued

System	Series	Geologic unit (pl. 2)	Thickness (feet)	General character	Water-bearing character
Tertiary and Quaternary	Pleistocene and Pliocene(?)	Laguna formation and related continental deposits	0–1,000+	Comprises the Laguna formation and, locally, Arroyo Seco gravel and gravel deposits of uncertain age of Piper and others (1939); includes unnamed equivalents of these formations north of the Mokelumne area. Laguna and its equivalents consist mostly of silt, sand, and clay; the unconformably overlying gravels are for the most part unsorted; is of heterogeneous lithology, consisting largely of Sierra Nevada basement complex detritus, but locally containing much volcanic rock detritus.	At most places only moderately permeable and not as good a water producer as the overlying Victor formation or the underlying volcanic rocks from the Sierra Nevada. However, permeable sands in the Laguna locally supply large quantities of water to deep wells. Arroyo Seco gravel and other gravel deposits are generally unimportant as sources of water.
	Pleistocene and Pliocene	Tehama formation and related continental sediments	0–2,500+	Comprises the Tehama formation, and, locally, post-Red Bluff stream-terrace deposits, Red Bluff(?) formation, and the so-called Cortina member of the Tehama formation.	(Refer to the description of the Tehama formation below.)
	Pliocene	Tehama formation	0–2,500+	Silt, sand, gravel, and clay of fluviatile origin and derived from the Coast Ranges west of the valley. Nomlaki tuff member in northern part of valley and a similar pumiceous tuff in southern part of valley occur in basal part of formation. Sediments are locally cemented, and are everywhere somewhat more compacted than overlying alluvial-fan deposits.	Permeability variable but generally less than that of overlying alluvial-van deposits. Highest yields from Tehama obtained in Camino Irrigation District near Corning in northern part of valley. One of most important sources of ground water in the valley and is becoming even more important as deeper wells having higher capacity are required.
	Pliocene	Tuscan formation	0–1,000+	Volcanic breccia and tuff-breccia, volcanic sandstone and conglomerate, coarse- to fine-grained tuff, tuffaceous silt and clay. Predominantly andesitic and basaltic, except for Nomlaki tuff member, a pumiceous dacite tuff near base. As shown on plate 2 locally includes basalt flow (Tertiary basalt) at base.	Moderately permeable except for beds of tuff and breccia of mud-flow origin which act as confining layers beneath the valley. Locally, near Chico volcanic sands yield copious amounts of water to wells. Perhaps the most important source of ground water in northeastern part of valley.
	Pliocene and Pleistocene(?)	Volcanic rocks of the Sutter Buttes: Andesite tuff-breccia Intrusive rhyolite and andesite, vent tuff	0–800±	Mudflow tuff-breccia of andesitic composition forming outer ring around Buttes. Porphyritic rhyolite and andesite forming sharp peaks of Sutter Buttes, vent tuff in central area of Buttes.	Poorly permeable, but supplies small amounts of water to wells near Buttes. Essentially not water bearing except in fractures.
	Pliocene(?) to Oligocene(?)	Sedimentary rocks of volcanic origin on west side of Sacramento Valley	0–400+	Siltstone, sandstone, shale, and conglomerate made up largely of andesitic detritus. Deposited in fluviatile, lacustrine, and shallow-water marine environments. Correlation uncertain.	Poorly permeable at most places. Contain fresh water near outcrop, but water contained beneath the valley is somewhat brackish.

Tertiary		Basalt	(?)	Flows, dikes, and sills of remarkably uniform microcrystalline to hemicrystalline dark gray to black augite basalt locally containing olivine.	Generally not water bearing, but may contain small quantities of water locally in jointed and brecciated zones.
	Pliocene to Eocene (?)	Volcanic rocks from the Sierra Nevada	0–2,000±	Includes Sutter, Mehrten, and Valley Springs formations; tuff at Oroville, andesite at Reeds Creek, and various other unnamed fragmental volcanic rocks derived from the Sierra Nevada. Consists mainly of poorly to well-consolidated siltstone, sandstone, conglomerate, and shale composed of andesitic and rhholitic detritus, but includes volcanic breccia, tuff-breccia, and tuff of mudflow origin, particularly along the eastern margin of the valley.	Permeability extremely variable. Well-sorted poorly consolidated sandstone and conglomerate strata locally yieldwater copiously to wells, but interbedded fine-grained and cemented strata are essentially impermeable and act as confining layers. Lower part of unit in south-central part of valley contains water of poor quality.
	Oligocene (?), Eocene and Paleocene	Undifferentiated sedimentary rocks	0–7,000±	Marine clastic sedimentary rocks in central and western parts of valley; nonmarine and deltaic sediments in eastern part of valley and in foothills of Sierra Nevada. Comprises Wheatland formation of Clark and Anderson (1938) (Oligocene?), Kreyenhagen, Domengine, Ione, and Meganos formations (Eocene). Martinez formation (Paleocene) occurs only in subsurface.	Ione formation contains fresh water near eastern edge of valley; is poorly to moderately permeable. The other formations, which are marine, are generally of very low permeability and contain connate or dilute connate water except at a few places near the western margin of the valley where the connate waters have been flushed out.
Cretaceous	Upper Cretaceous	Chico formation	0–15,000±	Marine clastic sedimentary rocks consisting mostly of siltstone, sandstone, and shale. In Coast Ranges along western margin of valley Kirby's usage of Chico series included Venado, Yolo, Sites, Funks, Guinda, and Forbes formations (Kirby, 1943b).	Essentially impermeable; the few relatively permeable beds contain connate marine water at depths of several thousand feet beneath most of valley.
	Lower Cretaceous	Shasta series	0–5,000±	Marine clastic sedimentary rocks consisting of siltstone, shale, and sandstone. Divided into Paskenta and Horsetown groups by F. M. Anderson (1943).	Similar to Chico formation.
	Pre-Tertiary	Basement complex of the Sierra Nevada block		Metamorphosed igneous and sedimentary rocks of late Paleozoic and early Mesozoic age, and intrusive igneous rocks of Late Jurassic or Cretaceous age.	Not water bearing where fresh and unjointed, but small supplies of water of good quality are obtained from weathered zones and highly jointed rock masses.

The 19 units may be assigned to two broad categories: rocks that yield little or no water and rocks that yield water more or less freely. The rocks of the first group comprise marine sedimentary rocks of Late Jurassic, Cretaceous, and early Tertiary age, and a basement complex of pre-Upper Cretaceous crystalline (igneous and metamorphic) rocks which underlie the water-bearing rocks beneath the valley and crop out in the hills and mountains surrounding the valley. Although the rocks in this group are not, strictly speaking, non-water bearing, most of them yield only small quantities of water to wells, and the water is largely of marine connate or dilute-connate origin and is too high in dissolved salts to be suitable for agricultural, domestic, or industrial use. The rocks of the second group consist predominantly of nonmarine valley-filling sediments of late Tertiary and Quaternary age and constitute the principal ground-water reservoir in the Sacramento Valley. The boundary between the two groups is not everywhere sharply defined, particularly beneath the southern part of the valley where the quality of water appears to deteriorate gradually with depth. Also, locally along the valley margins some of the connate waters in the marine sedimentary rocks have been flushed out and replaced with fresh water.

The 19 geologic units and the groups to which they have been assigned are listed below:

Rocks that yield water more or less freely [1]

River deposits
Basin deposits
Alluvial-fan deposits
Victor formation and related deposits
Red Bluff formation and related terrace deposits
Fanglomerate from the Cascade Range
Laguna formation and related continental sediments
Tehama and Red Bluff formations and related continental sediments
Tehama formation
Tuscan formation [3]
Volcanic rocks from the Sierra Nevada [3]

Rocks that yield little or no water [2]

Volcanic rocks of Sutter Buttes:
- Tuff-breccia [4]
- Intrusive rhyolite and andesite, vent tuff
- Volcanic sedimentary rocks on west side of Sacramento Valley [4]

Basalt
Sedimentary rocks of Paleocene to Oligocene(?) age, undifferentiated
Chico formation
Shasta series
Basement complex of the Sierra Nevada block

[1] Rocks that for the most part yield water in quantities sufficient for irrigation or other large-capacity wells.

[2] Rocks that yield water in quantities insufficient for irrigation or other large uses; locally yield a few gpm to domestic and stock wells.

[3] In part essentially non-water-bearing rocks.

[4] In part water bearing.

Inasmuch as this was a reconnaissance investigation, it was not feasible to map most of the geologic formations defined by earlier workers throughout the entire valley and foothill regions. Accordingly, many of the geologic units are not designated by formation names, and others consist of two or more formations which have been grouped together for simplicity. However, the formations included in these geologic units are described briefly and correlated tentatively wherever possible.

Much of the grouping of formations has been in the Eocene and older rocks which are largely non-water bearing. These rocks have been studied and mapped in some detail by oil companies interested in the gas contained. However, their formational subdivision is of no importance with regard to ground-water occurrence and, hence, to the grouping in this report. Some of the exposures of these rocks are too small to be shown on the geologic map (pl. 2).

Although a detailed subdivision of the post-Eocene water-bearing rocks in the Sacramento Valley region would be desirable as an aid to understanding ground-water occurrence and movement, these rocks are more difficult to classify and subdivide than the older rocks, and much generalization and grouping were necessary. There are two principal reason for this: The post-Eocene rocks and deposits are mostly nonmarine and therefore not only change greatly in lithology in short distances but contain few diagnostic fossils; and they have not been sampled and examined in detail by oil companies, most of whom are interested primarily in the underlying Eocene and Cretaceous gas-bearing sedimentary rocks.

Certain units, such as the Tuscan formation and the basalt of Tertiary age, have a lithology sufficiently distinctive to be delineated readily, but most of the post-Eocene rocks intergrade in a complex way. Some of the units of this report have been distinguished at the surface by soils and differences in topographic expression. However, such criteria are lacking beneath the surface, and most subsurface boundaries cannot be established with certainty.

Many of the geologic boundaries shown on the geologic map (pl. 2) are approximate or tentative and some of the units undoubtedly will be changed or subdivided when detailed mapping of smaller areas is done later.

ROCKS THAT YIELD LITTLE OR NO WATER

BASEMENT COMPLEX OF THE SIERRA NEVADA BLOCK (PRE-TERTIARY)

Crystalline rocks older than Tertiary in age are exposed throughout the Sierra Nevada, and they extend westward beneath the Sacramento Valley. (See pl. 3.) These rocks consist of metamorphosed igneous and sedimentary rocks of late Paleozoic and early Mesozoic age and igneous rocks that were intruded during the Late Jurassic or Early Cretaceous Nevadan orogeny and during a later intrusive episode in Late Cretaceous time (p. 118).

The metamorphic rocks exposed near the western margin of the Sierra are predominantly amphibolite, hornblende schist, and altered diabase, which probably were originally basic volcanic rocks— principally basalt and andesite. The strike of the foliation of the schistose rocks is approximately parallel to the main axis of the range—about north-northwest; the dips are vertical or nearly so. Hard zones of massive amphibolite and altered diabase, sometimes called "greenstone," occur between the schistose zones and form ridges trending approximately north-northwest.

The intrusive igneous (plutonic) rocks range in composition from granite to periodotite (largely serpentinized), but granodiorite and quartz diorite are the most extensive types. Most of the granodiorite bordering the Sacramento Valley is found in the area between the American and Bear Rivers. The granodiorite weathers more readily than most of the amphibolite and diabase; hence the topography of the granodiorite exposures is mostly subdued, and the physiographic boundary between the valley and mountain provinces is vague where granodiorite borders the valley. Much of the Laguna formation and the younger continental sediments on the east side of the valley consist of detritus derived from weathered granodiorite to the east.

Gabbro and diorite, probably of the Sierra Nevada block, were cored at the bottom of two gas-test wells in the Sutter Buttes; this is as far west as the Sierra basement rocks have been found beneath the Sacramento Valley (May and Hewitt, 1948). Several other deep wells on the east side of the Sacramento Valley also have been drilled into the basement complex.

Although small wells have been drilled or dug in the basement complex rocks in the Sierra foothills, the supply of water is negligible compared to that in the unconsolidated sedimentary rocks of the Sacramento Valley. Fresh and unjointed basement complex rocks are not water bearing, but small supplies of water of good quality may be obtained from weathered zones mantling the fresh rock and from highly jointed rock masses, such as some of the hornblende schist.

SHASTA SERIES (LOWER CRETACEOUS)

Lower Cretaceous marine sedimentary rocks several thousand feet thick are exposed in the Coast Ranges west of the Sacramento Valley and probably extended eastward several miles beneath the western part of the valley at great depth (pl. 3). Farther east, the Lower Cretaceous rocks are overlapped by Upper Cretaceous rocks. Gas-test wells several miles south of Sacramento enter pre-Tertiary crystalline rocks of the Sierra Nevada block below Upper Cretaceous marine sedimentary rocks. The Lower Cretaceous rocks belong to the Shasta series, which is divisible into two formations: the Paskento formation below and the Horsetown formation above. These two units have been treated as groups by Anderson (1943, p. 183). A somewhat older usage divided the Shasta series into the Horsetown and Knoxville formations (Wilmarth, 1938, p. 1969–1970), but the Knoxville formation is now considered to be Jurassic and not a part of the Shasta series.

The Shasta series, exposed west of the central part of the Sacramento Valley as shown on the geologic map (pl. 2), includes about 5,000 feet of the Horsetown formation as used by Kirby (1943c, p. 606). The major structure here is a sharp northward-trending anticline, the Sites anticline; and the overlying Chico formation flanks the beds of the Horsetown formation on both sides of the exposure. (See pl. 3.) The Horsetown consists mostly of grayish-green siltstone and shale containing interbedded thin hard sandstone and limestone (Kirby, 1943c, p. 606). Several gas wells in the Rumsey Hills area have been bottomed in rocks of the Horsetown formation, but wells farther east in the Sacramento Valley are not deep enough to reach the Horsetown.

The Lower Cretaceous rocks, far too deep to be tapped by water wells in Sacramento Valley, are mostly impermeable, and the few slightly permeable beds contain connate marine water.

CHICO FORMATION (UPPER CRETACEOUS)

The usage of Chico formation (Wilmarth, 1938, p. 42?) is not followed by all California geologists, and Chico series is used by some geologists for the Upper Cretaceous rocks of the Pacific Coast. Anderson (1943, p. 183) subdivided the Chico series into three groups, from youngest to oldest the Pioneer, Panoche, and Moreno; the groups were subdivided further into formations.

In the Sacramento Valley region the Chico formation is exposed in the Coast Ranges, in the Sutter Buttes, and discontinuously along the east side of the valley from Folsom to north of Red Bluff. (See pl. 2.) Gas wells throughout the valley are drilled into the Upper Cretaceous, indicating that these rocks probably underlie most of the area. (See pl. 3.)

Kirby (1943d, p. 282) described several formations constituting the Chico series in the Coast Ranges. In ascending order they are the Venado formation, which is predominantly sandstone forming bold cliffs and ridges at many places; the Yolo formation, which is mostly siltstone, containing only a few sandstone beds; the Sites formation, a prominent sandstone zone; the Funks formation, which is largely shale, rich in Radiolaria, and siltstone; the Guinda formation, mostly sandstone; and the Forbes formation, which is carbonaceous siltstone and silty shale, containing a few thin beds of sandstone. Most of these rocks are fossiliferous and were deposited in sea water of shallow to moderate depth. The section on the eastern flank of the Coast Ranges is very thick; a thickness of 9,700 feet is exposed near Sites, 12,000 feet is exposed in the vicinity of the Rumsey Hills, and 14,800 feet is exposed in Putah Creek canyon west of Winters (Kirby, 1943c, p. 606).

The section thins eastward; 4,350 feet is exposed in the Sutter Buttes (Johnson, 1943, p. 614), and the exposures on the eastern side of the valley are from a few feet to about 2,000 feet thick (Taff, Hanna, and Cross, 1940). The eastward thinning and overlap suggest a transgressing sea.

The Upper Cretaceous rocks exposed in the Sutter Buttes consist of a fossiliferous sequence of shale, siltstone, sandstone, and pebbly beds that have been referred to, at various times, as the Panoche, Moreno, or Chico formation (Johnson, 1943, p. 614).

The rocks exposed near Chico unconformably underlie the Tuscan formation (Pliocene) and are mostly medium-coarse to coarse grained. The type localities for the Chico formation, as originally described by Gabb (1869) and Whitney (1865, 1868), are on Big Chico Creek, Dry Creek (Butte Co.), and at Tuscan Springs, 10 miles northeast of Red Bluff. Unfortunately the sections in the type area are thin and incomplete. In Big Chico Creek canyon northeast of Chico the Upper Cretaceous sedimentary rocks underlie the fragmental volcanic rocks of the Tuscan formation and rest uncomformably on steeply dipping metamorphic rocks of the Sierra Nevada basement complex. The exposed section, which is about 2,000 feet thick, consists of bluish- and greenish-gray arkosic sandstone, thin sandy shale and carbonaceous shale, and some conglomerate near the base (Taff, Hanna, and Cross, 1940). Toward the valley the dips are low.

The Upper Cretaceous rocks exposed near Folsom occur as small, discontinuous bodies resting on pre-Tertiary granodiorite and overlain by either Eocene sedimentary rocks (Ione formation) or the volcanic rocks from the Sierra Nevada. Brownish to greenish sandstone, containing marine mollusks and pelecypods, is the predominant lithologic type, but conglomerate and siltstone also are present. The exposed sandstone in the bluff northeast of Nigger Bar, about a quarter of a mile northwest of the bridge at Folsom, is about 25 feet thick, and the outcrops 3 to 4 miles northwest of Folsom probably are no more than 50 feet thick. The Upper Cretaceous section, however, probably thickens abruptly west of these exposures.

Several deep wells in the Sacramento Valley have been drilled to the Upper Cretaceous rocks, which usually underlie the Eocene or

Paleocene sedimentary rocks. A few deep wells on the east side of the valley go through the Upper Cretaceous and reach the basement rocks below. (See pl. 3.) The meager data generally confirm the eastward thinning of the section. Gas is produced from sand in the Upper Cretaceous in the southwestern part of the Sacramento Valley at Potrero Hills and Winters, in the Sutter Buttes, the Dunnigan Hills area, near Willows, and at other scattered localities in the northern part of the Sacramento Valley.

The marine sedimentary rocks of the Chico formation crop out in the Coast Ranges and at most places underlie the Sacramento Valley at considerable depth. They underlie the alluvium at depths of less than 1,000 feet on the west side of the valley between Orland and Williams. Even in structurally high locations west of the valley and at Sutter Buttes salt water has been found in the Upper Cretaceous rocks, and it is likely that wells tapping permeable deposits of this age in the valley would yield connate marine water or dilute connate marine water high in chloride content.

PALEOCENE SERIES

Marine sedimentary rocks of Paleocene age are exposed in the Potrero Hills north of Suisun Bay, and several gas wells in the southern part of the Sacramento Valley have been drilled through these rocks. The Paleocene rocks of the California coastal region generally are called the Martinez formation. The type locality of this formation is near the town of Martinez on Carquinez Strait west of Suisun Bay.

The fossils from the Martinez formation indicate a transition from Cretaceous to Eocene, and the Martinez formation often is referred to the lower Eocene by petroleum geologists. The formation is missing in many subsurface sections in the southern part of the Sacramento Valley, and it is absent in outcrops along the southwestern margin of the valley, except at Potrero Hills. This hiatus may represent either nondeposition or subsequent removal by erosion, or both, in different areas.

The outcrops in the Potrero Hills consist of interbedded shale, sandstone, and conglomerate. Coarse sandstone beds, 2 to 6 feet thick, make up about 10 percent of the formation. The exposed thickness is about 2,000 feet (Weaver, 1949, p. 51).

In Richfield Natomas No. 1 well, in the American Basin, 1,500 feet of sandstone below Eocene Meganos formation (Capay shale as used by Weaver and others, 1944) may be the Martinez formation. This sandstone overlies shale of Late Cretaceous age and is cut out by an unconformity (overlap) in Richfield's Natomas No. 2 well, 3 miles southeast, where Oligocene and Miocene rocks overlie the Cretaceous rocks.

EOCENE SERIES

GENERAL DESCRIPTION

The Eocene series in the Sacramento Valley region is composed of marine sedimentary rocks in the central and western part of the Sacramento Valley and nonmarine and deltaic sediments of middle Eocene age in the eastern part of the valley and in the Sierra foothills. These rocks are shown as undifferentiated sedimentary rocks in table 1 and on plate 2.

Eocene rocks are exposed along the foothills of the Coast Ranges from Cache Creek to the Potrero Hills, in the Sutter Buttes, and discontinuously along the east side of the Sacramento Valley from Table Mountain near Oroville to and beyond Mormon Slough southeast of Lodi. The subsurface extent of the Eocene rocks is not certainly known, but gas wells near Chico have been drilled into marine Eocene sedimentary rocks, and farther south Eocene rocks have been found in many deep wells.

The Eocene series is less extensive than the Upper Cretaceous in the Sacramento Valley region, and many of the sedimentary rocks of middle Eocene age in the eastern part of the valley and in the Sierra Nevada foothills are nonmarine. Lower, middle, and upper Eocene rocks are found in the valley region, but parts of the Eocene series are missing at most places. Lower Eocene rocks are the most extensive; upper Eocene are the least.

Lack of general agreement on Eocene correlations in California and the absence of a universally accepted time subdivision of this epoch has caused some confusion in the past. Stewart (1949) proposed a subdivision of the Eocene in the Mount Diablo-Sacramento Valley region, and his usage, with the addition of the Capay formation of Crook and Kirby (1935) and the Wheatland formation of Clark and Anderson (1938), will be followed in this report. Correlation between Stewart's (1949) Eocene formations and the subdivisions adopted by the American Association of Petroleum Geologists subcommittee on stratigraphic nomenclature for the Mount Diablo-southern Sacramento Valley area (Clark, E. W., and others, 1951) is illustrated in the following chart.

LOWER EOCENE FORMATIONS

The lower Eocene in the Sacramento Valley comprises the Meganos formation and the Capay formation of Crook and Kirby (1935). Capay also has been used as a stage name for the interval between the Meganos and Domengine, and it is considered lowermost middle Eocene by some geologists (Merriam and Turner, 1937).

The type locality of the Meganos formation is on the north side of Mount Diablo (Clark and Woodford, 1927). In the Sacramento

Paleocene and Eocene correlation chart for the Sacramento Valley

Molluscan stage (Clark and Vokes, 1936)	Foraminiferal zone (Laiming, 1943)	A.A.P.G. Correlation Committee (Clark, E. W., and others, 1951) Rio Vista gas field west of Midland fault		Stewart (1949) Composite for southern Sacramento Valley		Age
Tejon	A-1	Markley formation	Sidney shale	Kreyenhagen formation	Markley sandstone member	Upper Eocene
			Markley sand			
	A-2	Nortonville or Emigh shale			Nortonville shale member	
Transition	B-1A	Domengine formation	Green sand	Domengine formation	Brown sand	Middle Eocene
Domengine	B-1		White or Emigh sand clays	Ione formation	White sand	
Capay	B-2 B-3 B-4	Meganos formation	Capay shale	Meganos formation	Marysville claystone member	Lower Eocene
	C		M. Hamilton sand			
Meganos	D		Meganos "C" shale			
			Anderson sand			
Martinez	E	Martinez formation	"McCormick sand"	Martinez formation		Paleocene

Valley region the Meganos is exposed in the Coast Ranges from Potrero Hills, north of Suisun Bay, to a short distance north of Putah Creek, and in the Sutter Buttes. Part of the formation is designated as the Marysville claystone member. The Capay shale of local usage probably is equivalent to the Marysville claystone member (Stewart, 1949).

The Capay formation of Crook and Kirby is exposed for about 14 miles along the west side of Capay Valley. It consists of as much as 2,400 feet of beds resting uncomfortably on the Upper Cretaceous rocks, ranging from channel conglomerate to fine-grained estuarine deposits (Crook and Kirby, 1935). The source of the detritus was said by Crook and Kirby to have been local. The Capay formation was deposited contemporaneously with at least part of the Marysville claystone member of the Meganos formation (Stewart, 1949).

The Meganos formation is as much as 2,500 feet thick in an exposure north of Vacaville, but is not as thick in the subsurface in the southern part of Sacramento Valley. Fine-grained sediments of the Marysville claystone member predominate in the Sutter Buttes exposures and throughout most of the outcrops in the Coast Ranges south of Cache Creek, but the basal part of the formation sandstone is in the southern part of the valley. A fossiliferous shale, the Walkup clay, exposed in a clay quarry near Lincoln on the east side of the valley is reported to be lower Eocene (Allen, 1929) and may be correlative with the Marysville claystone member. Highly fossiliferous marl resting on diabase of the basement complex, about 8 miles south of Folsom, may also be lower Eocene (Hertlein, L. G., written communication, 1950).

MIDDLE EOCENE FORMATIONS

Two formations constitute the middle Eocene section in the Sacramento Valley—the Ione formation and the Domengine formation. The Ione formation, as defined by Stewart (1949, includes Allen's (1929) Dry Creek formation which Stewart designated the Dry Creek sandstone member. The Domengine formation overlies the Ione formation in places beneath the south-central part of the Sacramento Valley.

The measured section of the Ione formation in the Sutter Buttes, which is about 130 feet thick, is the Dry Creek sandstone member as used by Stewart (1949). Marine fossils indicate a middle Eocene age, the same age assigned by Allen (1929) to the Ione formation on the east side of the valley. Some of the white sands of the Dry Creek member in the Sutter Buttes possibly contain anauxite, a micaceous clay mineral that typifies much of the Ione formation in the Sierra Nevada foothills. The Dry Creek member is exposed also near Dry Creek north of Oroville, which is the type locality (Allen, 1929).

The fossiliferous fine sandstone there lies beneath nonmarine sand and clay of the Ione formation.

Except for outcrops of upper Eocene rocks northeast of Wheatland and the fossiliferous lower Eocene(?) marl south of Folsom, the Eocene rocks on the east side of the valley belong to the Ione formation. The Ione consists of light-colored anauxitic sand and clay, dark-reddish or brownish ferruginous sandstone, quartz and metamorphic-rock gravel and conglomerate, and a minor amount of lignitic material. This lithology also has been indicated in drillers' logs of water wells west of the outcrops.

The exposed thickness of the Ione formation along the Sierra Nevada foothills ranges from a few feet to 400 feet or more. The original thickness undoubtedly was greater, as the top of the Ione is an erosion surface of moderate relief. Eastward the clay and sand interfinger with gravel deposited by the Sierran streams during the Eocene epoch, and both the distribution and the lithologic character of the Ione suggest a deltaic origin for the sediments along the eastern margin of the valley. A subtropical or warm temperate climate and a land surface of relatively low relief favored intensive weathering and, hence, the preponderance of such resistant minerals as quartz and anauxite.

The gravel of the Ione formation, or "pre-Volcanic Tertiary gravels" as they were designated by Lindgren (1911), interfinegrs with the deltaic and brackish-water sediments of the Ione formation. The gravel deposits along the old Sierran streams may be divided conveniently into two groups, the deep or channel gravel, and the bench gravel. At most places the deep gravel is confined to a rather narrow trench in the bedrock and is coarse and generally unweathered. The bench gravel is finer grained, contains abundant quartz pebbles, and is intensely weathered. The bench gravel accumulated on relatively broad flood plains of aggrading streams. The deep gravel probably is somewhat older than the bench gravel, though this relationship is not absolutely certain (MacGinitie, 1941, p. 12). The largest area of the bench and deep gravel shown on the geologic map is on the south side of the Yuba River near where the river leaves the Sierra Nevada. This locality probably is not far from where the mouth of the Yuba River was located during Eocene time.

In outcrops the Ione formation rests on the pre-Tertiary crystalline basement complex and is capped by volcanic rocks or Pleistocene gravel. A middle Eocene age is indicated by fossil flora found at several localities along the Tertiary streams of the Sierra Nevada, principally the old Yuba River (MacGinitie, 1941) and by marine mollusks from the Sutter Buttes exposure and from localities in the Sierra Nevada foothills.

The Domengine formation has been found in gas wells in the southern part of the Sacramento Valley but is exposed only as far north as the Potrero Hills north of Suisun Bay. In the Potrero Hills the Domengine is characterized by a fossiliferous coarse white sand, and it contains lignitic shale in the lower part (Stewart, 1949). The age assigned by Stewart is middle Eocene.

UPPER EOCENE FORMATIONS

The upper Eocene rocks are found principally in the southwestern part of the Sacramento Valley, although sedimentary rocks of late Eocene or Oligocene age are exposed on the east side of the valley northeast of Wheatland, and upper Eocene sedimentary rocks probably underlie much of the intervening area.

The upper Eocene rocks in the Sacramento Valley are predominantly marine and have been assigned to the Kreyenhagen formation and the Wheatland formation of Clark and Anderson (1938). The Kreyenhagen formation crops out along the west side of the valley south of Cache Creek and is found in wells east of this area. Stewart (1949) divided the Kreyenhagen into the Nortonville shale member, the Markley sandstone member, and the Sidney shale member of Clark and Campbell (1942). The Markley sandstone member is typically brown and contains abundant large muscovite flakes. In some areas, gray fractured shale is interbedded with the sandstone and the underlying Nortonville shale member has been recorded in several gas wells in the southwestern part of the Sacramento Valley. The Sidney shale member, which overlies the Markley sandstone member in the Mount Diablo area, apparently is missing in the southwestern part of the Sacramento Valley.

The Kreyenhagen formation is as much as 3,500 feet thick in the subsurface in the extreme southwestern part of the valley, and Stewart (1949) describes an exposed thickness of 4,300 feet a few miles north of Vacaville.

The Wheatland formation of Clark and Anderson (1938) is exposed for about 1.2 miles along the southeast bank of the Dry Creek flood plain northeast of Wheatland. In the following description of the exposed section the thicknesses measured by Olmsted are approximate.

	Thickness (feet)
Top of exposed section.	
Sandstone, fine- to medium-grained, grayish; contains interbedded finely laminated greenish siltstone; minerals include quartz, pale-green biotite, clay minerals, and possibly feldspar	14
Siltstone and silty shale; chaotic jointing in which a series of gray medium-grained broken and contorted sandstone beds and angular blocks is embedded; lavender-gray shale contains small angular fragments of tuff; somewhat tuffaceous sandstone contains carbonized wood pieces	16

	Thickness (feet)
Sandstone, massive, silty, grayish-white; contains very angular colored grains, possibly shards of quartz; probably tuffaceous	6
Unexposed interval	30+
Siltstone, soft punky, and very fine-grained sandstone; grayish-white to cream-white; visible grains of quartz and mica; possibly diatomaceous	15
Tuff or tuffaceous sandstone, violet	1
Clay, soft greenish; may be altered volcanic ash	4
Tuff-breccia, pink to violet; contains subangular volcanic fragments averaging ½–5 in across in a fine- to medium-grained tuff matrix; tuff has subrounded to angular grains of feldspar, biotite, hornblende(?), quartz, and volcanic rock groundmass; larger fragments include hornblende andesite, biotite dacite(?), pyroxene andesite, and pumice; tuff possibly is of dacitic composition	10
Thin unexposed interval	?
Siltstone and fine sandstone, rhythmically bedded; silty shale	10
Limestone, hard, light-gray to cream-colored	¼
Shale, silty; spheroidal fracture; brown lignite on fracture surfaces	3
Siltstone, lignitic; thin fine-grained sandstone partings	2
Shale, dark-gray; spheroidal fracture; lignite on fracture surfaces	2½
Siltstone and fine-grained sandstone, rhythmically bedded	2
Shale, silty, lignitic; odd spheroidal fracture	2
Limestone, hard, light-gray to cream-colored	½
Siltstone and fine-grained sandstone, rhythmically bedded; medium-grained sandstone beds, one-sixteenth to 6 in thick; siltstone, gray; yellow and brown sandstone has subangular grains of quartz, muscovite, biotite, weathered feldspar, and other minerals poorly cemented with yellow iron oxide and clay; lignitic material is fairly abundant on bedding planes	22
Siltstone and silty shale, light-gray, fairly hard; contains irregular curved fracture across individual beds averaging thickness one-half to 2 in; visible grains of green mica and clear quartz; abundant carbonized plant fragments in some bedding surfaces	20
Unexposed interval	?
Sandstone, coarse, massive, tuffaceous; sequence contains several ellipsoidal masses of siltstone averaging length 6–12 in; siltstone, fine-grained; has peculiar hackly fracture	20
Sandstone, coarse massive gray; contains few strata of fairly well bedded siltstone and fine sandstone; massive sandstone similar to sandstone below; has higher proportion of volcanic fragments; also contains sparsely scattered angular granules of gray and pink pumice and tuff	19
Shale, silty, gray; spheroidal fracture; somewhat lignitic	6
Sandstone, coarse, light to dark gray, slightly tuffaceous; dark gray phases firmly cemented with $CaCO_3$, weather dark brown; crumbly light-gray sandstone; grains of glassy quartz, white feldspar, biotite, hornblende, unidentified dark grains, and colored fragments—probably volcanic	4
Pebble conglomerate, hard; contains abundant marine mollusks; well-rounded to subrounded pebbles of metamorphic rocks, porphyritic andesite and dacite(?); white vein quartz in a calcareous-cemented coarse sandstone matrix; also angular siltstone fragments	5
Unexposed interval	?
Pre-Cretaceous diabase	?
Total thickness of exposed section	184

This sequence is capped by sand and cobble gravel of probable Pleistocene age. Assuming an average strike and dip of the bedding N. 10° W. and 4° WSW., the thickness of the Wheatland formation here, including the unexposed intervals, was computed to be 280 feet.

The marine mollusks in the conglomerate near the base of the formation indicate correlation with the lower part of the Gaviota formation (Upper Eocene or Oligocene) (Clark and Anderson, 1938). Forrest (1943, pl. III) assigns an Oligocene age to the Wheatland.

WATER-BEARING CHARACTER

The Eocene rocks may be divided into two categories on the basis of depositional environment and chemical character of the contained water: Predominantly nonmarine sediments near the eastern margin of the Sacramento Valley which largely contain fresh water; and marine sedimentary rocks in the central and western parts of the valley which largely contain connate marine water, some of it diluted by fresh water.

The Eocene sedimentary rocks cropping out along the east side of the valley are predominantly nonmarine, although marine sedimentary rocks crop out at Table Mountain near Oroville, Sutter Buttes, Wheatland, Lincoln, and north of the Cosumnes River. White sand strata in the Ione formation are known to produce supplies of fresh water at two localities; one southwest of Wheatland where some irrigation wells obtain part of their production from quartzose sand interbedded with varicolored clay of the Ione formation and the other southwest of Folsom where several wells have been drilled to supply water for gold dredges.

The average permeability of the Ione formation does not appear to be very high. Well 9/7-36C1 of the Capital Dredge Co. about 6 miles south of Folsom produced 500 gpm (gallons per minute) at a specific capacity (see definition on p. 137) of 8.3 gpm per foot of drawdown. Roughly half the 166 feet of perforations are opposite the volcanic rocks from the Sierra Nevada and half are opposite the underlying Ione formation. The yield factor (see p. 139) for the total perforated thickness was 5. Well 9/7E-36N1, about half a mile to the south, had a specific capacity of 8 gpm per foot of drawdown and a yield factor of 2.5 for the saturated thickness, about three-fourths of which is the Ione formation and one-fourth is volcanic rocks. Well 13/6E-27D1, about 4 miles north of the clay quarries at Lincoln, is 96 feet deep and was drilled into granite of the basement complex in the bottom 7 feet and clay, sand, and gravel of the Ione formation above. The well produced 50 gpm at a specific capacity of 2.8 gpm per foot of drawdown indicating a yield factor of 7 for 40 feet of aquifer tapped in the Ione.

Marine Eocene sedimentary rocks have been found in deep wells beneath the fresh-water deposits of the valley from Butte County southward. In structurally high locations these rocks have been subjected to some flushing, but as a general rule they contain water high in chloride content, indicative of a marine origin. Well 14/5E–21A1, about 3 miles north of Wheatland and drilled to 548 feet, yielded water containing 1,800 ppm (parts per million) of dissolved solids and 775 ppm of chloride. This well was probably drilled into the marine Wheatland formation of Eocene or Oligocene age (Clark and Anderson, 1938) which crops out 2.5 miles to the east. A well drilled for a municipal supply at Wheatland (Watts, 1892) yielded highly mineralized water at a depth of 552 feet.

In the Lincoln area Bryan (1923) reported three wells yielding water having an abnormally high chloride content. At the Gladding-McBean Co. plant at Lincoln, a well 30 feet deep yielded water containing 359 ppm of dissolved solids and 85 ppm of chloride. Although the mineral content is low, as indicated by the dissolved solids, the ratio of chloride to dissolve solids is abnormally high for waters on the east side of the Sacramento Valley. This well is about half a mile south of an outcrop of marine sedimentary rocks, the Walkup clay of Allen (1929). A well (12/6E–21) 600 feet deep, about 2 miles southwest of Lincoln, yielded water containing 7,613 ppm of dissolved solids and 3,834 ppm of chloride. At the Whitney Ranch, about 6 miles south of Lincoln, a well 1,155 feet deep flowed salty water containing 6,653 ppm of dissolved solids and 3,180 ppm of chloride. Marine Eocene or Upper Cretaceous sedimentary rocks are the probable source of the chloride in all three waters.

On the Haggin Ranch, about 9 miles northeast of Sacramento, two wells were drilled to a depth of 1,600 and 2,200 feet respectively. In both wells the water was reported to be too salty to use (Watts, 1892).

Eocene marine sedimentary rocks are exposed along the west side of the Sacramento Valley from Cache Creek south to the Potrero Hills. To the east they dip beneath younger deposits which they underlie as far north as the northern end of the Rumsey Hills.

Siltstone and fine- to medium-grained sandstone predominate in the Eocene section; sandstone makes up as much as 35 percent of the section in the southwestern part of the valley. Beneath the valley the Eocene rocks contain salty marine water, but in the Vaca and Pleasants Valleys west of Sacramento Valley the porous sandstone of the Markley member of the Kreyenhagen formation locally has been flushed of connate water and contains fresh water.

The Eocene rocks are too deep beneath the south-central and southwestern part of the Sacramento Valley to be tapped by water wells, even if the water were of a quality acceptable for irrigation.

(See pl. 3.) Only near the eastern margin of the valley and in Vaca and Pleasants Valleys and at a few other localities near the west margin of the Sacramento Valley are the Eocene sedimentary rocks present or a potential ground-water reservoir. Even at these places the low permeability of the rocks precludes development of irrigation supplies.

BASALT (TERTIARY)

Basalt of Tertiary age occurs at many places in the Sacramento Valley region. The basalt at most of the localities is of similar lithologic character and appears to be approximately contemporaneous. Basalt has been identified and studied on the south side of Stony Creek at Orland Buttes; along Big Chico Creek, Mill Creek, North Fork of Mud Creek, and elsewhere in the Cascade Range foothills bordering the Sacramento Valley on the northeast (included with Tuscan formation on plate 2); at Table Mountain and Campbell Hills north of Oroville; at Putnam Peak (1,224 ft.) and elsewhere in English Hills north of Vacaville; in the foothills of Coast Ranges between Putah Creek and Chickahominy Slough northwest of Winters; in the subsurface about 4 miles southeast of Vacaville; in the subsurface in Chico area; and in the subsurface in Arbuckle area.

The stratigraphic relations at the above localities suggest a Pliocene age for the basalt, although at some places the age could range from post-Eocene to late Pliocene. At Orland Buttes the basalt is at the base of the Tehama formation (upper Pliocene) and unconformably overlies Upper Cretaceous sedimentary rocks (Chico formation). The basalt flow at Table Mountain and Campbell Hills north of Oroville overlies the Ione formation (middle Eocene) and fragmental andesites that probably are correlative with the volcanic rocks from the Sierra Nevada (Eocene(?) to Pliocene). In the subsurface occurrence near Chico, in the outcrops along Big Chico Creek, and in some of the other streams in the Cascade Range foothills farther northeast, the basalt flows underlie the Tuscan formation (upper Pliocene) and unconformably overlie Upper Cretaceous marine sedimentary rocks (Chico formation). The basalt in the English Hills north of Vacaville and in the foothills northwest of Winters occurs either in the basal part of the Tehama formation or below the Tehama and are most likely of Pliocene age, although the basalt at Putnam Peak might be as old as Oligocene(?) (Thomasson, Olmsted, and LeRoux, in press). The basalt penetrated in several wells near Arbuckle is in the basal part of the Tehama formation and therefore probably is upper Pliocene.

Most of the basalt at the localities occurs in the form of flows, although some is in the form of small dikes and sills. The lithologic character is remarkably uniform. Most of the rock is microcrystalline (average crystal size about 0.5 mm), dark gray to black where fresh, and is cut by crude columnar joints approximately perpendicular to the upper and lower contacts. At many places the basalt is vesicular; and, locally, pillow structure, indicates extrusion in water as, for example, at Drakes Point in the English Hills north of Vacaville (Thomasson and others, in press).

Microscopic examination of the basalt at Big Chico Creek made by Ira E. Klein of the U.S. Bureau of Reclamation revealed that the rock is a hemicrystalline augite basalt containing no olivine. At Putnam Peak in the English Hills the basalt consists of phenocrysts of plagioclase, augite, and olivine embedded in a microcrystalline groundmass of labradorite (plagioclase), augite, and subordinate magnetite (Weaver, 1949, p. 131).

In the subsurface in the northern part of the Sacramento Valley the basalt produces little or no water but is important in that it serves as a barrier separating the underlying marine connate waters of the Eocene and Cretaceous rocks from the fresh waters of the overlying continental deposits. The basalt at the base of the Tuscan formation is 50 to 215 feet thick and underlies the valley beneath an area of more than 200 square miles. The basalt at Orland Buttes extends several miles to the east with dips that conform to the dip of the base of the Tehama formation (Anderson and Russell, 1939).

The basalt flows in Butte and Tehama Counties are buried at depths not reached by water wells in the irrigated agricultural areas. They generally are dense and impervious and not likely to yield water. At Table Mountain near Oroville and Campbell Hills small springs issue from the upper surface of the Ione formation. It is likely that the columnar jointing of the basalt cap permits the downward passage of rainwater.

SEDIMENTARY ROCKS OF VOLCANIC ORIGIN ON THE WEST SIDE OF THE SACRAMENTO VALLEY

GENERAL CHARACTER

The sedimentary rocks of volcanic origin on the west side of the Sacramento Valley were defined as the sequence of volcanic shale, sandstone, and conglomerate beds underlying the Tehama formation and overlying either basalt of Tertiary age or Eocene sedimentary rocks in the English Hills on the southwest side of the Sacramento Valley (Thomasson and others, in press). These sedimentary rocks of volcanic origin have been left unnamed, because their age and correlation are in considerable doubt.

The sedimentary rocks of volcanic origin, which are predominantly of andesitic composition, unconformably overlie marine sedimentary rocks of late Eocene age, and at one locality about 1½ miles east of

Putnam Peak in the English Hills, they are in depositional contact with basalt that probably is Pliocene but might be as old as Oligocene. The contact with the overlying Tehama formation apparently is conformable and at some places appears to be gradational. The exposed thickness of sedimentary rocks of volcanic origin in the English Hills is as much as 400 feet.

In the subsurface in the southwestern part of the Sacramento Valley the lower part of the predominantly nonmarine section above the marine Eocene sedimentary rocks may be correlative in part with the volcanic sedimentary rocks exposed in the English Hills. Soper (1943, p. 592) described the top 1,900 feet in Amerada Emigh No. 1 well in the Rio Vista gas field as Pleistocene to upper Miocene(?) nonmarine brown clay shale, black and dark-gray medium to coarse sand, gravel, and some green clay shale in the lower 600 feet. The lower part of this section may be equivalent to the volcanic sedimentary rocks in the English Hills.

Weaver (1949, p. 84, 85) assigned most of the sedimentary rocks of volcanic origin in the English Hills to the Neroly formation (upper Miocene), basing the correlation with the type Neroly of the Mount Diablo region (Clark and Woodford, 1927) on lithologic similarity and the occurrence of the sand dollar *Astrodapsis tumidus*. However, becouse the sedimentary rocks of volcanic origin overlie basalt, 1½ miles east of the Putnam Peak, that is similar to basalt in the basal part of the Tehama formation (upper Pliocene) a few miles farther north, there is some doubt that all the sedimentary rocks of volcanic origin in the English Hills are correlative with the Neroly formation.

The sedimentary rocks of volcanic origin are at least superficially similar to the Mehrten formation of the Mokelumne area on the southeast side of the Sacramento Valley. (See Piper and others, 1939, p. 61–71.) Both rocks are predominantly andesitic and contain crossbedded bluish-gray sandstone and conglomerate beds. The Mehrten formation, included in the section on the volcanic rocks from the Sierra Nevada in this report, has been dated as late Miocene through middle Pliocene.

It is possible that the sedimentary rocks of volcanic origin in the English Hills were derived from the Sonoma volcanics exposed in the Coast Ranges farther west. The Sonoma volcanics are reported to be interbedded with the Tehama formation in Berryessa Valley (Taliaferro, 1951, p. 147), and the Tehama overlies the volcanic sedimentary rocks, apparently in gradational contact, near Vacaville (Thomasson and others, in press).

The sedimentary rocks of volcanic origin on the west side of the Sacramento Valley consist of andesitic sedimentary rocks predominantly of fluviatile and lacustrine origin, but some of the beds are marine, based on the occurrence of *Astrodapsis tumidus* reported by Weaver (1949, p. 85).

Fine-grained light-colored tuffaceous beds are most abundant in the English Hills exposures; crossbedded medium- to coarse-grained volcanic sandstone and pebbly sandstone compose less than one-third the total thickness at most localities. Most of the sandstone is friable and has a characteristic bluish color similar to sandstones described in the Neroly formation by Huey (1948, p. 43). The blue color is believed by Lerbeckmo (1957) to be due to the presence of a montmorillonoid clay mineral encasing the individual sand grains.

A fairly representative section of sedimentary rocks of volcanic origin, exposed in a ravine in 6/1W–4M, about 3 miles north of Vacaville, is described below:

	Thickness (feet)
Tehama formation: (top not exposed)	
Sandstone, soft silty light brown, possibly tuffaceous(?)	22½
Conglomerate pebble-cobble; containing pebbles and cobbles of weathered basalt as dominant constituent; smaller amounts of pebbles and cobbles of andesite, vein quartz, and dark metamorphic rocks in coarse, sandy matrix	2
Sedimentary rocks of volcanic origin:	
Sandstone, pale purple, well-sorted fine; contains abundant bluish and reddish grains; some biotite	8½
Unexposed interval	14
Siltstone, pale pink; irregular to subconchoidal fracture	10
Siltstone, white; irregular to subconchoidal fracture	3
Siltstone, soft, very light gray, interbeds with medium light-gray, medium-grained sandstone containing abundant volcanic grains	7
Sandstone, moderate brown, hard medium-grain	½
Siltstone, pale pink, soft massive; few lenses of gray medium-grained sandstone. Siltstone becomes laminated in basal portion	22
Sandstone, massive gray medium-grained; well bedded; then interbedded with 6- to 12-in zones of laminated siltstone in basal portion	17
Siltstone, pale purple, thin-laminated; fractured and fairly hard; perhaps diatomaceous	65
Sandstone, soft, gray, medium- to coarse-grained; well stratified; contains subangular grains of quartz, feldspar, biotite, and volcanic rock fragments	11½
Sandstone, soft, gray; medium- to coarse-grain; cross-bedded; interbeds of 1- to 6-in zones of light gray siltstone at intervals of 6–36 in	22½
Sandstone, very coarse, pebbly friable; pebbles and granules include hornblende andesite porphyry, vein quartz, and dark metamorphic rocks	3
Sandstone, light bluish gray, cross-bedded, coarse; streaks of pebbles of purple and gray andesite, vein quartz, and dark chert	3½
Unexposed interval	11½

	Thickness (feet)
Sedimentary rocks of volcanic origin—Continued	
Siltstone, light bluish-gray, moderately well bedded, friable and sandstone fine- to medium-grained	6
Siltstone, light bluish-gray; massive; hard; contains abundant volcanic grains	19
Unexposed interval	45
Siltstone, soft, grayish-blue; massive; grades downward into sandstone, light-gray; massive, medium-grained	8½
Unexposed interval	10½
Siltstone, soft, grayish blue, massive; contains abundant volcanic grains	8
Unexposed interval	6
Sandstone, massive, coarse-grained; contains pebbles of andesite, dark siliceous rocks, and vein quartz; grades downward into medium-grained sandstone with many highly colored grains	7
Sandstone, silty, light brown, soft, massive; contains a few pink grains	7
Unexposed interval	9
Sandstone, silty, brown, soft; contains quartz, feldspar; red and black grains	2
Remainder of section obscured by basalt detritus in creek.	
Total thickness of sedimentary rocks of volcanic origin	327

The sedimentary rocks of volcanic origin differ from the tuffaceous beds in the Tehama formation in that they are mostly andesitic rather than dacitic and contain little pumice. The rocks generally are more consolidated and better stratified than the tuffaceous beds in the Tehama and are blue, violet, or gray in contrast to the pale-brown and grayish-orange color characteristic of the Tehama.

Except in the vicinity of Putnam Peak, pebbles and cobbles are rather scarce. The pebbly zones occur chiefly as thin, lenticular stringers in coarse-grained andesitic sandstone. Most of the pebbles are porphyritic andesite, but red jasper, quartzite, and various metamorphic rocks locally are numerous.

In the Putnam Peak area thick lenses of basalt conglomerate occur in the lower part of the volcanic sedimentary rocks. The basalt in these conglomerates is similar to the underlying basalt at Putnam Peak and was almost certainly derived from that basalt.

Some of the light-colored siltstone and mudstone beds are of very light weight and probably are diatomaceous. These rocks evidently were deposited in a lacustrine or lagoonal environment. Fragments of carbonized wood and ash are reported from cores of gas wells and are seen in a few outcrops.

WATER-BEARING CHARACTER

The sedimentary rocks of volcanic origin exposed west of the Sacramento Valley have been penetrated in many gas wells in the southwestern part of the valley. In the subsurface these rocks contain fresh to brackish water and lie beneath the fresh-water-bearing Tehama formation and above Eocene sedimentary rocks that contain connate marine water. To the east, these somewhat brackish-water-bearing beds probably interfinger with the volcanic rocks from the Sierra Nevada, the lower aquifers of which contain brackish water in the vicinity of Sacramento. Electric-log data suggest that the brackish-water-bearing volcanic sedimentary rocks thin northward and pinch out completely north of Putah Creek.

A few water wells tap the volcanic sedimentary rocks in the English Hills, but no water wells are known to tap these rocks beneath the Sacramento Valley. The brackish nature of the water would preclude its use for irrigation or human consumption. In structurally high locations in the English Hills, these beds have been flushed and produce some fresh water.

Production records of a few wells suggest that the volcanic sedimentary rocks in the English Hills are not very permeable. One well in the southern part of the English Hills, tested at 50 gpm, had a specific capacity of 0.5 gpm per foot of drawdown and a yield factor of only 0.4 for the saturated thickness of the aquifer. In the well field of the Pacific Gas and Electric Co., well 6/1W–22F3 about a mile east of Vacaville is 740 feet deep and taps both the basal part of the Tehama formation and the volcanic sedimentary rocks. This well, tested at 445 gpm, had a specific capacity of 12 gpm per foot of drawdown and a yield factor of 1.8 for the saturated thickness of the aquifer.

VOLCANIC ROCKS OF THE SUTTER BUTTES (PLIOCENE AND PLEISTOCENE?)

The volcanic rocks of the Sutter Buttes may be divided conveniently into two principal groups: the intrusive rhyolite and andesite and the vent tuffs of the central core; and the tuff-breccia that encircles the core.

INTRUSIVE RHYOLITE AND ANDESITE AND VENT TUFF

The rocks of the first group are principally porphyritic rhyolite and andesite and vent tuffs. They form the sharp peaks in the central area, which are eroded remnants of a plug or laccolith of stiff, viscous magmas intruded into and pushed up through the valley sediments in Pliocene time (Johnson, 1943 and Williams, 1929).

TUFF-BRECCIA

The tuff-breccia, which forms the second group, consists of angular blocks of rhyolite and andesite that moved down the slopes of the old volcano. The age of these rocks is not certainly known but probably is late Pliocene or possibly early Pleistocene, as the tuff-breccia beneath the valley interfingers with the Laguna formation and related deposits derived from the Sierra Nevada. The estimated maximum thickness of the tuff-breccia is about 800 feet.

WATER-BEARING CHARACTER

Tongues of permeable volcanic sand and gravel of fluviatile origin interbedded with tuff-breccia flows from Sutter Buttes supply water to a few irrigation wells in the Pennington and Sutter areas. The tuff-breccia flows may also contain fractured zones. Most of the irrigation wells producing water from the volcanic rocks of the Sutter Buttes are 500 to 600 feet deep and have moderate to low yields. In the Pennington area pump tests of 18 wells, obtaining water from the volcanic deposits, indicate an average yield of 780 gpm at an average specific capacity of 34 gpm per foot of drawdown. Yields range from 400 to 1,550 gpm and specific capacities from 8 to 80 gpm per foot of drawdown.

ROCKS THAT YIELD WATER FREELY

VOLCANIC ROCKS FROM THE SIERRA NEVADA (EOCENE? TO PLIOCENE)

DEFINITION AND GENERAL CHARACTER

The volcanic rocks from the Sierra Nevada are a sequence of fragmental volcanic rocks of Tertiary age, the source of which lay near the present crest of the Sierra Nevada about 50 miles east of the Sacramento Valley. These rocks, predominantly andesitic but including subordinate rhyolitic, dacitic, and basaltic rocks, are extensively exposed on the western slope of the Sierra where they cap many of the interstream divides. They also extend westward beneath much of the southeastern part of the Sacramento Valley.

The volcanic rocks from the Sierra Nevada, as herein defined by previous workers, include several formations and stratigraphic units, as well as previously unmapped equivalents of these formations and units. The formations and stratigraphic units making up the volcanic rocks from the Sierra Nevada are presented in the table on the following page.

AGE AND CORRELATION

The volcanic rocks from the Sierra Nevada range in age from Eocene to Pliocene, as indicated at many places by vertebrate paleontological and stratigraphic evidence.

Lindgren and Turner (1895a and b), in the folios of the northern Sierra Nevada in the Geologic Atlas of the United States, considered the age of the volcanic rocks of the superjacent series Neocene (Miocene and Pliocene), and they used two time subdivisions—a rhyolitic epoch and an andesitic epoch. The rhyolite, largely tuff and some interbedded sand, clay, and gravel, of the earlier epoch unconform-

Stratigraphic units in volcanic rocks from the Sierra Nevada as defined by earlier writers

Formation or stratigraphic unit	Age	References	General description	Thickness (feet)
Tuff at Oroville	Age unknown; pre-Pleistocene.	Lindgren (1911)	Tuff, sand, and clay underlying Pleistocene gravel deposits near Oroville.	Unknown
Sutter formation	Pliocene?	Dickerson (1916), Johnson (1943).	Thin-bedded to massive tuff, sand, and conglomerate at Sutter Buttes.	0-1,800(?)
Mehrten formation	Upper? Miocene, Pliocene?	Piper and others (1939).	Fluviatile volcanic sandstone, siltstone, and conglomerate; tuff-breccia of mudflow origin; in Mokelumne region.	75-400
Valley Springs formation.	Middle? Miocene	Piper and others (1939).	Rhyolitic ash, quartz sand, conglomerate, greenish clay in Mokelumne region.	75-525
Andesite at Reeds Creek.	Upper Eocene or Oligocene.	Clark and Anderson (1938).	Andesitic conglomerate, sandstone, tuff, tuffaceous clay, tuff-breccia of mud-flow origin east of Marysville, south of Yuba River.	0-200+
Andesite	Neocene	Lindgren (1894), Lindgren and Turner (1895a, 1895b).	Andesitic tuff and breccia	
Rhyolite tuff	Neocene	Lindgren and Turner (1895a, 1895b).	Rhyolite tuff, with some clay and gravel.	

ably overlies the Ione formation and auriferous gravel (believed by Lindgren and Turner also to be Neocene), and the andesite is unconformable on the rhyolite.

In the Mokelumne River region, Piper, and others (1939) divided the fragmental volcanic rocks and interbedded sedimentary rocks above the Ione formation (Eocene) and below the Laguna formation (Pliocene?) into two formations, the Valley Springs formation—in part equivalent to Lindgren's rhyolite—and the Mehrten formation—roughly equivalent to Lindgren's andesite.

The Valley Springs formation is inferred by some geologists to be middle Miocene, though absence of fossils in the Mokelumne region leaves the age somewhat in doubt. Hudson (1951) found that the rhyolite tuff of the Donner Pass area on the Sierra crest, about 80 miles northeast of Sacramento, probably is middle Eocene rather than middle or upper Miocene; therefore the Valley Springs formation may be considerably older than middle Miocene. As the Valley Springs unconformably overlies the middle Eocene Ione formation, a possible lower age limit of middle or late Eocene is definitely established.

The Mehrten formation, which unconformably overlies the Valley Springs formation, has yielded many fossils outside the Mokelumne region. Fossil flora from volcanic sedimentary rocks correlative with the lower part of the Mehrten at Remington Hill on the Tertiary Yuba River and at Table Mountain near Columbia in Tuolumne County indicate an age transitional between the Miocene and Pliocene (Condit, 1944a, p. 37, 1944b, p. 73). Vertebrate fossils from

Table Mountain suggest a possible late Miocene or early Pliocene age (VanderHoof, 1933a; and Merriam and Stock, 1933).

Vertebrate fossil material found 4 miles east of Oakdale, Stanislaus County, in volcanic sandstone, probably correlative with the uppermost part of the Mehrten formation of the type area, has been identified as middle Pliocene (Stirton and Goeriz, 1942, p. 455). Fossil flora have been found near the vertebrate locality in a bed about 125 feet stratigraphically lower than the bone-bearing bed; the flora are representative of the middle part of the middle Pliocene (Axelrod, 1944, p. 160).

In the San Joaquin Valley andesitic sedimentary rocks probably correlative with the Mehrten formation were found to overlie fossiliferous marine strata of middle Miocene age (Lohman, K. E., written communication, 1954) in a U.S. Bureau of Reclamation core hole near Madera.

Huey (1948, p. 44) and Louderback (1924, p. 16) correlated the Mehrten formation (andesitic rocks in the Sierra Nevada) with the Neroly formation across the Central Valley in the Coast Ranges. Abundant fossil vertebrates and flora in the Neroly formation suggest a Miocene to Pliocene transitional age (Condit, 1939; 1944; and Stirton, 1939), although marine invertebrate fossils in the Neroly have been considered upper Miocene.

A reasonable conclusion is that the Mehrten formation and its equivalents are upper Miocene through middle Pliocene.

Not all the andesitic detritus in the Sierra Nevada is of the same age as the Mehrten formation. Andesitic materials in the Reeds Creek area in the Sierra foothills east of Marysville are petrologically similar to pebbles and cobbles in the fossiliferous upper Eocene or Oligocene conglomerate near the base of the Wheatland formation a few miles south, suggesting a common source (Clark and Anderson, 1938). At Chalk Bluffs, along the Tertiary channel of the Yuba River 25 miles east of Reeds Creek, MacGinitie (1941) has described andesitic cobble-bearing gravel beds that overlie the Ione formation but are below the rhyolitic series. These gravel beds may be correlative with the deposits at Reeds Creek.

Fossil flora of late Eocene or early Oligocene age have been found in a dacite tuff at La Porte, also on a branch of the Tertiary Yuba River (Potbury, 1935). Hudson (1951) believed that the dacite tuff at La Porte is equivalent to andesite tuff in the Donner Pass area 40 miles southeast. This andesite tuff, which is separated from the overlying andesite agglomerate (Mehrten formation equivalent?) by a major unconformity, unconformably overlies a thick section of rhyolite tuff believed to be middle Eocene (Hudson, 1951).

A sequence of tuff, sand, and clay at Oroville, described by Lindgren (1911), underlies coarse terrace gravel of probable Pleistocene age. Lindgren believed that the tuffaceous beds did not have a Sierran source, but for convenience they have been included in the volcanic rocks from the Sierra Nevada in this report.

The Sutter formation exposed in the Sutter Buttes also is included in the volcanic rocks from the Sierra Nevada. Williams (1929) and Johnson (1943) believed that the andesitic sedimentary rocks of the Sutter formation had a Sierran source, because they antedate the volcanic activity at the Sutter Buttes and because they are petrologically similar to the Sierran andesites. The Sutter formation unconformably overlies fossiliferous marine Eocene sedimentary rocks and has been deformed by the igneous intrusion of the volcanic rocks of the Sutter Buttes, which probably occurred in the Pliocene.

The volcanic rocks from the Sierra Nevada as used in this report includes fragmental volcanic rocks of several different ages ranging from middle or late Eocene through middle Pliocene. All these rocks had a source near the present crest of the Sierra, and they form a more or less distinct stratigraphic unit on the east side of Sacramento Valley—a unit that unconformably overlies rocks as young as middle Eocene (Ione formation) and underlies upper Pliocene and Pleistocene continental sediments (Laguna formation and related continental sediments).

DISTRIBUTION AND THICKNESS

The volcanic rocks from the Sierra Nevada are exposed discontinuously along the eastern margin of the Central Valley from Table Mountain near Oroville on the north to near Merced in the San Joaquin Valley on the south. These rocks are extensively exposed on the west slope of the Sierra Nevada where they cap many of the interstream divides, and they extend westward beneath much of the southeastern part of the Sacramento Valley and northeastern part of the San Joaquin Valley. The volcanic rocks have been uplifted and brought to the surface by the Sutter Buttes igneous intrusion in the central part of the Sacramento Valley, but elsewhere in the central part of the valley the volcanic rocks are several hundred to several thousand feet below the surface.

The thickest accumulations of volcanic rocks are near their source along or just east of the present crest of the Sierra where fragmental andesite, rhyolite, basalt, and a few interbedded flows locally are more than 3,000 feet thick (Lindgren, 1897). The volcanic rocks along the eastern margin of the Sacramento and San Joaquin Valleys are largely reworked fluviatile sediments, the aggregate thickness of which probably is less than 1,000 feet. Father west near the center of the Central Valley trough the total thickness of volcanic sedimentary rocks increases to perhaps as much as 2,000 feet (Knox, 1943, p. 588), but many nonvolcanic sedimentary rocks are interbedded with the volcanic sedimentary rocks. At many places along the valley margin the volcanic rocks from the Sierra Nevada are only a few tens of feet thick, and at some localities the entire section is missing.

The volcanic rocks dip westward at about the same angle as the slope of the Sierra block—1 to 2 degrees. Evidence from wells indicates that the westward dip continues beneath the Sacramento Valley so that the volcanic rocks become progressively deeper westward to the axis of the valley trough.

Some of this westward dip doubtless is primary, but some of it also results from deformation, which probably began soon after the rocks were deposited and which reached a climax in early or middle Pleistocene time (Matthes, 1930; Piper and others, 1939). Similarly, in the northeastern part of the Sacramento Valley the Tuscan formation, which is lithologically similar to the volcanic rocks from the Sierra Nevada although somewhat younger, has been tilted and deformed.

PHYSICAL CHARACTER

Most of the volcanic rocks from the Sierra Nevada are fragmental and were deposited either as mudflows or by streams. A few lava flows are interbedded with the fragmental rocks near the crest of the Sierra Nevada, but none of these flows reached the foothills adjacent to the Sacramento Valley.

The mudflows, consisting of breccia and tuff-breccia, are most abundant in the higher parts of the range where at some places they make up more than three-fourths of the total thickness. These breccias and tuff-breccias generally are poorly sorted assemblages of angular and subangular blocks of andesite and basalt as much as several feet across in a matrix of finer grained volcanic material. The tuff-breccias tend to decrease in coarseness westward, although blocks more than a foot in diameter are common at some localities along the eastern valley margin.

The rhyolitic rocks in the high Sierra Nevada are mostly thick, massive beds of welded and compacted tuff that greatly resembles flow rock and at many places can be identified as a fragmental rock only with a petrographic microscope (Hudson, 1951). Most of the rhyolitic sequence farther west, adjacent to the valley, consists of tuff (probably streamlaid), gravel, sand, and clay. The rhyolitic sediments unconformably overlie either crystalline basement rock or the Ione formation of middle Eocene age, having been deposited after a cycle of erosion following deposition of the Ione. Most of the rhyolite is restricted to old stream canyons cut in the ancestral

Sierra Nevada during the Cretaceous and early Tertiary. The andesitic rocks, which are thicker than the underlying rhyolite, may have formed a nearly continuous plain in the northern Sierra Nevada before the Pliocene to Pleistocene erosion cycle.

The most northward exposures of volcanic rocks from the Sierra Nevada along the eastern margin of Sacramento Valley are at Table Mountain near Oroville in Butte County where scattered outcrops of andesitic sandstone, tuff, and conglomerate occur beneath the basalt flow of Table Mountain and above the Ione formation. As no fossils have been found in them, it is not known whether these andesitic sedimentary rocks are equivalent in age to the Mehrten formation of the Mokelumne region or to the andesite at Reeds Creek.

The tuff near Oroville is exposed along the river-cut bluff south of the city. The section consists of brown sandy tuff that grades downward into silty material. The total subsurface extent of the tuff is unknown, but it underlies most of the gravel south of Oroville and has been reported to occur beneath the dredging ground of the Yuba River still farther south (Lindgren, 1911).

Outcrops of volcanic rocks are missing between the tuff exposures near Oroville and the Yuba River. However, it is believed that the volcanic sedimentary rocks occur below the surface farther west, where a few deep water wells are reported to be drilled into volcanic materials and where a fairly thick section of andesitic sedimentary rocks is exposed in the Sutter Buttes 20 miles west of the Sierra Nevada foothills.

Volcanic rocks from the Sierra Nevada are exposed at Reeds Creek, just south of Yuba River, about 10 miles east of Marysville. The area of the exposures is extensive—about 8½ miles from north to south by 6 miles from east to west—but the thickness probably does not exceed 200 feet, because of the low westward dip. A section exposed along Marysville-Smartsville Road in 15/5E-3 is described as follows (after Clark and Anderson, 1938, p. 938):

	Thickness (feet)
Pleistocene gravels.	
Disconformity.	
Rhyolitic pumice tuff, no exposures	5+
Cross-bedded yellow clay	4+
Diatomaceous tuffaceous clay	5
Andesitic breccia	15
Andesitic cobble gravel	12
Grayish white sandy clay	5
Gray and white massive clay	10
Andesitic pebble and cobble gravel	1
Red and white clay grading downward to brown and white quartz-anauxite sand	10
Erosion surface.	
Greenstone of basement complex.	

Elsewhere in the Reeds Creek area, andesite cobble conglomerate predominates in the lower part of the section, whereas volcanic sandstone, claystone, and tuff-breccia constitute most of the upper part. Several deep water wells west of the outcrop were drilled into volcanic "gravel" and "sand" (probably cemented). Friable volcanic sandstone is exposed in small ravines between the Reeds Creek exposure and the Wheatland formation (of Clark and Anderson, 1938) and crops out along Dry Creek in 14/5E–13 and 14/6E–7 and 18. This indicates that the andesitic rocks at Reeds Creek probably interfinger with the Wheatland formation.

The foothills between the Reeds Creek area and Coon Creek near Lincoln have no exposures of the volcanic rocks from the Sierra Nevada, although many water wells west of the foothills penetrate volcanic material. The original eastward extent of the volcanic rocks probably was considerably greater than it is now.

A bed of andesite tuff-breccia about 10 feet thick forms the cap rock at the clay quarries in the Ione formation at Lincoln. Beneath the tuff-breccia and disconformably overlying the Ione formation are beds of biotite sand, sandy clay, gravel, and a grayish-white clay that probably is altered rhyolite ash. This sequence, which is as much as 25 feet thick, represents the rhyolitic epoch and probably is correlative with the Valley Springs formation in the Mokelumne area 35 miles south.

The volcanic rocks exposed east of U.S. Highway 99E, between Lincoln and Roseville, consist of tuff-breccia, conglomerate, sandstone, and tuff, mostly of andesitic composition. Most of the tuff-breccia is hard and forms a ridge cap, whose surface is strewn with residual blocks of purplish-gray andesite. Below the andesitic beds are light-colored beds of tuff and tuffaceous sandstone possibly of rhyolitic composition. These tuffaceous beds, which overlie either the Ione formation or pre-Tertiary granodiorite, may be correlative with the Valley Springs formation.

The volcanic rocks near Folsom are similar to those in the Lincoln-Roseville area. The prominent bluff along the north bank of the American River west of Folsom affords excellent exposures of cobble conglomerate, sandstone, tuff, and tuff-breccia; all are of predominantly andesitic composition. A representative section, exposed in the buff west of Folsom and immediately south of Greenback Lane (the road from Folsom to Orangevale), is described below:

	Thickness (feet)
Laguna formation and related continental sediments (terrace gravel):	
Cobble gravel, ill-sorted reddish-brown	15
Erosion surface.	
Volcanic rocks from the Sierra Nevada:	
Tuff, coarse-grained to very coarse-grained, sand-sized; violet, hard	13
Siltstone; tuffaceous; and sandstone, fine-grained, light brown to gray	10
Tuff-breccia, hard, brown; blocks larger than 2 in. in diameter not abundant	12
Sandstone, andesitic; medium-grained, bluish-gray, cross-bedded	5
Sandstone, andesitic; medium-grained to coarse-grained; purplish-gray, hard; siltstone, thin-bedded, in top 8 ft; yellowish-gray	19
Conglomerate, pebble and small-cobble, andesitic	9
Sandstone, arkosic, coarse, yellow-brown, cross-bedded	10
Conglomerate, pebble and small cobble, andesitic	10
Sandstone, medium-grained, white	7
Sandstone, medium-grained, gray, lenses of pebble conglomerate; contains quartz, feldspar, biotite; very little volcanic material	10
Exposed thickness of volcanic rocks	105
Base of cliff.	

South of Folsom the exposures of volcanic rocks from the Sierra Nevada are discontinuous, but the entire area west of the pre-Tertiary crystalline rocks exposures between the American and Cosumnes Rivers is underlain at shallow depth by the volcanic rocks. Volcanic materials have been reported beneath the old gravel deposits of the American River (Laguna formation and related continental sediments; gravel deposits of uncertain age; and Arroyo Seco gravel) in wells drilled for gold-dredging operations. Volcanic sandstone and conglomerate predominate in this area, but some tuff-breccia is found. The volcanic section is at least 250 feet thick.

At the Sutter Buttes the Sutter formation unconformably overlies middle Eocene marine sediments and is overlain unconformably by tuff-breccia of Pliocene or Pleistocene age derived from the Sutter Buttes volcano. The Sutter formation consists principally of thin-bedded to massive tuff, conglomerate, and sand. The maximum exposed thickness of the formation is reported to be about 1,800 feet (Johnson, 1943); however, data from gas wells drilled just east of the Sutter Buttes suggest that this figure may be too large.

WATER-BEARING CHARACTER

The volcanic rocks from the Sierra Nevada dip westward about 50 to 75 feet per mile beneath the younger sediments of the Sacramento Valley. Although the exposures along the eastern valley margin are discontinuous, the volcanic rocks coalesce valleyward and form a continuous body beneath the east side of the valley.

Permeable volcanic sand and gravel deposits of fluviatile origin occur beneath the valley, and the impervious tuff and tuff-breccia, which are so prominent in outcrop, make up a smaller proportion of the total thickness in the valley. Clay and silt probably are more abundant beneath the valley than sand and gravel and cause the water in the aquifers at most places to be under artesian pressure.

In general, the water contained in the coarse-grained volcanic sedimentary rocks is of good chemical quality, although in the Sacramento area, the lower part of the volcanic section from 1,500 feet below sea level downward generally contains relatively highly mineralized water. The top of the Mehrten formation is believed to be about 1,000 feet below sea level at the western edge of Sacramento (Piper and others, 1939, pl. 4). Eight miles to the northwest the top was cored at 345 feet below sea level in a water-supply well for McClellan Air Force Base. Cores from a gas-test well south of Sacramento, drilled by Jergins Oil Co. in 1945, indicate that volcanic sandstone, siltstone, and conglomerate extend to a depth of nearly 4,000 feet below sea level. The electric log of the Jergins well suggests that water from 1,500 to 2,100 feet below sea level is moderately mineralized, and that the formation water from 2,100 to 4,000 feet below sea level is very brackish. Connate marine water is found below 4,000 feet.

Bryan (1923, p. 276–280) reported that gas wells drilled by the Sacramento Natural Gas Co. at Sacramento between 1892 and 1909 produced natural gas and flowing salty water from permeable beds between 1,500 and 2,000 feet below sea level. Probably the gassy zone corresponds to the zone of moderately mineralized water between 1,500 and 2,100 feet below sea level at the Jergins well.

The McDonald Island gas field is in the San Joaquin-Sacramento Delta, about 10 miles south of the Rio Vista gas field and 40 miles south of Sacramento. Knox (1943, p. 588–590) describes (from cores) the section in McDonald Island Farms No. 1 well as follows:

	Depth (feet)
Sands, loose, dark gray, green; clays, yellow (Pleistocene and Pliocene; lower part may be equivalent to the Tehama formation)	0–1, 450
Sandstone, blue, cross-bedded, pebbly; siltstone, fine; clays, green and variegated (Miocene and (or) Pliocene Mehrten formation)	1, 470–2, 772
Clay, sand, conglomerate; ash beds below 2,797 ft; bentonite beds below 3,407 ft (fresh-water Miocene)	2, 797–3, 555
Sands, blue, black, brown; lignitic material, pyritized plant remains (brackish-water Miocene)	3, 570–3, 846
Sands, fine (marine Miocene)	3, 866–3, 968
Marine Eocene	3, 968–5, 178

The average permeability of the volcanic rocks varies widely from place to place. In general, wells tapping the volcanic rocks near the exposures along the eastern valley margin are not as productive as wells farther west where well-sorted coarse sand makes up a large proportion of the total thickness.

The most permeable volcanic sediments tapped by wells for which production data are available are in the Citrus Heights Irrigation District, 1 to 2 miles south of Roseville. District well 2 (10/6E-13N1) produced 1,000 gpm with a drawdown of 10 feet for a specific capacity of 100 gpm per foot of drawdown. The saturated section, 331 feet thick was mostly loose sand and gravel of the Mehrten formation. The yield factor for this section was 30. In district well 3 (10/6E-23G1), the casing was perforated for 193 feet, more than half of the perforated portion being opposite the Mehrten formation. This well had a specific capacity of 114 gpm per foot of drawdown and a yield factor of 59 for the saturated thickness of the deposits. However, the yield factors for these two wells are exceptionally high, as most of the other wells tapping the volcanic rocks have yield factors of 1 to 20.

Fair Oaks Irrigation District well 2 (9/7E-7H1) is typical of deep wells tapping the Mehrten formation in the southeastern part of the Sacramento Valley. This well had a test production of 1,440 gpm with a drawdown of 31.6 feet for a specific capacity of 46 gpm per foot of drawdown. The total saturated thickness, 482 feet, was mostly in the Mehrten formation but possibly in part of the Ione or Valley Springs formation near the bottom of the well. The yield factor for the saturated section was nearly 10.

As an indication of the low average permeability of the volcanic rocks in the outcrop areas, well 9/7E-12P2, about 3 miles south of Folsom, produced only 20 gpm at a drawdown of about 40 feet for a specific capacity of 0.5 and a yield factor of 1 for the saturated thickness of the deposits. More than half the rocks, through which this well passed, are tuff-breccias of extremely low permeability; the remainder of the rocks consist largely of partly cemented volcanic gravel and sand.

TUSCAN FORMATION (PLIOCENE)

DEFINITION AND GENERAL CHARACTER

The name "Tuscan formation" was first applied by Diller (1895) to a sequence of fragmental andesite and basalt exposed extensively at the southern end of the Cascade Range from Dry Creek, Butte County, to Little Cow Creek, Shasta County. Subsequently, Diller referred to the unit as the Tuscan tuff, the name formally adopted by the U.S. Geological Survey (Wilmarth, 1938, p. 2200). Anderson (1933) adopted the Tuscan formation usage and described the type section designated by Diller at Tuscan Springs, 8 miles northeast of Red Bluff (pl. 2). Anderson's description of the type section, which is herein quoted on page 70, indicates that the lithology of the unit is heterogeneous and that less than half the total thickness is tuff. Therefore, it is proposed here that the term Tuscan tuff be discarded and that the term Tuscan formation be adopted.

The eastern limits of exposures of the Tuscan formation are about 25 miles northeast of the Sacramento Valley where the Tuscan is covered by younger volcanic rocks. Beneath the Sacramento Valley, west of the outcrop, the fragmental volcanic rocks of the Tuscan formation interfinger with the predominantly nonvolcanic continental sediments of the Tehama formation. A few pre-Tuscan and post-Tuscan basalt flows are included in the Tuscan formation as shown on the geologic map (pl. 2), but these rocks are of minor importance, and differentiating them from the Tuscan was beyond the scope of this investigation.

In general, the structure of the Tuscan is homoclinal; the strata dips southwest. The structures as modified by a monocline along the northeastern edge of the Sacramento Valley and by several small northwestward-trending folds east of Red Bluff. (See fig. 2.) South of Chico, homoclinal dips of 2° to 3° characterize the Tuscan beneath the alluvium of the valley. Well records suggest that these dips continue beneath the valley. (See pl. 3.) The buried top of the Tuscan in this area is a plain incised by deep canyons, much like the rugged topography on the exposed Tuscan to the east and north. Northward from Chico, the dip of the formation along the valley border increases to a maximum of 20° near Red Bluff. The dips flatten to low angles beneath the valley, however. This structure, the Chico monocline, has produced the remarkably straight northeast margin of the Sacramento Valley between Chico and Red Bluff. (See pl. 2.)

East of the valley the Tuscan formation has an average thickness of about 1,000 feet, and records of deep gas wells indicate that the thickness is at least as great beneath the Chico area. Farther west the volcanic section probably thins where the Tuscan interfingers with the Tehama formation.

At most places the Tuscan formation overlies Upper Cretaceous marine sedimentary rocks or the basement complex with angular unconformity. Beneath the valley the Tuscan is overlain unconformably by Pleistocene fanglomerate.

AGE

The Nomlaki tuff member, which occurs near the base of both the Tehama and Tuscan formations, has been dated as late Pliocene from vertebrate fossils found in sedimentary rocks of the Tehama just above the tuff in western Tehama County. (See p. 73.)

Stratigraphic relations also suggest a probable late Pliocene age for the Tuscan formation.

At Welch's hydraulic mine on Dry Creek north of Oroville in the SW¼ sec. 18, T. 21 N., R. 4 E., the Tuscan formation overlies gravel containing fragments of the basalt similar to that at Table Mountain. This basalt is younger than part of the great series of fragmental volcanic rocks in the Sierra Nevada, which range in age from late Eocene to middle Pliocene. This relationship suggests that the Tuscan is not older than late Eocene and probably is younger.

The Tuscan has been deformed since its deposition, and some of the unconformably overlying alluvial-fan deposits and Red Bluff formation also have been arched or, at least, elevated (Anderson, 1933). Possibly the major deformation of the Tuscan formation was contemporaneous with the early or middle Pleistocene deformation of the Sierra Nevada to the south. If this assumption is correct, an upper age limit of early Pleistocene can be assigned to the Tuscan formation.

LITHOLOGY

The Tuscan formation consists of volcanic breccia and tuff-breccia, volcanic sandstone and conglomerate, coarse- to fine-grained tuff, and tuffaceous silt and clay. Most of the materials are of andesitic or basaltic composition, but the Nomlaki tuff member near the base of the formation is a coarse pumice tuff of dacitic composition.

The individual strata range from a few feet to more than 100 feet in thickness and are of variable hardness and resistance to erosion. Differential erosion and mass wasting of these beds have produced alternating cliffs and slopes. Much of the breccia and tuff-breccia contain angular and subangular blocks of andesite and basalt several feet across, although the average size of the large fragments is much less. Where differential erosion has removed most of the finer grained material, the large blocks are abundant at the surface, this gives a false impression of the proportion of such blocks in the original bed. Such exposures commonly are called "scab lands" and are of little economic use, even for grazing. The breccia and some of the tuff-breccia beds weather to a very hard concretelike mass, and these strata generally form the cliffs. The volcanic conglomerate and sandstone, tuff, tuffaceous clay, and some of the fine-grained tuff-breccia beds are relatively soft and tend to form gentle slopes.

According to Anderson (1933), the breccia and tuff-breccia are of mudflow origin and have a source in the Lassen Peak region northeast of the Sacramento Valley. These mudflow rocks are most abundant in the eastern area near the source, where the entire formation is more than 1,000 feet thick. Farther west the percentage of stream-laid materials—sandstone, conglomerate, and tuffaceous silt and clay—increases in relation to the percentage of mudflow breccias and tuff-breccias.

Most of the volcanic conglomerate is not as indurated or cemented as the breccia and tuff breccia. The conglomerate, which consists of waterworn pebbles, cobbles, and boulders of andesite and basalt in a sandy or silty matrix, obviously is of fluviatile origin, as is the volcanic sandstone which commonly is crossbedded and channeled. Volcanic sandstone and conglomerate make up less than a quarter of the total section at the type locality at Tuscan Springs, but these stream-laid deposits comprise from a third to half the section along the eastern border of Sacramento Valley. Logs of water wells in the Chico area indicate that fluviatile deposits constitute from one-half to all of the Tuscan formation beneath the valley.

The tuffs, which vary in texture and consist mostly of angular crystal fragments and pieces of volcanic glass, can be distinguished from the volcanic sandstone by the absence of crossbedding and stratification, better sorting, finer grain size, and the angular or subangular shape of the grains (Anderson, 1933, p. 230).

A typical exposure of the Tuscan formation on the north bank of Salt Creek just west of Tuscan Springs is described by Anderson (1933, p. 224) as follows:

	Thickness (feet)
Tuff-breccia	175
Fine tuff, sandy appearance	10
Tuff-breccia, cliff-forming	100
Crossbedded volcanic sand with intercalated volcanic conglomerate	25
Lapilli-tuff	5
Crossbedded volcanic sand	10
Tuff-breccia, cliff-forming	90
Volcanic conglomerate, with boulders near the top	25
Stratified volcanic sand, pebbles and cobbles appearing near the top	25
Coarse tuff, with decomposed plant stems	2
Massive medium tuff	5
Crossbedded volcanic sand	6
Fine blue-gray tuff	8
Volcanic sand	1
Massive coarse tuff with decomposed plant stems	1
Volcanic sand with scattered pebbles	5
Medium blue-gray tuff	6
Crossbedded volcanic sand with intercalated conglomerate	10
Fine, purple-gray tuff	2
Crossbedded volcanic sand with scattered pebbles and cobbles	5
Compact fine white tuff	3
Crossbedded volcanic sand with small lenses of conglomerate	10
Medium-blue-gray tuff	5
White vitric-crystal hornblende-hypersthene dacite tuff. Scattered pumice fragments from one-half to 4 in. in dimension (Nomlaki tuff)	100

	Thickness (feet)
Tuff-breccia	15
Medium-blue tuff	5
Volcanic conglomerate with few nonvolcanic pebbles	10
Medium-blue tuff	10
Conglomerate with 50 percent volcanic pebbles; 50 percent chert, quartzite, quartz, et cetera, pebbles	20
Total thickness	694

The section unconformably overlies sandstone and shale of Late Cretaceous age probably belonging to the Chico formation as originally described.

WATER-BEARING CHARACTER

The Tuscan formation is an important source of ground water in the northeastern part of the Sacramento Valley. Fresh water is found at all depths in the Tuscan. Throughout much of the northeastern part of the valley the relatively permeable volcanic rocks are separated from the underlying marine sedimentary rocks of Eocene age by a dense, impervious basalt flow, 50 to 215 feet thick (Ellsworth, 1948).

A total of 452 logs of wells in the vicinity of Chico (T. 21 N., Rs. 1 and 2 E; and T. 22 N., Rs. 2 and 3 E.) were studied to determine the subsurface extent of the Tuscan formation. The first lava, ash, volcanic ash, or other volcanic material reported by the driller was considered to be the top of the Tuscan formation. The Tuscan formation was penetrated in 159, or 35 percent of the 452 wells. However, irrigation and municipal supply wells were not differentiated from shallow domestic and stock wells in the analysis, so the proportion of irrigation and municipal wells tapping the Tuscan probably is much greater than 35 percent.

Production data are available on several representative wells that obtain all or most of their water from the Tuscan formation. Three wells drilled at the Chico airfield, less than a mile from outcrops of the Tuscan formation, appear to obtain all their water from permeable beds in the volcanic sequence. These wells are 402 to 428 feet deep and produce 900 to 950 gpm. The specific capacities range from 26 to 45 gpm per foot of drawdown and yield factors for the saturated thickness range from about 8 to 14.

Data are available for several wells of the California Water Service Co. at Chico. In the usual construction of these wells surface casing was set to depths of 40 to 60 feet and the well casing perforated opposite permeable beds in the alluvium (alluvial-fan deposits and fanglomerate from the Cascade Range), and perforated and gravel packed opposite the volcanic rocks of the Tuscan formation. The data are summarized as follows:

California Water Service Co. wells		Depth (feet)	Discharge (gpm)	Specific capacity (gpm per ft of drawdown)	Perforations		Yield factor for saturated thickness
Number	Station				Total length (feet)	Distribution	
22/1E-23P1	12	550	1,130	80	250	50 ft in alluvium 200 ft in Tuscan formation.	32
22/1E-26K1	9	572	1,345	94	332	82 ft in alluvium 250 ft in Tuscan formation.	28
22/1E-27G1	10	640	1,040	71	338	113 ft in alluvium 225 ft in Tuscan formation.	21
22/1E-35H1	11	550	955	42	356	92 ft in alluvium 264 ft in Tuscan formation.	12

The relative amounts of water produced in these wells from the Tuscan formation and from the overlying alluvial material cannot be determined, but scanty data on production of shallow wells in the Chico area suggest that the alluvial deposits are not more permeable, on the average, than the Tuscan.

TEHAMA FORMATION (PLIOCENE)

DEFINITION AND GENERAL CHARACTER

The Tehama formation is exposed in Tehama County on the northwest side of the Sacramento Valley, where Russell and Vander-Hoof (1931, p. 12) describe the formation, as follows:

> The Tehama formation is composed of about 2,000 feet of massive, pale greenish gray to pale buff sandy clays which are usually tuffaceous; intercalations of sand and gravel, often strongly cross-bedded, are present throughout. A massive coarse-grained pumice tuff member occurs near the base.

The tuff, named the Nomlaki tuff member from its type locality on the Nomlaki Indian Reservation in Tehama County, is near the base of both the Tehama and the Tuscan formations.

Below the surface, the Tehama formation extends as far east as the axis of the Sacramento Valley where, in the northern part, the dominantly fluviatile western-source sediments of the Tehama interfinger with the clastic volcanic rocks of the Tuscan formation, and in the southern part, with the eastern-source continental sediments of the Laguna formation.

The structure of the Tehama is broadly homoclinal, with generally low eastward dips toward the axis of Sacramento Valley. However, gentle northward- to northwestward-trending folds are superimposed on the regional structure at Corning Ridge, Rumsey Hills, Capay Valley, Dunnigan Hills, and Plainfield Ridge. (See fig. 2.) Dips of the bedding are more than 60° in the English Hills and in the foothills between Putah and Cache Creeks, but most dips are less than 20°.

Except where it overlies Pliocene(?) volcanic sedimentary rocks near Vacaville in the southwestern corner of the valley and basalt of Pliocene(?) age at scattered localities from Orland Buttes to south of Vacaville, the Tehama rests uncomformably on Eocene or Cretaceous marine sedimentary rocks, and a long hiatus is represented by the unconformity.

Little is known about the relation of the Tehama formation to the underlying rocks beneath the southern part of the Sacramento Valley; but fragmentary data, such as electric logs and cores of gas test wells, suggest that the hiatus represented by the uncomformity between marine sedimentary rocks of Eocene age and the Tehama formation in the English Hills exposures may be represented by more or less continuous deposition near the axis of the valley trough.

In the hills along the western margin of the valley the Tehama formation is overlain unconformably by the Red Bluff formation and related terrace deposits and by undeformed alluvium of late Pleistocene and Recent age, but nearly continuous deposition may have occurred beneath the central part of the valley. Unfortunately, the Tehama greatly resembles the overlying deposits, and satisfactory criteria for a subsurface distinction have not been established.

AGE

The Tehama formation interfingers with the Tuscan formation beneath the northern part of the Sacramento Valley. A pumiceous dacite tuff, the Nomlaki tuff member, near the base of both formations has been assigned to the upper Pliocene on the basis of vertebrate fossils obtained from fine-grained sediments of the Tehama formation, 10 feet stratigraphically above the tuff at a locality 18 miles west-northwest of Corning in Tehama County (VanderHoof, 1933b, p. 384).

A horse jaw found at the southern end of the Dunnigan Hills, 5 miles west of Woodland, was said by VanderHoof to be either upper Pliocene or Pleistocene (in Anderson and Russell, 1939, p. 250). The bone occurred in light greenish-gray sandy clay a few feet below a gravel cap of the Red Bluff formation. Anderson and Russell (1939, p. 250) stated that the bone-bearing sediments probably are correlative with the Tehama formation.

A horse tooth obtained from lenticular silt, sand, and gravel exposed in a gravel quarry in the southern part of the Plainfield

Ridge about 2 miles north of Putah Creek was described as follows by D. E. Savage (written communication, January 1951):

> Tooth—lower molar of *Equus*—more exact identification is uncertain. Appearance *suggests* that it is some type of horse found in earlier Pleistocene (Irvingtonian) of (San Francisco) Bay area.

The enclosing sediments probably are of the Tehama formation, the base of which was found at a depth of about 2,600 feet in Standard Oil Co. Hooper No. 1 gas well 1½ miles to the northwest. (See Kirby, 1943a, p. 600.)

A collection of vertebrate fossils from a locality in the northwestern part of the Montezuma Hills was dated as probably early middle Pliocene (Stirton, *in* Weaver, 1949, p. 97). The bone-bearing sediments, which were mapped as the Wolfskill formation by Weaver (1949), contain abundant volcanic material and are as similar to the Mehrten formation of Piper and others (1939) in the Mokelumne area as to the Tehama or Wolfskill formation exposed north of the Montezuma Hills. Paleobotanical and vertebrate paleontological evidence (Axelrod, 1944) suggests that the upper part of the Mehrten formation may be as young as middle Pliocene. The correlation of the bone-bearing sediments in the northwestern part of the Montezuma Hills with the Tehama formation is extremely doubtful.

At least several hundred feet stratigraphically above the bone-bearing sediments in the northwestern part of the Montezuma Hills is a bed of diatomaceous clay of Pliocene or Pliocene and Pleistocene age which occurs beneath the alluvial-fan deposits in sediments probably referable to the Tehama formation. The clay was penetrated at a depth of 18 to 22½ feet below the land about 2 miles north of the Montezuma Hills in a test boring made by the U.S. Army Corps of Engineers and at similar depths in two other test holes several hundred feet away. Samples of the clay were examined by K. E. Lohman of the Paleontology and Stratigraphy Branch of the U.S. Geological Survey who identified 20 species and varieties of diatoms. The diatom assemblage is essentially the same as part of a larger assemblage obtained from a similar and widespread stratum of diatomaceous lacustrine clay that occurs in the subsurface Tulare formation in the San Joaquin Valley to the south (Davis and others, 1959). Lohman (written communication, 1956) stated that there is little doubt that the bed north of the Montezuma Hills was deposited during the same interval of geologic time as the clay in the San Joaquin Valley and under extremely similar ecologic conditions.

The stratigraphic relationship of the Tehama formation to the continental deposits exposed in the Mokelumne area on the southeast side of the Sacramento Valley is somewhat uncertain. Presumably, the western-source Tehama sediments interfinger beneath the valley with eastern-source materials and with deposits brought in from the north by an ancestral Sacramento River. The Tehama probably is in part contemporaneous with the Laguna formation. Rather meager fossil evidence and indirect stratigraphic evidence suggest a late Pliocene to early Pleistocene(?) age for the Laguna (Piper and others, 1939, p. 61).

The Tehama formation appears to be in part equivalent in age to the Sonoma volcanics exposed in the Coast Ranges immediately north of San Pablo and Suisan Bays. Stratigraphic and paleobotanical evidence indicates a late Pliocene and possible early Pleistocene age for the Sonoma volcanics according to Kunkel and Upson (in press). The Sonoma volcanics interfinger with sedimentary rocks mapped by Taliaferro (1951, p. 147) as Tehama formation on the west side of Berryessa Valley in the Coast Ranges about 15 miles west of Winters.

The evidence suggests that the deposition af the Tehama formation was inaugurated by an orogeny at the end of middle or beginning of late Pliocene time that raised the present northern Coast Ranges and was closed by a middle Pleistocene orogeny that further affected the Coast Ranges and deformed the Tehama formation (Taliaferro, 1951, p. 145, 149). The Tehama, therefore, in the opinion of the writers, can be assigned to the upper Pliocene and possibly the lower Pleistocene. The Tuscan formation and probably, in part, the Laguna formation are correlatives of the Tehama in the Sacramento Valley region.

DISTRIBUTION AND THICKNESS

The Tehama formation is exposed along the foothills of the Coast Ranges from a few miles south of Vacaville near the southwestern corner of the Sacramento Valley to the region west of Redding, Shasta County. South of Cache Creek and from Cortina Creek to the South Fork of Willow Creek the Tehama is grouped with younger continental sediments that may include the Red Bluff formation. The resultant combined unit is designated the Tehama formation and related continental sediments on the geologic map of Sacramento Valley (pl. 2) and is discussed briefly on pages 81 to 82.

Below the surface the Tehama formation extends as far east as the axis of the valley where it interfingers in the northern part with the Tuscan formation and in the southern part with the Laguna formation.

The maximum thickness of the Tehama is more than 2,000 feet in the northern part of the area in Glenn and Tehama Counties (Anderson and Russell, 1939). The Nomlaki tuff member is about

700 feet above the base near the axis of the northern part of the Sacramento Valley, but farther west the Nomlaki tuff member, or even younger beds, may rest on the Cretaceous rocks, indicating a westward overlap (Anderson and Russell, 1939).

In the south-central part of the valley the Tehama formation appears to have a maximum thickness of 2,500 to 3,000 feet, although none of the exposed sections of the formation are as thick. An eastward thickening of the Tehama from the northern English Hills toward the southern part of the Yolo Basin is indicated by electric logs of numerous gas test wells (Thomasson and others, in press). On the basis of dips in surface exposures, the Tehama formation appears to be no more than about 1,200 feet thick in the northern part of the English Hills near Winters, but in gas wells near the eastern margin of the hills the formation appears to have a stratigraphic thickness of about 1,800 feet of probable Tehama. In the southern part of the Plainfield Ridge wells have penetrated more than 2,600 feet of fresh-water-bearing continental sediments, presumably all the Tehama formation.

Probably not all the nonmarine sediments older than late Pliocene beneath the central part of the Sacramento Valley are correlative with the Tehama formation exposed to the west. As shown on geologic sections *A–A′* and *B–B′* (pl. 3) these deposits are termed the predominantly nonmarine post-Eocene sediments, and they may include sediments of Oligocene, Miocene, and early Pliocene age not exposed along the valley margins. Possibly they include the Valley Springs and Mehrten formations (volcanic rocks from the Sierra Nevada) in the lower part.

PHYSICAL CHARACTER

In its type area on the west side of the northern part of the Sacramento Valley, the Tehama formation consists of poorly sorted fluviatile sediments, comprising massive sandy silt, silty sand, and clayey silt enclosing lenses of crossbedded sand and gravel (Anderson and Russell, 1939, p. 233). These sediments probably were deposited under flood-plain conditions and had a northern and western source, as indicated by the crossbedding of the coarser sediments, the abundance of Coast Ranges and Klamath Mountains minerals and rock types, and the eastward decrease in average grain size (Anderson and Russell, 1939, p. 233). However, the eastward decrease in grain size at many places is masked by the interstratified beds of relatively coarse volcanic detritus of the Tuscan formation, particularly as shown by logs of deep water wells in the Corning and Orland areas.

The fine-grained sand, silt, and clay of the Tehama formation in large part are pale yellowish to greenish gray and weather to grayish orange or yellowish brown. These deposits generally are compact but are not cemented.

The coarse-grained beds are poorly sorted and, for the most part, are unconsolidated, although cemented gravel is reported in many drillers' logs of water wells, and in the English Hills calcium carbonate-cemented conglomeratic beds are common in the lower part of the Tehama formation.

The proportion of coarse-grained material in the Tehama varies considerably, both areally and vertically. In general, the materials in the basal part of the section are coarsest in the southern area of exposures, principally in the Dunnigan Hills-English Hills region; less is known about the northern area; but there, too, the basal part of the Tehama formation probably is relatively coarse grained. The materials in exposures from the Dunnigan Hills to the English Hills, on the average, are somewhat coarser than those of the Tehama of the type area in the northern part of the valley, although fine-grained materials predominate in all but the basal few hundred feet in both northern and southern areas.

The Nomlaki tuff member, which is exposed for about 40 miles along the northwest side of Sacramento Valley, is a pale-gray or salmon-pink poorly consolidated dacite tuff composed of white pumice fragments in a matrix of glass shards and crystal fragments. The tuff generally is porous and poorly assorted; evidence of stream reworking is only local. The thickness is variable; most exposures on the west side of the valley are a few feet or tens of feet thick, whereas northeast of the valley in the Lassen Peak area as much as 200 to 300 feet of the tuff is exposed and indicates an eastern source (Anderson and Russell, 1939). Peléan-type eruptions are believed to have distributed the Nomlaki; the deposits probably accumulated within a relatively brief period (Anderson and Russell, 1939, p. 246).

A pumiceous tuff near the base of the Tehama formation in the area of exposures from the Dunnigan Hills south may be the Nomlaki tuff member and has been so mapped by Kirby (1943b) and Taliaferro (1951). In the English Hills the tuff occurs in several distinct strata and has been, at least in part, reworked by streams. Like the Nomlaki the tuff in the English Hills contains abundant pumice fragments and is of rhyolitic or dacitic composition. However, the tuff interbedded with the Tehama in the southern part of the Dunnigan Hills, the exact correlative of that in the English Hills, is believed by Anderson and Russell (1939, p. 250) to be unrelated to the Nomlaki because the refractive index of the glass is higher, plagioclase is more abundant and sodic in composition, hornblende and hypersthene are less abundant, and augite is more abundant than in the Nomlaki. Weaver (1949, p. 131) suggests that the tuffs in the English Hills may be related to the volcanic activity that produced the basalt at Putnam Peak and other nearby localities.

The section above the pumice tuff beds in the English Hills contains fairly abundant pumice fragments and a large amount of reworked tuffaceous material. Some of the clays probably are montmorillonite or related minerals, although little work has been done on them to verify this supposition.

The gravel beds in the English Hills and in the foothills between Putah and Cache Creeks contain abundant subrounded pebbles and cobbles of chert, sandstone, shale, and serpentine of the types found in the Franciscan group and the Knoxville formation; dark highly siliceous rocks that probably were derived from pre-Franciscan basement complex; andesite, rhyolite, and dacite; and locally numerous pebbles and small cobbles of basalt. The pebbles commonly are surrounded by encrusting masses of calcite-cemented sandstone, particularly in the stratigraphically lower beds. It is not known whether this cementation is as common below the water table as in surface exposures, but if it is widespread, the permeability of even the well-sorted gravel beds of the Tehama formation must be only moderate, at best. Although many of the gravel and sand beds are lenticular and of restricted extent, in the northern part of the English Hills some strata, as noted both in well logs and in exposures, appear to be relatively consistent over an area of several square miles.

WATER-BEARING CHARACTER

The Tehama formation is one of the most important sources of ground water for irrigation in the Sacramento Valley and will be an even more important future source when the groundwater body is more extensively developed and deeper wells are drilled.

It is believed that the alluvium of late Pleistocene and Recent age overlying the Tehama generally is less than 150 feet thick, although the Red Bluff formation and earlier Pleistocene deposits not exposed in the hills along the western edge of the valley may extend to considerably greater depth in the valley proper. However, in the following discussion it will be assumed that the top of the Tehama is within about 150 feet of the land surface in most of the western part of the Sacramento Valley.

In the subsurface the Tehama formation in the northern part of the valley consists mostly of massive sandy silt and silty clay, containing lenses and tongues of poorly consolidated sand and gravel that generally make up less than 15 percent of the section. The coarse-grained deposits locally are abundant in the western part of the El Camino Irrigation District, T. 25 N., R. 3 W., secs. 9, 10, 15, 16, 21, and 22, where several water wells tap a thick (50 to 100 feet) gravel zone at a depth ranging from about 300 to 450 feet. Wells in this district produce large volumes of irrigation water from the permeable sand and gravel beds which may be interfingered in part with volcanic sediments of the Tuscan formation.

Production data and drillers' logs were examined for 20 wells of the El Camino Irrigation District. Well depths range from 268 to 1,001 feet and average 506 feet, discharge range from 540 to 2,260 gpm and average 1,080 gpm, and specific capacities range from 32 to 170 and average 76 gpm per foot of drawdown. The deepest well, 25/3W–3N1, was drilled through clay, sand, and gravel of the Tehama formation to a depth of 446 feet. Volcanic ash, clay, and volcanic sand and gravel of the Tuscan formation were found from 446 to 1,001 feet. The well produced 1,000 gpm with 15 feet of drawdown, which indicates a specific capacity of 67 gpm per foot of drawdown. The yield factor for the saturated section was about 7. Well 25/3W–16Q1, 440 feet deep, produced 1,030 gpm at a 6-foot drawdown for a specific capacity of 170 and a yield factor of 40 for the saturated material. The yield factor for the aquifers tapped was 175, which compares favorably with yield factors for the most permeable sand and gravel beds in the alluvium on the west side of the Sacramento Valley. Well 25/3W–16Q1 and three other wells have high yield factors and specific capacities above 100, are less than 550 feet deep, and produce water from the thick gravel section described in the preceding paragraph.

The high production obtained from wells tapping sedimentary deposits of the Tehama and Tuscan formations in the El Camino District is not typical of wells along the west side of the valley. The Tehama formation in the Corning area consists of yellow clay, poorly consolidated sandstone, and conglomerate. Well 24/3W–3B1, drilled through clay, sandstone, and gravel of the Tehama from about 50 to 375 feet, produced 580 gpm at 28.3 feet of drawdown. The specific capacity was 20.5; the yield factor for the aquifers was 38. Well 24/3W–10H1, 220 feet deep, owned by the Maywood Packing Co., pumped 140 gpm at a drawdown of 2.3 feet. The specific capacity was 61 gpm per foot of drawdown; the yield factor for the aquifers was 135.

Irrigation wells on the Capay land grant in T. 22 N., R. 2 W., and T. 23 N., R. 2 W., tap clay and sandstone of the Tehama formation below depths of 100 to 200 feet. Many wells in this area obtain 500 to 1,000 gpm from the Tehama and overlying younger deposits.

The Tehama formation underlies the Stony Creek alluvial fan at depths of 200 feet or less. However, it is not an important source of irrigation water, because the overlying alluvial deposits are far more permeable and yield large quantities of water to shallow irrigation wells. The Tehama formation is at a relatively shallow depth south of Artois on the southern part of the Stony Creek alluvial fan and beneath the low plains as far south as Williams. A few deep wells obtain water from the Tehama formation, but in general the results have been disappointing, probably because of the scarcity of coarse-grained materials. At Willows a municipal well of the California Water Service Co., 700 feet deep, produced 830 gpm at a drawdown of 23.1 feet. The yield factor for the sand and gravel aquifers, which total only 32 feet in thickness, was 115, which indicates that these coarse materials are very permeable but not thick.

Most of the west side of the valley from Willows to Williams is irrigated with surface water from the Glenn-Colusa Irrigation District canals. However, Bryan (1923) reported several early attempts to develop irrigation-water supplies by deep drilling. The Tehama formation in in this area is mostly fine grained and not very permeable, but several wells had small artesian flows.

A well drilled for the Maxwell Public Utility District, 639 feet deep, yielded 450 gpm at a drawdown of 71.6 feet for a specific capacity of only about 6.

Many irrigation wells southwest of Arbuckle in T. 13 N., R. 2 W., have been drilled to depths of 600 to 800 feet. These wells extend through a thick section of poorly assorted fluviatile sediments characterized by thick beds of yellow clay and layers of pebbly clay and poorly sorted gravel. These deposits probably are of the Tehama formation although their position immediately north of the Dunnigan Hills anticline suggests the possibility that they represent rapid deposition of alluvial fans after the major middle Pleistocene folding in the Coast Ranges and Dunnigan Hills.

Several unsuccessful attempts have been made to develop irrigation wells in the Tehama formation exposed in the Dunnigan Hills. The earliest and deepest well was 730 feet deep on the Gable Ranch in the valley of Oat Creek. In 1912, this well was drilled through clay, cemented gravel, clay and gravel, and sandstone and failed to produce water in appreciable quantities (Bryan, 1923). Several subsequent attempts to develop wells in the same area also have been unsuccessful.

Many deep irrigation wells south of Cache Creek and in the Putah Creek area of Solano County have high production rates and specific capacities. However, most of the wells may yield most of their water from highly permeable sand and gravel beds of the late Pleistocene and Recent alluvium (alluvial-fan deposits on geologic map) within about 150 feet of the land surface.

In a study of pump-test data furnished by the Pacific Gas and Electric Co. in the Putah area of Solano County, Thomasson, Olmsted, and LeRoux (in press) found that the yield factors for aquifers in the Tehama formation were much lower than the yield factors for the sand and gravel beds of the overlying alluvium in the same area. Where the alluvium is relatively thick and of high average permeability, as in the area between Winters and Dixon, wells less than 200 feet deep have sufficiently high discharges and specific capacities for irrigation requirements, but at many other places where the alluvium is thin or fine grained, wells more than 300 feet deep are needed.

The deepest water well in the Putah area, drilled for the University of California College of Agriculture at Davis, is 1,450 feet deep. The well is perforated only below 1,264 feet and thus gives useful data on the productivity of aquifers of the Tehama formation in the area. The water in the deep aquifers has considerable artesian head; at the start of the development test water was flowing slightly. When pumped the discharge was 1,800 gpm at a drawdown of 153 feet; the yield factor for the aquifers tapped was about 10—a figure representative of the aquifers of the Tehama in the general area but less than a tenth that of the sand and gravel of the overlying alluvium.

TEHAMA FORMATION AND RELATED CONTINENTAL SEDIMENTS, UNDIFFERENTIATED (PLIOCENE AND PLEISTOCENE

In two foothill areas along the western side of the Sacramento Valley the Tehama formation is grouped with younger continental sediments of fluviatile origin. On plate 2 these areas, one from Cache Creek south to the Montezuma Hills and the other between Cortina Creek and the South Fork of Willow Creek, are shown as the Tehama formation and related continental sediments, undifferentiated. This unit consists mainly of the Tehama formation described in the preceding pages, but south of Cache Creek it includes also the Red Bluff(?) formation and stream-terrace deposits younger than the Red Bluff, and between Cortina Creek and the South Fork of Willow Creek it includes a sequence of sediments that in part possibly are of Red Bluff age.

Most of the area south of Cache Creek was mapped as part of a detailed geologic and hydrologic investigation by Thomasson, Olmsted and LeRoux (in press). Owing to the difficulty in distinguishing the Tehama formation from the overlying Red Bluff(?) formation and stream-terrace deposits younger than the Red Bluff both in the foothills and beneath the valley, these units were assembled in one geologic unit—the Tehama formation and related continental sediments.

South of Putah Creek Weaver (1949) assigned the deformed continental sediments to two formations, the Wolfskill formation (Pliocene) and the Montezuma formation (Pleistocene). However, Taliaferro (1951, p. 147) recommended that the name Wolfskill be abandoned, inasmuch as the name Tehama antedates Wolfskill in the literature and the two formations are equivalent at least in part.

Difficulty in subdividing the continental sediments south of Cache Creek arises in part from the fact that Weaver's Wolfskill and Montezuma formations cannot be differentiated satisfactorily in the field. As described and mapped by Weaver, the Wolfskill appears to be essentially equivalent to the Tehama formation farther north, but the Montezuma formation appears to be a thicker and more heterogeneous unit than the Red Bluff formation north of Cache Creek.

The foothill belt between Cortina Creek in the northern Dunnigan Hills and the South Fork of Willow Creek west of Willows was mapped in detail by geologists of the U.S. Bureau of Reclamation, who assigned the name Cortina member of the Tehama formation to a sequence of deformed continental sediments believed to be in part correlative with the Tehama formation and in part possibly equivalent in age to the Red Bluff formation. In this area the terrace deposits and older alluvium younger than the Red Bluff are included in the alluvial-fan deposits on the geologic map (pl. 2).

The geologic unit mapped as Tehama formation and related continental sediments, undifferentiated, consists mainly of the Tehama formation but locally includes sediments of younger age. These sediments were combined into a single unit because of the difficulty of discriminating among them in the field. It was even more difficult to distinguish the same units in the subsurface section from the well records. In general, however, the water-bearing properties are similar to those of the Tehama formation.

LAGUNA FORMATION AND RELATED CONTINENTAL DEPOSITS (PLIOCENE(?) AND PLEISTOCENE)

DEFINITION

The Laguna formation and related continental deposits include three formations mapped by Piper and others (1939) in the Mokelumne area; namely, Laguna formation, Arroyo Seco gravel, and gravel deposits of uncertain age.

The Laguna formation is a sequence of predominantly fine-grained, poorly bedded somewhat compacted continental sedimentary deposits laid down after the major andesitic episode in the late Miocene and early Pliocene and before the last major tilting of the Sierra Nevada in the Pleistocene. The Arroyo Seco gravel and the gravel deposits of uncertain age are coarse-grained, poorly sorted deposits that form a discontinuous cap on the Laguna and older formations and probably in large part were deposited after the Pleistocene tilting of the Sierra.

Equivalents of these three formations can be traced northward from the Mokelumne area; but, because this investigation was limited —in time available for field work, the equivalent of the three formations are mapped together.

At many places, it is difficult to determine the subsurface boundaries between the Laguna formation and the underlying volcanic rocks from the Sierra Nevada and the overlying Victor formation and related deposits particularly near the axis of the valley where deposition may have continued during the hiatuses represented by unconformities near the valley margin. Accordingly, in the east-central part of the valley the predominantly nonvolcanic sediments below depths of 50 to 150 feet and above the largely andesitic detritus have been arbitrarily considered the Laguna formation, with the understanding that these sediments are not a well-defined lithologic and stratigraphic unit strictly equivalent to the Laguna formation of the outcrop areas.

AGE

The Laguna formation is probably Pliocene and possibly, in part, Pleistocene in age (Piper and others, 1939, p. 60). It overlies the Mehrten formation (late Miocene through middle(?) Pliocene) with apparent conformity and is unconformably overlain by the Arroyo Seco gravel (middle or late? Pleistocene). Beneath the central part of the Sacramento Valley the Laguna formation probably interfingers with deposits of an ancestral Sacramento River and with the western-source Tehama formation (late Pliocene).

A horse tooth obtained from clayey silt probably of the Laguna formation, in a well near Galt, Sacramento County, was determined by Stirton (1939) to be early late Pliocene in age or probably equivalent in age to the upper part of the Etchegoin formation of the San Joaquin Valley (Piper and others, 1939, p. 61).

The Arroyo Seco gravel is a pediment covering deposited after the last major uplift of the Sierra Nevada. Piper (Piper and others, 1939, p. 53) assigned a middle or late Pleistocene age to the uplift, but Matthes (1930, p. 29) placed the date of tilting at the end of the Pliocene or beginning of the Pleistocene, which would make the Arroyo Seco possibly early Pleistocene.

The gravel deposits of uncertain age are older than the Victor formation (late Pleistocene), but their relation to the Arroyo Seco gravel cannot everywhere be determined. Some of these gravel beds are younger than the Arroyo Seco, but in places they may be as old as the Laguna formation.

PHYSICAL CHARACTER

The exposures of the Laguna formation and related continental deposits are expressed topographically as a dissected plain near the eastern valley margin, and the outcrop areas approximate or coincide with the dissected alluvial uplands west of the Sierra Nevada (geomorphic unit 11 on pl. 1). Exposures, generally few because of the extensive soil cover, are in road and railroad cuts and steep stream banks, but only a few feet or tens of feet of stratigraphic thickness is exposed in these outcrops.

The soils are principally of four groups as classified by the U.S. Department of Agriculture Bureau of Soils: Redding series, Corning series on the Arroyo Seco and other gravel deposits, Whitney series, and San Joaquin series on the fine-grained sediments of the Laguna formation. Although they are gravelly, the Redding and Corning soils at many places are poorly drained because of a firmly cemented hardpan layer a few inches to a few feet below the land surface. Hardpan, mostly cemented by iron oxide or silica, is also extensive in the Whitney and San Joaquin soil; deep vertical percolation is greatly inhibited; and direct recharge from precipitation on areas underlain by the Laguna formation probably is minor in amount.

In general, the Laguna formation is an extremely heterogeneous assemblage of silt, clay, sand, and minor lenticular gravel beds deposited on broad flood plains by meandering, sluggish streams. Somewhat compact light-gray to yellowish-brown clayey silt to silty fine sand are most abundant; clean well-sorted sand occurs chiefly in relatively thin zones. Gravel beds, which are scarce, are mostly ill-sorted and of low permeability.

The mineralogy of the deposits indicates derivation chiefly from granitic and metamorphic rocks of the Sierra Nevada basement complex, although minor quantities of volcanic detritus from the Mehrten and other volcanic formations are present at most places. In outcrop, the gravel beds in the Laguna may be distinguished from those in the volcanic rocks from the Sierra Nevada by the relative scarcity of volcanic pebbles and cobbles, but it is impossible to make such a distinction in many well logs because most drillers do not indicate the composition of the pebbles and cobbles.

The type section of the Laguna formation exposed along Hadselville Creek in the Mokelumne area was described by Piper, Gale, Thomas, and Robinson (1939, p. 58), as follows:

	Thickness (feet)
Concealed, grass-covered slope	20
Silt or clay, dark earthy brown to red, iron-stained	6
Interval covered, probably sand	4
Sand, coarse and medium, cross-bedded	3
Gravel, lenticular bed (break or unconformity?)	0–6
Silt and very fine sand, reddish, iron-stained, some clay and medium to coarse sand	14
Silt and clay, well-sorted, gray	10
Thickness of measured section	57

Another excellent exposure of the Laguna is in the bluff on the north bank of the American River just east of the bridge at Fair Oaks. The section is described below:

Top of bluff.	Thickness (feet)
Sand, arkosic, cemented, reddish, well sorted, medium coarse to coarse	20
Silt, sandy, tough, white, thin-bedded	3
Silt, massive, deep-red, iron-cemented	5
Sand, medium to fine, gray-green	3
Sand, coarse, buff; contains thin lenses of gravel	25
Base of bluff.	
Total thickness of measured section	56

The sand in this section is arkosic and contains abundant weathered feldspar, biotite, and angular quartz grains. Sand of this type obviously was derived from the granodiorite exposed in the Sierra foothills to the east. Quartz is less abundant, and clay is more prominent in the fine-grained sediments west of the amphibolite and diabase exposures, such as in the area between Oroville and Wheatland.

In general, the sediments of the Laguna formation are finer grained and more compact than the overlying deposits, although it is difficult to determine the subsurface boundary in most well logs. Logs of water wells that penetrate the Laguna show a predominance of hard silt and clay with smaller amounts of sand, "tight" sand, and sandstone. Gravel is not abundant and is rarely described as "clean," but some is usually reported as "tight" gravel, clay and gravel, or cemented gravel.

It is difficult to measure dips of the Laguna formation in the exposures because of the rather massive character of the fine-grained sediments. The coarser materials are crossbedded and mostly lenticular but appear to dip generally westward at angles of less than 5°. Data from well logs indicate that the top of the Mehrten formation (or base of the Laguna) has an average dip of about 70 feet to the mile (about 0°45′) beneath the southeastern part of the

Sacramento Valley, south of the American River (Piper and others, 1939, pl. 4). The sediments of the Laguna formation appear to form a wedge above the volcanic rocks, thinning near the Sierra Nevada and thickening toward the axis of the valley. The average thickness of the Laguna beneath the eastern part of the valley probably is less than 500 feet; however, the deposits may be more than 1,000 feet thick near the axis of the valley, and the roughly equivalent Tehama formation is more than 2,000 feet thick beneath the western part of the valley.

The Arroyo Seco gravel, a relatively thin deposit unconformably capping the Laguna formation and older rocks to the east, has been described at several localities. A representative section exposed in a gravel pit near Elk Grove was described by Piper, Gale, Thomas, and Robinson (1939, p. 51), as follows:

	Thickness (feet)
Sand, unsorted, chiefly fine and medium, also unsorted gravel and sand in alternating beds 3 to 9 inches thick. Base of member uneven, with a vertical range of 2 feet	3–5
Sand, unsorted, dominantly fine and medium, iron-stained	7–5
Gravel; commonly less than 1 inch in diameter, but some cobbles 4 inches, with matrix of unsorted iron-stained silt and sand; encloses some coarse sand in discontinuous beds as much as 4 inches thick	8–9
Base of section is floor of pit, which uncovers light-gray sandy silt (Laguna formation?)	
Maximum thickness of measured section	19

The Arroyo Seco gravel, the gravel deposits of uncertain age, and other deposits of similar origin north of the Mokelumne area are extensive, particularly near the eastern edge of the outcrop area of the Laguna formation and related continental sediments. In the area between the American River and Auburn Ravine, however, gravelly deposits generally are absent.

The gravel deposits near Oroville are very coarse and are more than 100 feet thick in places—much thicker than most of the deposits farther south. The gravel deposits on the old terraces of the American River between Folsom and Elk Grove are more than 50 feet thick in places.

Most of the gravel deposits are coarse and contain abundant cobbles of quartz and metamorphic rocks in a red silty or sandy matrix. The gravel overlaps the older sedimentary rocks. Many of the areas shown on the geologic map as Laguna formation and related continental sediments are thin gravel deposits mantling the volcanic rocks from the Sierra Nevada, sedimentary rocks of Eocene age (Ione formation), and basement complex.

The gravel deposits have been dredged extensively for gold, particularly along the old channels of the American and Feather Rivers.

The tailings left by these operations consist of huge ridges of cobbles and small boulders standing 5 to 50 feet or more above the adjacent land surface.

WATER-BEARING CHARACTER

The Laguna formation and related continental deposits are mostly relatively fine grained and are compacted or cemented; permeable sand and gravel at most places are of minor extent and thickness. Most of the Arroyo Seco gravel and gravel deposits of uncertain age are above the saturated zone in the outcrop areas along the eastern margin of the valley; farther west, beneath the alluvial deposits of late Pleistocene and Recent age, the gravel beds commonly are cemented or are tightly bound by a matrix of silt and clay.

Ill-sorted, predominantly fine-grained strata of the Laguna formation yield moderate quantities of water to wells at most places along the eastern margin of the Sacramento Valley. Permeable medium-grained to coarse-grained sand in the Laguna locally is sufficiently thick to supply large quantities of water to deep irrigation and municipal wells, but the finer grained compact sediments predominate at most places, and the wells of high capacity generally tap the overlying Victor formation, and (or) the underlying volcanic rocks from the Sierra Nevada and the Laguna formation.

Well yields are variable, as might be deduced from the heterogeneous character of the deposits. Where coarse-grained well-sorted sand is abundant, the yields are high. For example: Well 9/6E–19N1, north of the American River and northeast of Sacramento, produced 1,000 gpm at a drawdown of 24 feet for a specific capacity of 42 gpm per foot of drawdown. The yield factor for a total of 27 feet thickness of sand tapped by the well was about 150. This compares favorably with yield factors for the sand and gravel aquifers in the post-Laguna alluvial sediments on the east side of the Sacramento Valley.

Well 9/5E–11A2 produced 1,000 gpm at a drawdown of 40 feet for a specific capacity of 25 gpm per foot of drawdown. The yield factor was 100 for a total thickness of 25 feet of water-bearing material tapped by the well. This comprised 11 feet of brown micaceous sand and 14 feet of coarse sand and fine gravel.

Well 9/5E–13L1 of the Ben Ali Water Co. had a yield factor of about 110 for 40 feet of gravel opposite perforations. Well 9/5E–23L2 at the U.S. Geological Survey building had a yield factor of about 190 for 26 feet of sand and gravel from 444 to 470 feet deep in the lowermost part of the well.

An exceptionally high yield factor for an aquifer in the Laguna formation was 250 for 23 feet of loose sand tapped by well 9/5E–31N1 of the California Packing Corp. in Sacramento. This sand probably is an old deposit of the Sacramento River; it may be inferred that the sand is coarse grained and very well sorted.

In the Gridley area north of Marysville the sand stratigraphically equivalent to the Laguna formation is very productive. Well 18/2E-36Q1, 328 feet deep, had a specific capacity of 60 gpm per foot of drawdown and a yield factor of 330 for a total thickness of 18 feet of sand.

The yield factor for the entire saturated thickness of the Laguna formation penetrated in well 9/6E-19R1 was only about 8. Well 9/5E-22G1 had a yield factor of 18 for the saturated section tapped. Well 9/5E-23F1 of the Ben Ali Water Co. had a yield factor of only about 8 for the saturated thickness; the yield factor for the sand strata alone was 46. Well 9/5E-23L1 near the U.S. Geological Survey building had a saturated-thickness yield factor of about 8; the yield factor for the sand alone was nearly 60.

Well 6/6E-2D1, 455 feet deep, obtains its water mostly, if not entirely, from the Laguna formation and may be considered representative of the Laguna in the area between the Cosumnes and American Rivers. This well produced 1,840 gpm at a drawdown of 37 feet for a specific capacity of 50 gpm per foot drawdown. The yield factor for the saturated thickness was about 12; for the sand (described as "sandstone") it was 67.

It is apparent from the figures above that some of the sand aquifers in the Laguna formation are highly permeable, although the average permeability of the entire formation is only low to moderate. Silt, clay, and fine sand nearly everywhere constitute most of the thickness of the Laguna formation; the average percentage of fine-grained deposits reported in logs of wells tapping the Laguna is more than 60 percent.

FANGLOMERATE FROM THE CASCADE RANGE (PLEISTOCENE)

DISTRIBUTION AND GENERAL CHARACTER

The fanglomerate from the Cascade Range is exposed along the northeast margin of the Sacramento Valley from 5 miles northeast of Red Bluff to 2 miles east of Chico. The fanglomerate, which consists almost entirely of detritus derived from the Tuscan formation, has the surface form of alluvial fans that now are much dissected. The fanglomerate forms the dissected alluvial uplands west of the Cascade Range (geomorphic unit 12 on pl. 1). In cross section the fanglomerate is wedge shaped, laps out against the Tuscan formation on the east, and thickens toward the west. The fanglomerate unconformably overlies the Tuscan formation, from which it can be distinguished by the absence of mudflow tuff and tuff breccia. North of Pine Creek in the area of regional uplift (fig. 2), the fanglomerate is less than 150 feet thick (geologic section *a–a′*, pl. 4), but locally west of Chico it is more than 600 feet thick. The overlying alluvial deposits west of the exposures are nearly everywhere less than 50 feet thick.

AGE AND CORRELATION

Although no fossils have been found in the fanglomerate from the Cascade Range, the relationship to adjacent formations of known age suggests that it is Pleistocene.

The fanglomerate unconformably overlies and abuts the westward-dipping beds of the Tuscan formation, and it postdates the folding that produced the Chico monocline. Anderson (1933, p. 244) correlates the fanglomerate with the Red Bluff formation to the west. Both units unconformably overlie upper Pliocene rocks, and both have been uplifted and dissected since their deposition.

The fanglomerate in part may be correlative with the Arroyo Seco gravel to the south as well as with the Red Bluff formation to the west.

PHYSICAL CHARACTER

The fanglomerate is being dissected by the larger streams from the Cascade Range. The fan surfaces generally are smooth between the streams, although there is considerable local microrelief, and large cobbles and boulders dot much of the surface. The typical soils are stony clay loam and gravelly clay loam of the Tuscan soils series.

The exposed fanglomerate is almost indistinguishable from the volcanic sediments of the Tuscan formation. Volcanic sand, gravel, and silt are typical of both deposits. However, unlike the Tuscan formation, the fanglomerate contains no mudflow tuff and tuff-breccia. Locally, the beds are well indurated and stand in nearly vertical exposures more than 25 feet high.

The materials reported in well logs in the Chico area are similar to the exposed fanglomerate on the north and east. Gravel, cemented gravel, and clay and gravel make up an average of about half the total thickness; the remainder is largely yellow, brown, or red clay containing a few beds of sand.

WATER-BEARING CHARACTER

The fanglomerate from the Cascade Range appears to be similar in water-bearing character to the underlying Tuscan formation. Wells of large capacity near Chico and east of Chico produce most of their water from the Tuscan formation; the fanglomerate and overlying alluvium are not sufficiently thick in these areas to provide large quantities of water to irrigation wells. West of Chico, however, the fanglomerate is thick enough to yield large amounts of water to deep wells. These wells obtain most of their water from sand, as most of the coarse gravel is firmly cemented and of low permeability.

Pumping tests of wells known to obtain all their water from the fanglomerate indicate production rates of 400 to 2,800 gpm at specific capacities of 15 to 80 gpm per foot of drawdown. Differences in specific capacities of wells in the fanglomerate are more a function of depth than of differences in average permeability of the deposits; the yield factors for saturated thickness of these wells have a much narrower range—from about 8 to 20.

One of the deeper wells, 21/1E–7L1, 640 feet deep, pumped 1,935 gpm at a drawdown of 24.3 feet for a specific capacity of 80 and a yield factor of 13 for the saturated thickness.

Well 21/1E–5P1, 191 feet deep, had a specific capacity of only 27 gpm per foot of drawdown, but the yield factor of 16 compares favorably with those of the deeper wells.

In general, only the wells more than 500 feet deep have specific capacities in excess of 30 gpm per foot of drawdown. The average irrigation well in the fanglomerate near Chico has a specific capacity of 20 to 30 gpm per foot of drawdown and a discharge of 500 to 1,500 gpm.

Most of the irrigation in Tehama County east of the Sacramento River is by diversions from creeks draining the Cascade Range. However, a few large-capacity wells obtain all or part of their water from the fanglomerate. Unfortunately, too few drillers' logs are available to determine precisely the subsurface boundaries of the fanglomerate, so the relative yields of this unit, the underlying Tuscan formation, and the overlying alluvial-fan deposits cannot be determined.

RED BLUFF FORMATION (PLEISTOCENE)

DISTRIBUTION AND GENERAL CHARACTER

The Red Bluff formation (Diller, 1894), which was named from its type locality at Red Bluff at the northern end of the Sacramento Valley, unconformably overlies the Tehama and Tuscan formations of late Pliocene and older rocks and is overlain unconformably by alluvial-fan deposits of late Pleistocene and Recent age. The Red Bluff at most places is less than 50 feet thick, and it rests on an erosion surface sloping eastward from the Klamath Mountains and northern part of the Coast Ranges. The belt of exposures averages about 8 miles in width and extends southward discontinuously about 130 miles along the western margin of the Sacramento and Anderson-Cottonwood Valley from near Redding to the vicinity of Cache Creek.

The subsurface extent of the Red Bluff formation is not known. There probably are deposits beneath the western part of the Sacramento Valley that are coeval with the Red Bluff or in part equivalent, but such deposits at most places cannot be differentiated from the underlying Tehama formation or from the overlying alluvial-fan deposits.

AGE AND CORRELATION

The Red Bluff formation is Pleistocene in age. Hershey (1902) related the Red Bluff to various Pleistocene deposits throughout California, and he concluded that the formation was deposited during the early part of the last quarter of the Pleistocene epoch. Hinds (1933) correlated the Red Bluff gravel in the Redding area with the Klamath gravel to the west. Bones of Pleistocene animals have been found in the Klamath gravel. Melting Pleistocene glaciers may have supplied much of the coarse detritus of the Red Bluff and Klamath gravel deposits (Hinds, 1933).

Anderson (1933) questionably correlated the Red Bluff formation with the fanglomerate from the Cascade Range on the northeast side of the Sacramento Valley. Both deposits have been considerably dissected, and the gravel remnants of the Red Bluff near Iron Canyon, north of Red Bluff, on the Sacramento River north of Red Bluff lie as much as 200 feet above the present channel. A pre-Recent age is definitely indicated by this evidence. Kirby (1943b) mapped the Red Bluff formation in the Rumsey and Dunnigan Hills and assigned a Pleistocene age to the formation.

Weaver (1949) named the Montezuma formation from the Montezuma Hills at the southern end of the Sacramento Valley, and he mapped this unit as far north as Putah Creek. The lower part of his Montezuma apparently includes some of the Tehama formation as mapped by Kirby (1943b) farther north. Because of the uncertainty of correlation of the Montezuma with the Tehama and Red Bluff formations in the Dunnigan and Rumsey Hills and because of the extreme difficulty of delineating a Red Bluff equivalent in the hills south of Cache Creek (Thomasson and others, in press), the Red Bluff and Tehama formations herein are mapped as one unit south of Cache Creek, namely, the Tehama formation and related continental sediments (pl. 2). Deposits possibly equivalent in age to the Red Bluff also are included in the Tehama formation and related continental sediments between Cortina Creek and the South Fork of Willow Creek.

The Red Bluff formation may be essentially coeval with the Arroyo Seco gravel of Piper Gale, Thomas, and Robinson (1939) in the Mokelumne area in the southeastern part of the Sacramento Valley. Both these gravel deposits unconformably overlie finer grained sediments of late Pliocene and possibly of early Pleistocene age and generally are of similar lithology.

PHYSICAL CHARACTER

In its type area near the city of Red Bluff the Red Bluff formation consists of an ill-sorted pebble and small-cobble gravel having a distinctly reddish silty or sandy matrix. Clay, locally abundant, probably is of residual origin; the Red Bluff appears to have undergone considerable weathering after its deposition on a broad, gentle surface cut on the Tehama and Tuscan formations and older rocks. As a result, most of the larger fragments are of hard and chemically resistant rocks, such as quartzite, chert, and various siliceous metamorphic rocks.

The average grain size of the Red Bluff formation generally decreases eastward from its source region in the Klamath Mountains and northern Coast Ranges. The coarsest deposits are in the Redding region north of the Sacramento Valley where large cobbles and boulders are abundant. Farther south, near Red Bluff and Corning, the Red Bluff is thinner and finer grained, although it still contrasts vividly with the yellowish to grayish fine-grained Tehama formation, which it overlies in this area.

The lithology of the Red Bluff formation in the Rumsey and Dunnigan Hills has not been described in any detail in the literature. In general, the lithology is similar to that farther north; gravel containing a reddish silty or sandy matrix predominates.

The terrace gravel deposits that postdate the Red Bluff formation along Cache Creek are lithologically similar to that formation. These gravel deposits occur on stream-cut terraces below the Red Bluff surface and generally are less than 20 feet thick.

The Red Bluff, itself, is less than 50 feet thick at most places, and it caps an erosion surface cut on the Tehama formation and older rocks. Within the area shown on the geologic map (pl. 2) it is entirely on the Tehama formation. In places, such as in the Rumsey and Dunnigan Hills and near Corning, the Red Bluff has been gently folded.

The soils on the Red Bluff have been classified as Corning gravelly loam by the U.S. Department of Agriculture, Bureau of Soils. These soils commonly have a hardpan layer within a few feet of the land surface and are not suitable for most agricultural purposes. Similar soils are characteristic of exposures of the Arroyo Seco gravel and gravel deposits of uncertain age (Laguna formation and related continental sediments on the east side of the valley).

WATER-BEARING CHARACTER

The Red Bluff formation is largely above the zone of saturation in the outcrop areas west of the Sacramento Valley. Locally the Red Bluff may contain small bodies of perched water, but these are of little economic significance. For the most part the extent and character of the Red Bluff formation beneath the western part of the valley are unknown. However, some of the shallow gravel deposits that yield water to wells in the Corning area may belong to the Red Bluff.

The exposures of the Red Bluff formation in the foothills of the northern part of the Coast Ranges may serve as an intake area for water moving eastward toward the valley trough. The widespread hardpan, however, probably inhibits downward percolation of rainfall.

VICTOR FORMATION AND RELATED DEPOSITS (PLEISTOCENE)

DEFINITION

As herein defined, the cartographic unit termed the Victor formation and related deposits includes the Victor formation of Piper, Gale, Thomas, and Robinson (1939) in the Mokelumne area, unnamed equivalents of the Victor north of the Mokelumne area to the Chico alluvial fan, and flood-plain deposits composed mainly of reworked Tuscan formation and fanglomerate from the Cascade Range north of the Chico fan.

The Victor formation was named from its type locality in the town of Victor in the Mokelumne area, where the type section was described by Gale (Piper and others, 1939, p. 38). As shown on the geologic map of the Sacramento Valley (pl. 2), the Victor formation and related deposits north of the Mokelumne area are believed to be essentially coeval with the type Victor and in large part were deposited in a similar environment. For convenience, these deposits will be termed "Victor formation" in the following discussion.

STRATIGRAPHIC RELATIONS AND DISTRIBUTION

The top of the Victor formation is a constructional surface, locally dissected slightly, which has been called the Victor plain in the Mokelumne area (Piper and others, 1939, p. 15, 45). Except for the Chico alluvial fan and part of the lowland area of Butte Creek, the boundaries of the Victor exposures coincide generally with the boundaries of geomorphic units 7 and 8—the low alluvial plains and fans west of the Sierra Nevada and Cascade Range (pl. 1).

The base of the Victor formation rests on the buried extension of the dissected Arroyo Seco pediment in the western part of the Mokelumne area (Piper and others, 1939, p. 45); farther north, the Victor probably rests on an erosional surface formed at about the same time as the Arroyo Seco pediment. Tongues of the Victor extend eastward across the dissected pediment and unconformably overlap the Laguna formation and related continental sediments, the volcanic rocks from the Sierra Nevada, and sedimentary rocks of Eocene age. The greatest dissection of the Arroyo Seco pediment occurred along its eastern margin where, in places, the base of the

Victor formation is 250 to 300 feet below the pediment surface (Piper and others, 1939, p. 39). Farther west toward the axis of the Sacramento Valley trough the depth of the trenches cut in Victor time in the pediment surface approaches zero, and the Victor formation overlies the Laguna formation and related continental sediments probably in conformable contact.

By projecting the slope of the Arroyo Seco pediment westward, Gale computed the maximum thickness of the Victor to be about 125 feet near the sea-level contour along the western margin of the Mokelumne area (Piper and others, 1939, p. 46). Farther east the thickness diminishes; over most of the area of exposure, the Victor formation probably is less than 100 feet thick. A somewhat vague and inconclusive break in lithology, suggested by water-well logs north of the Mokelumne area, indicates that the Victor generally is between 50 and 150 feet thick. North of the Chico fan the Victor formation, which there consists predominantly of volcanic detritus, unconformably overlies the fanglomerate from the Cascade Range and generally is less than 50 feet thick.

Along the western margin of its outcrop the Victor formation at many places is conformably overlain by basin and river deposits of Recent age. However, to the east the Victor plain has been trenched by all but the smallest eastern tributaries of the Sacramento and Feather Rivers, and the Victor formation is unconformably overlain by Recent river deposits filling the trenches.

In the subsurface the Victor probably extends westward to the axis of the valley trough where it interfingers with the lower part of the alluvial-fan deposits from the Coast Ranges.

CORRELATION AND AGE

The Victor formation and related deposits probably are of late Pleistocene age. Deposition of the Victor followed the cutting of the Arroyo Seco pediment after the last major uplift of the Sierra Nevada block in middle or early Pleistocene time (Piper and others, 1939, p. 49).

Geomorphic evidence in the form of stream-cut terraces in the area between the American and Cosumnes Rivers indicates that at least two depositional cycles of the American River intervened between the deposition of the Arroyo Seco and Victor. The northern extension of the Victor plain of the Mokelumne area is the lowest major terrace above the Recent flood plain of the American River. Above this terrace are two distinct terraces cut below the Arroyo Seco pediment by the American River. Similarly, the northern equivalent of the Victor plain also is the lowest terrace above the flood plains of the Feather and Yuba Rivers—the other two principal streams on the east side of the Sacramento Valley. The various terraces have been described by Bryan (1923, p. 21–25), who proposed two hypotheses—a climatic and diastrophic origin—to explain these features. Possibly all the terraces, including the Victor plain and the Arroyo Seco pediment, are genetically related to the several Pleistocene glacial stages that have been identified in the Sierra Nevada. (See Matthes, 1929, 1930; Blackwelder, 1931.)

The Victor plain and its northern correlatives are essentially the constructional or aggradational surface of the Victor formation. Little or no deposition is now taking place on this surface, which at some places is being slightly dissected. Nearly all the large streams on the east side of the Sacramento Valley have cut trenches into the Victor plain. These trenches, which contain the relatively narrow present flood plains of these streams, are floored by river deposits of Recent age and along the eastern margin of the valley are as much as 50 feet below the adjacent Victor plain. The flood plains of the Feather, Yuba, and Bear Rivers, and a few smaller streams have been choked with tailings from hydraulic mining in their upper reaches. With the exception of these streams and all the streams near the axis of the valley where the trenches are shallowest and parts of the Victor plain occasionally are flooded, the east-side streams are sufficiently entrenched below the Victor plain to contain the floodwaters.

The soils formed on the Victor formation reflect stable conditions on a surface where little or no deposition has taken place in Recent time. Well-developed soil profiles and "hardpan" B horizons are widespread and afford supporting evidence of a pre-Recent age for the Victor.

The geomorphic evidence summarized in the preceding paragraphs indicates a late Pleistocene age for the Victor formation and related deposits. Fragmentary vertebrate fossils found at several widely scattered localities confirm the Pleistocene age. The left scapula of a horse, probably of the genus *Equus*, was found 1½ miles north of Elk Grove and near the eastern margin of the Victor plain (Piper and others, 1939, p. 49).

A skull and teeth fragments of *Elephas columbi?* were found 12½ feet below the surface near Sacramento in sec. 32, T. 9 N., R. 5 E. (Piper and others, 1939, p. 49). Unfortunately, the geologic age of the deposits in which the fossil fragments were found is uncertain. Piper, Gale, Thomas and Robinson (1939, p. 49) describe the land as being topographically continuous with the Victor plain to the south; however, the locality was visited by Olmsted, who found that it is in the flood plain of the American River. The deposits at the surface obviously are Recent river deposits, but it is possible that the bone-bearing sediments at a depth of 12½ feet belong to the Victor formation.

Bones tentatively identified as those of a Pleistocene mastodon were found near Live Oak, Sutter County, in sediments probably correlative with the Victor formation. At other localities, including one near Sacramento, the Victor formation has yielded Pleistocene vertebrate remains.

Bones of Pleistocene vertebrates, including several proboscidean tusks, have been found in a clay bed in the channel of Putah Creek. The clay probably is equivalent in age to the upper part of the Victor formation to the east.

LITHOLOGIC CHARACTER

The Victor formation consists, for the most part, of a heterogeneous assemblage of silt, sand, gravel, and clay transported by shifting streams from the Sierra Nevada and Cascade Range. The most noteworthy characteristic of the Victor is the extreme variability in grain size of the deposits in short distances, both laterally and vertically. In the Mokelumne area, Piper, Gale, Thomas, and Robinson (1939, p. 44, 45) were unable to correlate individual strata between wells, even where wells were spaced less than half a mile apart, and they concluded that sand and gravel tongues, if they exist as functional ground-water arteries, are too narrow, too devious, and too closely braided to be delineated with the available well logs. Such lenticularity of strata and overall heterogeneity of the deposits is characteristic of flood-plain deposits laid down by frequently shifting streams. Thin beds of coarse sand and fine silt interfinger intricately; the particles of an individual bed grade abruptly from coarse to fine either laterally or vertically, and contacts between beds, although distinct at many places, are neither plane nor parallel.

Although the sand and gravel tongues within the Victor formation at most places are indefinable, areas underlain by predominantly coarse-grained deposits to depths of 50 to as much as 150 feet below the surface were delineated with the aid of a peg model of the Sacramento Valley. The model shows that a zone of coarse-grained materials underlies much of the Victor plain south of the American River from Folsom to the vicinity of Elk Grove. The coarse deposits, usually reported by drillers as "gravel" or "clay and gravel," extend to depths of 30 to 60 feet below the surface and overlie predominantly fine-grained compact sediments of the Laguna formation. It is inferred that the gravel was deposited by the American River during latest Pleistocene time.

Ill-defined tongues of sand and gravel, which underlie areas adjacent to the Feather and Yuba Rivers to depths of as much as 150 feet, may represent channel deposits laid down by these streams during Victor time, although some of these deposits probably are of Recent age.

Except beneath the Recent flood plains of the larger streams where the Victor formation appears to be essentially in stratigraphic and hydraulic continuity with the overlying coarse-grained Recent river deposits, most of the coarse-grained materials in the Victor are overlain by at least a few feet of comparatively fine-grained material. The principal exception to this situation appears to occur in the area south of the American River from Folsom to Elk Grove; however, even there, hardpan layers occur above the gravel beds over wide areas. Apparently a general decrease in the sediment-carrying power of the depositing streams occurred toward the end of the Victor depositional cycle.

In general, the average grain size of the Victor formation appears to decrease westward, as might be expected in a formation having an eastern source. Local variability, however, tends to mask this regional trend; coarse sand and gravel lenses occur as far west as the axis of the valley. Based on statistics from numerous logs of wells in the Victor, the percentage of sand and gravel in the interval from the land surface to a depth of 50 feet decreases from a maximum of 80 to 90 percent in wells in the eastern part of the valley to a minimum of less than 10 percent in the central part of the Central Valley. The proportion of bluish- and greenish-gray fine-grained silt and clay, which are indicative of deposition in a non-oxidizing environment, such as a flood basin or a lake, becomes greater as the proportion of fine-grained strata increases.

The sand and silt in the Victor formation generally are reddish to yellowish and contain abundant subrounded to subangular grains of quartz, feldspar (mostly altered, in part, to clay minerals), mica, and local concentrations of heavy minerals such as magnetite, pyroxene, and amphibole. The reddish and yellowish colors are due to ferric oxides from decomposed iron-bearing minerals. Some sand, which is highly arkosic and contains clear quartz, feldspar, and abundant foils of partly altered light-brown biotite, obviously was derived from weathered granodiorite of the Sierra Nevada basement complex to the east.

A section of the Victor formation exposed in the north bank of the Mokelumne River near Lockeford is described by Piper, Gale, Thomas, and Robinson (1939, p. 40), as follows:

	Thickness (feet)
Soil and concealed	6
Very fine sand and silt, light gray; one 9-inch bed of brown medium sand near the middle	6½
Sand, unsorted, chiefly coarse to medium, gray to brown	1
Very fine sand and silt, thin-bedded, light gray	2½
Coarse sand, well sorted	3
Concealed	5
Silt, well sorted, white with brown streaks	2

	Thickness (feet)
Coarse sand, brown, with some pebbles as much as half an inch in diameter; matrix of fine sand to silt with some thin beds of fine sand, unsorted	6
Fine sand, well sorted, brown, with white to brown silt, in beds of 1 to 6 inches thick	3
Sand, unsorted, light gray, probably chiefly fine sand but with some grains 5 millimeters in diameter; one discontinuous bed of coarse sand 6 inches in maximum thickness at top	5½
Very fine sand and silt, well sorted	3
Thickness of measured section	43½

The above description illustrates the variability in degree of sorting of the sediments. The well-sorted medium-coarse and coarse sands probably are highly permeable, whereas the unsorted materials are of very low permeability even where coarse sand and small gravel are abundant.

Unlike the Victor formation and its correlatives south of the Chico alluvial fan, which contain abundant granitic- and metamorphic-rock detritus, the deposits to the north consist almost entirely of reworked volcanic detritus, derived from the Tuscan formation, and fanglomerate from the Cascade Range. Quartz is scarce in these predominantly andesitic and basaltic sediments, which generally are ill-sorted and contain an abundance of clay. The deposits are not thick; the underlying cemented gravel and sand of the fanglomerate from the Cascade Range are exposed in many of the deeper stream cuts only a few feet or tens of feet below the constructional surface of the adjacent plain. Despite the difference in lithology, the depositional environment of the deposits north of Chico appears to have been similar to that of the Victor formation to the south.

In general, the Victor formation is not appreciably consolidated, although some of the beds have a high proportion of clay and silt which act as a binder. Hardpan layers, representing buried soil zones, occur at various depths; however, most of the hardpan is in the present soil zone within about 6 feet of the land surface. Most of these hard layers are cemented with hydrous iron and aluminum silicates, although calcareous cementation is common in areas of high water table adjacent to the flood basins.

Hardpan is characteristic of many, but not all, of the soils developed on exposures of the Victor formation. The San Joaquin and Rocklin series of brownish-red hardpan soils derived from granitic sediments are widespread. Alamo series soils are similar to the San Joaquin and Rocklin series but generally are heavier textured and are dark gray rather than brownish red (Weir, 1950, p. 110). Perkins soils occur where the coarse sand and gravel beds extend to the land surface, as, for example, south of the American River from Folsom to the vicinity of Elk Grove.

Two important soil groups having little or no profile and no hardpan are the Honcut and Hanford series. Honcut soils are characteristic of sediments derived from the basic igneous and metamorphic rocks of the Sierra Nevada basement complex; the soils of the Hanford series are formed on sediments derived from the granitic rocks of the Sierra. Both groups are described as Recent soils in the soil-survey reports of the U.S. Department of Agriculture and the University of California (Weir, 1950, p. 113–115; Cosby and Carpenter, 1937, p. 22, 23), although they typically occur on the Victor plain, which is late Pleistocene in age (Piper and others, 1939, p. 42).

Soils of the Stockton series commonly form upon the fine-grained sediments of the Victor formation adjacent to the Recent flood basins. The western part of the exposures of the Victor north of the Sutter Buttes consists largely of Stockton soils.

WATER-BEARING CHARACTER

Except for the Recent river deposits, the Victor formation and related deposits generally are the most permeable water-bearing units on the east side of the Sacramento Valley. At most places the Victor is moderately permeable throughout. Tongues of sand and gravel and well-sorted medium-coarse to coarse sand are highly permeable and yield large volumes of water to irrigation and supply wells.

Nearly all the domestic wells and many of the small irrigation wells on the low alluvial plains on the east side of the valley are completed in the Victor formation. High-capacity wells obtain much of their water from the Victor, but most of these wells obtain additional water from the underlying Laguna formation and related continental sediments. At most places the Victor formation is more permeable than the Laguna, but the wetted thickness of Victor generally is insufficient to support high-capacity wells producing more than 1,000 gpm.

The Victor formation probably does not exceed 150 feet in thickness anywhere on the east side of the Sacramento Valley. From the American River north to the Yuba River and as far west as the Feather River the Victor appears to be not more than 50 feet thick. Between the Yuba River and Honcut Creek the unconsolidated sand and gravel of the Victor extend to depths of 70 to 100 feet below the land surface. West of the Feather River the coarse-grained unconsolidated deposits extend to depths of 50 to 110 feet. In the area north of the Chico alluvial fan the deposits equivalent to the Victor probably do not exceed 50 feet in thickness. In much of that area the underlying fanglomerate from the Cascade Range is within 15 feet of the land surface.

In spite of its limited thickness the Victor formation is the principal water-bearing material for thousands of wells that irrigate the low plains east of the Sacramento River.

Average depth of wells, pump capacity, and specific capacity, computed from data supplied by the Pacific Gas and Electric Co., are shown on figure 3 and listed in table 2.

Average well depths appear to be inversely related to the thickness and permeability of the Victor formation. East of the Feather River and between the American and Yuba Rivers, where the Victor formation generally is less than 50 feet thick, the average depth of irrigation wells is more than 300 feet. West of the Feather River and north of Sutter Buttes, where the Victor averages about 60 feet in thickness, the average depth of wells is 260 feet.

On the other hand, in areas where the thickness of the Victor formation is 100 feet or more, average irrigation-well depths are only about 200 feet. In the Peach Bowl area of Sutter County and in the area north of the Yuba River in Yuba County, where coarse-grained deposits extend to depths of 100 feet below land surface, the average depth of irrigation wells is 180 and 200 feet, respectively.

Most of the area north of the Chico fan, underlain by deposits related to the Victor formation, is irrigated by surface-water supplies. The few irrigation wells in the area draw most of their water from permeable zones in the underlying fanglomerate from the Cascade Range. However, adequate domestic wells have been completed in the Victor formation where the wetted thickness is sufficient.

Unfortunately, few pump-test data are available for wells that tap only the Victor formation. However, data from several wells perforated solely or primarily opposite Victor aquifers indicate that the sand and gravel are highly permeable. Well 11/4E–21H1, about 15 miles north of Sacramento, is 102 feet deep and has a total of 50 feet of perforated casing. The well produced 1,600 gpm at a specific capacity of 33 gpm per foot of drawdown. The yield factor was 66 for the total perforated thickness; however, for the 12 feet of this thickness logged as sand, the yield factor was 275.

Well 18/2E–25R1 in Gridley produced 300 gpm at a specific capacity of 56 gpm per foot of drawdown. The well is only 74 feet deep and taps 30 feet of sand, for which the yield factor was 185.

Although these yield factors are no higher than those of the best aquifers in the underlying Laguna formation, the proportion of highly permeable beds generally is greater in the Victor formation than in the Laguna, and the average permeability of the Victor is higher at most places. The volume of production gained per foot of well is less in the Laguna than in the Victor formation, although at most places both formations must be penetrated to assure a production rate sufficient for an irrigation well.

ALLUVIAL-FAN DEPOSITS (PLEISTOCENE AND RECENT)

DEFINITION

The alluvial-fan deposits are herein defined as the fluviatile sediments of late Pleistocene and Recent age that have been and are being deposited on alluvial fans in the Sacramento Valley, including the fans of Stony, Big Chico, Little Chico, and Butte Creeks, and various smaller streams, such as those draining Sutter Buttes. For convenience the flood-plain deposits of several streams on the west side of the valley are included in this unit, although they are not typical alluvial-fan deposits. This second category includes deposits of Cache and Putah Creeks, and several smaller west-side streams.

The alluvial-fan deposits of this report were classified as younger alluvium by Bryan (1923), and they generally have been classified as Quaternary alluvium in other published and unpublished works dealing with the Sacramento Valley.

Alluvial-fan deposits are coextensive with the following geomorphic units: Low alluvial plains and fans on west side of valley (geomorphic unit 6); low alluvial plains and fans west of Cascade Range, the portion south of Chico Creek (geomorphic unit 8); alluvial fans of Sutter Buttes (geomorphic unit 9). (See pl. 1.)

AGE AND CORRELATION

As herein delineated, the alluvial-fan deposits are largely of Recent age at the land surface. The dominant geologic process at the surface of the fans is deposition rather than erosion—a condition reflected by the soils, which are, for the most part, immature and do not have strongly developed profiles.

The Recent deposits, however, probably are not more than a few feet thick. Bones of Pleistocene mammals have been found in a compact silty clay in the channel of Putah Creek between Davis and Winters (Thomasson and others, in press). The top of this clay bed, into which Putah Creek is cut throughout the reach from Winters to Yolo Basin, generally is about 25 feet below the surface of the adjacent Putah plain. The material exposed above the clay, presumably Recent, is predominantly fine sandy silt. Data from well logs in the Putah plain to the south of the present channel of Putah Creek suggest that the Recent deposits are mostly fine grained and range in thickness from a featheredge to perhaps 30 feet. In a comprehensive report on the geology and water resources of the Solano County area (Thomasson and others, in press), Olmsted and

LeRoux divided the deposits called alluvial-fan deposits into two geologic units: Younger alluvium—the predominantly fine-grained deposits of Recent age; and older alluvium—the underlying deposits of probable late Pleistocene age, which include the fossiliferous silty clay exposed in the bed of Putah Creek. Old soils having strong profile development in extensive areas in the western and southern parts of Putah plain are interpreted as exposures of the older alluvium of Thomasson, Olmstead, and LeRoux, or the Pleistocene portion of the alluvial-fan deposits of the present report. Similar old soils farther north along the western margin of the Sacramento Valley probably represent exposures of deposits of equivalent age.

The Victor formation and related deposits on the east side of the valley are believed to be essentially correlative with the lower part of the alluvial-fan deposits. Vertebrate fossils and other evidence indicate a late Pleistocene age for the Victor. The upper part of the fan deposits is equivalent in age to the adjoining basin deposits and to the river deposits in the central and eastern parts of the Sacramento Valley.

DISTRIBUTION AND THICKNESS

The alluvial-fan deposits are exposed in three areas, a broad belt in the western part of the valley from the Montezuma Hills to Thomes Creek, about 14 miles south of Red Bluff; the Chico alluvial fan on the east side of the valley; and the small fans surrounding Sutter Buttes in the center of the valley.

The western outcrop belt measures about 130 miles from north to south and ranges in width from 1 to 20 miles. On the west, the alluvial-fan deposits overlap and abut against older sediments ranging from the Red Bluff formation of Pleistocene age to marine sedimentary rocks of the Chico formation of Late Cretaceous age. On the east the fan deposits grade laterally into and interfinger with the Recent deposits of the Colusa and Yolo Basins, with the Recent deposits of the Sacramento River north of Glenn, and subsurface with the Victor formation and related deposits of late Pleistocene age. Although definite lithologic criteria for a subsurface distinction of the alluvial-fan deposits from the underlying Tehama and Red Bluff formations are lacking at most places, it is believed that the alluvial-fan deposits on the west side of the valley generally are less than 150 feet thick.

The Chico alluvial fan on the east side of the valley measures about 12 miles from north to south and 4 to 8 miles from east to west. The fan deposits, which at most places are less than 50 feet thick, overlie the fanglomerate from the Cascade Range and the Tuscan formation, and in part are equivalent to the adjacent Victor formation and related deposits, into which they grade laterally. To the west, near the mouth of Big Chico Creek, the fan deposits interfinger with the river deposits of the Sacramento River. Along the eastern margin of the valley the fan deposits abut against the Tuscan formation.

The fan deposits of the Sutter Buttes form a ring surrounding the buttes and extend toward their center in narrow valleys cut into andesite tuff-breccia. The width of this ring ranges from less than half a mile to as much as 2 miles opposite the mouths of the larger canyons. The deposits range in thickness from a feather edge on their inward margins to perhaps as much as 100 feet on their outer edges where they grade laterally into deposits equivalent to the Victor formation, the basin deposits, and the river deposits. The fan deposits unconformably overlie the andesite tuff-breccia that surrounds the core of the buttes.

LITHOLOGIC CHARACTER

The alluvial-fan deposits of the Sacramento Valley are of exceedingly varied lithology. This variability is due in large part to frequent shifting of stream courses across broad plains and to differences in rock types in the drainage basins of the streams.

The alluvial-fan deposits, like the other late Pleistocene and Recent deposits in the valley, are less compacted and cemented than the underlying older sediments. However, the degree of compaction and cementation appears to increase gradually with depth—at few places there is a sharp break between the fan deposits and the underlying sediments. The base of the alluvial-fan deposits is particularly ill defined where fine-grained materials predominate in both the alluvial-fan and the older deposits.

The alluvial-fan deposits of Solano and southern Yolo Counties were divided by Olmsted and LeRoux (Thomasson and others, in press) into two stratigraphic units, younger alluvium and the underlying older alluvium. A hasty geologic reconnaissance by the authors and data from U.S. Department of Agriculture soil reports suggest that a similar twofold subdivision of the fan deposits could be made farther north, along the west side of the Sacramento Valley, but time to do this was not available during the present investigation.

The younger alluvium (upper part of alluvial-fan deposits) of the Putah area consists mostly of grayish-brown silt and fine sand but includes some clay, coarse sand, and gravel. The silt and fine sand have been deposited along small channel ridges of distributaries of Putah Creek and to a lesser extent along the small streams draining the English Hills south of Putah Creek. Coarse sand and gravel are of relatively minor extent and occur chiefly along the stream channels. True clay likewise is inextensive; most of it has been deposited adjacent to the Yolo Basin along the eastern and southeastern margins of the exposures of alluvial-fan deposits. Most of the soils with younger alluvium are moderately to highly permeable, and they permit recharge, to the underlying ground-water body from precipitation and irrigation.

The older alluvium of the Putah area is more heterogeneous than the younger alluvium. Impermeable silty clay and clay are more abundant in the older alluvium, but so are highly permeable coarse sand and gravel.

Where exposed, the older alluvium is characterized by soils having mature profiles, in contrast to the immature soils on the younger alluvium. Even where the surface soil layer (*A* horizon) consists of coarse sand, vertical percolation is impeded by the underlying B horizon of dense clay. Consequently, the soils on the older alluvium are nearly everywhere poorly permeable, surface drainage is poor after winter rains, and most types of irrigated agriculture are not feasible. Mound-and-depression tpography (hog wallows), which is widespread in the exposures of older alluvium, also serves to inhibit surface drainage, and small ponds frequently remain for days or weeks after heavy rains.

Although the older alluvium, where it lies near the land surface, is largely impermeable, lenses and tongues of highly permeable coarse sand and gravel are abundant, particularly beneath the area of Recent deposition by Putah Creek, extending eastward from Winters to Davis and southeastward from the northeast tip of the English Hills to the vicinity of Dixon. These coarse-grained deposits, which in places extend to depths of more than 100 feet, supply large quantities of water to irrigation wells in the area.

Except for containing a greater proportion of sand and gravel, the alluvial-fan deposits underlying the plain of Cache Creek are generally similar to those underlying the Putah plain. As beneath the Putah plain, however, fine-grained deposits are more abundant than the sand and gravel, which occur chiefly as tongues within the fine-grained silt and clay.

From Cache Creek north to the vicinity of Williams the Dunnigan and Rumsey Hills are flanked by a series of small coalesced alluvial fans. The streams that have constructed the fans are small and flow only for brief periods after winter rains. The fan deposits, which have been derived largely from the Red Bluff and Tehama formations exposed in the hills to the west, are typically heterogeneous and range from silt and clay to coarse sand and gravel.

From Williams north to Willows the fan deposits underlie a narrow belt between the foothills of the Coast Ranges and the Colusa Basin. Sandstone, siltstone, and shale of Late Cretaceous age are exposed in the foothills and supply detritus to the small intermittent streams;

the fan deposits, accordingly, are mostly fine grained and virtually indistinguishable from the basin deposits to the east.

The broad, gently sloping plain from Willows north to about the Tehama County line generally is known as the Stony Creek alluvial fan. (See Bryan, 1923, p. 27.) The fan, which has been built in small part by Willow Creek and in large part by Stony Creek, is bounded on the west and north by low foothills underlain by the Tehama and Red Bluff formations, on the east by the Sacramento River lowlands, and on the south by the Colusa Basin. Stony Creek drains a sizable area in the northern Coast Ranges and has deposited predominantly coarse-grained materials in late Pleistocene and Recent time. Clean, well-sorted gravel underlies most of the fan to depths of 40 to about 125 feet, is more extensive than the gravel beneath the alluvial plains of Putah and Cache Creeks, and seems to be in the form of sheets and broad lenses rather than tongues and sinuous channels. The sediments of the underlying Tehama formation are considerably less permeable, on the average, than the fan deposits.

The alluvial-fan deposits of Sutter Buttes have been derived largely from the volcanic rocks composing the central area and from the tuff-breccia of the slopes surrounding the central area, although the Cretaceous and Tertiary sedimentary rocks exposed in the buttes have contributed some of the fan detritus. The fan deposits consist largely of silt, clay, gravel, and sand of low permeability and are less than 50 feet thick, except along the outer margins of the fans where they may be as much as 100 feet thick.

The Chico fan, the only large Recent alluvial fan on the east side of the valley, is underlain by late Pleistocene and Recent deposits ranging in thickness from 0 to more than 50 feet. The fan deposits have been laid down by Big Chico, Little Chico, and Butte Creeks, which drain the southwestern part of the exposures of the Tuscan formation. The materials, therefore, are largely reworked volcanic detritus derived from the Tuscan formation. Although the average grain size of the fan deposits appears to be less than that of the underlying fanglomerate from the Cascade Range and the Tuscan formation, the fan materials are less compacted and cemented than the older units and probably are more permeable.

To the south and southwest the deposits of the Chico fan grade into the Victor formation and related deposits, which, unlike the fan deposits, probably are of late Pleistocene age at the land surface. The fan deposits include a veneer of Recent material which thins to a featheredge along the southern margin of the fan. The Recent deposits also feather out along the northern margin of the fan, 2 to 4 miles north of Big Chico Creek, but on the west they grade into Recent deposits of the Sacramento River.

WATER-BEARING CHARACTER

The alluvial-fan deposits vary widely in permeability from place to place. The deposits of small streams, such as those along the flanks of the Dunnigan Hills and Rumsey Hills, tend to be poorly sorted; and the deposits of streams that drain areas underlain by mostly fine-grained rocks, such as the streams draining the Coast Ranges from Williams to Willows, are largely fine grained. However, the deposits of the larger streams, such as Putah, Cache, and Stony Creeks, include tongues, lenses, and sheets of some of the most permeable sand and gravel of the valley.

The coarse sand and gravel deposited by Cache Creek in the vicinity of Woodland is extremely permeable. The average yield factor for the saturated thickness, computed for wells tested by the Pacific Gas and Electric Co. in the Woodland area, was 47 (table 2). However, the average proportion of sand and gravel in the interval between 20 and 200 feet below the surface, computed from drillers' logs in ground-water storage unit B5 (see p. 177), is only 25 percent. Assuming that all the water is yielded by the sand and gravel and none by the fine-grained and cemented materials, the average yield factor for the sand and gravel is 190.

Development-test data on several irrigation wells near Woodland confirm the high yield factors of the sand and gravel. Well 10/1E–13B1, 3 miles northwest of Woodland, is 219 feet deep and has casing perforated from 40 to 52 feet and 198 to 214 feet depth opposite gravel. The specific capacity of the well was 36 gpm per foot of drawdown; the yield factor for the 28 feet of gravel was 130.

Well 10/1E-14D1, only 132 feet deep and probably entirely in alluvial-fan deposits, produced 1,400 gpm at a drawdown of 6.3 feet for a specific capacity of 220 gpm per foot of drawdown. The yield factor for 66 feet of saturated gravel was more than 300, which indicates probable average permeability of several thousand gallons per day per square foot (Poland and others, 1959).

The water-yielding character of the gravel tapped by well 10/1E–14D1 apparently is not exceptional for the area. A well in 10/2E–7 had a yield factor of 570 for 21 feet of sand and gravel, and well 10/2E–20K1 had a yield factor of 330 for 94 feet of gravel.

The gravel of the Stony Creek fan also is highly permeable. The average yield factor for the saturated thickness, computed for wells tested by the Pacific Gas and Electric Co. in the Orland-Willows area, was 41 (table 2). The average depth of irrigation wells in this area is 210 feet; the average proportion of sand and gravel in the interval from 20 to 200 feet below the land surface is one-third. Assuming that all the water is yielded from the sand and gravel strata, the average yield factor for these aquifers is 125.

Well 21/2W-32H1, about 10 miles northeast of Willows, is fairly typical of that area. The well, which is 200 feet deep and taps mostly alluvial-fan deposits, produced 2,700 gpm at a drawdown of 37 feet for a specific capacity of 73 gpm per foot drawdown and a yield factor of 110 for 68 feet of gravel and sand.

The gravel and sand deposited by Putah Creek in Solano County and southern Yolo County yield abundant supplies of water to irrigation wells. The average yield factor was 35 for the saturated thickness of sediments penetrated in irrigation wells tested by the Pacific Gas and Electric Co. (table 2). However, silt and clay of very low permeability make up 70 percent of the total thickness in the 20- to 200-foot depth range, so assuming that all the water is from the remaining 30 percent of the section, the average yield factor for these coarse-grained materials is about 120. Many of the wells tap the Tehama formation, which is less permeable than the fan deposits; probably the average yield factor for sand and gravel in the fan deposits alone is considerably more than 120.

Except for that of the coarse deposits of Stony, Cache, and Putah Creeks mentioned in the foregoing paragraphs, the average permeability of the alluvial-fan deposits is low to moderate. Besides being only moderately permeable, at most, many of these deposits are only a few feet or tens of feet thick, and irrigation wells must tap the underlying geologic units to obtain adequate yields. This is particularly true of the alluvial fans of the Sutter Buttes, Chico alluvial fan on the east side of the valley, and the small areas of alluvial-fan deposits in the Corning area of Tehama County. In these areas, only domestic and stock wells of low yield have been completed in the fan deposits.

RIVER DEPOSITS (RECENT)

DEFINITION

The river deposits as defined in this report consist of sand, gravel, silt, and minor amounts of clay deposited in Recent geologic time along the Sacramento and Feather Rivers, the major streams on the east side of the Sacramento Valley, Cache Creek between Rumsey Hills and Dunnigan Hills, and Putah Creek west of Winters. They correspond in a general way to the flood plains and natural levees of the Sacramento and Feather Rivers (geomorphic units 3 and 4) and the stream channels and flood plains on the east side of Sacramento Valley (geomorphic unit 5). See plate 1. Two principal exceptions are the river deposits in the western part of Butte Creek lowland, which underlie the flood basins (geomorphic unit 1) and the river deposits along the western valley reaches of Cache and Putah Creeks, which underlie a part of the low alluvial plains and fans on the west side of the valley (geomorphic unit 6). Compare plates 1 and 2.

The river deposits of this report are roughly equivalent to Bryan's river-lands subdivision of the younger alluvium (Bryan, 1923, pl. 3) and to Piper's alluvium along the Mokelumne and Cosumnes Rivers and the smaller streams of the Mokelumne area (Piper and others, 1939, pl. 1).

DISTRIBUTION AND GENERAL CHARACTER

The river deposits have accumulated in three principal depositional environments, low-water channels; flood plains having sharp, distinct boundaries; and natural levees.

The low-water channels generally are several feet below the adjacent flood plains or natural levees and are underlain mostly by sand and gravel. These relatively coarse-grained deposits are constantly shifting and moving downstream during periods of high water. On some streams, such as Cache Creek between the Rumsey Hills and Dunnigan Hills, the low-water channels are not distinctly defined and merge almost imperceptibly with the flood plains.

The channels of the lower Sacramento and Feather Rivers are stable and are enclosed by artificial levees which have been constructed on top of the natural levees. The channels, which range from 300 to nearly 1,000 feet in width, are floored by finer grained deposits (mostly sand and silt) than most of the other channels of streams in the Sacramento Valley.

The sharply bounded flood plains are herein defined as those areas that lie along the major streams and are subject to flooding, and are bordered by alluvial-fan deposits or by older rocks or deposits.

The sharply bounded flood plains, which lie mostly below the adjacent low alluvial plains and fans and above the low-water channels, are floored with finer grained material than the channels—mostly silt and fine sand. The flood plains along the major streams of the Sacramento Valley range in width from a few hundred feet to more than 3 miles. The topography is characterized by sinuous abandoned channels and ridges. The boundaries of the plains, as implied by the definition, are sharp and, at most places, consist of steep banks several feet to several tens of feet high. However, the Yuba and Bear Rivers have been choked with hydraulic-mining debris from the Sierra Nevada and now stand as high and even higher than the adjacent low plains.

The sharply bounded flood plains occur typically along the upper-valley reach of the Sacramento River from Red Bluff to Hamilton City, along the Feather River from Oroville to Marysville, and along the Yuba, Bear, American, Cosumnes, and Mokelumne Rivers and other east-side tributaries of the Sacramento and Feather Rivers. Smaller flood plains occur along two west-side streams, the Cache Creek between the Rumsey Hills and Dunnigan Hills, and Putah Creek west of Winters.

Many flood plains, particularly those of the east-side tributaries of the Sacramento and Feather Rivers, overlie backfilled trenches cut into older sediments of the Victor and Laguna formations. The trenches probably were cut during a period of lowered base level of the streams—possibly during the lowered sea level of the Wisconsin glacial stage—and were backfilled by the river as base level rose.

The sharply bounded flood plains on the Sacramento and Feather Rivers grade downstream into natural levees, which stand higher than the adjacent flood basins. The natural levees occur along the Sacramento River below Hamilton City and along the Feather River below Marysville. Similar, but smaller natural levees, called "channel ridges" by Bryan (1923, p. 28, 29), occur on the alluvial plains of Cache and Putah Creeks on the west side of the Sacramento Valley, but these are here included in the alluvial-fan deposits.

The natural levees are relatively broad, low ridges adjacent to the stream channel. They are formed during floods and slope gently away from a crest near the edge of the channel toward the low-lying flood basins on either side. Under ordinary flood conditions that existed prior to the construction of artificial levees on top of the natural levees, the flood waters flowed over the stream banks as a smooth sheet (Bryan, 1923, p. 33). Here the velocity diminished, and the coarser fractions of the sediments were deposited on the natural levees. The finer silt and clay in suspension were deposited subsequently in the quiet water in the flood basins. At some places, as for example on the west banks of the Sacramento River near Colusa, breaks have formed in the natural levees at various times and smaller subsidiary levees or channel ridges extend from the breaks out into the flood basins.

The natural-levee deposits at most places are not sharply defined; the silt and sand deposited where the river begins to drop its load on the levees grade laterally into and interfinger with the fine silt and clay of the flood basins.

The boundaries of the river deposits (pl. 2) are based wholly on soils and topography. However, the base of the river deposits of Recent age at most places cannot be delineated by well-log data. For convenience, therefore, the predominantly coarse-grained deposits at relatively shallow depth that appear to be hydraulically continuous with the present stream channels, flood plains, and natural levees are treated as Recent river deposits, although some of this material may be of late Pleistocene age.

AGE AND STRATIGRAPHIC RELATIONS

The river deposits, like the basin deposits and alluvial-fan deposits, are still accumulating, or would be accumulating under natural conditions. On the east side of the valley these three cartographic units might well be grouped as Recent alluvium to distinguish them from the underlying older continental deposits, comprising the Victor formation and related deposits (Pleistocene) and Laguna formation and related continental sediments (Pliocene and Pleistocene).

The river deposits obviously are of Recent age at the surface, but the lower boundary of the Recent material is difficult to ascertain by using well-log data.

Fairly well defined tongues of sand and gravel underlie the present flood plains of the Feather, Yuba, Bear, and American Rivers, and wells adjacent to the Sacramento River and other streams penetrate much coarse material. These coarse-grained deposits may have accumulated in trenches that were eroded when sea level was lower during glacial epochs in the Pleistocene. Sea level rose when the glaciers of the latest stage (Wisconsin) retreated. If the period of filling is included in the Recent epoch, the youngest of these deposits are entirely Recent in age.

At the fossil locality described by Piper, Gale, Thomas, and Robinson (1939, p. 49) in sec. 32, T. 9 N., R. 5 E., about 1,000 feet north of the American River and 600 feet west of the Southern Pacific Railroad, the surface was said to be topographically continuous with the Victor plain to the south. Here a skull and tooth fragments of an elephant, tentatively identified by Vickery as *Elephas columbi?* (Pleistocene), were found in lenticular beds of sand and gravel about 12½ feet below the surface. This site, now filled in, was visited by one of the present authors (Olmsted), who ascertained that the surface at the locality of the find is not continuous with the Victor plain to the south, as stated by Piper (Piper, and others, 1939), but lies within the Recent flood plain of the American River. If the sand and gravel in which the bones were found are equivalent in age to the coarse channel deposits revealed in core holes at the Elvas Bridge site half a mile east, and if the bones were in place and were correctly identified, the Recent deposits of the American River and probably of other streams in the Sacramento Valley consist only of a thin veneer at the surface.

Observation wells in the Mokelumne River flood plain between Lodi and Lockeford were drilled through beds of gravel and coarse sand from 25 to 45 feet below the land surface. They are not believed to be channel deposits at the base of the Recent alluvium, because similar coarse-grained deposits occur at all depths in the

Victor formation (Pleistocene) and because the gravel and coarse sand resemble the Victor in texture, mineral composition, and degree of weathering (Piper and others, 1939, p. 37).

Much of the coarse-grained material beneath the flood plains of the upper Feather and the Yuba and Bear Rivers is hydraulic-mining debris, dating from the last half of the nineteenth century. Gilbert (1917) estimated that 684 million cubic yards, or 424,000 acre-feet, of debris was removed from the Tertiary gravel channels of the upper Yuba River from 1849 to 1909. Of this amount 330 million cubic yards, or 204,000 acre-feet, of debris was deposited along the Yuba between the narrows above the canyon mouth and the junction with the Feather River. The average thickness of this deposit is more than 12 feet, but in places the thickness is much greater. Gilbert (1917) estimated that more than half the material consisted of gravel and coarse sand, about a fourth was sand, and the remainder was silt.

LITHOLOGIC CHARACTER

The river deposits generally are unconsolidated and range from cobble and boulder gravel to fine silt and clay. Rock and mineral types are diverse because of the great number of parent rock types exposed within the drainage basins of most of the larger Sacramento Valley streams. The deposits of the trunk stream—the Sacramento River—are of particularly heterogeneous mineralogy, because mineral assemblages from the Coast Ranges, Klamath Mountains, Cascade Range, and Sierra Nevada are present.

In general, the river deposits, as well as the basin deposits and alluvial-fan deposits of Recent age, contain a greater variety of minerals than the Tertiary and Pleistocene sedimentary rocks, owing to the geologically rapid decomposition and solution of the less stable minerals. The feldspars, which generally are abundant in all the source rocks for the sediments in the Sacramento Valley, alter to clay minerals upon weathering and tend to reduce the permeability of the older sediments. Fresh or slightly weathered feldspar is more abundant and clay less abundant in the deposits of Recent age.

Clean well-sorted sand and gravel are more abundant in the river deposits than in the older sediments in the valley. Most of these coarse permeable materials have been deposited along the stream channels and are hydraulically continuous with the stream beds. In areas where the water table on either side of the stream is lower than the water in the channel and where the deposits are permeable, seepage from the stream takes place rapidly through the channel deposits.

Soils formed on the river deposits are principally of the Columbia, Sycamore, Hanford, Honcut, Chualar, and Sacramento series of the classification used by the U.S. Bureau of Soils and the College of Agriculture of the University of California. These soil groups and the soils within each group differ somewhat in texture and mineralogy, but all are similar in their lack of significant profile. The general character of soils on the river deposits might be summarized as: Absence of well-defined profile; homogeneity, in some places to depths of more than 10 feet; and moderate to high permeability.

At some places the soil overlies deposits of different origin, many of older semiconsolidated sediments. At such places the river deposits consist entirely of the "soil" layer and form a veneer on the Victor or Laguna formations or other pre-Recent deposits. Elsewhere, the soil layer may grade downward into similar materials, or it may overlie coarse sand and gravel beds of earlier stream channels. The present stream channels generally have no true soils and are classified in soil surveys as river wash or tailings.

Subsurface data, unfortunately, are too meager in most places to support any general statements on the character and thickness of the river deposits. Little is known of the subsurface extent of the Recent deposits of the Sacramento River. Few wells have been drilled in these deposits, and the available well logs show no systematic changes in the lithologic character either vertically or laterally.

Well-defined sand and gravel trains can be identified in the Victor formation and related deposits (Pleistocene) on both sides of the Feather River flood plain. Few wells have been drilled in the Recent flood plain, however, and the subsurface extent of any possible Recent river deposits cannot be ascertained with the available data. Wells near the junction of the Feather and Bear Rivers tap coarse deposits that have a base from 130 to 140 feet below the land surface, but these deposits probably belong to the Victor formation.

Because of inadequate well-log data along the Yuba River, it is difficult to determine the limits of sand and gravel bodies beneath the present flood plain. A top zone of sand and gravel extends to about 100 feet below the land surface near Marysville, but the base of the coarse-grained deposits is somewhat shallower to the northeast.

Most of the wells in the Bear River flood plain penetrate gravelly deposits from 15 feet to about 60 feet below the land surface. The overlying deposits are described as silt or clay and probably are at least in part slickens from hydraulic mining upstream. The gravel in part is Pleistocene; tongues of gravel extend beyond the land-surface boundaries of the river deposits and, accordingly, should be assigned to the Victor formation.

The American River probably is the best place to study the Recent river deposits, because water-well log coverage is fairly good and because test-hole data are available for the Elvas Bridge foundations at Sacramento and for the U.S. Bureau of Reclamation at Nimbus dam site, between Fair Oaks and Folsom. The river deposits near Folsom are only a few feet thick and consist of clean sand and gravel on a surface cut on granodiorite and volcanic rocks from the Sierra Nevada. At Nimbus Dam the river deposits probably are not more than 20 feet thick, and volcanic rock is exposed in the stream bed in places.

Two wells in the flood plain about 10 miles east of Sacramento are drilled through 30 feet of sand and gravel overlying fine-grained sediments. Several wells in the Brighton area just east of Sacramento record gravel to a depth of as much as 67 feet, but some of this gravel may belong to the underlying Victor formation. Near the Elvas Bridge site, just north of Sacramento, test holes and nearby water wells indicate sand and gravel to a depth of about 55 feet, or 30 feet below sea level. The gravelly deposits extend to the surface in the present channel of the river; elsewhere they are overlain by silt and sand. The width of the sand and gravel fill is not certainly known, but the fill is at least three-fourths of a mile wide at the Elvas Bridge site. The gravel rests on brown silty clay, presumably belonging to the Victor formation of Pleistocene age.

It is difficult to interpret the data farther west. Wells in and near the Southern Pacific Railroad yards penetrate sand and gravel to a depth of as much as 107 feet below the surface. These deeper strata, however, probably are pre-Recent sediments deposited by the Sacramento River.

On the west side of the Sacramento Valley, Cache Creek has a well-defined train of coarse stream-channel deposits, and Putah Creek west of Winters has a thin sand and gravel deposit beneath the narrow flood plain. Elsewhere, the west side streams have deposited their material on broad, low alluvial plains or fans rather than along restricted strips adjacent to the present stream courses. Coarse, well-sorted gravelly deposits underlie the Cache Creek area east of the Dunnigan Hills. These deposits are as much as 150 feet thick near Esparto, but farther west the base of the gravel apparently is higher, and the gravelly deposits may be only about 40 feet thick immediately south of the Dunnigan Hills. How much of these deposits is of Recent age is not known, but the gravel at the land surface obviously is Recent. East of the Dunnigan Hills the gravel beds, which average 1 to 1½ miles wide west of the hills, seem to fan out and do not lie in any one well-defined train.

The Recent channel deposits of Putah Creek are relatively thin and insignificant and occur mostly west of Winters.

WATER-BEARING CHARACTER

Wells on the flood plains and natural levees of the major streams of the central and southern parts of the Sacramento Valley are drilled through thick sections of well-sorted, highly permeable sand and gravel. Some of this coarse material is undoubtedly river deposits of Recent age, but much of it probably is Pleistocene. Coarse, clean gravel deposits occur beneath the flood plains of the Sacramento, Cosumnes, American, Bear, Yuba, and Feather Rivers and Cache and Stony Creeks. These coarse-grained deposits are tapped by many large-capacity irrigation, industrial, and municipal wells. Some of the most productive wells in the valley draw their water from the coarse river deposits and the lithologically similar stream-channel deposits of the Victor formation of late Pleistocene age. Although ample ground-water supplies are available, development has been limited because of the availability of cheap surface-water supplies from the streams. The fine sand and silt of the natural-levee deposits supply some water to stock and domestic wells.

The specific yield of the river deposits, calculated from thicknesses of various materials shown in drillers' logs, shows a general downstream decrease in the river deposits of the major streams of the Sacramento Valley. In the river flood-plain and channel deposits of the Sacramento River north of Colusa, estimated specific yields were 12.8 percent and 11.2 percent, respectively, for the depth zones 20–50 feet and 50–100 feet (table 4). For the reach of the river south of Colusa the estimated specific yields were 9.7 and 10 percent, respectively, for the zones 20–50 feet and 50–100 feet (table 4).

A few irrigation wells are bottomed in the Recent channel deposits, but wells of large capacity commonly penetrate older sediments as well. Pump-test results for 59 irrigation wells drilled near the Sacramento River in Colusa, northern Sutter, and Glenn Counties (fig. 3) indicated an average production rate of about 1,700 gpm for a specific capacity of 85 gpm per foot of drawdown. Pump-test results for 42 irrigation wells in the river lands of Yolo, southern Sutter, and Sacramento Counties (fig. 3) indicated an average yield of 750 gpm for a specific capacity of 42 gpm per foot of drawdown. Average depths of the irrigation wells in both areas are about the same—300 to 315 feet.

FLOOD-BASIN DEPOSITS (RECENT)

DEFINITION

The flood basin deposits are predominantly fine-grained sediments of Recent age which have accumulated in the flood basins in the central part of the Sacramento Valley. The fine silt and clay, which constitute most of the flood-basin deposits, were carried in suspension in flood waters of the Sacramento River and its major tributaries and settled in the relatively quiet waters in the basins.

With the exception of Butte Creek lowland, which is underlain mostly by river deposits and the Victor formation and related deposits, the boundaries of the flood basins geomorphic unit coincide approximately with the exposures of the flood-basin deposits. (Compare pls. 1 and 2.)

AGE AND CORRELATION

The flood-basin deposits have been deposited by seasonal floodwaters of the Sacramento and Feather Rivers and smaller streams on both sides of the valley. The material obviously is of Recent age at the land surface, but the thickness of these Recent deposits has not been determined. It is likely that flood basins existed during the Pleistocene and possibly before, although the outlines of these ancestral basins probably were somewhat different from those now in existence. Coarse-grained sediments, including gravel, underlie many of the basins at varying depths. Unfortunately, logs of water wells are few, and it was impossible to trace definite ancestral river-channel deposits beneath the basins.

The presence of many small, low mounds and ridges underlain by the San Joaquin series soil, a type characteristic of the Victor formation to the east, is an indication that the Recent deposits may be thin in the American Basin. These mounds probably are outliers of the Victor formation that have not been buried by the flood basin deposits. The Recent deposits of most of the Butte Creek lowland probably are represented by only a few feet of dark soil (Stockton clay adobe). This soil, ordinarily formed on Recent basin deposits, overlies semiconsolidated yellow-brown sediments of the Victor formation, and materials underlying the area are mapped as the Victor formation and related deposits rather than as basin deposits. (See pl. 2.)

DISTRIBUTION AND CHARACTER

The basin areas have been divided into five more or less distinct units, the Colusa Basin, Butte Creek lowland, Sutter Basin, Yolo Basin, and American Basin. All the basins are bounded on one side by the low plains along the sides of the valley and on the other side by the natural levees of the Sacramento River. In general, the surface extent of the basin deposits is the same as that of the geomorphic unit called flood basins (pl. 1), although the so called Butte Basin, or Butte Creek lowland, differs from the other basins (see p. 209).

The flood basin deposits have formed by the accumulation of silt and clay that were carried in suspension by floodwaters and settled slowly when the current slackened. These deposits grade laterally into and interfinger with the adjacent river deposits on one side and with the upper part of the alluvial-fan deposits on the other. (See pl. 4.)

The boundaries of the flood-basin deposits of the Sacramento Valley (pl. 2) were modified from those on soils maps of the U.S. Department of Agriculture, Bureau of Soils, and the University of California College of Agriculture, Division of Soils. The boundaries are vague at many places and must be drawn on very arbitrary differences in soils. The soils mapped as flood-basin deposits are dark-gray clay and clay adobe containing more than 50 percent clay-size particles at many places.

Few water wells have been drilled in the basins, and it is difficult to determine the subsurface extent and character of the deposits from the meager data available. In the Sutter Basin, soil and yellow clay as much as 48 feet thick are reported above blue clay, blue sand, gray clay, and gravel. The significance of the change from yellow to blue sediments is not fully understood, except that oxidation of the iron has been prevented in the deeper sediments, or that the iron was once oxidized and subsequently reduced. A yellow clay above blue clay or coarse-grained sediments is as much as 170 feet thick in Yolo Basin, 100 feet in American Basin, and 170 feet in Colusa Basin. It is unlikely that the color change has any age significance, however, and the thickness of the Recent flood-basin deposits is unknown.

Data on the sediments in the Butte Creek lowland come from Army engineer core holes drilled prior to construction of levees on Butte Creek. These data, from holes 20 to 50 feet deep, indicate that silty clay predominates. Mechanical analyses of samples taken from an average depth of 15 to 20 feet indicated the following grain-size proportions: Clay, 40 to 60 percent; silt, 30 to 50 percent; sand, 0 to 20 percent.

WATER-BEARING CHARACTER

Clay and silt of the flood-basin deposits provide little water to wells, although locally sand and gravel deposited in ancestral stream channels supply large quantities of water. The Butte and American Basins probably are underlain at relatively shallow depth by the Victor formation and related deposits, but great thicknesses of dark clay and silt with very few coarse-grained beds are penetrated by wells in the Colusa, Sutter, and Yolo basins and indicate that flood-basin or lacustrine deposition has long been a feature of the poorly drained low central part of the Sacramento Valley. Tongues of sand and gravel tapped by wells are believed to represent buried stream channels and distributaries, rather than any marked change in the regimen of deposition of the basin materials themselves.

In general, a combination of inadequate yields of wells and the availability of abundant surface-water supplies have discouraged ground-water development in the Yolo and Colusa basins. The water in Sutter Basin is contaminated at all depths with high chloride content that makes it unsuitable for irrigation or domestic use (California State Water Resources Board, 1952). In the Butte Creek lowland and American Basins irrigation supplies are obtained from the Victor and related deposits underlying the Recent flood-basin deposits.

Irrigation wells, locally producing in excess of 2,000 gpm, have been completed in the Yolo and Colusa Basins, notably in the Grimes area in the eastern part of Colusa County and in the central part of Yolo Basin west and southwest of Sacramento, but these wells produce the bulk of their water from river-laid sand and gravel rather than from the typical fine-grained flood-basin deposits.

GEOLOGIC HISTORY

In view of the uncertainty regarding correlation of the salient events in the geologic history of the northern part of the Coast Ranges with the events in the Sierra Nevada and Cascade Range, the history of these two sides of the Sacramento Valley will be discussed separately in this report. Wherever possible, an attempt has been made to place the events in the general geologic history of northern California, as it has been discussed by many previous workers in this region, principally Becker (1885), Lindgren and Turner (1895 a, b), Diller (1906), Allen (1929), Matthes (1930), Anderson and Russell (1939), Piper, Gale, Thomas, and Robinson (1939), MacGinitie (1941), Kirby (1943c), Jenkins (1943b), Johnson (1943), and Taliaferro (1951).

Inasmuch as the detailed field investigations by the present authors were restricted to local areas along the eastern margin of the valley and to Solano County and the southern part of Yolo County on the west side of the valley, only a reconnaissance being made of the remainder of the valley, most of the geologic history given here is a synthesis of conclusions reached by the authors listed above. Except where one author has disagreed fundamentally with another in interpreting the geologic record, references to specific sources are omitted in the following discussion.

SIERRA NEVADA, CASCADE RANGE, AND EASTERN SACRAMENTO VALLEY

The first geologic event pertinent to this discussion of the Sierra Nevada, the Cascade Range, and the eastern side of the Sacramento

Valley was the formation of an ancestral Sierra Nevada by folding, faulting, and igneous intrusion in Late Jurassic or Early Cretaceous times. This ancestral range was more extensive than the present Sierra Nevada; it probably bordered a sea many miles west of the western foothills of today. The eastern limit of the range is not known, but a land mass extended into the present Great Basin in northern Nevada and probably farther east.

The mountain building, called the Nevadan or Nevadian orogeny, produced a folded mountain range. Remnants of the structure are preserved as intensely folded, steeply dipping metamorphic rocks having fold axes with a north to northwest strike—parallel to the present axis of the range. This ancestral range was at least moderately high, because the intrusive rocks, which must have formed at depths of at least several thousand feet, were partially uncovered by erosion by the end of the Cretaceous. The westward extent of the old Sierra Nevada is not certainly known, but Sierra-type rocks have been found in the bottoms of two gas wells in the Sutter Buttes (May and Hewitt, 1948, p. 132, 136), and seismic evidence suggests that the Sierra block may extend beneath the western part of the Central Valley (Vaughan, 1943, p. 68).

Age determinations of samples of granitic rock from the Sierra Nevada reported by Curtis, Evernden, and Lipson (1958) indicate that at least two major intensive episodes occurred in the Sierra Nevada region during the latter part of the Mesozoic era. The first episode, correlated by Curtis and his colleagues with the Nevadan orogeny, took place during Late Jurassic time in the interval 133 to 143 million years ago; the later episode occurred during Late Cretaceous time 78 to 95 million years ago.

During the Cretaceous period enormous quantities of rock were removed from the mountains by erosion. Probably most of the detritus is represented by the thick marine Cretaceous rocks in the present Coast Ranges, although studies by Taliaferro (1943) in the central Coast Ranges indicated that many of these Cretaceous rocks had a western source. The old Sierra Nevada was planed down to a surface of low relief by early Eocene time, and much of the granitic intrusive rock emplaced during the Nevadan orogeny was uncovered.

While erosion was going on in the Cretaceous period, the sea gradually transgressed eastward over the eroded surface of the old Sierra Nevada. Lower Cretaceous rocks are thick in the Coast Ranges but do not extend as far east as the Sutter Buttes. Upper Cretaceous marine sedimentary rocks at least 4,350 feet thick crop out in the Sutter Buttes but are relatively thin or absent on the east side of the Sacramento Valley. (See pls. 3.) The eastward marine transgression was accompanied by a gradual subsidence of the planed-off western part of the ancestral Sierra, because the Upper Cretaceous sedimentary rocks indicate a shallow to moderate depth marine environment throughout.

At the end of Cretaceous time the region near the eastern margin of the sea was upwarped, and a land mass was created east of the present position of the Sutter Buttes. This land mass furnished sediments to a shallow sea during Eocene time. The geologic record of this upwarping consists of a hiatus and a possible unconformity between Cretaceous and Eocene rocks in the Sutter Buttes and in the subsurface in the eastern part of the Sacramento Valley as shown by logs of gas wells.

During Late Cretaceous and Paleocene time the land gradually subsided until the shoreline of early and middle Eocene time occupied a position east of Sutter Buttes. The early Eocene sea may have extended as far east as Lincoln in Placer County, where fossiliferous marine sediments of probable early Eocene age are exposed in a clay quarry. Middle Eocene marine sandstone and siltstone are exposed near Dry Creek between Oroville and Chico.

A warm and humid climate in the northern Sierra Nevada during the middle Eocene is indicated by the broad-leaved types of plant fossils found in the old river-channel and delta deposits. Lignite seams and severely weathered sediments of the Ione formation also attest to the warm, humid climate and the attendant strong weathering.

Laterite and lateritic soils formed on the bedrock, then a slight regional uplift or a change in base level brought about a mild dissection of the weathered surface. Clay and sand were deposited in low, broad deltas while quartz and metamorphic-rock gravel and sand were deposited along the Sierran streams to the east. The drainage pattern was controlled largely by the bedrock zones of differing hardness; long reaches of the Eocene stream courses trend northwestward and southeastward, parallel to the bedrock structure.

Commencing in the middle or late Eocene and continuing sporadically into Miocene time, volcanic eruptions deposited rhyolitic, andesitic, and basaltic pyroclastic and flow rocks near the present crest of the Sierra Nevada. The earliest eruptions in the Yuba River drainage area were rhyolitic and resulted in the deposition of welded rhyolite tuff in the upper reaches of the stream valleys. Rhyolitic ash and pumice fell farther west, damming and diverting the smaller streams in places. The streams concurrently eroded this material and redeposited it downstream as water-laid tuff, tuffaceous sand, and volcanic gravel. The next eruptions were andesitic and dacitic and probably took place during the late Eocene or Oligocene, as indicated by fossil flora in a dacite tuff on the upper Yuba River, and marine mollusks in andesitic conglomerate in the Wheatland formation of Clark and Anderson (1938) on the east side of the Sacramento Valley.

The first volcanic activity seems to have been accompanied by mild upwarping of the land. The deposits along the streams during this time consisted of fresh material, including chemically unstable minerals such as biotite and feldspar, which would suggest more vigorous erosion and more rapid accumulation of the sediments

Meanwhile, the sea began to withdraw from the Sacramento Valley, but marine deposition continued for a short time as far east as the present exposures of the Wheatland formation near Wheatland. The association of volcanic pebbles and cobbles with upper Eocene or Oligocene mollusks in a conglomerate near the base of the formation indicates that marine deposition here was approximately contemporaneous with the early volcanic activity to the east.

Deep drilling in search of gas has revealed a major subsurface erosional unconformity, which has a maximum relief of about 3,000 feet in the south-central Sacramento Valley. This feature, named the "Markley Gorge" by Davis (1953, p. 186), was described by Almgren and Schlax (1957). The unconformity has been traced a distance of about 40 miles from north of the city of Sacramento southwestward to and beyond Rio Vista. (See pl. 3.) According to Almgren and Schlax the "Markley Gorge" was eroded into a sequence of marine beds ranging in age from Late Cretaceous to the late Eocene Sidney shale member of the Kreyenhagen formation (p. 106), and was filled with predominantly nonmarine deposits during Oligocene and possibly Miocene time. The fill consists of shale, sandstone, and conglomerate beds characterized by considerable lateral and vertical variation. The sandstones are of two general types. One, limited to the lower part of the fill, is grayish green to greenish brown, earthy, poorly sorted and consists largely of grains of volcanic rocks; the other is blue, generally coarse grained, and fairly well sorted. Almgren and Schlax (1957) correlate the fill in part with the Oligocene Wheatland formation of Clark and Anderson (1938) and in part with the San Pablo formation of the Mount Diablo area.

By Miocene time, when the last of the rhyolitic materials were being deposited, the sea apparently had withdrawn from most of the present Sacramento Valley region. The rhyolitic deposition in the Sierra Nevada was largely restricted to the valleys occupied by the streams established in Eocene and Late Cretaceous time, but broad, low fans and deltas were formed in the Sacramento Valley.

After a period of erosion and relative quiet, predominantly andesitic eruptions began during the late Miocene in the northern Sierra Nevada and sent a flood of mudflow breccia and ash down the western slopes. Streams continually reworked these deposits and spread them over broad areas to the west. All but the highest hills and ridges eventually were inundated by the volcanic debris. Drainage repeatedly was disrupted, the old stream canyons were buried, and a new consequent drainage pattern developed on the volcanic surface.

During this prolonged period of volcanic activity, which continued into the middle Pliocene, the Sierra Nevada block was outlined by faulting near its present eastern border and tilted westward. Lindgren (1911) believed that first faulting, delineating the present Sierra block, took place during the Cretaceous period, but later workers have failed to find any substantial evidence to support this view and prefer to place the time of the first major faulting and tilting not earlier than Miocene and possibly much later. A view differing from that of Lindgren was taken by Louderback (1924) in a study of the fault scarps in the Lake Tahoe region. Louderback found no evidence for more than one stage of faulting, and he stated (1924, p. 22) that the scarp-producing faulting of the northern part of the Sierra Nevada occurred after the eruptions of andesitic deposits.

Hudson (1951), in a study of the Donner Pass region at the crest of the Sierra, found evidence for faulting during middle Miocene time as well as later. The northern part of the Sierra Nevada appears to have been upwarped before or during the early stages of the andesite eruptions, and fissures were formed from which the lavas were extruded.

This second period of vigorous vulcanism in the northern Sierra Nevada has been dated by fossil flora and rather scanty fossil vertebrate remains in the Mehrten formation. The fossils indicate a late Miocene through middle Pliocene age. The climate in the Sierra foothills was milder than the present climate. Annual precipitation was about the same as it is now, but more rain fell during the summer.

The volcanic activity waned and died out, and the latter part of the Pliocene epoch was marked by erosion in the Sierra Nevada and subaerial deposition (Laguna formation) in the Sacramento Valley. The streams, which were consequent on the volcanic surface, cut through the volcanic deposits into the underlying basement complex and established essentially the present drainage pattern. The detritus removed by these streams was deposited in low, broad plains in the valley trough. That the erosion during the late Pliocene and early Pleistocene(?) was not as vigorous as it was later is indicated by the relatively fine grain size of the materials in most of the Laguna formation on the east side of the Sacramento Valley.

During late Pliocene time, volcanoes in the southern part of the Cascade Range north of the Sierra Nevada poured out successive mudflows of basaltic and andesitic material similar to the Sierran volcanic material. These deposits were reworked continually and redeposited as far west as the present axis of the valley trough where they interfingered with predominantly nonvolcanic detritus from the Coast Ranges. The volcanic deposits (Tuscan formation) reached a thickness of more than 1,000 feet, and they completely overwhelmed the old topography, which by this time was an erosion surface of low relief on Sierra-type basement-complex rocks and Upper Cretaceous sediments.

At some time in the Pliocene an andesitic plug pushed up through the Sacramento Valley sediments, shattering and deforming them. This was the first igneous activity of the Sutter Buttes. After a period of erosion, rhyolitic domes or necks were intruded into the plug and around its periphery. More erosion followed; then there were a series of explosive eruptions accompanied by fresh magma from a central crater and minor craters near the margins of the laccolith. Great angular blocks of rhyolite and andesite, as much as 15 feet across, as well as abundant finer grained material, swept down the slopes of the volcano chiefly in mudflows although hot gaseous blasts may have been important also in forming tuff-breccia deposits. The tuff breccia subsequently was tilted and faulted. In the final stages of eruption the crater of the volcano was filled with tuff—the vent tuff in the present central area of the buttes. The cone formed above the core probably reached a maximum altitude of 5,000 feet, but subsequent erosion reduced the height by more than half, and the present peaks of the central area of the buttes are principally erosional remnants of the andesite core.

Deposition of the fluviatile sediments of the Laguna formation in the eastern Sacramento Valley was terminated by a major uplift or series of uplifts that elevated the Sierra Nevada to approximately its present altitude. The movement appears to have consisted of a simple westward tilt of the mountain block accompanied by vertical movement along faults that bound the block on the east. Lindgren (1911), Piper, Gale, Thomas, and Robinson (1939), Matthes (1930), and others have assumed that the Sierra Nevada acted as a rigid block during the Pleistocene faulting. However, in recent studies of the long profile of the Tertiary Yuba River and of the volcanic and prevolcanism rocks of the Donner Pass region, Hudson (1951, 1955) concluded that the post-Eocene deformation in the northern part of the Sierra Nevada involved folding and block faulting west of the crest rather than a simple tilt of a single rigid block. Matthes (1930, 1947) placed the time of uplift at the end of the Pliocene or beginning of the Pleistocene. Piper (Piper and others, 1939), however, dated the uplift as middle Pleistocene, which would correspond to the middle Pleistocene orogeny of Taliaferro (1943), Reed (1933), and others in the central Coast Ranges.

Moraines and erosional features of at least three glacial stages have been recognized in the Yosemite Valley region by Mathes (1930), and Blackwelder (1931) has delineated three, and possibly four or five, stages on the eastern slope of the Sierra Nevada. The high Sierra was repeatedly mantled with glaciers during the Pleistocene, and there were long interglacial periods when the ice disappeared or waned considerably. It is unlikely that the altitude of the crest produced by late Tertiary uplifts was sufficient to permit the formation of glaciers; so most of the last uplift must have just preceded the first glacial stage. If Blackwalder's possible four or five stages correspond to the continental glacial stages recognized in the eastern United States and Canada, the major uplift would have occurred not later than early Pleistocene.

Matthes' (1930) studies of the cross profiles of Merced River canyon and other lines of evidence suggest that the last major deformation added about 6,000 feet to the altitude of the Sierra crest in the Yosemite region. Farther north the uplift was less, though in the Mokelumne River region, the westward slope was nearly doubled. Matthes estimated that the increased competence of the Merced River enabled it to deepen its gorge to twice the depth of its original Pliocene valley.

The other northern Sierra Nevada rivers also cut deep, narrow gorges, and great quantities of coarse detritus were transported to the Central Valley. Some of this coarse material was supplied by glaciers, which were effective in eroding the upper reaches of the canyons.

In the Central Valley the rejuvenated streams cut laterally and truncated the soft sediments (Laguna formation) that had been deposited during the late Pliocene. Most of the detritus was carried westward to be deposited near the axis of the valley, but some of the coarser material was left as a capping gravel on the older beds. As might be expected, the gravel deposits are coarsest and thickest adjacent to the present large streams, particularly the Feather, Yuba, and American Rivers.

The last major uplift of the northern part of the Sierra Nevada may have been essentially contemporaneous with an uplift and folding of the Tuscan formation in the Cascade Range to the north. The volcanic rocks of the Tuscan were folded into a monocline trending about north-northwest, parallel to the axis of the Sierra

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Nevada farther south. The streams that flowed on the constructional surface of the volcanic breccia cut down with increased vigor following the folding, and alluvial fans of reworked volcanic material (fanglomerate from the Cascade Range) built up rapidly west of the monocline.

After the deposition of the coarse gravel derived from the Sierra Nevada (Arroyo Seco gravel), regional upwarping, a change in base level, or climatic change brought about dissection of the gravel and the underlying Laguna formation. The sediments that had been accumulating in the center of the valley (Victor formation and related deposits) transgressed progressively eastward, burying the western part of the older material and filling some of the low areas farther east. The alluvial fans west of the Cascade Range likewise were dissected, and the eroded fan material accumulated farther west or was carried away by the Sacramento River.

Glaciation during the Pleistocene epoch resulted in worldwide fluctuations of sea level. Sea level declined during the glacial advances and rose as the glaciers retreated. Whether these changes in sea level had an appreciable effect on the regimen of the streams in the Sacramento Valley is not known. The lower reaches of the major streams may have cut into the soft alluvial material as sea level declined and backfilled these trenches or channels as the level rose.

Sand and gravel tongues that might be associated with sea-level fluctuations may be traced in the Victor formation in the eastern part of the Sacramento Valley. Many of these subsurface "channels" are several miles from the present river courses but originate near the point where the present streams leave the bedrock of the Sierra Nevada. The Pleistocene gravel trains of the American River are south of the present flood plain, as are the gravel beds of the Yuba River. The Pleistocene sand and gravel deposits of the Feather River are on both sides of the present flood plain.

The last significant drop of sea level probably was associated with the last glacial stage—the Wisconsin stage in eastern North America. The larger streams in the Sacramento Valley now may occupy positions established during the Wisconsin trenching, although the evidence for this interpretation is by no means conclusive.

Under the present regimen, the streams are eroding the low alluvial plains and dissected uplands and aggrading the river flood plains and channels, alluvial fans, and flood basins.

NORTHERN COAST RANGES AND WESTERN SACRAMENTO VALLEY

The sediments in the present Sacramento Valley trough have accumulated, with local interruptions, since Early Cretaceous time. A shallow marine basin existed at the site of the present northern

Coast Ranges and western part of the Sacramento Valley during the Early Cretaceous. While the ancient Sierra Nevada to the east was being planed down by erosion, the basin of deposition subsided slowly and the shoreline moved eastward across the beveled edge of the Sierra land mass. Material was washed in from both sides of the basin—from the ancestral Sierra Nevada on the east and from the old land mass of the Coast Ranges on the west.

At the end of the Cretaceous period, regional uplift brought about a withdrawal of the sea from a large part of the present northeastern Coast Ranges and western Sacramento Valley. The presence of Paleocene marine sedimentary rocks in the southern part of the Sacramento Valley as recorded in the logs of a few gas wells indicates that the upwarping did not bring about complete withdrawal of the sea. Unfortunately, these Paleocene rocks have been destroyed in places by erosion as a result of later land movements.

A large part of the Sacramento Valley was occupied by a shallow gulf during the Eocene epoch. The shoreline fluctuated widely as a result of slight changes of sea level or warping of the land, but parts of the northern Coast Ranges remained above sea level during this time. The sea was more extensive in early Eocene than in middle and late Eocene time. The marine waters extended north of the Chico area during part of early and middle Eocene time. Erosion of the northern Coast Range land mass supplied much detritus, some of it coarse gravelly material, such as that occurring at the base of the Capay formation of Crook and Kirby (1935) in Capay Valley.

The middle Eocene gulf was nearly as extensive as the early Eocene, and in places it may have extended farther east. Intense weathering in the source areas is suggested by the dominance of such stable minerals as quartz and anauxite in many of the marine sediments. In general, the sea did not extend as far west in middle Eocene as in early Eocene time; at any rate, middle Eocene sedimentary rocks are missing in the present Coast Ranges north of the Potrero Hills.

The late Eocene basin of deposition shifted slightly westward in the southern part of the Sacramento Valley, and thick shallow to moderate depth marine sediments from a source in the Coast Ranges accumulated in the present English Hills region. The northern and eastern shorelines of the late Eocene sea can only be inferred, because post-Eocene land movements seem to have brought about the removal of much of the material of late Eocene age. However, it seems unlikely that the sea extended as far north as the present Sutter Buttes in the center of the valley and Cache Creek on the west side. The eastward extent of the late Eocene gulf also is unknown, but upper Eocene marine sedimentary rocks do not occur east of the Sacramento River, except for the Wheatland formation near Wheatland. However, the Wheatland formation may be of early Oligocene age (Forrest, 1943, pl. 3).

At about the close of the Eocene the sea generally withdrew from the Sacramento Valley region, although marine sedimentation may have continued sporadically, and swampy conditions were widespread in the southern part of the valley during the Oligocene Miocene, and possibly the early Pliocene. Volcanic detritus was washed in from the Sierra Nevada, and lesser amounts of nonvolcanic debris were contributed by streams from the west.

In middle or late Pliocene time an uplift of the present northern Coast Ranges inaugurated a period of erosion in the mountains and deposition of coarse detritus to the east. The Sacramento Valley trough began to assume approximately its present outline. At that time, the sea had withdrawn completely from the Sacramento Valley trough. Sedimentation kept more than abreast of the sinking of the valley area, and the land surface remained above sea level.

Volcanic eruptions in the southern part of the Cascade Range during the late Pliocene distributed ash (Nomlaki tuff member) in the northwestern part of the Sacramento Valley. Similar ash falls, probably with a different source—perhaps in the Coast Ranges—took place in the southwestern part of the valley.

On the west side of the Sacramento Valley fluviatile deposition continued through the Pliocene and possibly into the early Pleistocene. The streams continually shifted across broad, low flood plains, and the deposition of predominantly fine-grained materials (Tehama formation) characterized the latter part of the epoch.

During this time of deposition, the Sacramento Valley was more extensive than it is now. The western margin of the valley was as much as 20 miles west of the present edge west of Red Bluff, and the northern end of the valley was near Redding. The axis of the trough was several miles west of its present position.

Some time during the Pleistocene epoch, probably in the middle part, the Coast Ranges were folded, faulted, and elevated and began to assume their present general outline and form. The Pliocene to Pleistocene(?) fluviatile sediments (Tehama formation) and older rocks were involved in the folding and uplift.

During and after this mountain-building activity, erosion was vigorous, and much of the Tehama formation was removed and redeposited in the center of the valley or carried southward by the Sacramento River.

Poorly sorted gravelly material (Red Bluff formation) eventually was deposited on the eroded surface of the Tehama formation. Some of the gravel may have been furnished by glaciers that existed in the higher parts of the Coast Ranges and Klamath Mountains. The numerous streams flowing from the west were loaded with coarse debris; and, as they debouched onto the valley floor, they deposited their loads on broad alluvial fans and flood plains.

More uplift and folding followed, usually along axes outlined in the previous folding episode. A series of gentle folds and warps blocked off the part of the old valley north of Red Bluff, and the entire valley region north of Orland and Chico was elevated. The gravel at the Red Bluff formation that had been deposited after the previous orogeny was dissected and partly eroded away to be redeposited on broad fans and piedmont slopes. The time of this last orogeny is not certainly known, but it probably was during the latter half of the Pleistocene epoch.

Intermittent uplifts and (or) climatic fluctuations caused the streams flowing from the northern Coast Ranges to form terraces commonly capped with poorly sorted gravelly deposits. These terraces are well defined along the larger streams, such as Cache, Stony, and Elder Creeks, but are poor or absent along the minor streams.

The present cycle is one of continued erosion in the Coast Ranges and the low hills, formed by the Pleistocene orogenies and deposition in the valley. Except on the Stony Creek alluvial fan, along Cache Creek, and a few other smaller west-side streams, the latest deposits are predominantly fine grained. Parts of the alluvial plains, such as those in the southwestern corner of the valley north of the Montezuma Hills, have reached equilibrium where little deposition or erosion is taking place.

GEOLOGIC STRUCTURE

REGIONAL FEATURES

The Sacramento Valley occupies most of the northern part of the Great Valley structural trough. To the east is the Sierra Nevada, a block mountain range tilted upward on the east that dips westward beneath the Central Valley. West of the Sacramento Valley are the Coast Ranges, a complexly folded and faulted mountain mass essentially parallel to the Sierra Nevada. The Sacramento Valley proper is terminated on the north by the Red Bluff arch, a gentle anticline that crosses the valley normal to its long direction. The principal structural trough, however, extends about 30 miles farther north. (See fig. 2.) Geophysical investigations have shown that the Sierra Nevada block continues westward almost to the flanks of the Coast Ranges beneath the floor of the Central Valley (Vaughan, 1943, p. 67, 68).

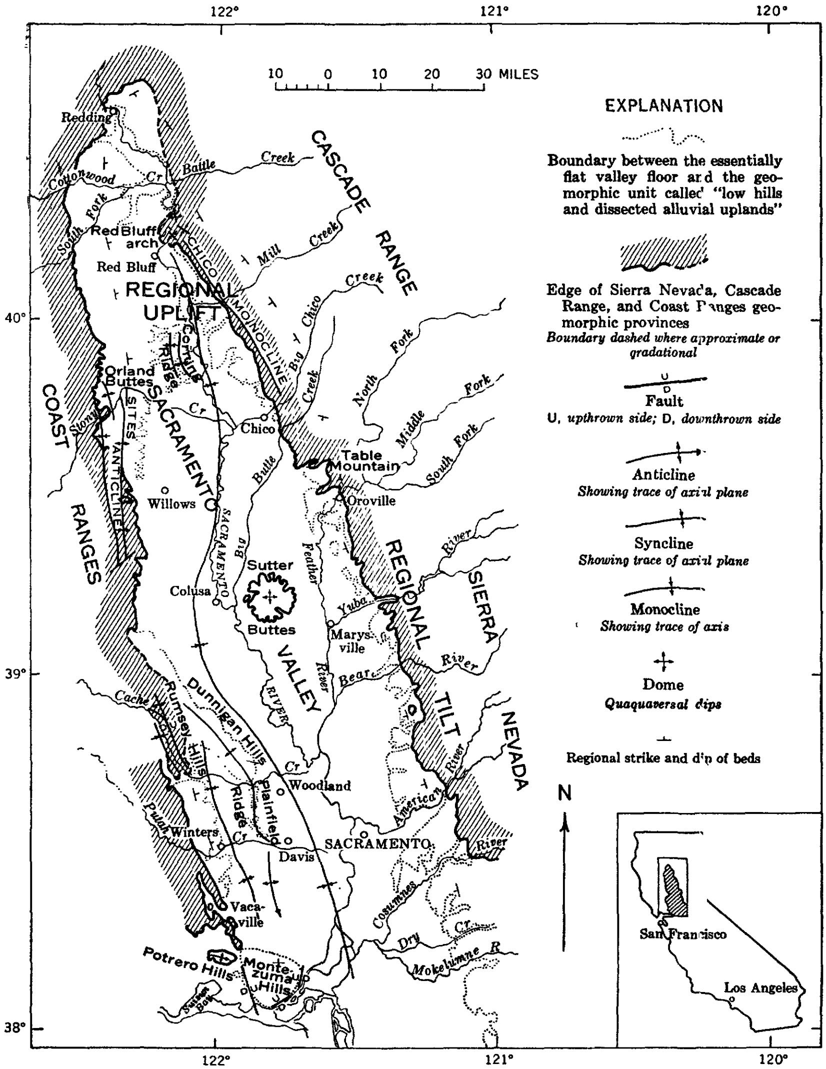

FIGURE 2.—Map showing geologic structure of the Sacramento Valley, California.

SIERRA NEVADA

In broad outline the Sierra Nevada consists of a great block of the earth's crust which has been dislocated and tilted toward the southwest (Matthes, 1930). However, the block has been modified somewhat by folding and faulting, at least in the northern part (Hudson, 1951, 1955). The Sierra Nevada, thus, is appropriately termed a block mountain range. On the east the block is bounded by a system of master faults along which the earth's crust has been dislocated—the west side rising relative to the east side. The displacement along these faults is several thousand feet—at least 8,000 feet in the vicinity of Owens Lake (Matthes, 1930, p. 24). The causes of the tilting of the Sierra Nevada are not clear, but it seem probable that they were major deep-seated earth movements of great magnitude. Vaughan (1943) suggested that the tilting of the Sierra Nevada, the downwarping of the Central Valley, and folding and faulting of the Coast Ranges were interrelated structural movements of continental scope caused by compressional forces exerted from the west.

The core of the Sierra Nevada block is composed of igneous rocks ranging in composition from granite to peridotite, although granodiorite is the most abundant type. Together they form the Sierra Nevada batholith, an igneous-mass that crystallized at considerable depth below the earth's surface. The outstanding feature of the batholith is that it is exposed at the surface over large areas despite its deep-seated origin. The explanation is that the former roof of the batholith has been largely stripped off by erosion, leaving only remnants of the once more extensive metamorphosed older rocks that formed the cover. These metamorphic rocks are more abundant in the northern part of the Sierra Nevada east of the Sacramento Valley, than in the southern part, east of the San Joaquin Valley.

Deep wells that reach the basement complex of the Sierra Nevada in the Sacramento Valley indicate that the surface of the block slopes more steeply beneath the Central Valley than it does to the east. (See pl. 3.) The flatter slope of the present exposed surface of the range has resulted from post-Cretaceous beveling of the block by erosion. The slope of the basement complex in the exposed eastern part of the Sierra Nevada block generally is considered to be that of an erosion surface formed largely in Eocene time (Lindgren, 1911). The surface of the basement complex that slopes more steeply farther west beneath the Sacramento Valley is necessarily an older erosion surface, because Upper Cretaceous sedimentary rocks overlap it as far east as the present Sierra Nevada foothills.

NORTHERN COAST RANGES

Bordering the Sacramento Valley on the west are the northern Coast Ranges, which are characterized by longitudinal ridges and intervening valleys trending north to northwest. Folding and faulting of alternating hard and soft sediments control this trend.

The western part of the Sacramento Valley is bounded throughout much of its central and southern portions by strike ridges underlain by Cretaceous and lower Tertiary marine sedimentary rocks. Compressive forces deformed the Coast Ranges sediments into tightly folded anticlines, synclines, and local thrust faults. Vaughan (1943) suggested that these same compressive forces caused the tilting of the rigid Sierra Nevada block by forcing its western part down below its position of isostatic equilibrium.

Several local folds and faults of the Coast Ranges type have deformed the upper Tertiary and Quaternary sedimentary rocks along the western border of the valley. Because the water-bearing sediments of the valley were involved in these movements, the resulting structures are of particular interest in this report. The major structural trends are shown on figure 2. The structures of the Dunnigan Hills, Plainfield Ridge, Potrero Hills, and Montezuma Hills are expressed topographically. The rocks of the Dunnigan Hills that extend 20 miles in a northwestward direction from south of Cache Creek to the Colusa County line form an asymmetrical anticline, steep on the east flank and gentle on the west flank. Both the Tehama and Red Bluff formations were deformed in the Dunnigan Hills folding. The anticline plunges to the south burying the Tehama and Red Bluff formations beneath younger valley alluvium, about 4 miles south of Cache Creek.

The Tehama formation is exposed in Plainfield Ridge, a series of low hills north of Putah Creek. Kirby (1943a) stated that the ridge is an anticlinal fold of low relief oriented northwest. The Plainfield Ridge may be either a continuation of the Dunnigan Hills anticline or en echelon to it. There appears to be a syncline between the Dunnigan Hills-Plainfield Ridge anticline and the Coast Ranges proper, occupied on the north by Hungry Hollow and on the south by the low plains between Cache and Putah Creeks.

The Potrero Hills, about 3 miles southeast of Fairfield, are the surface expression of an eastward-trending anticline that plunges eastward (Weaver, 1949). Its eastward trend is contrary to the general northwestward trend of Coast Ranges structure, but a major fault crosses the structure in a northwestward direction, maintaining the regional structural trend.

Eocene rocks are exposed at the surface in several small structural features between the Potrero Hills and Montezuma Hills. Bradtmoor Island and Kirby Hill are the most prominent. Kirby Hill is a steeply dipping anticline faulted on both the east and west sides. The principal fault, the Kirby fault, appears to have at least 2,000 feet of displacement; the relative movement is down on the west side.

The Montezuma Hills, a roughly circular group of low hills about 10 miles in diameter, represent a broad, gentle uplift which is modified by faulting. The hills merge gradually with the Sacramento Valley plains on the north, but on the east, south, and west the hills are bordered by steep bluffs. Reiche (written communication 1950) described two fault scarps of Pleistocene or Recent age at the base of the bluffs. The one on the east side is near Rio Vista; the other is on the west side near Collinsville. Coring by the U.S. Bureau of Reclamation (Paulsen, oral communication, 1950) indicated that the bluff facing the Sacramento River on the southeast also is probably a fault scarp.

The relationship between the Montezuma Hills and the Rio Vista gas field structural closure is complex. It formerly was assumed that the hills were simply the surface indication of the deep structural feature, which is a broad dome broken into segments by a series of faults trending N. 5° W. to N. 30° W. and cross faults trending N. 30° E. to N. 40° E., none of which have been detected at the surface. The subsurface high lies to the southeast of the hills beneath the Sacramento-San Joaquin delta. Contours on the base of the fresh-water-bearing deposits show little relation to the surface features. The Montezuma Hills lie on the downthrown side of the Midland fault, the principal fault crossing the deep structure. From the available evidence it appears that the faulting and uplift expressed topographically by the Montezuma Hills are not closely related to the deep structural features of the Rio Vista gas field.

Contours on the base of the fresh-water body (pl. 5) indicate a broad benchlike feature extending 10 miles eastward beneath the Sacramento Valley along its west side between Maxwell and Willows. Throughout this area Upper Cretaceous sedimentary rocks are reached in wells at depths of less than 1,000 feet. To the west in the Coast Ranges foothills the Cretaceous rocks are folded in a steep nearly isoclinal fold, the Sites anticline, which strikes due north, paralleling the valley border for a distance of 25 miles (Kirby, 1943c). (See pl. 3.) The valley plains abut against strike ridges in the folded Cretaceous rocks, and dips are steep along the valley margin, but the subsurface extent of shallow Cretaceous beds suggests that the beds must flatten a short distance east beneath the valley.

SACRAMENTO VALLEY

The Sacramento Valley is a large structural basin filled with sedimentary rocks ranging in age from Early Cretaceous to Recent. The older rocks have been uplifted and deformed to the west of the valley and now form the eastern part of the northern Coast Ranges. The valley trough is asymmetrical; the deepest part of the basin lies near the western margin of the valley west of the present axis. (See fig. 2.) The valley deposits thin eastward and overlap the crystalline rocks of the Sierra Nevada basement complex of pre-Tertiary age.

Throughout Cretaceous time and during most of the early Tertiary, the axis of thickest marine sedimentation west of the ancestral

Sierra Nevada shifted eastward. Westward projection of the slope of the Sierra Nevada basement complex suggests that sedimentary deposits may be more than 20,000 feet thick along the southwestern margin of the valley. In this area the Cretaceous rocks alone probably are more than 2 miles thick, but only about 4,350 feet of Upper Cretaceous marine sedimentary rocks crops out at Sutter Buttes near the center of the valley, and there are only a few scattered outcrops of Upper Cretaceous rocks along the southeastern margin of the valley. About 2,000 feet of Upper Cretaceous marine sedimentary rocks is exposed beneath the Tuscan formation and above the Sierra Nevada-type basement complex near Chico.

Eocene marine sedimentary rocks are limited roughly to the present extent of the Sacramento Valley, although marine and deltaic deposits crop out in a narrow band in the hills along the southwestern and southeastern margins of the valley. In the southwestern part of the Sacramento Valley the thickness of the Eocene section averages about 3,000 feet, although the Eocene rocks in the English Hills farther west are as much as 6,800 feet thick (Thomasson and others, in press). Between the Sierra Nevada foothills and the center of the valley the thickness is somewhat less—about 1,000 feet. North of Sutter Buttes the Eocene sedimentary rocks are less than 1,000 feet thick. The Eocene rocks along the southeastern margin of the valley are largely deltaic and continental (Ione formation), and generally are less than 400 feet thick in exposed sections.

Post-Eocene sedimentary rocks in the Sacramento Valley primarily are nonmarine, except for a few marine and brackish-water deposits of questionable age penetrated by gas wells in the southern part of the valley. Great thicknesses of pyroclastic rocks were contributed from the Sierra intermittently from Eocene through middle Pliocene time. During the Pliocene epoch, volcanoes in the southern part of the Cascade Range contributed basaltic and andesitic debris to the mudflows of the Tuscan formation that border the northern part of the Sacramento Valley between Chico and Red Bluff.

The greatest amount of sediments and pyroclastic rocks were accumulated during late Pliocene and early Pleistocene when flood-plain deposits filled a broad alluvial valley similar to but considerably larger than the present Sacramento Valley. In the northwestern part of the valley the Tehama formation, derived from the Coast Ranges to the west, is as much as 2,000 feet thick.

The post-Eocene nonmarine sediments in the southwestern part of the Sacramento Valley attain a maximum thickness of perhaps more than 4,000 feet, although at most places the nonmarine rocks are less than 3,000 feet thick.

Sutter Buttes are the surface expression of an intrusion of semi-solid andesite porphyry, which now is exposed at the core of the hills (Williams and Curtis, 1953). Encircling this steep-sided igneous plug, a band of tilted, folded, and faulted sediments, ranging in age from Late Cretaceous to Pliocene, dip radially away from the central plug. Aside from the upturning effect and faulting in the immediate vicinity of the Sutter Buttes the emplacement of the andesitic plug appears to have had little structural effect upon the continental deposits of the valley.

The northern part of the Sacramento Valley, roughly the triangular area between Chico, Orland, and Red Bluff, is in the border area of five geologic provinces; the Sierra Nevada, the Great Valley, the Cascade Range, the Klamath Mountains, and the Coast Ranges. Each province has its distinctive structural characteristics, and the northern part of the valley differs from the southern part.

The general aspect of the area north of the southern boundary of Tehama County suggests a broad regional uplift involving the Red Bluff formation and older sediments. Between the Cascade Range and the Coast Ranges the Pliocene and Pleistocene alluvial sediments of the Red Bluff and Tehama formations are exposed over a broad area at elevations of 200 to 1,000 feet above sea level. The Sacramento River flows through a flood plain, 1 to 3 miles wide, between bluffs cut into these older alluvial deposits.

Several strctural features of the northern part of the Sacramento Valley have been described by Anderson and Russell (1939), Bryan (1923), and Kirby (1943d); the Chico monocline, Red Bluff arch, Corning Ridge, and Orland Buttes are the best known. Between Chico and Red Bluff, a distance of nearly 40 miles, the western border of the Tuscan formation is marked by a sharp monoclinal fold, the Chico monocline, which accounts for the rather straight boundary of the Tuscan formation along the east side of the valley (pl. 2). From Dry Creek to Chico the dips in the deposits of the Tuscan formation average 2°–3° SW. beneath the alluvium of the Sacramento Valley. North of Chico the dips increase to a maximum of 20° SW. at Antelope Creek. The beds east of the monocline dip about 2°–3° SW.

In the vicinity of Red Bluff the Chico monocline is terminated by the Red Bluff arch, a northwestward-trending anticline in the Tuscan formation which crosses the Sacramento River at Iron Canyon upstream from Red Bluff. Anderson (1933) stated that the Red Bluff formation (Pleistocene) was not involved in the folding which deformed the Tuscan at Iron Canyon.

The Tehama formation is exposed at the surface in a series of low hills between Corning and the Sacramento River, known as the Corning Ridge. Discontinuous outcrops of the Tehama formation extend 10 miles in a southward direction between Thomes and

Rice Creeks. Corning Ridge is the surface expression of a northward-trending anticline. The structural closure may be modified by faulting. It appears that the anticline is flanked on the east and west by synclines—expressed on the east by the Sacramento River and on the west by the lowland area between Corning and Kirkwood.

The Orland Buttes area has been described by Anderson and Russell (1939). At this locality the Upper Cretaceous marine sedimentary rocks and a Tertiary basalt flow are exposed for a distance of 6 miles in a ridge trending N. 15° W. Anderson and Russell indicate that the uplift of the Cretaceous in this locality was accomplished by faulting along the western flank of the ridge.

CONFIGURATION OF THE BASE OF THE PRINCIPAL BODY OF FRESH WATER

Deposits containing fresh water extend to depths ranging from a few hundred feet along the flanks of the valley to more than 3,000 feet in the southwestern part of the valley about 10 miles southeast of Dixon. Plate 5 shows contours drawn on the base of the principal fresh-water body as determined from electric logs and logs of water wells that tap saline water. In much of the valley this contact represents a stratigraphic horizon, the boundary between continental and marine deposits. Locally, however, marine deposits have been flushed of connate water, and in some areas continental deposits contain saline waters. Furthermore, in much of the Sacramento Valley, especially its southern part, the change from marine deposits to continental deposits is transitional, possibly because of sedimentation in a brackish environment such as that described by Woodring, Stewart, and Richards (1940, p. 27) in reference to the San Joaquin formation exposed at Kettleman Hills. In many gas test wells this transition apparently occurs over an interval of several hundred feet.

For the purposes of this report a specific conductance of 3,000 micromhos (roughly 2,000 ppm of dissolved solids) was selected as a measure of the upper limit of fresh water. Electric logs of gas test wells were interpreted by a method described by Schlumberger Well Surveying Corp. (1950, p. 112). In this method the resistivity of the water in the formation or its reciprocal, conductivity, is determined from the true resistivity of the formation and the formation resistivity factor as expressed in the following equation: $Rw = Rt/F$, where Rw equals resistivity of the water in the formation; Rt equals true resistivity of the formation; and F equals a formation resistivity factor, which is related to the porosity and degree of cementation of the deposits. According to Guyod (1944, fig. 12–4), F will fall in the range of 3 to 5 for unconsolidated sand of 28- to 50-percent porosity.

The true resistivity (R_t) of the formation was determined by a method described by the Schlumberger Well Surveying Corp. (1950, p. 51) which employs "resistivity departure curves" to relate the true resistivity to the apparent resistivity, the resistivity of the drilling fluid (adjusted to the formation temperature), the electrode spacing, and the diameter of the borehole.

In interpreting electric logs certain simplifying assumptions are required. It was assumed that negligible filtration of the drilling fluid into the wall rock of the hole had occurred, that the formations were homogenous, isotropic, and of infinite extent, that they were traversed by a cylindrical hole, and that the exploring device was made up of point electrodes located on the axis of the hole. A formation factor of four was assumed for the deposits penetrated.

On many logs the distinction between fresh waters of low conductivity and highly conductive saline waters was so clear cut that an interpretation could be made simply by inspection. However, in all cases where doubt existed—for example, in zones of transitional types of water, calculations of the resistivity of the water in the formation (Rw) were made for sand zones in the vicinity of the pertinent change in conductivity. Rw was then converted into specific conductance by means of the following expression:

$$\text{Specific conductance (micromhos)} = \frac{1 \times 10^4}{Rw \text{ (ohm meter}^2 \text{ meter)}}$$

In a general way the base of the fresh-water body reflects the general synclinal nature of the valley and delineates several of the important structural features. The principal synclinal axis of the Sacramento Valley is indicated by a narrow trough at the base of the fresh water, which has its axis 3 to 10 miles west of the topographic axis, extending from near Willows southward toward a deep depression bisected by the boundary line of Yolo and Solano Counties about 10 miles southeast of Dixon. Other structures indicated by the contours on the base of the fresh water are the Dunnigan Hills and Plainfield Ridge anticline (p. 130), extending from Dixon north beyond Cache Creek, the syncline between the Dunnigan Hills and Plainfield Ridge anticline and the Coast Ranges proper (p. 130), the Montezuma Hills (p. 130), and Sutter Buttes (p. 132).

The contours on the base of the fresh-water body indicate several pronounced features in addition to known geologic structural features. Chief among these are a shallow body of saline water trending north-south a few miles south of Sacramento, a poorly defined but definite mound in the underlying saline water body in the Sutter Basin between the Sacramento and Feather Rivers south of Sutter Buttes, a mound in the saline water immediately west of Sutter

Buttes, and a high in the saline water body in the area northeast of Willows and southeast of Orland that divides the main syncline of the valley into south and north basins.

The shallow body of saline water south of Sacramento apparently is a perched body of indeterminate origin. It may represent a saline evaporation residue or, more likely, a body of estuarine marine water trapped when the sediments were laid down. In several wells in the area fresh-water-bearing deposits several hundred feet thick were found beneath the perched saline water body, which was 600 to 800 feet thick.

The saline water found at shallow depth in wells south of Sutter Buttes is contained in continental sediments but appears to be continuous from near the land surface downward to the saline water in known marine deposits. Its origin is problematical, however; it may be the result of upward migration of deep marine connate waters through defective, abandoned, or improperly constructed deep wells, as suggested by the California State Water Resources Board (1952, p. 35); or, on the other hand, it may be merely a large body of evaporation residue in the Sutter Basin.

The saline waters found at shallow depth immediately west of Sutter Buttes are contained in marine sediments believed to be of Late Cretaceous age, which are found within 500 feet of the land surface.

The broad platform described by the contours in Glenn and Butte Counties is believed to conform roughly with the top of marine sediments at the base of the fresh-water body. The explanation for this feature is not known. If it is a structural high, then it is in almost complete disagreement with geologic trends in the area that are expressed topographically. In fact, the deepest depression in the base of the fresh water in the northern part of the valley generally coincides with an area believed to have been involved in a regional uplift in late Pleistocene time.

YIELD OF WELLS

Data on yield of wells in the Sacramento Valley have been furnished by the Pacific Gas and Electric Co. for Solano, Yolo, Colusa, Glenn, Tehama, Butte, Yuba, Sutter, and Placer Counties and by the Sacramento Municipal Utility District for Sacramento County. The results of pumping tests for 2,783 large-capacity irrigation, industrial, and municipal wells in 21 areas in the valley are summarized in table 2.

The areas listed in table 2 and shown on figure 3 embrace one or more operating districts of the Pacific Gas and Electric Co. and the Sacramento Municipal Utility District. In a very general way these areas correspond to the ground-water storage units (compare figs. 3 and 4), although there are many local modifications, based on types of agriculture or other economic factors.

The number of wells tested in each area is the number of irrigation wells for which one or more pumping tests were made by the Pacific Gas and Electric Co. or the Sacramento Municipal Utility District through 1948. Where more than one test had been made on a well, the results of the tests were averaged.

The average discharge is the average yield, in gpm (gallons per minute), of the tested wells in each area. These figures are rounded to the nearest 10 gpm, which is believed to be the order of accuracy of most of the measurements.

TABLE 2.—*Yield characteristics of irrigation wells in Sacramento Valley*

[Computed from information furnished by Pacific Gas & Electric Co. and Sacramento Municipal Utility District]

Area No. (fig. 3)	Area	Number of wells tested	Average discharge (gpm)	Average specific capacity (gpm per ft of drawdown)	Average depth to static water level (ft)	Number of irrigation-well logs	Average depth (ft)	Average saturated thickness (ft)	Average yield factor [1] for saturated thickness
12	Cache Creek	52	1,220	95	22	67	120	98	97
13	Woodland	198	1,350	106	30	372	256	226	47
3	Orland-Willows	238	1,030	76	23	250	210	187	41
19	Dixon	98	770	67	35	116	226	191	35
8	Honcut	23	840	60	23	28	200	177	34
16	Putah North	61	750	50	38	52	205	167	30
9	Peach Bowl	261	730	47	24	249	182	158	30
2	Los Molinos	46	770	70	26	42	268	242	29
6	Colusa	59	1,690	85	18	77	315	297	29
7	Gridley	119	980	58	17	89	258	241	24
1	Red Bluff-Corning	292	470	55	31	179	274	243	23
20	Sacramento	125	490	43	33	113	219	186	23
17	Davis	61	990	55	31	119	295	264	21
10	Yuba-Bear	108	850	48	23	109	292	269	18
11	South Sutter	121	960	47	24	104	324	300	16
4	Chico	498	1,000	51	23	356	357	333	15
21	Cosumnes-American.	103	380	38	46	54	317	271	14
18	Vacaville	118	440	30	39	123	256	217	14
14	Verona-Knights Landing	45	740	42	10	84	303	293	14
5	Williams	103	620	33	92	71	494	402	8
15	North Sacramento-Fair Oaks	54	250	21	40	41	334	294	7
	Total	2,783				2,695			

[1] Gallons per minute per foot of drawdown divided by saturated thickness, in feet, times 100.

The specific capacity of a well is the discharge (gpm) divided by the drawdown (feet) and is a measure not only of the productivity of the well but also of the transmissibility of the aquifer. The coefficient of transmissibility is defined as the number of gallons per day transmitted by a vertical section of the aquifer 1 foot wide under a hydraulic gradient of 1 foot per foot, or by a section 1 mile wide under a gradient of 1 foot per mile, at the prevailing temperature of the water.

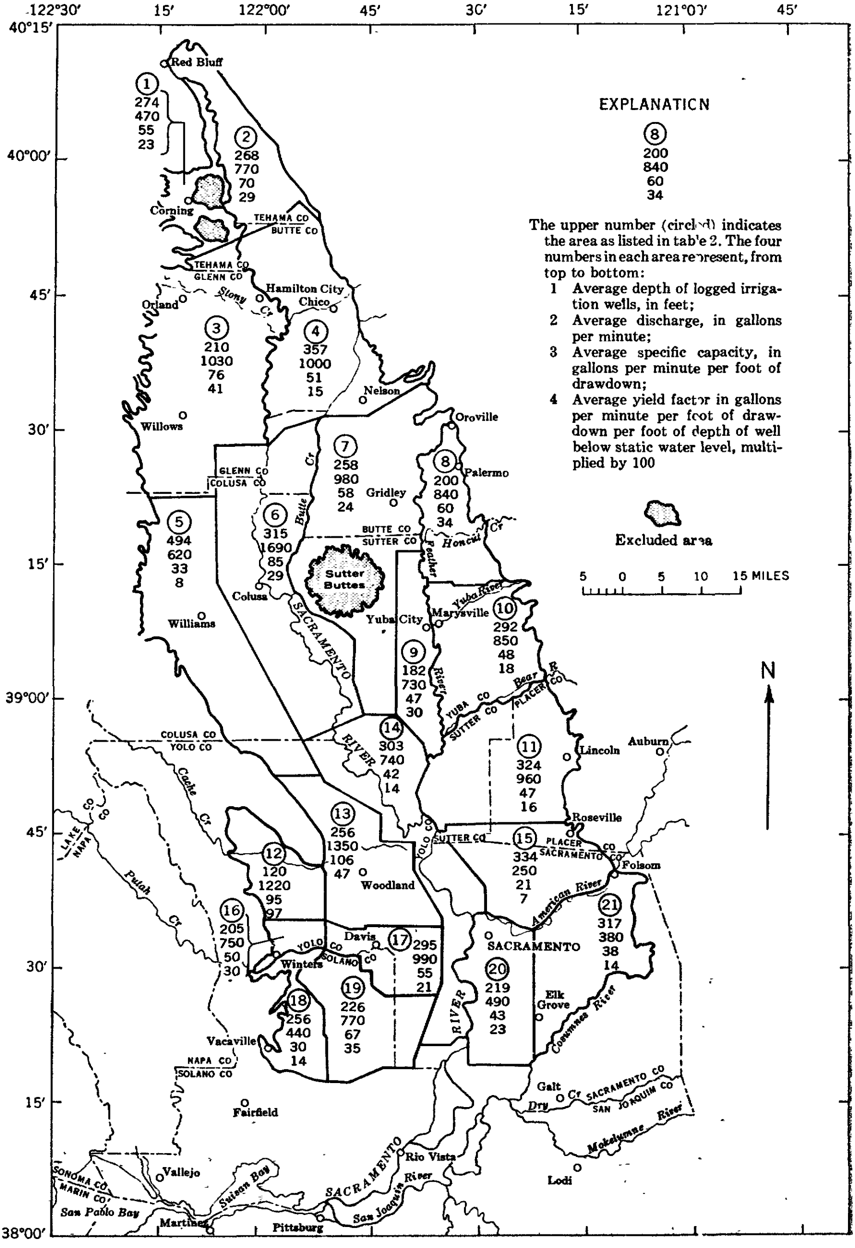

Figure 3.—Map showing yield characteristics of wells of the Sacramento Valley, Calif.

The average static water levels were derived by averaging the standing (nonpumping) levels reported on the pumping tests of wells in each area.

The irrigation-well logs in each area do not apply necessarily to the wells for which pump-test data were available; pump tests were not identified by individual wells but merely by township, range, and section location. It is believed, however, that the average depths, computed from the logged wells, are close to the average depths of the tested wells.

The figures for average saturated thickness were derived by subtracting the average of the standing water levels reported on the pump-tested wells from the average depths of the logged wells.

"Yield factor for saturated thickness," the quantity reported in the last column of table 2, is herein defined as the specific capacity divided by the thickness in feet of saturated material penetrated by a well (depth of well below static water level), multiplied by 100. The yield factor thus affords an approximate measure of the average permeability of the saturated materials penetrated by the well and generally is independent of other factors, such as well depth and rate of pumping. In an earlier part of the report in which the water-bearing character of several of the geologic units was discussed, a yield factor for only the thickness of aquifer open to the well (opposite the perforated section of the casing) was given in addition to the yield factor for the saturated thickness. This yield factor for aquifers corresponds to the term yield factor as originally defined by Poland and others (1959).

Although the yield factor for saturated thickness affords an approximate measure of the average permeability of the saturated material penetrated by wells in which the casings are perforated for the entire length, it will be too low for wells that are perforated only at certain intervals or for wells that have caved in or otherwise failed. However, the average yield factors for the areas listed in table 2 are believed to be usable for purposes of comparison.

The yield factors correspond to the geologic features of the valley in general. Major differences in yield factor definitely are related to geologic features—differences in permeability of aquifer materials —whereas minor differences probably are not significant. Unfortunately, the choice of geographic units shown on figure 3 was dictated by power-company operating districts rather than mapped geologic units, so a comparison is difficult in some areas.

The highest yield factors were for wells on the west side of the valley where water is drawn from relatively more permeable Recent and Pleistocene alluvial-fan deposits of the major streams draining the Coast Ranges. The wells that draw water from consolidated, poorly sorted, or fine-grained deposits have low yield factors.

Coarse gravel deposits in the Cache Creek area are responsible for the highest yield factor for saturated thickness (97) in the Sacramento Valley (area 12, fig. 3). Clean, highly permeable gravel, extending to a maximum depth of 150 feet below the surface near

Cache Creek, yields large quantities of water to shallow wells with small pumping drawdown. There is very little coarse gravel farther than 1.5 miles from Cache Creek, and wells draw water from fine-grained alluvial-fan deposits of minor west-side streams or from the fine-grained compacted Tehama formation beneath. The high average yield factor of wells in this area corresponds to the high specific yields of the 20–50 feet and 50–100 feet depth zone of groundwater storage unit A1. (See table 6.)

Irrigation wells in the Woodland area (area 13, fig. 3) draw large quantities of water from permeable sand and gravel deposits in alluvial-fan deposits of Recent and late Pleistocene age. The Recent deposits probably are less than 50 feet thick, but the underlying upper Pleistocene deposits contain many coarse gravel and sand tongues that yield water freely to wells. The high yield factor (47) is directly related to the high permeability of the coarse beds in the Pleistocene alluvial-fan deposits.

Most of the irrigation wells in the Orland-Willows area (area 3, fig. 3) are on the alluvial fan of Stony Creek. The permeability of the Recent and Pleistocene alluvial-fan deposits is reflected in a high yield factor of 41. Irrigation wells draw most of their water from coarse, clean gravel and sand tongues in the alluvial-fan deposits, although a number of deep wells in and near the Capay land grant, near the Sacramento River, draw some water from sandstone and conglomerate beds in the Tehama formation.

Alluvial-fan deposits of Pleistocene age are the major source of ground water in the Dixon area (area 19, fig. 3). The veneer of Recent fan deposits probably does not exceed 30 feet in thickness. Because the Recent deposits are above the water table throughout most of the Dixon area, they are not an important source of water. Permeable sand and gravel tongues within about 130 feet of the land surface in the Pleistocene fan deposits yield water freely to wells. The yield factor of 35 indicates the high permeability of these coarse materials, which compose less than half the total thickness of the alluvial-fan deposits at most places. Some additional water is derived from the underlying Tehama formation and related continental sediments which, however, are much less permeable than the alluvial-fan deposits (Thomasson and others, in press).

The high yield factor (34) for wells in the Honcut area (area 8, fig. 3) is due in part to the presence of highly permeable gravel lenses in the Victor formation and related deposits east of the Feather River. These extensive gravel deposits are presumed to be old channel deposits of the Feather River. Most wells in this area draw a part of their water from the underlying Laguna formation and related continental sediments as well.

Irrigation wells in the Putah North area (area 16, fig. 3) draw the greatest part of their water supply from moderately to highly permeable gravel and sand beds of the alluvial-fan deposits. Additional water is obtained from the underlying Tehama formation and related continental sediments, which are considerably less permeable than the alluvial-fan deposits. The average yield factor for wells in the area is moderate (30).

Irrigation wells in the Peach Bowl area in the western part of Sutter County (area 9, fig. 3) produce from permeable sand beds in the Victor formation (upper Pleistocene) and the Laguna formation (upper Pliocene?). A few wells in the flood plain of the Feather River draw water from coarse, permeable river deposits. The yield factor (30) reflects the high permeability of the thin sands in the Victor formation and related deposits which supply moderate quantities of water to relatively shallow wells.

Wells in the Los Molinos area (area 2, fig. 3) draw an appreciable quantity of water from thin permeable beds in the Recent and Pleistocene deposits of the Sacramento River and from equivalents of the Victor formation, but semiconsolidated sand and gravel lenses in the fanglomerate from the Cascade Range and the underlying Tuscan formation are the major sources of ground water in the area. The yield factor (29) suggests at least a moderate permeability for the somewhat indurated coarse deposits in the old fanglomerate and Tuscan formation.

Recent river deposits of the Sacramento River are a source of some water in the Colusa area (area 6, fig. 3), but the largest supplies are developed from buried channel deposits of probable Pleistocene age. Wells normally are drilled through a considerable thickness of impervious clay deposits characteristic of the flood basins, but highly permeable, well-sorted gravel and sand lenses in the section supply large quantities of water to wells. The moderately high yield factor (29), despite the predominantly fine grain of the section, confirms the high permeability of the coarse deposits.

The Gridley area (area 7, fig. 3) includes parts of the geomorphic units called the low alluvial plains and fans, flood plains and natural levees, and flood basins. Most of the irrigation wells in the area are on the low plains west of the Feather River, although a few wells have been drilled on the Feather River flood plain and on the alluvial fans surrounding Sutter Buttes. The yield factor (24) is somewhat lower than that of wells in the Peach Bowl area to the south. Wells in both areas draw large quantities of water from thin but highly permeable sand lenses in the Victor formation and related deposits. Many wells penetrate the underlying Laguna formation and related continental sediments and draw some water from the moderately indurated sand and gravel beds of Pleistocene(?) and Pliocene age.

Wells irrigating the lowland portions of the Red Bluff-Corning area (area 1, fig. 3) draw a considerable part of their supply from thin Recent river deposits and alluvial-fan deposits overlying the Red Bluff and Tehama formations. Although sand and gravel of the Recent deposits are permeable and yield water freely to wells, large-capacity wells draw a large portion of their water from the Tehama formation. Cemented gravel and sandstone of low permeability are common in the Tehama, although locally the coarse beds are uncemented and yield water freely to wells. The yield factor (23) reflects the moderate permeability of the Tehama formation, which is the major source of water in the area.

Wells in the Sacramento area (area 20, fig. 3) produce water from the Victor formation and related deposits, from Recent deposits of the American and Sacramento Rivers, and from the Laguna formation and related continental sediments. The river deposits are largely clean coarse sand and gravel lenses of high permeability that yield water freely to wells. Wells drilled on the low plains draw water from the Victor formation and the underlying Laguna formation. The moderate yield factor (23) reflects the fact that most of the wells in the area are located on the low alluvial plains and draw a considerable part of their supply from the poorly to moderately permeable Laguna formation.

Wells in the Davis area (area 17, fig. 3) draw their water from two prominent gravel zones 20 to 30 feet thick—the middle of one at a depth of about 110 feet, the middle of the other at 300 feet. The remainder of the section is predominantly fine-grained silt and clay that provides little water, which accounts for the relatively low yield factor of 21.

Most wells in the Yuba-Bear area (area 10, fig. 3) draw water from a thin mantle of the Victor formation and related deposits and from the underlying Laguna formation and related continental sediments. A few wells on the flood plains of the Yuba, Bear, and Feather Rivers obtain water from Recent river deposits. Several deep wells in the eastern part of the area obtain an appreciable supply of water from the volcanic rocks from the Sierra Nevada and the underlying Eocene rocks (Ione formation). The low yield factor (18) is due to the fact that the relatively permeable Victor formation is at most places less than 50 feet thick and that the underlying Laguna formation, the major source of water in the area, generally is of low permeability.

Wells in the South Sutter area (area 11, fig. 3) draw water from essentially the same deposits as those in the Yuba-Bear area. As might be expected, the yield factor (16) of wells in this area compares closely with that of wells in the Yuba-Bear area (18).

The source of most of the irrigation water in the Chico area (area 4, fig. 3) is the fanglomerate from the Cascade Range, and the underlying Tuscan formation. The relatively low yield factor (15) reflects the fact that many wells drilled in the Tuscan formation pass through thick beds of impermeable mudflow breccia and tuff-breccia before reaching enough sand and gravel beds to support the desired well capacity. Some irrigation wells near the Sacramento River in the western part of the area draw all their water from the overlying fanglomerate.

Wells in the Cosumnes-American River area (area 21, fig. 3) draw water from the Laguna formation and related continental sediments, from the Victor formation, and from the volcanic rocks from the Sierra Nevada. A few wells near the foothills also obtain some water from Eocene rocks (Ione formation). Much of the water pumped from the Victor formation is from coarse gravel tongues believed to be ancient channel deposits of the American River. The thickness of the Victor is less than 60 feet at most places, so most irrigation wells draw a large part of their supply from the poorly to moderately permeable Laguna formation. Wells drilled on the Cosumnes River flood plain draw appreciable quantities of water from the Recent river deposits of that stream. Because the greatest part of the irrigation water pumped in the Cosumnes-American area is from the semiconsolidated, predominantly fine-grained Laguna formation, the yield factor (14) is correspondingly low.

Generally fine-grained Pleistocene alluvium of the minor streams south of Putah Creek yields some water to wells in the Vacaville area (area 18, fig. 3), but most of the production is from semiconsolidated sediments of the Tehama formation. Some wells obtain small amounts of water from Eocene rocks. The low yield factor (14) reflects the low permeability of the Tehama formation and the overlying alluvial-fan deposits.

Wells drilled in the Verona-Knights Landing area (area 14, fig. 3) in the southern reach of the Sacramento River draw water from deposits similar in character and age to those of the Colusa area. The lower yield factor (14) appears to be the result of a progressive decrease in average grain size downstream. Buried stream deposits are represented in the upper reach of the river by gravel, but in the lower reach by fine to coarse sand.

Generally fine-grained alluvial-fan deposits of Recent and Pleistocene age, and similar fine-grained compacted sediments of the underlying Tehama formation, supply moderate quantities of water to wells drilled on the low alluvial plains of the west side of the valley in the Williams area (area 5, fig. 3). Most of the alluvial-fan deposits of the minor streams of the west side are of low permeability and do not yield water readily to wells. The low yield factor (8) is corroborated by the very low specific yields of all three depth zones of ground-water storage units B6 and D3, which constitute most of the Williams area. (See table 4.)

The Laguna formation and related continental sediments furnish most of the water to irrigation wells in the North Sacramento-Fair Oaks area (area 15, fig. 3). Wells on the low alluvial plains draw little water from the thin veneer of Victor formation and related deposits, and wells drilled farther east in the dissected uplands (pl. 1) obtain all their supply from the Laguna formation and the underlying volcanic rocks from the Sierra Nevada. Although the coarse sand of the Laguna formation is highly permeable, most of the Laguna consists of clay, silt, and fine sand of low permeability. The sandstone and conglomerate beds of volcanic rocks of the Sierra Nevada are only moderately permeable. As a result the specific capacities are low, and it is necessary to drill deep wells to assure adequate supplies. The average yield factor (7) is the lowest for any area in the valley.

GROUND-WATER STORAGE CAPACITY

The ground-water storage capacity estimated for this report is the volume of water that would drain by gravity from the materials underlying the designated ground-water storage areas if the regional water level were lowered from 20 feet below the surface to a depth of 200 feet. It may be defined also as the volume of water required to resaturate the deposits after their drainage.

Briefly, the storage capacity was estimated by multiplying the total volume of deposits in each unit considered by an estimated average specific yield. Specific yield may be defined as the ratio of the volume of water drained from a sample of material to the total volume of the sample. This procedure involved several basic steps as follows:

1. The valley was divided into 4 "storage groups" which were in turn subdivided into a total of 29 "storage units."
2. Three depth zones were selected, 20 to 50 feet, 50 to 100 feet, and 100 to 200 feet below the land surface.
3. The materials indicated in the well logs were grouped into several categories of material.
4. A three-dimensional model (peg model) of the valley was constructed.
5. Specific yields were assigned to the several categories of material.
6. Ground-water storage capacity was computed.

ELEMENTS CONSIDERED

SUBDIVISION OF THE VALLEY INTO STORAGE UNITS

For the purpose of estimating ground-water storage capacity, the Sacramento Valley was divided into 4 storage groups, and these in turn were subdivided into a total of 29 storage units. (See fig. 4.)

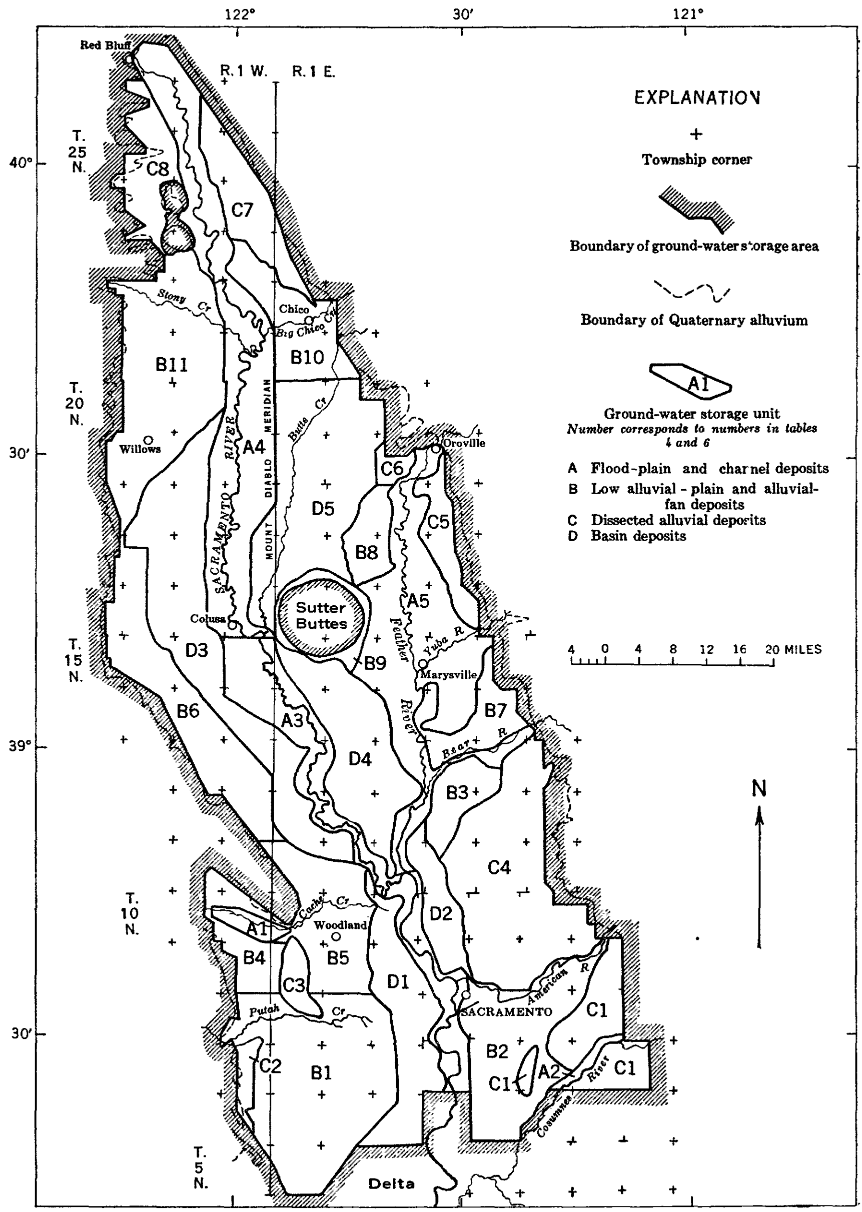

FIGURE 4.—Map showing ground-water storage units of the Sacramento Valley, Calif.

The areal subdivision into groups and into the smaller storage units was first made on the basis of differences in physiography and soils—that is, from what can be seen at the land surface—and the boundaries of the units were then modified on the basis of the lithologic character of the deposits underlying the areal units to a depth of 200 feet, as shown by the peg model. This subdivision is not an exclusively geologic subdivision; hence, the map of ground-water storage units (fig. 4) does not correspond to the geologic map of the Sacramento Valley (pl. 2). Throughout most of the valley wells pass through at least two and at many places more than two geologic units within 200 feet of the surface. (Refer to p. 213.) In parts of the valley, however, similar conditions of deposition have persisted from the Pleistocene epoch to the Recent, and as a result the Recent deposits are often lithologically similar to and in hydraulic continuity with the deposits of Pleistocene age.

Stratigraphic units in order of importance in ground-water storage units

Unit A. River flood-plain and channel deposits
- River deposits
- Victor formation and related deposits
- Alluvial-fan deposits
- Laguna formation and related continental sediments
- Tehama formation
- Tehama formation and related continental sediments

Unit B. Low alluvial-plain and alluvial-fan deposits
- Alluvial-fan deposits
- Victor formation and related deposits
- Laguna formation and related continental sediments
- Tehama formation
- Tehama formation and related continental sediments
- Red Bluff formation
- Fanglomerate from the Cascade Range
- Volcanic rocks from the Sierra Nevada
- River deposits
- Eocene series

Unit C. Dissected alluvial deposits
- Laguna formation and related continental sediments
- Tehama formation
- Tehama formation and related continental sediments
- Fanglomerate from the Cascade Range
- Red Bluff formation
- Tuscan formation
- Volcanic rocks from the Sierra Nevada
- Eocene series

Unit D. Basin deposits
- Basin deposits
- Victor formation and related deposits
- Alluvial-fan deposits
- River deposits

Special emphasis was placed on the hydrologic character of the sediments and the continuity of water-bearing beds in the top 100 feet (the upper and middle zones) in the selection of storage units. This was done for three reasons. First, it is believed that the storage units should be representative of the depth range most subject to unwatering or resaturation under present conditions or under moderately increased use in the near future. Second, for nearly all the storage units in the valley, except the flood-basin deposits, the specific yield above the 100-foot depth is larger than that below. Third, with reference to natural or artificial recharge at or near the land surface, the distribution of water-bearing beds in the near surface deposits is of primary importance.

SELECTION OF DEPTH ZONES

At the request of the California Division of Water Resources the storage capacity of the water-bearing deposits of the Sacramento Valley was estimated for three depth zones: 20 to 50 feet; 50 to 100 feet; and 100 to 200 feet below the land surface.

The only area in which estimates were not made for three depth zones is that south of Marysville between the natural-levee deposits of the Sacramento River on the west and the channel of the Feather River on the east. The Division of Water Resources reported that water of poor quality exists there at relatively shallow depth and that, because of saline intrusion, it is not generally practicable to draw down the average water level to more than 100 feet below the land surface. Accordingly, in that area the storage capacity was estimated only for the deposits in the top 100 feet (the upper and middle zones).

It is believed that for most of the valley it would not be practicable to store much water in the deposits less than 20 feet below the surface, even where they are permeable, because of the danger of waterlogging parts of the area. Also, for economic reasons extensive unwatering to a depth of more than 200 feet in the Sacramento Valley is considered to be unlikely. In the near future the average water levels in the valley probably will not be drawn down much below the 100-foot depth. However, with more complete integration of surface- and ground-water supplies and with an increase in demand, it is wholly likely that water levels in the better ground-water reservoirs will be drawn down into the second hundred feet.

CLASSIFICATION OF MATERIALS IN DRILLERS' LOGS

In order to estimate the storage capacity of the water-bearing deposits it was necessary to classify the materials of the subsurface, as described in drillers' logs, into groups to which arbitrary specific yields could be assigned. Although many logs reported only gravel, sand, and "clay" (actually silt or clayey silt in most places) or gradations between these primary units, other logs reported as many as 10 to 20 types of material. After a review of the many types described, the materials as logged were grouped into five general classes:

1. Gravel.
2. Sand, including mixed sand and gravel.
3. Tight sand, hard sand, and sandstone, with which were combined 26 different drillers' terms that included material having similar hydrologic properties.
4. Cemented gravel, and clay and gravel, which embraced 19 additional drillers' terms.
5. "Clay," which included 19 different types of material ranging from silt through clay and shale and included lava and volcanic ash.

Sand, and sand and gravel were arbitrarily combined in a single category, because all gradations from sand to sand and gravel occur. The separate category comprising tight sand, hard sand, sandstone, and other coarse-grained deposits of low or restricted permeability was set up to embrace those materials that have moderate specific yield. The hard volcanic, soft volcanic, bedrock, and silt and sandy clay categories were included with "clay" in the storage-capacity study, because of their impermeable character.

PEG MODEL

A peg model of the Sacramento Valley, based on drillers' logs, was constructed to aid in recognition of hydrologic units and geologic features. Each well log was represented by a wooden peg a quarter of an inch in diameter, mounted on a base map of the valley. The vertical scale of the model was 50 feet to the inch and the horizontal scale was 4,000 feet to the inch.

Nine major lithologic types were recognized; namely, Gravel; sand and gravel; sand; clay and gravel and cemented gravel; silt, sandy clay, and sand and clay; clay; hard volcanic rocks; soft volcanic rocks; and bedrock.

Each type of material was distinguished by a different color on the pegs. Three datum planes, the land-surface altitude as interpolated from topographic sheets, sea level, and 1,000 feet below sea level, were marked on each peg. Each peg was set at its location in a hole bored in a wooden table so that the table top represented the datum plane 1,000 feet below sea level.

At the scale used for the base map (4,000 feet to the inch), it was neither practical nor effective to use all the well logs. Therefore, where well spacing was closer than 1,500 feet, only the deep logs were used. With this selection about 3,000 well logs were used in the model. These same logs were used for the estimates of specific yield and storage capacity.

In order to estimate the storage capacity of the valley, the near-surface deposits were subdivided into hydrologic units. The peg model was of great value in making this subdivision. In addition, much geologic information was learned from the peg model, such as the continuity of sand and gravel strata, the depth to bedrock, and the extent and position of volcanic flows and of buried gravel beds of ancient stream courses.

ASSIGNMENT OF SPECIFIC-YIELD VALUES

It was beyond the scope of this investigation to make an extensive field investigation to determine the specific yield of the different types of water-bearing material in the Sacramento Valley. Therefore, it was necessary to assign an estimated specific-yield value to each of the five general categories of material on the basis of available data.

Only two extensive field investigations were undertaken in California prior to 1950 to determine the specific yield of water-bearing materials. The most extensive of these was the study by Eckis and Gross (1934) of the water-holding capacity of the sediments in the south-coast basin of the Los Angeles area. In this appraisal several hundred samples of typical gravel, sand, and clay of the south-coast basin were taken from surface exposures and borings, and about 2,000 samples were collected from wells during drilling. The porosity was determined for the samples taken in place and for those taken from wells; the specific retention was determined by several methods on materials ranging from gravel to clay; and specific yield was determined as the difference between porosity and specific retention. The porosity of a rock or soil is its property of containing interstices or voids. It is expressed quantitatively as the percentage of the total volume of the rock that is occupied by interstices or that is not occupied by solid rock material. The specific yield of a rock or deposit is the ratio of the volume of water which, after being saturated, it will yield by gravity to its own volume. The specific retention of a rock or deposit is the ratio of the volume of water which, after being saturated, it will retain against the pull of gravity to its own volume.

In the Mokelumne investigation (Piper and others, 1939) two methods were used to determine specific yield. In the first method the volume of material saturated and unwatered by alternate addition and withdrawal of measured volumes of water from columns of undisturbed soil was determined for materials from 13 localities.

Estimated specific yield, in percent, of sediments in the south-coast basin in California

	Gravel				Sand		Clay	
	Boulders (256+ mm)	Coarse (64–256 mm)	Medium coarse (16–64 mm)	Fine (8–16 mm)	Coarse and medum (½–8 mm)	Fine (⅛–½ mm)	Sandy	Clay
Unweathered:								
Surface alluvial	13.6	14.2	20.5	26.5	30.9	21.2	10	1
Subsurface alluvial	13	14	20	25	28	16	5	1
Weathered subsurface:								
Tight [1]	9	9	13	17	----------	16	--------	--------
Clayey [2]	4	5	7	8	----------	5	--------	--------
Residual clay [3]	1	1	1	1	----------	1	1	--------

[1] Lime-cemented gravels are included in tight gravels.
[2] Lime-cemented sands are included in clayey sand.
[3] The specific yield of 1 percent makes allowance for small sandy or gravelly streaks; pure clay would have a specific yield near zero.

This is a direct volumetric method of determining specific yield. In the second method the difference between the porosity and the specific retention of samples of undisturbed material was determined on 16 samples in duplicate after drainage for periods as long as 390 days. This is an indirect method similar to those employed by Eckis and Gross (1934). The results obtained by Piper (Piper and others, 1939, p. 121) are summarized below:

Material	Specific yield by volumetric method	Specific yield by drainage method	Averages of both methods
Gravel and coarse sand	34.5	35	34.8
Medium and fine sand	22.6	26	24.2
Very fine sand, silt, and clay	5.0	3.5	4.2

On the basis of the results obtained in these two investigations, together with specific-yield data from less detailed studies by others, the following modified specific yields were assigned to the five groups of material classified in the well logs of the Sacramento Valley:

Material	*Specific yield (percent)*
Gravel	25
Sand, including sand and gravel, and gravel and sand	20
Tight sand, hard sand, fine sand, sandstone, and related deposits	10
Clay and gravel, gravel and clay, cemented gravel, and related deposits	5
"Clay," silt, sandy clay, lava rock, and related fine-grained deposits	3

The lithologic and hydrologic character of the sediments of the Sacramento Valley necessitated certain modifications of the specific yields obtained by experiments in earlier investigations. The conditions under which alluvial deposition occurred in the Sacramento

Valley were different from those in the other areas and are the principal reason for the modifications.

In contrast to the south-coast basin where continental sediments, composed essentially of alluvial-fan deposits, were laid down by intermittent streams of steep gradient, the sediments of the Sacramento Valley are predominantly slack-water deposits laid down by the Sacramento River and its tributaries on broad, flat, alluvial plains and fans. In general, the alluvial deposits of the south-coastal basin are much coarser than those of the Sacramento Valley. Also, most of the clay in the pre-Recent deposits of the south-coast basin is the result of weathering rather than deposition from water; hence, a gravel deposit may contain considerable clay in the form of weathered pebbles that would not reduce the permeability of the deposit as much as would an equal amount of interstitial clay deposited from water.

The samples tested in the Mokelumne area are not considered representative of the sediments in the 20- to 200-foot depth range in the Sacramento Valley, because they were all taken at depths of less than 15 feet in unconsolidated deposits of late Pleistocene and Recent age. Most of the wells drilled to a depth of 200 feet penetrate sediments of early Pleistocene and Pliocene age throughout the eastern and northern parts of the valley. These older deposits are more indurated and presumably of lower specific yield than the younger alluvium.

Probably the most important departure from the experimental results was the specific yield of 20 percent assigned to the sand category. It is believed that material ordinarily logged as sand by well drillers in the Sacramento Valley is somewhat more consolidated and hence of lower specific yield than sand in the south-coastal basin and sand samples from the younger alluvial deposits of the Mokelumne area. Facts tending to support this idea are that drillers frequently distinguish the unconsolidated sand from the more or less consolidated sand by use of the terms "loose sand," "running sand," "quicksand," and "caving sand"; and that a considerable part of the water-bearing deposits of the eastern and northern parts of the Sacramento Valley are firm enough to stand without casing. A common practice in casing is to set casing down to a depth of 50 to 70 feet or to the first firm clay bed and to leave the lower part of the well uncased. Wells completed in this way in some areas have stood open for many years.

Enough well logs mentioned tight sand, hard sand, sandstone, cemented sand, and other descriptive terms indicating restricted permeability that an intermediate category was set up with an assigned specific yield of 10 percent.

A specific yield of 5 percent was assigned deposits, such as clay and gravel, "dry" gravel, cemented gravel, and gravelly clay, which, although they are obviously of low permeability, supply small quantities of water to wells.

The fine-grained deposits, including clay, silt, sandy clay, hardpan, muck, shale, volcanic ash, and lava, were assigned a specific yield of 3 percent. In any one well log, deposits included in this category generally constitute more than half the sediments penetrated in the 20- to 200-foot depth range; only locally do the coarse-grained deposits occupy more than half this depth range. The specific yield of 3 percent is higher than that used for clay in the study of the south-coast basin, but it is midway between the values used for clay and sandy clay in the unweathered subsurface alluvial deposits in that area. Material logged by the drillers as "clay" is likely to include many beds that are silty, sandy, or even gravelly, if they contain much material so fine that it remains in suspension in the drilling fluid. Mechanical analyses by the Corps of Engineers on core samples from the Butte Creek, Putah Creek, and Willow Slough areas in the Sacramento Valley indicate that even in the areas of quiet-water depositional environments, such as the flood basins, clayey silt and clayey sand are more common than true clay.

The specific yield of 25 percent assigned to gravel agrees fairly closely with experimental results obtained by Eckis (Eckis and Gross, 1934) and by Piper (Piper and others, 1939).

COMPUTATION OF STORAGE CAPACITY

The computation of the ground-water storage capacity of the Sacramento Valley involved the following six steps:

1. The valley deposits were divided areally into 4 storage groups (table 3), and these in turn were subdivided into a total of 29 storage units (table 4), as shown on figure 4 and discussed in the section on subdivision of the valley into storage units.
2. For each of the 29 storage units the area within each township or portion of a township included was measured to the nearest 10 acres with a scale or planimeter on quadrangle maps of the valley at a scale of 1:31,680 or, in a few cases, at a scale of 1:62,500. The township or part of a township became the basic subunit for the computation of storage capacity. (See table 6.)
3. For each of the 3 depth zones under consideration (20 to 50, 50 to 100, and 100 to 200 feet below the land surface) materials logged in selected wells in each township subunit were classified into 5 categories. An arbitrary specific yield was assigned to each of the 5 categories.

4. Using these arbitrary specific-yield values, the average specific yield was computed for each depth zone in each township subunit. This was done by adding up the footages in each of the five categories, dividing each footage figure by the total footage to obtain the percentage of that category in the depth zone, multiplying this percentage by the specific yield of the category, and adding the products thus obtained to get the average specific yield for the zone. Where a well penetrated less than half a depth zone, the footage was not calculated and was not included in the total for that zone.
5. The storage capacity in each township subunit, rounded to the nearest 100 acre-feet, was obtained as the product of average specific yield (to nearest 0.01 percent) times volume of sediments in the depth zone. The average specific yields were rounded to the nearest 0.1 percent in tables 3-6.
6. The ground-water storage capacity for each storage unit was obtained as the sum of the storage capacities in all the subunits. The total for each depth zone of each storage unit was rounded to the nearest 1,000 acre-feet. These then were totaled by storage groups and rounded to the nearest 10,000 acre-feet to give the estimated ground-water storage capacity for the Sacramento Valley (table 3). As explained in the discussion of selection of depth zones, the storage capacity of the 100- to 200-foot depth zone in the Sutter Basin (unit D4) was excluded because of the high salinity of the ground water.

In addition to the tables mentioned in the preceding paragraphs, table 6 was prepared to summarize the ground-water storage capacity of the valley by townships within each storage unit. The total storage capacity of each storage unit is the sum of the storage capacities of the several township subunits.

Several modifications of the computation procedure outlined above were employed, depending on local problems. For example, if there was an insufficient number of wells within any one township subunit, wells from one or more adjacent townships were included, and the resultant specific yields used for all the township subunits so treated. Where well logs were few, such as in the American Basin storage unit (D2), all logged wells within the area were used to obtain the average specific yields of the three zones.

Tables 3 to 6 summarize the estimates of ground-water storage capacity of the Sacramento Valley. Table 3 shows the estimates by the 4 major storage groups (A to D); table 4 shows the estimates by groups for the total of 29 storage units (A1 to A5, B1 to B11, C1 to C8, and D1 to D5). Table 5 shows the estimates by townships—150 in all. Table 6 shows the estimates by storage units and townships subunits. As shown in table 3, the estimated ground-water storage capacity of the Sacramento Valley in the interval 20 to 200 feet below land surface is about 33½ million acre-feet. Because the flood-basin deposits are fine grained and therefore in large part unusable, the storage capacity, excluding these deposits, is reduced to a total of slightly more than 28 million acre-feet.

DESCRIPTION OF GROUND-WATER STORAGE UNITS

FLOOD-PLAIN AND CHANNEL DEPOSITS (GROUP A)

The flood-plain and channel deposits (fig. 4) are associated with flood plains, natural levees, and distributaries, and near the surface they are roughly equivalent to the geologic unit called river deposits (pl. 2). Most of the soils are silty and sandy loams. The flood-plain and channel deposits contain a high proportion of sand and gravel laid down by the Sacramento River and its major tributaries. Nearly all this material has been deposited adjacent to present or old stream courses in times of flood, as a result of channel filling and natural-levee construction. In general, the flood-plain and channel deposits have the highest specific yield of the four groups in all three depth zones. The estimated ground-water storage capacity of the flood-plain and channel deposits (group A) in the depth range 20–200 feet is about 10 million acre-feet, which is 30 percent of the total in the Sacramento Valley. (See tables 3 and 4.)

CACHE CREEK (UNIT A1)

Storage A1 includes an area of 12,420 acres on the flood plain of Cache Creek, extending half a mile north and 1½ miles south of the creek and roughly paralleling it for a distance of 10 miles between the Coast Ranges on the west and the Dunnigan Hills on the east. Cache Creek emerges from the Coast Ranges near the town of Capay, flows eastward on a broad flood plain along the south margin of Hungry Hollow to the Dunnigan Hills and passes through a terraced constriction between these hills and the Plainfield Ridge, which extends southward to Putah Creek.

Part of the flood plain is irrigated with surface water diverted from Cache Creek upstream from the town of Capay and delivered through the Adams Canal north of the creek and the Madison Canal south of the creek. However, most of the plain is irrigated by ground water from wells that tap coarse, permeable gravel beds. Throughout most of the reach from Capay to the Dunnigan Hills, Cache Creek occupies a broad, gravel-floored channel, as much as several hundred feet wide, that is subject to flooding and is of little agricultural value.

Beneath the flood plain, gravel deposits extend to depths of 50 to 150 feet below the land surface. Coarse materials make up more than half the depth interval between 20 and 100 feet and reach a maximum of 72 percent in the 20- to 50-foot depth interval in T. 10 N., R. 1 E. These gravel deposits probably were laid down by Cache Creek during the Recent and part of the Pleistocene epochs.

The coarse-grained deposits are underlain by a generally fine-grained section of hard clay beds and occasional layers of hard sand or cemented gravel. The lithologic character of these underlying deposits suggests that they are part of the Tehama formation which crops out in the Dunnigan Hills to the east and in the foothills of the Coast Ranges to the west. Drillers' logs indicate that clay and silt make up 78 percent of the 100- to 200-foot interval in spite of the fact that in some places the coarse overlying gravel extends to a depth of 150 feet.

The Cache Creek storage unit is separated from the Sacramento Valley floor by the Dunnigan Hills anticline. As shown on figure 2, an anticlinal trend extends from the northern end of the Dunnigan Hills southeastward beyond Cache Creek to the vicinity of Putah Creek. The Cache Creek storage unit lies in a shallow syncline between the Dunnigan Hills anticline and the Coast Ranges but extends across the syncline approximately normal to the structural trend. Bryan (1923, p. 19) suggested that the eastern face of the Dunnigan Hills was a fault scarp, but subsequent investigations by geologists of several oil companies indicate that the uplift is anticlinal. In either case, the structure has a definite effect upon ground-water occurrence and movement in the area. The base of the principal fresh-water body in this area is warped in reflection of structural features of the area and shows several hundred feet of relief. Ground-water levels in wells also are controlled to a large extent by the Dunnigan Hills anticline. The water table slopes eastward along Cache Creek at a nearly uniform rate to the Dunnigan Hills. Immediately east of the crest of the anticline the slope of the water table increases greatly for a short distance, indicating a subsurface damming effect or at least a restriction to the free eastward movement of ground water across the anticline. Prior to the beginning of spring and summer pumping for irrigation, the water table west of the anticline ordinarily stands 20 feet or more higher than levels in wells east of the hills. Few recent data are available, but in the spring of 1942, at the end of a period of above-average rainfall, water levels were within 10 feet of the land surface in most of the area included in the Cache Creek storage unit (U.S. Bureau Reclamation, 1947). Hence, the Cache Creek storage unit was filled about to capacity in 1942.

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Specific yields computed from well logs reflect the lithologic features of the subsurface deposits; as computed for individual townships within the storage unit, the specific yield ranged from 11 to 19.1 percent in the two upper depth zones and from 3.8 to 7.3 in the 100- to 200-foot zone. Average specific-yield values for the 20- to 50-foot, 50- to 100-foot, and 100- to 200-foot depth zones are 18, 14.8, and 6.8 percent, respectively. The estimated storage capacity of the deposits in the Cache Creek storage (unit A1) for these depth zones is 67,000, 92,000, and 84,000 acre-feet, respectively, or a total of 243,000 acre-feet. (See tables 4 and 6.)

COSUMNES RIVER (UNIT A2)

For the purpose of this study of ground-water storage capacity, only that part of the Cosumnes River flood plain that traverses the valley north of T. 7 N. was included in the A2 storage unit. This unit comprises 7,970 acres of the bottom land paralleling the Cosumnes from the foothills of the Sierra Nevada to the southern limit of the area (fig. 4).

The flood plain of the Cosumnes ranges in width from two-thirds of a mile to 1½ miles. The floor of the flood plain, lying 20 feet or less below the level of the surrounding low plains, is essentially featureless and is ineffectively drained by a discontinuous network of sinuous, shallow channels. Under natural conditions the floor was flooded frequently during even moderately high water; however, the natural regimen of the Cosumnes has been modified by the construction of levees that contain the river and permit the cultivation of the bottom lands. Most of the irrigation water used in this storage unit is supplied by wells, but in 1949 about 950 acres was irrigated with surface water diverted from the river (California Department Public Works, Division Water Resources, 1950).

The Recent deposits of the Cosumnes River consists of unconsolidated silt, sand, and gravel extending to depths of 15 to 25 feet. Underlying the Recent deposits and adjoining them on the low plains are fluviatile sand, silt, and gravel deposits of the Victor formation (Pleistocene). The Victor is lithologically similar to and presumably in hydraulic continuity with the Recent river deposits; hence, in most wells the two deposits are virtually indistinguishable.

Drillers' logs indicate that harder, more indurated alluvial deposits, probably belonging to the Laguna formation and related continental sediments (upper Pliocene and Pleistocene), lie beneath the Cosumnes flood plain 40 to 80 feet below the land surface. In this area the Laguna is characterized by thick beds of clay interstratified with thin beds of hard sand or "sandstone."

Relative proportions of coarse and fine materials are in accord with the geologic conditions, as determined from drillers' logs. Gravel makes up 24 percent of the deposits in the 20- to 50-foot zone, 14 percent in the 50- to 100-foot zone, and only 5 percent in the 100- to 200-foot zone. The 100- to 200-foot depth zone is typical of the sand-clay succession found in the Laguna formation. Here the clay category composes 56 percent, the hard-sand category 25 percent, and the sand category 9 percent of the total section; the percentage of hard sand might have been higher if the hardness or degree of cementation of the sand layers had been recorded by all drillers.

Specific yields computed from well logs indicate that the two upper zones, although they differ markedly in lithology, have roughly the same specific yield—11.8 percent and 11.2 percent for the 20- to 50-foot and 50- to 100-foot zones, respectively. The specific yield of 7.6 percent of the 100- to 200-foot depth zone is consistent with the impermeable character of the Laguna formation penetrated in that interval.

Unpublished data assembled by the U.S. Bureau of Reclamation in the Cosumnes River area indicate that the water table has a westward slope, and that as of October 1947 the depth to ground water beneath the flood plain was between 20 and 30 feet throughout the area included in the Cosumnes River ground-water storage unit.

The estimated ground-water storage capacity of the deposits in the Cosumnes River (Unit A2) in the three depth zones, 20 to 50, 50 to 100, and 100 to 200 feet, is 28,000, 45,000, and 60,000 acre-feet, respectively, or a total of 133,000 acre-feet. (See table 6.)

SACRAMENTO RIVER SOUTH OF COLUSA (UNIT A3)

Ground-water storage unit A3 extends from Colusa south to the Sacramento-San Joaquin delta near Clarksburg and includes an area of 146,000 acres. Unit A3 varies in width from about 8 miles near Meridian to 1¼ miles near Grand Island, but for the most part it averages about 3 to 4 miles. From Colusa to Sacramento the Sacramento River follows a southeastward course, approximately parallel to the trend of the Dunnigan Hills, but at Sacramento it turns and flows in a southward course to the delta. Flood basins border the natural levees of the river on both sides throughout most of this reach—the Colusa and Yolo Basins on the west and the Sutter and American Basins on the east.

The river channel is a sixteenth to a quarter of a mile wide between the natural levees. From Colusa southward to the confluence of the Feather River, the course is sinuous, and the flood plain is characterized by many small oxbow lakes, marking abandoned channels. South of the confluence of the two rivers the course is characterized by smooth large bends 4 to 5 miles in length. In this lower reach there are few abandoned channels; these suggest that the present channel is stable and long established.

The population of the trough of the Sacramento Valley is concentrated largely along the natural levees of the river. The levee lands have the best soil and in the past, prior to construction of the extensive bypasses that now carry the flood flows, were an area that offered some flood protection in their elevation above the basins.

The availability of inexpensive surface-water supplies to lands along the river tends to minimize the use of ground water, but there has been extensive ground-water development in the northern part of this storage unit near Grimes and Meridian, and from the confluence of the Feather River southward. In 1949 in the area between Colusa and Sacramento, 165 pumping plants diverted water from the Sacramento River (California Department Public Works, Division Water Resources, 1950). Most of these plants pumped water for use on lands adjacent to the river, but the greatest portions of the total diversions, listed as 837,918 acre-feet, were by large plants pumping into canals that carried the water to the flood-basin lands.

Only river deposits of Recent age crop out in the river lands, but Pleistocene deposits are reached in wells within 100 feet of the surface. Drillers' logs indicate that there are no systematic vertical changes in the lithology of the river deposits north of the confluence of the Sacramento and American Rivers. Where wells are closely spaced, it is possible in a few instances to trace individual beds of sand and gravel for 3 or 4 miles. Usually, however, it is impossible to correlate beds between wells as close as a quarter of a mile.

Many drillers' logs from the Grimes-Meridian area record a color change in the fine-grained deposits that may be significant. Between 50 and 350 feet below the surface the clays change from yellow or brown to blue. The significance of this color change is not clearly understood. A blue color generally indicates that the sediments have been in nonoxidizing environment of at least a considerable period since their deposition; a yellow or brown color indicates that the sediments were either deposited in an oxidizing environment or have undergone oxidation subsequently. The fact that yellow and brown clays overlie blue clays but are not interbedded with them suggests that the post-depositional environment, possibly the position of the water table, may have been the controlling influence in this color variation.

Wells in the Grimes-Meridian area penetrate a generally fine-grained alluvial section in the 20–200 foot depth interval. Clay and silt make up 70, 78, and 73 percent of the section in the 20–50, 50–100, and 100–200 foot intervals, respectively. The coarse-grained beds are about equally divided between clean and well-sorted gravel and sand deposits laid down as channel deposits in an ancestral Sacramento River.

The southern part of the storage unit, A3, south of the Knights Landing Ridge, is effectively separated from the northern part by an area of few wells between Grimes and Knights Landing. Cache Creek, the Feather River, and the American River have contributed large volumes of coarse debris to the river deposits; consequently, the river deposits here contain a greater proportion of coarse material than do those to the north. Clay and silt make up only 48, 41, and 57 percent of the upper, middle, and lower depth zones, respectively, compared to the 70 to 78 percent in the Grimes-Meridian area. At Sacramento, just south of the confluence of the American and Sacramento Rivers the proportion of coarse sand and gravel in the near-surface deposits reaches 100 percent in some wells, and tongues of coarse-grained deposits, probably belonging to both the Victor formation and the river deposits of Recent age, can be recognized to a depth of more than 100 feet.

Calculated specific yields reflect the regional trend in a general way, although there are exceptions locally. For example, the weighted average specific yields in the northern district, T. 12 N. through T. 15 N. are 8.5, 8.4, and 7.9 percent, respectively, in the depth zones at 20–50 feet, 50–100 feet, and 100–200 feet, respectively. On the other hand, in the southern district, T. 7 N., to T. 11 N., where the sedimentary contributions of Cache Creek and the Feather and American Rivers are significant, the corresponding weighted averages are 11.3, 12.2, and 9.5 percent, respectively. The overall weighted averages for the storage unit as a whole (table 6) are lower than usual in the flood-plain and channel deposits.

Figures for the 20- to 50-foot zone (table 6), representing the unconsolidated Pleistocene(?) and Recent deposits in all the storage units in group A, show that the specific yield of the Sacramento River deposits south of Colusa is the lowest of the whole storage group. This may be attributed to the fact that all the other storage units are closer to the mountain source of coarse-channel deposits and are traversed by streams of steeper gradient than that of the lower Sacramento. The comparison is not as clear for the two deeper zones, because older deposits of low permeability are found between 50 and 200 feet in several other storage units.

As might be expected, the water table in the river deposits is closely related to the river stage. During the winter, when the river stage is higher than the land surface in the adjoining basin country, the water table slopes steeply away from the river, indicating movement in that direction (U.S. Bur. Reclamation, 1949a). During the summer, heavy irrigation of the basin lands with imported surface water causes the formation of a ground-water ridge between the river and the troughs of the basins, and water moves toward the river as well as toward the troughs. Throughout most of the lower reach of the Sacramento River, ground water drains into the river during the summer, except locally where heavy pumping reverses the groundwater gradient.

Annual fall water-level measurements of selected wells in the Sacramento Valley made by the California Division of Water Resources have indicated that the depth to water throughout storage unit A3 was even less than 20 feet and in many wells has been less than 15 feet. The estimated ground-water storage capacity of the deposits in this storage unit (A3) in the three depth zones, 20 to 50 feet, 50 to 100 feet, and 100 to 200 feet, is 425,000, 729,000, and 1,256,000 acre-feet, respectively, or a total of 2,410,000 acre-feet. (See tables 4 and 6.)

SACRAMENTO RIVER NORTH OF COLUSA (UNIT A4)

The flood-plain and channel deposits of the Sacramento River north of Colusa are included in storage unit A4, which comprises 237,100 acres. This area extends from the north end of the Sacramento Valley near Red Bluff, 72 miles southward to the southern limit of T. 16 N., 2 miles south of the city of Colusa. The Sacramento River follows a southeastward course parallel to the general trend of Sacramento Valley from Red Bluff to Hamilton City, where it turns and takes a southward course to Colusa. A strip of channel and flood-plain deposits, ranging in width from 1 mile near Vina to 8 miles at Butte City, flanks the river throughout this reach (pl. 2).

From Red Bluff to Hamilton City the flood plain ranges in width from 1 to 3 miles and lies between fairly steep bluffs. Lying from 10 to 20 feet below the general level of the flood plain, the river occupies a sinuous channel marked on one side by sand bars and islands that are separated from the main channel by side channels or sloughs. The flood-plain surface is broken by many long, shallow depressions, generally less than 10 feet deep, that carry water during flood stages.

Downstream from Hamilton City the lands along the river resemble those to the south between Colusa and the confluence of the

Feather River. The river follows a meandering course between natural levees, 10 to 20 feet high, that slope away from the channel on either side. For some distance from the channel the terrane is cut by abandoned channels and cut-off meanders, some intersecting the water table to form elongate oxbow lakes.

The narrow strip of Victor formation and related deposits that extends from the boundary line of Butte and Tehama Counties northward along the east side of the valley, as shown on the geologic map (pl. 2), was included in this storage unit. Although the surface of these deposits is a terrace elevated above the Sacramento River flood plain, the deposits themselves are lithologically and hydrologically similar to the river flood-plain and channel deposits and appear to be in hydraulic continuity with them. Thus, they have been grouped in one ground-water storage unit.

Agricultural development of the Sacramento River flood plain between Red Bluff and Hamilton City has been discouraged by the danger of flooding and by the irregular nature of the land surface which is cut up to a great extent by flood channels several feet deep. Large-scale irrigation would call for expensive land leveling which in the past has not been economically feasible. Only a small volume of Sacramento River water is diverted north of the Tehama County line, and irrigation wells are few.

The Victor formation and related deposits on the east side of the valley have been cultivated extensively in the area between Red Bluff and the Tehama County line. Nearly all the irrigation water in this area is supplied by diversions from Deer, Mill, and Antelope Creeks.

South of Hamilton City lands along the river support considerable agriculture. Although large tracts of uncultivated land still remain, particularly east of the Sacramento River, most of this area is irrigated by either surface or ground water. River diversions used to irrigate the river lands total about 115,000 acre-feet, of which approximately one-half was used in the Princeton-Codora-Glenn Irrigation District in Glenn and Colusa Counties (California Dept. Public Works, Div. Water Resources, 1950). Much of the area between Hamilton City and Colusa is supplied with surface water by irrigation and reclamation districts, but there has been extensive ground-water development between Colusa and Princeton in Colusa County and on both sides of the river for several miles south of Hamilton City.

Recent river deposits are the only materials exposed at the surface, except for the Victor formation and related deposits (Pleistocene) exposed along the east side of the valley in Tehama County. The Recent deposits consist of gravel and sand deposited in the river channel and silt deposited on the flood plains. Logs of wells drilled on the flood plain east of Red Bluff indicate that dominantly coarse-grained clean sand and gravel extend to a depth of about 50 feet below the surface. Below this depth, there is cemented gravel, sandstone, and hard clay of the Tehama and Tuscan formations (Pliocene), which crop out along the west and east sides of the valley, respectively. Gravel and sand make up almost half the section in the 20- to 50-foot zone in townships 26 and 27 N. Wells drilled in the Victor formation and related deposits penetrate deposits similar to those found beneath the Sacramento River flood plain to a maximum depth of about 50 feet. However, many wells are drilled into partially consolidated sandstone and cemented gravel of the fanglomerate from the Cascade Range within 25 feet of the land surface.

Indurated sediments described by drillers as sandstone are found within 70 feet of the surface as far south as the bridge over the Sacramento on the Corning-Vina highway. Still farther south, near the Tehama county line, wells drilled on the Sacramento River flood plain penetrate sandstone between 125 and 200 feet below the surface. These hard beds probably represent the Tehama formation which crops out at the Corning Ridge anticline not far to the west (pl. 2).

Relative proportions of coarse- and fine-grained materials in the Red Bluff-Hamilton City area are in general accord with the geologic features of the area. In the Recent and Pleistocene river deposits of the 20- to 50-foot zone, gravel and sand make up an average of 50 percent of the total thickness of alluvium, whereas in the deposits of Pliocene age coarse materials average 32 and 23 percent, in the 50- to 100-foot zone and the 100- to 200-foot zone respectively. These relatively high percentages of coarse deposits in the Tuscan and Tehama formations indicate the coarseness of these older materials in the northern end of the valley. Probably much of the gravel and sand found in the Tehama formation is somewhat cemented and should be considered as such, but in logs of wells it is commonly impossible to discriminate between the loose and consolidated materials.

Specific yields computed from drillers' logs also reflect the geologic features. Weighted averages of the specific yields for unit A4 from Red Bluff to Hamilton City indicate a general southward decrease in specific yield in accordance with the decrease in average grain size of the deposits. The weighted averages for this area are 14.3, 10.8, and 8.9 percent for the 20- to 50-foot zone, the 50- to 100-foot zone, and the 100- to 200-foot zone, respectively.

The river deposits south of Hamilton City are similar to those in the southern area of the Sacramento River, below Colusa. Gravel and sand were deposited in the river channel and clay and silt on the natural levees. Only materials of Recent age are exposed at the surface, but wells penetrate Pleistocene deposits within 100 feet of the land surface. In contrast to conditions in the area north of Hamilton City, only unconsolidated deposits are found within 200 feet of the land surface. Well logs indicate that the only important change in the vertical interval is that the 100- to 200-foot zone has a greater proportion of clay and a smaller proportion of gravel than the two upper zones. Clay makes up 69 percent of the 100- to 200-foot zone but only 53 and 56 percent of the 20- to 50-foot and the 50- to 100-foot zones respectively.

A general decrease in average grain size southward was noted in the deposits between Hamilton City and Colusa. With but few exceptions, figures for all three depth zones show an increase in the percentage of clay and a decrease in the percentage of gravel toward the south. This is in accord with the mechanics of sediment transportation. The gradient of the Sacramento River decreases southward; hence, the rate of flow, and in turn the ability of the river to transport sediment, decrease also.

Weighted averages of the specific yields indicate little difference in the 20- to 50-foot and 50- to 100-foot zones, with values of 11.5 and 11.4 percent, respectively; but the average for the finer-grained interval between 100 and 200 feet below the surface is appreciably lower—only 8.2 percent.

Between Red Bluff and Hamilton City the water table slopes from the sides of the valley toward the Sacramento River and down the valley from north to south. Under natural conditions the water table sloped away from the river toward the flood basins south of the Stony Creek fan. However, the distribution of irrigation in 1949 was such that the natural conditions were greatly modified. In the winter, when the river stage was high, the water table in the reach south of the Stony Creek fan sloped away from the river toward the flood basins but sloped from the Stony Creek fan northward toward the river (U.S. Bureau of Reclamation, 1949a). During the summer, the water table sloped toward the river, and ground water drained into the river throughout this reach, except where heavy pumping locally reversed the regional gradient.

Measurements of selected observation wells by the California Division of Water Resources indicated that, during the fall of 1947 and 1948, the depth to water beneath the lands near the river ranged from about 10 feet between Colusa and Hamilton City to as much as 25 feet east of Red Bluff.

The estimated ground-water storage capacity of the deposits along the Sacramento River north of Colusa (storage unit A4) in the three depth zones, 20 to 50 feet, 50 to 100 feet, and 100 to 200 feet, is 911,000, 1,329,000, and 2,147,000 acre-feet, respectively, or a total of 4,387,000 acre-feet. (See tables 4 and 6.)

FEATHER, YUBA, AND BEAR RIVERS (UNIT A5)

The Victor formation and related deposits and the deposits of Recent and Pleistocene age of the Feather, Yuba, and Bear Rivers are considered to be a single hydrologic unit and are treated as a single ground-water storage unit A5 in this report. This unit embraces 208,730 acres of land, extending about 50 miles in a southerly direction from Oroville at the mouth of the Feather River canyon to the confluence of the Feather and Sacramento Rivers near Verona and about 17 miles from the Sierra Nevada foothills west to Sutter Buttes. The Feather River is described on page 24.

The Yuba River occupies a debris choked channel 1 to 3 miles wide (pl. 2) that stands as much as 10 feet above the adjacent plains. Like the Yuba, the Bear River also occupies a raised channel enclosed between artificial levees. Much of the area shown as low alluvial plains and fans west of the Sierra Nevada on the geomorphic map (pl. 1) is included in the flood-plain and channel deposits in the ground-water storage study. Bordering the Feather and Yuba flood plains and extending several miles back from the rivers, these low plains are underlain by coarse sand and gravel deposits of the Victor formation and related deposits which probably were laid down by the ancestral Feather and Yuba Rivers. At the land surface these deposits are level to slightly dissected, gently sloping plains that stand 10 to 15 feet above the present flood plain of the Feather River. Unconsolidated sand and gravel found in wells in this area appear to be continuous with the river deposits underlying the present river flood plains.

Storage unit A5 includes the best agricultural land in Sutter and Yuba Counties with the population centers of Oroville, Marysville, and Yuba City. Most of the arable land in the area is under irrigation by surface or ground water. In 1948 an area of 11,368 acres east of the Feather River and north of the Yuba River was supplied with surface water by the Cordua and Hallwood Irrigation Districts which divert water from the Yuba River north of Hammonton (Calif. Dept. Public Works, Division of Water Resources, 1950). Some 1,833 acres of the Yuba River flood plain was irrigated by the canals of the Farm Land Investment Co. Because of the availability of surface supplies, ground-water supplies have not been developed extensively east of the Feather River. West of the Feather, however, there has been intensive ground-water development, and as of 1949 an overdraft existed in the area south of Yuba City

(California State Water Resources Board, 1952). As of 1949, in the northern part of Sutter and the southern part of Butte Counties, 25,825 acres was irrigated with Feather River water delivered by the Sutter-Butte Canal Co.; and south of Yuba City, the Garden Highway Mutual Water Co. and the Oswald Water District served an area of 3,318 acres with Feather River water. West of Wheatland, 1,580 acres on the Bear River flood plain was served with water diverted from the Bear River by the Camp Far West Irrigation District (California State Water Resources Board, 1952).

Recent river deposits and the Victor formation and related deposits (Pleistocene) are the only materials exposed at the surface in unit A5. The river deposits consist of sand and gravel deposited in the river channels during the time of decreasing flow, and silt and fine sand deposited on the flood plains and natural levees during floods. The Victor consists of sand, silt, and gravel deposited by the ancestral Feather River and its tributaries in building the low alluvial plains.

Well-defined channels of coarse gravel underlie the flood plains of the Feather, Yuba, and Bear Rivers. The depth to the base of the gravel is about 30 feet near Oroville, increasing to 85 feet or more at the bridge east of Gridley. Wells on the Yuba River flood plain east of Marysville are drilled into coarse unconsolidated gravel deposits to a depth of about 100 feet. A general decrease in the proportion of coarse-grained materials away from the canyon mouths is noted in the deposits of the Feather, Yuba, and Bear Rivers. Along the Feather River, for example, the percentage of sand and gravel in the 20- to 50-foot zone decreases from 62 percent in T. 19 N., near Oroville, to 32 percent in T. 16 N., upstream from the confluence of the Yuba. Wells on the low plains segment penetrate unconsolidated sand, silt, and gravel to depths of 50 to 110 feet. West of the Feather River, gravel, sand, and silty clay extend to as much as 110 feet below the land surface. North of Yuba City these coarse-grained materials, overlie brown cemented sand and hard brown clay of the Laguna formation, but south of Yuba City and in the Marysville area the underlying Laguna is mostly blue clay.

East of the Feather River and north of the Yuba River the Victor formation and related deposits extend to depths of 70 to 100 feet and rest upon cemented sand, gravel, and hard clay of the Laguna formation and related continental sediments. South of the Yuba the thickness of the unconsolidated deposits does not appear to exceed 50 feet.

The Recent river deposits and the Victor formation and related deposits are underlain throughout the storage area by moderately indurated silt and sand of the Laguna formation and related continental sediments. The ground-water storage figures reflect this regional feature in that the specific yields computed for the 100- to 200-foot zone (below the base of the unconsolidated deposits in most of the area) are invariably much lower than the values obtained for the upper zones.

The storage computations for the 20- to 50-foot and 50- to 100-foot zones are in close accord with the known geology of the area. The 20- to 50-foot zone, which embraces little more than the river deposits, is a good example. The most significant systematic change noted in the area is a general decrease in grain size of the sediments away from their mountain sources. The proportion of gravel in the upper zone reaches a maximum of 48 percent in T. 18 N., R. 3 E., and decreases to only 5 percent in T. 11 N. and T. 12 N., just above the Sacramento-Feather River confluence. In these same townships, however, the proportion of sand increases from 7 percent in T. 18 N., R. 3 E., to 55 percent in T. 11 N. and T. 12 N.

Specific yields for the 50- to 100-foot zone indicate the position of the Laguna formation at many places. In areas where the younger deposits do not extend far below 50 feet, the specific yields computed for the 50- to 100-foot zones are comparable to those of the deeper zone, whereas in areas where they extend to 100 feet or more, the specific yields of the 50- to 100-foot zones are close to those of the 20- to 50-foot zone.

The weighted average specific yield for the 100- to 200-foot zone, 6.2 percent, is fairly representative of specific yields in the Laguna formation. Specific yields in the 50- to 100-foot zone vary considerably, depending upon the depth to the base of the younger unconsolidated deposits. In the Oroville area the coarse character of the Laguna is reflected in generally high specific yields.

Water-level measurements by the California Division of Water Resources (California State Water Resources Board, 1952) show that the water table in Sutter and Yuba Counties sloped from the north, east, and west toward a trough that roughly parallels the Feather River. The northern part of this trough extended to Tudor about 4 miles south of Yuba City. A small ground-water mound between Tudor and Nicolaus separated the northern part from the southern extension of the trough which crossed the Feather near Nicolaus and extended southward beneath the American Basin. Ground water moved toward the trough in the direction of the slope of the water table from the Sierra Nevada foothills on the east, from an area of heavy surface-water irrigation between Sutter Buttes and the Feather River on the north, and from Sutter Basin also an area irrigated by surface supplies—on the west.

The Feather, Yuba, and Bear Rivers undoubtedly contribute much water to the ground-water body. Water-level contours, based on water-level measurements in the fall of 1948 (California State Water Resources Board, 1952), indicated that only the Feather River was receiving any water from the ground-water body and this contribution occurred only in the reach above Marysville where there was heavy application of surface water for irrigation on both sides of the river.

Water levels in wells in 1950 were within 35 feet of the land surface throughout the Feather-Yuba-Bear River area. The maximum depth to water was in the water-table depression south of Yuba City where fall depths to water ranged between 20 and 35 feet. Throughout much of the area served by surface ditches, particularly on the alluvial plains west of the Feather River north of Yuba City and east of the Feather north of Marysville, the water table was within 10 feet of the surface and had in some areas caused serious waterlogging.

The estimated ground-water storage capacity of the deposits in the Feather, Yuba, and Bear Rivers storage unit (A5) in the three depth zones, 20 to 50 feet, 50 to 100 feet, and 100 to 200 feet, is 718,000, 1,025,000, and 1,138,000 acre-feet, respectively, or a total of 2,881,000 acre-feet (table 6).

LOW ALLUVIAL-PLAIN AND ALLUVIAL-FAN DEPOSITS (GROUP B)

The low alluvial-plain and alluvial-fan deposits (group B, fig. 4) appear at the land surface as undissected or slightly dissected plains having gentle slopes. Included in this group are the major alluvial plains and fans built by Putah, Cache, Stony, and Big Chico Creeks, as well as alluvial deposits of the lesser streams of the valley that are not included in the river flood-plain and channel deposits (group A). Because the Recent deposits of the American River generally are thin and appear to be hydraulically continuous with the Victor formation and related deposits, they were included in storage group B.

Permeability and specific yield of the low alluvial-plain and alluvial-fan deposits are higher than those of the dissected alluvial deposits (group C) and the basin deposits (group D) but generally not as high as those of the river flood-plain and channel deposits (group A). The estimated storage capacity of the deposits in group B between 20 and 200 feet is about 13,060,000 acre-feet, or 39 percent of the total for the Sacramento Valley (tables 3 and 4).

PUTAH PLAIN (UNIT B1)

Storage unit B1 includes an area of 221,490 acres in the eastern part of Solano and the southern part of Yolo Counties, extending from the Montezuma Hills to a short distance north of Putah Creek and from the English Hills to the Yolo Basin. This area, which has been designated the "Putah plain" by Thomasson, Olmsted, and Le Roux (in press), is about 24 miles north-south by 18 miles east-west. The land increases in altitude from less than 5 feet above sea level along the margin of Yolo Basin to 150 feet near Winters at the western margin of the plain.

A large part of the Putah plain has been constructed by Putah Creek and is marked by many abandoned channel ridges that extend southward and southeastward from the present channel, indicating that the creek has changed its course many times during the late Pleistocene and Recent. At present, Putah Creek flows almost due eastward across the northern part of the plain in a channel which is cut as much as 40 feet below the tops of its natural levees.

The western and southern parts of the Putah plain have been constructed by small streams flowing out of the English Hills—principally Ulatis and Sweeney Creeks. The materials deposited by these small streams generally are finer grained than those materials deposited by Putah Creek.

The upper Pleistocene and Recent alluvial-fan deposits beneath Putah plain generally are less than 150 feet thick and consist of silt, sand, gravel, and clay. These unconsolidated deposits are underlain by the somewhat compacted and partly cemented less permeable sediments of the Tehama formation.

Drillers' logs of more than 400 wells in the Putah plain show that silt and clay make up an average of 70 percent of the total thickness in all three depth zones. The remaining 30 percent is largely sand and gravel and lesser amounts of cemented sand and gravel, clay and gravel, and other cemented or poorly sorted materials. Average specific yields for all three depth zones are essentially the same—about 7.8 percent. In general, the highest average specific yields are for wells in the area south of Putah Creek in the triangle made by the towns Dixon, Davis and Winters; the lowest specific yields are for wells in the southwestern and southern parts of the Putah plain. (See table 6.)

Although the well-log data suggest that the average specific yields and the relative proportions of coarse- and fine-grained deposits do not vary appreciably with depth, an analysis of pump-test data on wells in the Putah plain, supplied by the Pacific Gas and Electric Co., indicated that the Tehama formation and related continental sediments geologic unit, which makes up the larger part of the 100- to 200-foot depth interval, is considerably less permeable than the overlying alluvium (Thomasson and others, in press). Apparently either the logs are inaccurate or the coarse-grained deposits in the

Tehama are less well sorted or more cemented than the coarse deposits in the overlying alluvial-fan deposits. Therefore, the average specific yield of 7.8 percent in the 100- to 200-foot depth zone in the Putah plain storage unit probably is too high relative to the shallower zones. For similar reasons it is possible that the average specific yields of the 100- to 200-foot zones in many of the other storage units of the valley (table 6) are too high. However, no data were collected that could be used to refine these estimates.

Most of the water used for irrigation is pumped from wells, although small areas north of Putah Creek are irrigated with surface water from Cache Creek, and a few owners of riparian rights use creek water as a supplemental supply in late spring and early summer. A well canvass by the Geological Survey in 1948–49 showed that there were more than 700 active irrigation wells on the Putah plain that yielded 200 to more than 2,000 gpm (Thomasson and others, in press). Most of the irrigated acreage is devoted to high-value truck crops, alfalfa, irrigated pasture, sugar beets, almonds, and deciduous fruits. Development of irrigation up to the late forties was concentrated in the triangular area between Winters, Davis, and Dixon. On the southern and western parts of the plain the soils are nearly impermeable and ground-water supplies are small, and hence, much of the land is used for pasture or unirrigated grain.

In the years 1948–51 the alluvial deposits of the Putah plain were saturated at relatively shallow depths (Thomasson and others, in press). The depth to water in wells ranged from 5 feet or less near the Yolo Basin to 50 feet or more at the margin of the foothills and in the area of heavy pumping around Dixon. The ground water was moving generally from west to east (Thomasson and others, in press). A relatively large drawdown of water levels in the Dixon area, which has persisted at least since 1932, was due to a concentration of pumping near Dixon and possibly in part to areal changes in transmissibility of the water-bearing materials beneath the Putah plain.

The estimated ground-water storage capacity of the deposits in the Putah plain (storage unit B1) for the three depth zones 20 to 50 feet, 50 to 100 feet, and 100 to 200 feet, is 521,000, 875,000, and 1,733,000 acre-feet, respectively, or a total of 3,129,000 acre-feet (table 6).

LOW PLAINS SOUTH OF THE AMERICAN RIVER (UNIT B2)

Storage unit B2 occupies the low plains south of the American River and includes a strip of flood plain and channel deposits along the flood plain of the river. It covers an area of 127,010 acres that extend about 18 miles from the American River on the north to the

Cosumnes River on the south and 9 to 16 miles from the dissected alluvial uplands on the east to the river lands of the Sacramento River on the west. The plain is a gently westward-sloping slightly dissected surface that rises from about 15 feet above sea level at its western edge to 185 feet near Folsom. The tongue of low plains that extend eastward is actually a terrace or series of terraces underlain by coarse gravelly deposits. Thus, it appears that much of the area consists of ancient flood plains of the American River. The river is confined on the north by steep bluffs in the old dissected alluvial deposits (geologic unit designated as Laguna formation and related continental sediments) and, therefore, has deposited most of its material south of the present channel.

The only deposits exposed at the surface in storage unit B2 are the Victor formation and related deposits and the river deposits. Wells in the area pass through these deposits and indicate that the underlying Laguna formation and related continental sediments are within 200 feet of the surface.

Recent deposits underlie the flood plain of the American River but are thin and appear to be hydraulically continuous with the Victor formation; hence, the two geologic units were included in the same storage unit. The river deposits consist of well-sorted gravel, sand, and silt that decrease in average grain size westward. At Folsom, coarse gravel only a few feet thick overlies Cretaceous sandstone and Sierran basement complex rocks. At Nimbus Dam, 4 miles to the southwest, gravel and sand of the Recent river deposits extend to a maximum depth of about 20 feet where they overlie the volcanic rocks from the Sierra Nevada (U.S. Bur. Reclamation, written communication, 1950). Several test borings at the Elvas bridge site near Sacramento penetrated about 55 feet of gravel and sand underlain by the hard, semiconsolidated Laguna formation or Victor formation. Wells in the Sacramento area penetrate a maximum of 107 feet of coarse-grained deposits, but these probably belong in large part to the Victor formation and related deposits.

In the Victor formation tongues of gravel that are old channel deposits of the American River can be recognized in many well logs between the American River and Elk Grove, but for the most part the sediments penetrated beneath the low plains are too irregular to allow correlations between wells. The thickness of the Victor ranges from a few feet along the eastern margin of the low plains to about 125 feet on the west at the Sacramento River.

Wells drilled on the low plains pass from the Victor formation into the Laguna formation and related continental sediments. The Laguna consists of heterogeneous deposits of hard silt and clay, and smaller amounts of tight sand or sandstone. Gravel is not common and is generally ill sorted, contains a silty or clayey matrix, and is somewhat indurated. These old continental sediments are mostly finer grained than the younger deposits. Probably most of the deposition was on broad flood plains by meandering sluggish streams of low carrying power.

Specific yields computed from well logs reflect the geologic conditions. The average specific yield in the 20- to 50-foot zone is 9.9 percent, almost 2 percent higher than the overall average for all the low alluvial-plain and alluvial-fan deposits. This high specific yield is due to the abundance of predominantly coarse-grained materials deposited throughout the area by the American River in late Pleistocene and Recent time.

Most wells penetrate both Victor and Laguna formations in the 50- to 100-foot depth zone. The specific yield for this zone is 7.3 percent—the same as the average specific yield for all three depth zones throughout the low alluvial-plain and alluvial-fan deposits of the valley (group B).

Because the maximum thickness of the Victor formation is only 125 feet, specific yields of the 100- to 200-foot zone for the most part represent the Laguna formation. The average specific yield for the zone is 6 percent as compared with 6.2 percent for the overall average of the 20- to 200-foot interval in all the dissected alluvial deposits (group C).

The irregular distribution of the gravel tongues of the American River of late Pleistocene age obscures the effect of distance from the source on average grain size of the deposits; however, it is significant that the proportion of sand and gravel in the 20- to 50-foot zone in wells T. 8 N., R. 5 E., T. 7 N., R. 5 E., and T. 6 N., R. 5 E., is much less than in townships farther east. From east to west, the proportion of sand and gravel in individual wells decreases from maximums of 80 to 90 percent to minimums of 5 to 10 percent.

The deposits of the low plains south of the American River historically have been saturated at relatively shallow depths. The depth to water in wells has ranged from 15 feet or less near the American and Sacramento Rivers to 55 feet near Florin. Water-level contours based on measurements in April 1947 by the U.S. Bureau of Reclamation indicate that ground water was moving toward a southward-trending depression that extended from Florin to Bruceville, about 3 miles southeast of Franklin. The contours suggest that recharge was taking place by seepage loss from the American River and by movement from the river deposits of the Sacramento River that lie to the west. It appears that the Cosumnes River also contributed to the ground-water body south and east of Elk Grove.

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Ground-water development in storage unit B2 began at an early date. Bryan (1923, p. 5) reports that in 1914 there were 939 pumping plants that irrigated 10,625 acres in the area between the American and Mokelumne Rivers. In 1950, the Sacramento Municipal Utility District, which serves most of Sacramento County with electricity, had more than 3,200 agricultural accounts that represented pumping plants. Except for a few small diversions along the American and Sacramento Rivers, this extensive plain was irrigated exclusively by ground water.

The estimated storage capacity of the deposits in the low plains south of the American River (storage unit B2) in the three depth zones, 20 to 50 feet, 50 to 100 feet, and 100 to 200 feet, is 379,000, 463,000, and 759,000 acre-feet, respectively, or a total of 1,601,000 acre-feet (tables 4 and 6).

LOW PLAINS SOUTH OF THE BEAR RIVER (UNIT B3)

Storage unit B3 includes 38,090 acres on the low plains south of the Bear River. It is bounded on the north by the Bear River flood plain, on the west by the Feather River flood plain, on the southwest by the American Basin, and on the southeast and east by the dissected alluvial deposits of storage unit C4. The storage unit is about 12 miles long in a northeastward direction and about 5 miles wide.

The low plains south of the Bear River in unit B3 are slightly dissected and slope southwestward from about 80 feet above sea level near the Sutter-Placer County line to 25 feet at the American Basin. Coon Creek and several unnamed minor streams cross the plains from northeast to southwest and discharge into the Natomas cross canal which drains the American Basin. These small streams have cut trenches 5 to 10 feet below the general level of the plain, and provide minor features on an otherwise monotonous landscape.

Although most of the low plains are under cultivation, much of the land in this storage unit is not irrigated. Lack of surface-water supplies and the necessity for drilling deep wells to assure an adequate water supply, combined with the fact that the soils of the area are at many places underlain by hardpan, have restricted irrigation development in the past. Since about 1946, however, much land that was previously dry-farmed has been leveled and has been irrigated by ground-water supplies.

The Victor formation and related deposits form the only geologic unit exposed at the surface in the area, although drillers' logs suggest that the Victor is underlain by hard silt, clay, and sand of the Laguna formation at depths ranging from a few feet to a few tens of feet. In the northeastern part of unit B3 near the Placer County line, the top of the Laguna (and base of the Victor) is 30 to 65 feet below the surface. Farther west near the Feather River the base of the Victor locally may extend to a depth of 115 feet or more.

The Victor formation is composed of unconsolidated fluviatile silt, clay, sand, and gravel deposited by streams draining the Sierra Nevada foothills and the dissected uplands to the east. Sand and gravel make up only 15 to 20 percent of the deposits in the 20- to 50-foot zone. The predominance of fine-grained material and the absence of extensive gravel deposits suggest that the sediments were deposited by small streams of low carrying power, similar to those flowing across the plains today.

The Laguna formation in this area is similar to the overlying Victor, but contains more beds described in well logs as "tight" or "cemented." The few beds of gravel are usually cemented and are of low permeability.

The only systematic change shown by the specific yields is the change with depth from the unconsolidated Victor formation to the semiconsolidated Laguna. The weighted average of specific yield for the 20- to 50-foot zone was 6.5 percent as compared with 5.2 percent for the 50- to 100-foot zone. The higher specified yield in the shallow zone reflects the fact that the shallow deposits of the Victor formation are generally coarser and more permeable than the deep sediments of the Laguna. Even so, the average for the shallow zone is less than the average specific yield of 8 percent computed for the same zone in the low alluvial-plain and flood-plain deposits group as a whole.

In the fall of 1948 water levels in wells that tap the alluvial deposits beneath the low plains south of the Bear River were from 10 to 30 feet below the land surface throughout the area. Water-level contours drawn by the California Division of Water Resources (California Water Resources Board, 1952) indicate that water was moving from east to west beneath most of the area. However, along the northern edge movement was southward from the flood plain of the Bear River, and on the southwest the water table sloped from the low plains toward the American Basin, indicating movement of ground water in that direction.

The estimated ground-water storage capacity of the deposits beneath the low plains south of the Bear River (storage unit B3) in the three depth zones, 20 to 50 feet, 50 to 100 feet, and 100 to 200 feet, is 74,000, 99,000, and 160,000 acre-feet, respectively, or a total of 333,000 acre-feet (tables 4 and 6).

LOW PLAINS SOUTH OF THE DUNNIGAN HILLS (UNIT B4)

The low plains south of the Dunnigan Hills (storage unit B4) cover an area of 45,680 acres and extend approximately 15 miles north-south by 5 miles east-west, lying between the Coast Ranges on the west and the Dunnigan Hills and Plainfield Ridge on the north and east. This low plain area is a part of the Sacramento Valley, but is separated from the main valley trough by an anticline expressed at the land surface as a belt of low hills—the Dunnigan Hills and the Plainfield Ridge. The northern part of the plain, known as Hungry Hollow, is isolated from the southern part by the gravelly flood plain of Cache Creek which crosses the area from west to east. The flood-plain deposits along Cache Creek are treated separately as storage unit A1.

Both surface and ground-water supplies are used for irrigation in this storage unit. Several thousand acres of land are irrigated from the Capay Canal, which skirts the Coast Ranges foothills from Capay southward to Winters, and ground water also is available at shallow depths throughout most of the area south of Cache Creek. Much of the land in the eastern part of this storage unit between the Southern Pacific Railroad and the Plainfield Ridge has an accumulation of alkali in the soil caused by evaporation of ground water at the land surface. In recent years much of this uncultivated land has been placed under irrigation by ground-water supplies.

Unconsolidated alluvial-fan deposits of Recent age are the only materials exposed at the land surface in storage unit B4. The Recent fan deposits are not readily distinguishable from similar underlying Pleistocene deposits which in places nearby appear at the land surface. Fossil evidence, however, indicates that silty clay of Pleistocene age crops out in the bed of Putah Creek east of Winters, about 20 to 40 feet below the surface of the low plains. A like depth is assumed for the base of the Recent deposits farther north.

The alluvial-fan deposits consist of unconsolidated yellow and blue silt and clay, and interbedded sand and gravel deposited by the small streams that drain the Coast Ranges. The Tehama formation and related continental sediments underlie the alluvial-fan deposits at depths believed to be generally less than 150 feet and are composed of hard silt, clay, and some sand and gravel. The Tehama formation is lithologically similar to the fan deposits, except that the Tehama commonly contains cemented or partly cemented sand and gravel beds.

Average specific yields computed from drillers' logs (table 6) are approximately the same for the 20- to 50-foot and the 50- to 100-foot zones but are appreciably higher for the 100- to 200-foot zone. The percentage of sand and gravel in each zone shows a similar trend. Beneath the low plains north of Cache Creek, sand and gravel deposits constitute 11 percent, 12 percent, and 24 percent of the section in the three-depth zones, respectively. In the area south of Cache Creek, sand and gravel make up 22 percent, 20 percent, and 29 percent of the corresponding zones. The significance of this increase in coarse-grained materials in the 100- to 200-foot zone is not fully understood. The coarse deposits south of Cache Creek may have been laid down by Cache Creek at some time in the past when it discharged into Putah Creek. However, it is unlikely that the coarse material north of Cache Creek was deposited by that stream. It may have been deposited by tributaries of Cache Creek under conditions of steeper slope and greater rainfall in the past.

The alluvial deposits are saturated to within 20 feet of the surface throughout most of storage unit B4, and water levels as shallow as 3 feet below the surface were measured in the fall of 1948. Locally, along the edge of the low plains where the land rises rapidly, the depth to water exceeded 25 feet. Water levels measured by the Corps of Engineers in the fall of 1948 indicated that in the central part of this unit the water table sloped generally eastward from an elevation of 170 feet above sea level near Capay to 100 feet above sea level near the Plainfield Ridge. North of Cache Creek ground water was moving generally southward and southeastward toward the creek. In the southern part of the area the direction of water-table slope changed sharply from eastward to southeastward toward Putah Creek, indicating a change in direction of movement of the ground water.

The estimated storage capacity of the deposits in the low plains south of the Dunnigan Hills (storage unit B4) in the three depth zones, 20 to 50 feet, 50 to 100 feet, and 100 to 200 feet, is 91,000, 149,000, and 370,000 acre-feet, respectively, or a total of 610,000 acre-feet (tables 4 and 6).

LOW PLAINS EAST OF THE DUNNIGAN HILLS (UNIT B5)

Storage unit B5 comprises the low plains built by Cache Creek, Willow Slough, and minor streams draining the Coast Ranges. The area includes 91,040 acres and measures about 20 miles in a northwest direction by about 10 miles in a northeast direction. It is bordered by the Yolo Basin on the east, the Colusa Basin on the northeast, and the Dunnigan Hills and the Plainfield Ridge on the west. The northern boundary was arbitrarily placed at the north line of T. 11 N. and the southern boundary at the south line of T. 9 N.

The Cache Creek plain is a smooth low plain, which rises from 25 feet above sea level at the edge of the Yolo Basin to 100 feet at the head of the plain, where Cache Creek crosses the Dunnigan-Plainfild anticline through an erosional notch about a mile wide. The surface of the plain is marked by several branching and interlacing channel ridges — abandoned channels of Cache Creek — that rise 10 to 25 feet above the surrounding plain. Cache Creek trends northeasterward across the plain from the Dunnigan Hills to the town of Yolo where it turns and follows an eastward course to the Yolo Basin. One of the largest channel ridges in the Sacramento Valley, the Knights Landing Ridge, extends from the bend in Cache Creek at Yolo northeastward to the Sacramento River at Knights Landing and separates the Yolo and Colusa Basins. This ridge, now occupied by a sluggish drain known as Cache Creek Slough, represents a recently abandoned channel that was occupied by the creek at a time when it was directly tributary to the Sacramento River. Willow Slough, the principal stream draining valley lands south of Woodland and Madison, crosses the Plainfield Ridge through a low saddle and flows easterly and northeastward to the Yolo Basin. Willow Slough has only a small drainage area and is dry most of the year, but at times of heavy rainfall it carries a large volume of runoff from the valley plains, and it has been a serious flood hazard in the past.

Irrigation has a long history on the Cache Creek plain. Surface diversion from the creek began with the construction of the Moore ditch in 1856 to irrigate the valley floor west and southwest of Woodland. The success of this venture encouraged similar developments; and by 1870 three ditches, the Moore, Adams, and Cottonwood ditches, were diverting water from the creek. Litigation among the ditch companies caused the abandonment of some of the ditches by 1900, and a legal decision in 1920 limiting the outflow from Clear Lake to Cache Creek has to date prevented any significant enlargement of surface irrigation. Records of the California Public Utilities Commission show that in the period 1914–1945 an average of 17,300 acres was served with Cache Creek water. The larger part of the water was used in the area southwest and west of Woodland.

Ground-water development also began early in this area. The first irrigation well in the Sacramento Valley was installed near Woodland in 1877 (Bryan, 1923). Originally intended to supplement ditch supplies, ground-water pumpage from this and other wells has now largely supplanted surface-water irrigation. Wells drilled to moderate depths on the Cache Creek plain have the second highest average discharge and the highest average specific capacity in the Sacramento Valley (table 2).

With the exception of a narrow band of river deposits along Cache Creek, alluvial-fan deposits are exposed at the land surface throughout the area. Although the Recent fan deposits cannot be distinguished from the underlying Pleistocene fan deposits in well logs, it seems likely that the Recent deposits form merely a thin surface veneer that extend to depths of a few feet or tens of feet. The occurrence of Pleistocene mammalian fossils within 35 feet of the surface, in a silty clay in the bed of Putah Creek only a few miles south of this area supports this interpretation. No important discontinuities in the subsurface section are known to exist between Putah Creek and Cache Creek.

In general the deposits within 200 feet of the surface are largely alluvial-fan deposits of late Pleistocene and Recent age, although hard silt and clay and cemented sand and gravel of the Tehama formation generally are penetrated in the 100- to 200-foot depth interval. The alluvial-fan deposits are composed of unconsolidated silt and clay, gravel, and sand laid down in stream channels and in the interstream areas at times of high water. Computations of the average thickness of sand and gravel in the 20- to 200-foot depth interval for more than 400 wells for which logs were available indicate no significant change in water-bearing character with depth for the area as a whole. That is, the relative proportions of sand and gravel in the 20- to 50-foot, and 50- to 100-foot zones are virtually identical—26 percent in the 20- to 50-foot zones, and 27 percent in the 50- to 100-foot zone—and in the 100- to 200-foot interval the percentage (24 percent)—only slightly lower. However, the permeability and specific yield of the materials probably are considerably less in the 100- to 200-foot zone than in the upper two zones.

The plotting on a map of the percentages of sand and gravel in the various depth zones by township brings out significant areal differences in water-bearing character that appear to be related to distance from the source of the materials and to the sedimentary environment. For example, in T. 11 N., R. 1 W., which is north of the area of Cache Creek deposition, the percentage of sand and gravel in the 3 depth zones ranges from 14 to 20 percent and averages 18 percent for the 20- to 200-foot interval. In the adjoining township on the east, T. 11 N., R. 1 E., which includes the most northward deposits of Cache Creek as well as deposits of several minor streams that drain the Dunnigan Hills the percentage of sand and gravel is somewhat higher, averaging 22 percent for the 20- to 200-foot interval. The proportion of coarse water-bearing deposits is significantly higher in T. 10 N., R. 1 E., which includes the upstream end of the Cache Creek plain. There the proportion of sand and gravel ranges from 30 to 43 percent, and averages 36 percent for the 20- to 200-foot interval. Farther east, in the Woodland area, T. 10 N., R. 2 E., the sand and gravel averages 26 percent.

The geologic features of alluvial plains throughout of the Sacramento Valley are well brought out by the foregoing figures. Sand and gravel are most abundant where a major stream debouches on the plain; the proportion of coarse material in the section decreases with distance away from the head of the plain, and the areas beyond the influence of major stream deposition, as T. 11 N., R. 1 W., are characterized by generally finer grained deposits.

Specific yields computed from the well logs imply a lack of change in water-bearing character with depth, although, these figures probably are misleading. Average specific yields for the 20- to 50-foot, 50- to 100-foot, and 100- to 200-foot zones are 8.3, 8.3, and 8.2 percent, respectively.

Water-level measurements by the Corps of Engineers in the fall of 1948 indicate that the depth to water ranged from as little as 5 feet near the Yolo Basin to as much as 43 feet west of Woodland. Water-level contours indicate that ground water was moving generally eastward beneath the low plains east of the Plainfield Ridge. North of Cache Creek the direction of movement of ground water generally was to the north. Most water-level contour maps of the Woodland area prepared in the past have indicated an eastward bulge in the contours near Cache Creek; this suggests that the creek recharges the ground-water body.

The estimated ground-water storage capacity of the deposits in the low plains east of the Dunnigan Hills (storage unit B5) in the three depth zones, 20 to 50 feet, 50 to 100 feet, and 100 to 200 feet, is 228,000, 378,000, and 749,000 acre-feet, respectively, or a total of 1,355,000 acre-feet (table 6).

ALLUVIAL FANS, WEST SIDE, DELEVAN TO ZAMORA (UNIT B6)

At the surface, storage unit B6 is a narrow apron of small coalescing alluvial fans that flank the foothills of the Coast Ranges and are bounded on the east by the Colusa Basin. Cache Creek plain borders the area on the south, and a small embayment of basin-type deposits that extends westward to the Coast Ranges near Delevan serves as a northern boundary. The area measures 38 miles north-south and ranges from 3 to 8 miles east-west. Some 129,730 acres of alluvial plains are included within the storage unit.

The western border of the Sacramento Valley in this area is characterized by two widely differing types of topography. From Delevan south to Salt Creek the plains rise from about 75 feet above sea level at the edge of the Colusa Basin to about 150 feet at the valley margin in a distance of 6 miles or more. On the west the low plains are abruptly terminated by northward-trending ridges of steeply dipping hard Cretaceous sediments, through which many minor intermittent streams have carved canyons to reach the valley. These streams, flowing out of the Coast Ranges closely adjacent to one another, have built the low plains composed of a series of coalesced alluvial fans.

South of Salt Creek the valley border is formed by gently dipping sediments of the Tehama and Red Bluff formations exposed on the eastern flanks of the Rumsey Hills and Dunnigan Hills anticlines. The Rumsey Hills form the valley border from Salt Creek southwest to Buckeye Creek where the valley margin is offset sharply to the east at the northern end of the Dunnigan Hills. From this point south to Cache Creek the Dunnigan Hills form the western border of the valley. Most of the streams draining the Rumsey and Dunnigan Hills rise within the hills and derive their sediments from the dissection of the moderately indurated deposits of the Tehama formation that crop out in the hills. Deposition takes place only during floods, as the streams are not perennial; consequently, the material is poorly sorted, and the land surface is characterized by many abandoned channels. The plain constructed by these streams slopes steeply to the northeast, as much as 50 feet per mile in places.

More than half the low plains north of Cortina Creek lie below the Central Irrigation Canal of the Glenn-Colusa Irrigation District and are served with surface water diverted from the Sacramento River near Hamilton City. The lands above the canal and south of Cortina Creek are irrigated by ground water. However, irrigation development has been slow because wells drilled on the low plains generally tap fine-grained poorly permeable deposits of the Tehama formation at relatively shallow depth, and yields generally are low. The only intensive ground-water development has been in a small area southwest of Arbuckle where wells 600 to 800 feet deep produce moderate yields from coarse-grained deposits of Pliocene or Pleistocene age.

Poorly sorted fine-grained silt and sand of the alluvial-fan deposits of Recent age are exposed throughout the area. In general the deposits of Recent age are believed to be fairly thin and are underlain at shallow depth by alluvial-fan deposits of Pleistocene age.

From Delevan south to Sand Creek the wells drilled on the low plains tap poorly sorted unconsolidated yellow silt and clay and a few interbedded thin sands to a depth of about 100 feet. These unconsolidated materials are underlain by moderately indurated hard silt and clay, sandstone and conglomerate that probably belong to the Tehama formation exposed to the south in the Rumsey Hills.

The proportion of silt and clay that occurs within 200 feet of the land surface in this northern area ranges by townships from 65 to 96 percent of the section and averages 76, 84, and 88 percent in the 20- to 50-foot, 50- to 100-foot, and 100- to 200-foot zones respectively.

Wells on the plains west and southwest of Arbuckle, between Sand Creek and the north end of the Dunnigan Hills, are drilled into a section of ill-sorted silt and clay, clayey gravel, and gravel and clay within 200 feet of the surface. Well drillers describe the thick beds of coarse material variously as "gravel and clay," "broken clay, sand and gravel," "boulders and clay," "rock and clay," "gravelly cement," "rocks bound in clay," "tight gravel," "gravel," and "boulders," but it is unlikely that these materials are highly permeable, as most irrigation wells are about 500 feet deep, and their yield factors are low, averaging only 8. In spite of the generally coarse texture of the deposits, the proportion of materials described as well-sorted gravel or sand in drillers' logs is not high—only 20 percent in the 20- to 50-foot zone, 21 percent in the 50- to 100-foot zone, and 18 percent in the 100- to 200-foot zone.

The deposits underlying the low plains in T. 13 N., R. 1 W., and T. 12 N., R. 1 W., are more typical of the west-side deposits than those discussed in the foregoing paragraphs. The deposits in the 20- to 200-foot depth interval consist of yellow silt and clay and a few tongues of clean well-sorted sand and gravel that make up 10 to 22 percent of the section. Average thicknesses of sand and gravel are 14, 19, and 18 percent, respectively, for the 20- to 50-foot, 50- to 100-foot, and 100- to 200-foot depth zones.

Specific yields computed from well logs bear out the lithologic features discussed previously. Specific yields of the alluvium underlying the low plains in the northern area between Delevan and Sand Creek ranged from 3.8 to 7.6 percent. A general decrease with depth was noted throughout, corresponding to the generally lower permeability of the semiconsolidated Tehama formation found within 200 feet of the surface. In the area west and southwest of Arbuckle, T. 13 N., R. 2 W., the coarse-grained character of the deposits was reflected by higher specific yields than those in the area to the north; 7.2, 8.7, and 7.5 percent for the 20- to 50-foot, 50- to 100-foot, and 100- to 200-foot zones, respectively. Specific yields in the area south and east of Arbuckle, T. 13 N., R. 1 W., and T. 12 N., R. 1 W., ranged from 5.4 to 8.1 percent and averaged 7 percent for all three depth zones.

Depths to water beneath the west-side alluvial fans differ appreciably depending upon the slope of the land surface and type of agricultural development. Water-level measurements were made in selected wells by the California Division of Water Resources in the fall of 1949. Depth to water ranged from a few feet below the land surface near the Colusa Basin to 75 feet on the alluvial fans to the west. Measurements made by the Pacific Gas and Electric Co. in conjunction with pumping-plant tests indicate static levels as deep as 280 feet as of 1948 at high elevations on the alluvial fan southwest of Arbuckle. Not enough information is available, however, to indicate whether the deep water levels in this area were due to a pumping overdraft on the ground-water supply. Bryan (1923) reported that in the fall of 1912 and 1913 the depth to water at the top of the Arbuckle fan was 80 to 100 feet.

The estimated storage capacity of the deposits in the alluvial fans along the west side of the Sacramento Valley between Delevan and Zamora (storage unit B6) in the three depth zones, 20 to 50 feet, 50 to 100 feet, and 100 to 200 feet, is 229,000, 392,000, and 768,000 acre-feet, respectively, or a total of 1,389,000 acre-feet (table 6).

LOW PLAINS NORTH OF THE BEAR RIVER (UNIT B7)

Storage unit B7 occupies an area of 47,070 acres or about 73 square miles in the area between the Bear River and the Feather River. It is bordered by the Bear River on the south, the foothills of the Sierra Nevada on the east, and the Feather River on the west. On the north, it adjoins storage unit A5. An extensive body of channel deposits (unit A5), consisting largely of coarse sand and gravel deposits of the Victor formation and related deposits which probably were laid down by an ancestral Yuba River, extends southward as a re-entrant into unit B7 virtually isolating the northwestern part of unit B7 from the rest of the unit.

A considerable part of this low plains storage unit is shown as dissected alluvial uplands on the geomorphic map (pl. 1). These dissected uplands were included with the low plains north of the Bear River as a single storage unit for three principal reasons: The dissected uplands are irregularly shaped erosional remnants separated by bands of younger deposits that extend up stream valleys; the Victor formation, underlying the low alluvial plains of this area, has been derived largely from the Laguna formation underlying the dissected uplands and, hence, has similar lithologic character; and the low plains are underlain at relatively shallow depths by the Laguna formation, which is exposed at the surface in the dissected uplands. Thus, the two different geomorphic types constitute a single storage unit and were treated as such.

Like the low plains south of the Bear River, much of this area is cultivated without irrigation. Several thousand acres adjoining the Feather River flood plain on the west are served with surface supplies from the canals of the Farm Land Investment Co. To the east, surface-water supplies are not available, and the combination of hardpan soils and the necessity for deep wells for adequate irrigation supplies has deterred irrigation development in the past. Since the early forties, however, many deep wells have been drilled, and the irrigated acreage has increased rapidly.

The exposed deposits include the Victor formation and related deposits, the Laguna formation and related continental sediments, thin Recent deposits in certain stream valleys, and small patches of volcanic rocks from the Sierra Nevada which crop out near the eastern margin of the area.

The Victor formation and related deposits consist of silt, sand, and gravel deposited by the ancestral Feather River and its minor tributaries on the low plains. These deposits are heterogeneous and lenticular because of their varied origin. The sediments in the western part of the area, between Marysville and Plumas Lake, and from Plumas Lake southward to the Bear River are largely flood-plain deposits of the Feather and Yuba Rivers. These deposits are thin—at most places less than 50 feet thick. The contact with the underlying more consolidated hard blue clay and hard sand of the Laguna formation and related continental sediments is possibly a buried erosion surface.

Many wells in the eastern part of the area penetrate into the Victor and Laguna formations and reach deposits of sand and gravel that may belong to the volcanic rocks from the Sierra Nevada or possibly to the Wheatland formation of Clark and Anderson (1938). In R. 4 E. and farther west only the Victor and Laguna formations are penetrated within 200 feet of the land surface.

Wells east of the Southern Pacific Railroad in the area north of Wheatland are drilled through fine-grained deposits of the Victor formation and related deposits and pass into the Laguna at relatively shallow depths. The Victor consists of alluvial-fan deposits laid down by small streams that drained the dissected uplands to the east. Because the Laguna formation exposed in the uplands is generally fine grained, the Victor deposits derived from it also are fine grained.

The Laguna formation exposed along the east border of the unit and underlying the Victor formation beneath the low plains consist of heterogeneous deposits of firm silt and clay and a small percentage of fine-grained sandstone. To the west near the Feather River the clay generally is blue, indicative of a nonoxidizing environment—possibly flood basin or lacustrine conditions. East of the Western Pacific Railroad the clay in the Laguna is mostly yellow, brown, or red, indicating that the deposits have been oxidized.

In general, little highly permeable material is found within 200 feet of the surface in this storage unit and specific yields computed from drillers' logs reflect this condition. The specific yields computed for the 20- to 50-foot and 50- to 100-foot zones are 4.7 and 4.5 percent, respectively (table 6)—low even for the Laguna formation. The relative amounts of the various materials reported in drillers' logs show that the proportion of sand and gravel in the 20- to 50-foot zone ranges from 5 to 15 percent for all townships.

Specific yields computed for R. 5 E. are higher in the 100- to 200-foot zone than in the shallower zones. This anomalous situation is explained by the presence of sand and gravel deposits of the volcanic rocks from the Sierra Nevada or sedimentary rocks of Eocene age within 200 feet of the land surface in the eastern part of the area.

Depths to water in wells ranged from 15 to 35 feet throughout most of the area in 1948. Water-level contours based on measurements made in the fall of 1948 by the California Division of Water Resources show that water was moving toward the low plains north of the Bear River from the Sierra Nevada foothills on the east, from the Bear River flood plain on the south, and from the Yuba River flood plain on the north. The water table sloped from east to west but not as steeply as the land surface. Water stood within 20 feet of the surface in the western part of the area but was 25 feet or more below the surface in the eastern part.

The estimated ground-water storage capacity of the deposits in the low plains north of the Bear River (storage unit B7) in the three depth zones, 20 to 50 feet, 50 to 100 feet, and 100 to 200 feet, is 67,000, 105,000, and 253,000 acre-feet, respectively or a total of 425,000 acre-feet (table 6).

LOW PLAINS WEST OF THE FEATHER RIVER (UNIT B8)

Storage unit B8 covers an area of 30,670 acres on the divide between the Feather River on the east and Butte Creek on the west. The unit measures about 12 miles north-south by about 6 miles east-west.

The land is a smooth plain which slopes gently southwestward from about 100 feet above sea level near the Feather River flood plain in the northeastern part of the area to about 75 feet near the margin of the Butte Creek lowland. Under natural conditions small creeks and sloughs drained generally westward toward Butte Sink and southward around the east side of Sutter Buttes to Sutter Basin. The only topographic features interrupting the flat surface of the plain are these minor channels incised 3 to 5 feet below the surrounding lands.

Irrigation from surface supplies began at an early date with the construction of the Sutter-Butte Canal. Bryan (1923) reported 14,000 acres under irrigation in 1912 from the Sutter-Butte Canal. In 1949 surface water supplied by the Sutter-Butte Canal and the Biggs-West Gridley Water District was used to irrigate 37,300 acres, of which about 27,000 acres was within this storage unit. Ground-water development has been small, because of the ample surface supply, but a few irrigation wells have been drilled in recent years to supply water to lands not irrigated from surface-water sources.

The only material exposed at the surface is the Victor formation and related deposits. The interval within 200 feet of the land surface is characterized by a high proportion of yellow and brown clay and silt that average 80, 72, and 77 percent of the 20- to 50-foot, 50- to 100-foot, and 100- to 200-foot zones respectively. Thin sand beds, many firm and cemented, and occasional fine-gravel layers are interstratified with the clay and silt. The firm, cemented character of some of the sand layers from 25 to 70 feet below the surface suggests that the Laguna formation lies at shallow depth, but the clean uncemented sand of the Laguna usually described in the drillers' logs as "free" sand is highly permeable and yields large quantities of water to wells. Aside from the cementation at shallow depth no significant lithologic changes occur either laterally or vertically in the section between 20 and 200 feet.

Specific yields computed from the few available drillers' logs range from 4.0 to 8.1 percent, but they do not indicate any general areal trends as in many other storage units. Rather, they tend to confirm that the section is heterogeneous alternating silt and sand of low average specific yield.

As might be expected in an area where imported surface-water supplies are used extensively, the alluvial deposits are saturated at very shallow depths. Water-level measurements by the U.S. Bureau of Reclamation in August 1947 indicate that depths to water in this area ranged from less than 5 feet to about 20 feet and average about 8 feet for the area as a whole. Ground water was moving eastward toward the Feather River, westward toward Butte Creek lowland, and southward toward the Yuba City area from a broad ground-water mound that extended generally north through the city of Gridley.

The estimated storage capacity of the deposits in the low plains west of the Feather River (storage unit B8) in the three depth zones, 20 to 50 feet, 50 to 100 feet, and 100 to 200 feet, is 53,000, 92,000, and 158,000 acre-feet, respectively, or a total of 303,000 acre-feet (table 6).

ALLUVIAL PLAINS ENCLOSING SUTTER BUTTES (UNIT B9)

The ring of coalescing alluvial fans surrounding Sutter Buttes includes an area of 15,930 acres extending outward from the flanks of the buttes for a short distance in all directions. The width of this strip of Recent fan material ranges from less than half a mile to as much as 2 miles opposite the mouths of canyons that drain a sizable area of the buttes. Flood-plain deposits of the Feather River border the fans on the east, but basin deposits surround the fans on the other three sides.

The Recent alluvium extends as narrow bands up the canyons that drain the buttes. The land increases in altitude from about 40 feet along the flood basins to as much as 100 feet in the canyon mouths.

Much of the land in this storage unit is still dry farmed, despite its classification as class 1 agricultural land (California Division Water Resources, 1931). Water for irrigation can not be obtained by wells in much of the area, and the limited width and wide range in altitude of the alluvial deposits make importation of surface water impracticable. Most of the irrigation at present is limited to small areas in the Sutter and Pennington districts.

Wells drilled on the alluvial fans surrounding the Buttes reached hard volcanic rocks within 100 feet of the surface and at many places within 25 feet of the land surface. These rocks are overlain by alluvial deposits of Recent age at the land surface and possibly by deposits of Pleistocene age beneath, which consist of poorly sorted silt and clay, gravel, and sand of low permeability and specific yield. The proportion of water-bearing sand and gravel found in wells in the three depth zones was 8, 12, and 4 percent in the 20- to 50-foot, 50- to 100-foot, and 100- to 200-foot depth zones, respectively. Specific yields computed from drillers' logs reflect the absence of coarse water-bearing materials in the 20- to 50-foot, and 50- to 100-foot zones and suggest the impervious nature of the volcanic rocks below 100 feet.

Few data are available on depth to water beneath the alluvial fans surrounding Sutter Buttes, except in the Pennington and Sutter districts. Water levels measured by the Pacific Gas and Electric Co. in connection with pumping-plant tests between 1938 and 1948 indicate that the depths to water in wells in both these districts ranged from 20 to 65 feet below the land surface.

The estimated storage capacity of the deposits in the alluvial plains surrounding Sutter Buttes (storage unit B9) in the three depth zones, 20 to 50 feet, 50 to 100 feet, and 100 to 200 feet, is 23,000, 46,000, and 59,000 acre-feet, respectively, or a total of 128,000 acre-feet (table 6).

CHICO ALLUVIAL FAN (UNIT B10)

The alluvial fans formed by Big Chico, Little Chico, and Butte Creeks and several minor streams between Big Chico and Pine Creeks together form a compound fan known as the Chico alluvial fan, which covers an area of 75,100 acres underlain by Recent alluvial-fan deposits. The area is bounded on the east by the barren foothill slopes of the Cascade Range, which are underlain by the fragmental volcanic rocks of the Tuscan formation; on the northeast by the dissected alluvial uplands flanking the foothills of the Cascade Range; on the west by the flood plain of the Sacramento River; and on the south by the low-lying poorly drained Butte Creek lowland. The area extends about 20 miles north by about 8 miles west.

The land surface of the Chico fan rises from about 125 feet above sea level near the Butte Creek lowland to about 300 feet above at the apex of the fan where Big Chico Creek leaves the foothills. The creeks that cross the fan flow in a general southwestward direction, except for Butte Creek which turns abruptly upon leaving the foothills and flows generally southward toward Butte Creek lowland. At low flow the creeks occupy narrow gravel-floored channels 10 to 20 feet deep, but during floods they may top their banks in the lower reaches and cover the lower part of the fan with flood water. The land slopes about 13 feet per mile on most of the fan but steepens near the apex.

Development of irrigation has been slow in the Chico area, and much potentially irrigable land as of 1950 was still farmed by dry-farming methods. The only extensive surface-water supply is to the former Durham State Land Settlement where a diversion from Butte Creek provides water for the irrigation of more than 2,700 acres east of the creek, near Durham. Large supplies of water for irrigation generally are obtainable from wells in the water-bearing sand and gravel deposits of the Tuscan formation (Pliocene). However, much of the Tuscan formation consists of tough impermeable volcanic breccia that must be penetrated to reach the water-bearing deposits, and in the past the high cost of drilling the hard volcanic rocks prohibited extensive development of ground-water supplies. However, in recent years high prices for farm produce have encouraged irrigation development, and much land that formerly was used for growing grain without irrigation has been leveled and now is under irrigation with ground water.

Recent alluvial-fan deposits occur at the land surface throughout the area. However, these Recent fan materials represent only a relatively thin veneer that covers Pleistocene fanglomerate from the Cascade Range and the Tuscan formation. Wells drilled on the low plains commonly pass through less than 20 feet to perhaps as much as 50 feet of soil, sand, and clay of the Recent alluvial-fan deposits before entering the older deposits below. The Recent deposits probably thicken westward toward the flood plain of the Sacramento River.

Along the eastern edge of the Chico fan, particularly in the area south of Big Chico Creek, the Recent deposits directly overlie the volcanic deposits of the Tuscan formation, but semiconsolidated clay, sand, and gravel of the old fanglomerate from the Cascade Range underlie the Recent alluvial-fan deposits throughout most of the fan. The eroded surface of the Tuscan deposits dips steeply to the west, and the thickness of the fanglomerate increases to 400 feet within about 4 miles of the outcrop of the Tuscan formation. The fanglomerate consists of hard silt and clay, sand, and cemented gravel of fluviatile origin derived from the volcanic deposits of the Tuscan formation. An individual sample of the fanglomerate material may be lithologically indistinguishable from some of the stream-laid gravel and sand beds of the Tuscan formation, but as a unit the fanglomerate deposits may be distinguished by the absence of mudflow volcanics, by the fluviatile origin of all the fanglomerate deposits, by the more intense weathering of the fanglomerate material, and by the admixture of nonvolcanic material derived from the pre-Tertiary deposits exposed in the canyons of Big Chico, Little Chico, and Butte Creeks.

Although many wells in the Chico area obtain water from the volcanic sand and gravel of the Tuscan formation, the Tuscan is not penetrated within 200 feet of the surface, except near the margin of the valley. Wells in T. 22 N., R. 2 E., and in T. 21 N., R. 2 E., east of Butte Creek are the only wells that penetrate the volcanic rocks in the upper 200 feet. The drillers' logs of 332 wells on the Chico fan indicate that unconsolidated sand and gravel comprise 26, 12, and 8 percent of the 20- to 50-foot, 50- to 100-foot, and 100- to 200-foot depth zones, respectively. The proportion of sand and gravel in the 20- to 50-foot zone ranges from 15 percent in T. 22 N., R. 2 E., to 40 percent in T. 22 N., R. 1 W. Thus, it can be seen that the proportion of coarse deposits in the 20- to 50-foot interval reaches a maximum beneath the western part of the fan and is lowest near the apex. The low figure for T. 22 N., R. 2 E., reflects the presence of indurated fanglomerate and the Tuscan formation within 50 feet of the surface beneath the eastern part of the fan.

A similar trend occurs in the deposits between 50 and 100 feet. As in the upper zone, the greatest proportion of sand and gravel—29 percent—is in the western part of the fan in T. 22 N., R. 1 W., and the lowest proportion—7 percent—is beneath the eastern part in T. 21 N., R. 2 E. The proportion of sand and gravel in the 100- to 200-foot depth zone ranges from 4 to 20 percent in T. 22 N., R. 1 W. Thus, the logs indicate a general decrease in the proportion of coarse water-bearing deposits with depth and an increase in a general westerly direction. The decrease of sand and gravel with depth is accounted for by the fact that the proportion of the indurated deposits of the fanglomerate found in wells increases with depth; the general westerly increase in the proportion of sand and gravel is related to the fact that the Recent deposits thicken to the west, and the streams constructing the Chico fan deposited better sorted material toward the outer edge of the fan. It also is possible that some of the coarse clean gravel beneath the western part of the Chico fan actually are old channel deposits of the Sacramento River rather than alluvial-fan material.

Specific yields computed from drillers' logs reflect the relative thickness of the unconsolidated deposits of Recent age. On the western part of the fan mostly Recent deposits are encountered within 50 feet of the land surface, and average specific yields are correspondingly high—more than 10 percent in the 20- to 50-foot zone. To the east the semicoisolidated fanglomerate from the Cascade Range is at progressively shallower depths, and specific yields are lower in the shallow depth zone. Beneath the eastern part of the fan only the older deposits are found in the 100- to 200-foot interval, and specific yields are correspondingly low, ranging from 4.9 to 6.8 percent. On the outer part of the fan the unconsolidated deposits extend into the 50- to 100-foot interval, and the specific yields computed for this interval fall between the high values of the 20- to 50-foot depth zone and the low values of the 100- to 200-foot zone.

Depths to water in wells on the Chico fan, measured by the U.S. Bureau of Reclamation in August 1947, ranged from less than 10 feet near the Sacramento River flood plain and Butte Creek lowland to more than 70 feet beneath the apex of the alluvial fan east of Chico. The water table sloped southward and westward with the plain, although at a lower angle. Ground-water elevations in August 1947 ranged from 110 feet above sea level near the southern edge of the Chico fan to 180 feet about 2 miles east of Chico. A broad ground-water ridge existed in the area between Big Chico and Butte Creeks, suggesting considerable recharge from these perennial streams.

The estimated ground-water storage capacity of the deposits in the Chico alluvial fan (storage unit B10) in the three depth zones, 20 to 50 feet, 50 to 100 feet, and 100 to 200 feet, is 213,000, 244,000, and 426,000 acre-feet, respectively, or a total of 883,000 acre-feet (table 6).

STONY CREEK ALLUVIAL FAN (UNIT B11)

The alluvial fans of Stony and Willow Creeks, storage unit B11, form a broad low alluvial plain that extends from the Tehama County line on the north to the Colusa County line on the south. This plain is about 36 miles north-south by about 12 miles east-west. It covers an area of 185,840 acres, or 290 square miles, and is bordered on the east by the flood plain of the Sacramento River, on the southeast by the Colusa Basin, and on the west and north by low hills underlain by uplifted and dissected sediments of the Tehama formation.

The Stony Creek fan slopes generally southeastward from an altitude of about 350 feet at its apex, near Orland, to about 100 feet at the edge of the Colusa Basin. The creek has swung back and forth in a quarter circle between the bluffs of the dissected uplands on the north and the foothills of the Coast Ranges on the west. The drainage pattern and shape of the alluvial plain suggest that the southern portion, presently drained by Willow Creek, may have been built by Stony Creek. Stony Creek leaves the foothills of the Coast Ranges about 4 miles west of Orland and crosses the alluvial plain in a southeastward direction to its confluence with the Sacramento River a few miles south of Hamilton City. Several minor streams, heading in the foothills northwest of Willows, join to form Willow Creek which then crosses the southern part of the alluvial plain and discharges into the Colusa Basin southwest of Willows. Extending out radially from the head of the Stony Creek fan, numerous small channels that now carry off surface drainage in the past may have been channels of Stony Creek. The surface of the plain is not smooth but is broken by these small channels, lying 1 to 5 feet below the general land surface, and by low gravelly ridges that probably are other old channels of the creek.

Irrigation on the Stony Creek fan dates from 1906 when the first water deliveries were made from the newly completed Central Irrigation Canal, now the Central Canal of the Glenn-Colusa Irrigation District. Water is pumped into the canal from the Sacramento River north of Hamilton City and flows by gravity southwestward along the outer portion of the Stony Creek fan. Gravity water from this canal irrigates most of the outer part of the fan lying below the 125-foot contour.

In 1916 the Orland project of the U.S. Bureau of Reclamation began to supply water to an area of 20,000 acres on the apical portion of the fan in the vicinity of Orland. Water is diverted from Stony Creek at Orland Buttes and flows by gravity through two canals to service areas north and south of Stony Creek. In 1946 approximately 16,600 acres were irrigated with gravity water in the project area. Continued irrigation with surface water in recent years has caused considerable damage because of the rising water table and subsequent waterlogging of deep-rooted crops.

The remainder of the fan is served with irrigation water from ground-water pumping. The Bureau of Reclamation estimated that in 1947 the area irrigated by ground water on the Stony Creek fan north of Willows was 27,000 acres. Most of the area is underlain by class 1 soils, and ground-water supplies are readily available to wells of moderate depth. Probably the most critical features that limit development in this area are the unsuitability of the climate for high-value crops and the irregular topography on much of the alluvial fan.

Recent deposits are exposed at the surface everywhere on the fan. It is believed that the Recent deposits are only a veneer 20 to 30 feet thick that mantles similar fan materials of Pleistocene age. These Pleistocene alluvial-fan deposits extend to depths of 40 to about 125 feet where they are underlain by predominantly fine-grained moderately indurated sediments of the Tehama formation (upper Pliocene). Coarse water-bearing sand and gravel deposits, becoming increasingly thick to the east, make up more than 35 percent of the alluvial-fan deposits beneath the Stony Creek fan. In general, the proportion of unconsolidated gravel and sand deposits is highest in the 20- to 50-foot interval, although locally, particularly beneath the outer portion of the Stony Creek fan in T. 22 N., R. 2 W., T. 21 N., R. 2 W., T. 20 N., R. 2 W., and T 20 N., R. 3 W., coarse gravel and sand make up as much and sometimes more of the 50- to 100-foot interval than of the 20- to 50-foot zone. Wells generally tap fine-grained indurated sediments of the Tehama formation within 125 feet of the surface; consequently, the percentage of gravel and sand in the 100- to 200-foot depth zone is ordinarily appreciably lower than in the two shallower zones. The average proportion of gravel and sand in the 100- to 200-foot zone of this storage unit as a whole is 22 percent as compared with 37 and 31 percent for the 20- to 50-foot and 50- to 100-foot zones, respectively. A notable exception to this occurs in T. 21 N., R. 2 W., and T. 20 N., R. 3 W., on the outer part of the fan where coarse unconsolidated deposits of gravel and sand, probably Sacramento River deposits of Pleistocene age, extend to depths of more than 200 feet, and the proportion of gravel and sand in the 100- to 200-foot depth interval is greater than 30 percent in both townships. The coarse gravel and sand deposits of Recent and Pleistocene age thin toward the west, and the underlying fine-grained indurated sediments of the Tehama formation are at shallow depth toward the apex of the fan. As a result, beneath the western part of the fan the percentage of gravel and sand in the 50- to 100-foot interval is appreciably lower than in the 20- to 50-foot depth zone and is nearly the same as the proportion of coarse deposits in the 100- to 200-foot zone.

Coarse-grained deposits make up a smaller proportion of the alluvial-fan deposits beneath the southern part of the low plains south of Willows than beneath the Stony Creek fan. Most of the material at the surface in this southern area was contributed by streams draining the Coast Ranges foothills on the west; consequently, it is generally finer grained than the Stony Creek fan deposits. Moreover, the proportion of gravel and sand decreases markedly with depth, reflecting the presence of the Tehama formation close to the land surface.

An examination of the proportion of sand and gravel recorded in 268 well logs indicates that for the 20- to 50-foot zone the distribution of coarse-grained deposits is generally in accord with the principle of coarsest deposition near the apex of an alluvial fan. The fact that the greatest amount of sand and gravel in the 50- to 100-foot and 100- to 200-foot depth zones occurs beneath the outer portion of the Stony Creek fan does not necessarily conflict with this principle, as the underlying finer-grained Tehama deposits are at greater depths beneath the outer portion of the fan than near the apex. Moreover, it is likely that the coarse unconsolidated materials penetrated in drilling wells in the eastern part of the fan may be ancient channel deposits of the Sacramento River rather than Stony Creek fan deposits.

The deposits beneath the low plains are saturated to within 35 feet of the surface throughout this area, and in places the water table is close enough to the surface to constitute a serious problem to farming. In the spring of 1947 water stood within 10 feet of the surface in the area served by the Glenn-Colusa Irrigation District Central Canal, and in the Orland project area water stood between zero and 23 feet below the surface. The U.S. Bureau of Reclamation estimated that in June 1946 there were 770 acres of the project area where the water table was at or within 1 foot of the surface and an additional 1,792 acres where it was less than 4 feet below the surface.

In 1946 ground water was moving away from Stony Creek and the Orland project area. North of the creek the water table sloped toward the northeast, and south of the latitude of Orland it sloped generally southeastward. Measurements by the U.S. Bureau of Reclamation in August 1947 suggest that a broad ground-water ridge extended eastward in the vicinity of Stony Creek, indicating that there was recharge to the ground-water body from the creek. Heavy pumping on the Capay land grant west of Hamilton City caused a local depression in the regional high water table associated with Stony Creek.

The estimated storage capacity of the deposits in the Stony Creek alluvial fan (storage unit B11) for the three depth zones, 20 to 50 feet, 50 to 100 feet, and 100 to 200 feet, is 583,000, 891,000, and 1,438,000 acre-feet, respectively, or a total of 2,912,000 acre-feet (table 6).

DISSECTED ALLUVIAL DEPOSITS (GROUP C)

The dissected alluvial deposits in the Sacramento Valley generally crop out in dissected plains and low hills having moderate to steep side slopes. Minor areas of low alluvial-plain and alluvial-fan deposits, particularly in the northwestern part of the valley, were included in this storage group, and, on the other hand, small areas of dissected alluvial deposits were included in the low alluvial-plain and alluvial-fan storage group B, in order to simplify computations.

The dissected plains along the valley margins are underlain largely by the Tehama and Laguna formations and related continental sediments of late Pliocene and early Pleistocene age. These sediments at many places have a pronounced reddish color, locally are characterized by the development of microrelief known as "hog-wallows," and generally are more indurated than the younger deposits of late Pleistocene and Recent age.

Calculated specific yields average higher than those of the basin deposits but generally are lower than those of the low alluvial-plain and alluvial-fan deposits and in the 20- to 100-foot interval are much lower than those of the river flood-plain and channel deposits.

Wells drilled in the dissected alluvial deposits indicate a wide range in depth to water that cannot be attributed entirely to topographic position. In some places where it might be expected to be much deeper the water level stood within a few feet of the surface; in other places the depth to water in wells was much deeper than might be expected. Water levels in wells in the dissected alluvial deposits were in part a function of well depth; water-level altitudes in nearby wells of different depth locally were several feet or even several tens of feet apart. The explanation is that water occurring in the coarser materials may be confined by the interbedded fine-grained sediments which have a lower permeability.

The estimated ground-water storage capacity of the dissected alluvial deposits (group C) between 20 and 200 feet is nearly 5 million acre-feet, or 15 percent of the total for the Sacramento Valley (tables 3 and 4).

DEPOSITS SOUTH OF THE AMERICAN RIVER (UNIT C1)

The dissected alluvial deposits south of the American River in storage unit C1 cover an area of 75,330 acres in three separate segments, the uplands along the eastern border of the Sacramento Valley between the American and Cosumnes Rivers; the uplands south of the Cosumnes River extending south to the south edge of T. 7 N., the arbitrary southern boundary of the area investigated; and an isolated outlier of dissected alluvial deposits extending north from Elk Grove, a distance of about 5 miles. This dissected upland belt extends 18 miles from north to south and ranges in width from $1\frac{1}{2}$ miles on the north to about 12 miles on the south.

The uplands south of the American River constitute the erosional remnants of three definite terraces. Altitudes of the terrace remnants range from 85 feet above sea level near Elk Grove to 325 feet above sea level along the eastern margin of the valley. The drainage is generally southwestward, parallel to the Cosumnes and American Rivers, in minor streams that join the Cosumnes River to the south or flow across the low alluvial plains toward the Sacramento River.

Irrigation development in this area is limited by adverse slope conditions and poor soils. Soils of the Corning and Redding series, which are mostly gravelly, underlain by heavy clay and hardpan, and characterized by poor subdrainage, underlie most of the upland terrace land. These soils are treeless and barren under natural conditions and in this area generally are devoted to pasturage. A few deep wells have been drilled to irrigate plots of permanent pasture where slope conditions are favorable, but most of the area is devoted to cattle grazing and gold dredging operations.

The Laguna formation and related continental sediments geologic unit, which crops out at the land surface throughout the dissected uplands, consists of siltstone, fine sandstone, and poorly sorted gravel of fluviatile origin. The volcanic rocks from the Sierra Nevada are exposed at the surface along the eastern margin of the area and dip beneath the Laguna formation with westward dips of 45 to 65 feet to the mile. Tuff, tuff breccia, and volcanic sand and gravel derived from the erosion of the pyroclastic rocks make up the volcanic rocks unit.

Wells drilled in the western part of the dissected uplands generally tap only the heterogeneous hard silt, clay, tight sand, and gravel deposits of the Laguna formation within 200 feet of the surface, but wells to the east pass through an increasing proportion of volcanic rocks from the Sierra Nevada above the 200-foot depth. As a general rule, the volcanic deposits beneath the valley contain a larger proportion of coarse sand and gravel than does the Laguna, but the two units cannot be distinguished in many drillers' logs.

Specific yields computed from drillers' logs show no systematic variation in water-bearing character, either laterally or vertically, with but one exception—T. 9 N., R. 7 E. The specific yields for this township are 9.3, 12.2, and 10.9 for the 20- to 50-foot, 50- to 100-foot, and 100- to 200-foot zones—significantly higher than the average yields for these intervals in either storage unit C1 or in storage group C as a whole. This anomalous situation is explained by the fact that most of the wells in T. 9 N., R. 7 E., are near the eastern margin of the valley and penetrate coarse sand and gravel of the volcanic rocks from the Sierra Nevada from a few feet below the surface to several hundred feet. Specific yields for the whole storage unit averages 7.1, 6.2, and 7.1 percent for the 20- to 50-foot, 50- to 100-foot, and 100- to 200-foot zones, respectively, and 6.9 percent for the whole interval. These values are slightly but not significantly higher than the overall averages for all the dissected alluvial deposits. The estimated storage capacity of the deposits south of the American River (storage unit C1) in the three depth zones is 160,000, 232,000, and 538,000 acre-feet, respectively, or a total of 930,000 acre-feet (table 6).

DEPOSITS SOUTH OF WINTERS (UNIT C2)

The dissected alluvial deposits south of Winters in storage unit C2 extend as a narrow belt of rolling uplands, one half to 3 miles wide, along the eastern margin of the English Hills for a distance of 10 miles from Putah Creek on the north to near Vacaville on the south. The area covers 11,290 acres, or 17.6 square miles The summits of the dissected uplands rise to more than 500 feet above sea level at the western edge of the belt where the uplands merge with the higher, more rugged western part of the English Hills. The drainage is generally eastward through small valleys floored with Recent alluvial deposits.

There is little irrigation in the area. The land generally is classified as class 2 agricultural land or poorer because of the steep slope and is devoted to pasturage and to unirrigated orchards where the soils are suitable. A few irrigation wells have been drilled and are equipped with small pumps of less than 10 horsepower.

The uplands are underlain by semiconsolidated to consolidated continental sediments of the Tehama formation, which has gentle eastward dips of less than 10°. The older Tertiary rocks exposed to the west dip steeply beneath the Tehama and do not lie within 200 feet of the surface, except in a narrow belt along the contact. Here the Tehama formation is comprised of compact silty clay, sandy silt, conglomerate, sandstone, and pumice tuff. In general, the part of the Tehama formation that is penetrated between 20 and 200 feet in wells is finer grained than the basal 500 feet of the formation, although drillers' logs report some coarse-grained deposits within 200 feet of the surface. The proportion of sand and gravel penetrated in wells is 15, 12, and 12 percent for 20- to 50-foot, 50- to 100-foot, and 100- to 200-foot zones, respectively, and averages 12.7 percent for the full interval.

Specific yields in individual township segments in this storage unit, computed from drillers' logs, range from 5.5 to 7.6 percent but do not reveal any systematic changes or trends in water-bearing character. The average specific yield of the storage unit as a whole, 6.1 percent, compares closely with the 6.2 percent yield obtained by averaging the specific yields for all the dissected alluvial deposits in the valley. The estimated storage capacity for the deposits south of Winters (storage unit C2) in the three depth zones, 20 to 50 feet, 50 to 100 feet, and 100 to 200 feet, is 20,000, 35,000, and 69,000 acre-feet, respectively, or a total of 124,000 acre-feet (table 6).

PLAINFIELD RIDGE (UNIT C3)

The Plainfield Ridge is an isolated body of dissected alluvial deposits, storage unit C3, which extends northward 10 miles from Putah Creek to Cache Creek and covers an area of 15,230 acres. It is actually a discontinuous belt of low, rounded hills that rise 25 to 50 feet above the adjoining low plains.

Most of the area is devoted to unirrigated pasture and grain farming, because of steep slopes and a general lack of surface or ground-water supplies. A few deep irrigation wells are used to water the gently sloping low lands in the southern part of this storage area.

The Tehama formation and related continental sediments crop out in the hills. The Tehama consists of hard silt and clay, sandstone, and cemented gravel of low transmissibility that yield little water to wells. These sediments are at or close to the surface along the crest of an anticline of low relief, as discussed in the section on geologic structure.

The proportion of clay and silt reported in drillers' logs ranges from 69 to 92 percent within depth zones by townships and for the entire storage unit averages 76, 82, and 87 percent for the 20- to 50-foot, 50- to 100-foot, and 100- to 200-foot depth zones, respectively. The small difference in the percentage of fine-grained materials in the 50- to 100-foot and 100- to 200-foot zones probably is not significant, but the slightly lower average for the 20- to 50-foot interval may indicate the presence of coarse gravelly deposits on the flanks of the fold. Specific yields computed from drillers' logs do not indicate any systematic changes in water-bearing character, except to reflect the presence of a slightly higher proportion of coarse-grained deposits in the 20- to 50-foot depth zone in the southern part of the area. The estimated storage capacity of the deposits in the Plainfield Ridge storage unit (C3) in the shallow, intermediate, and deep zones is 27,000, 39,000, and 74,000 acre-feet, respectively, or a total of 140,000 acre-feet (table 6).

DEPOSITS BETWEEN THE AMERICAN AND BEAR RIVERS (UNIT C4)

Storage unit C4 includes 188,810 acres in the eastern part of the Sacramento Valley, and extends from the flood plain of the American River 30 miles northward to the Bear River flood plain. The area narrows near the north end but generally averages about 12 miles in width. It is bounded on the south by the American River flood plain, on the west by the American Basin, on the northwest by low plains south of the Bear River, and on the east by the Sierra Nevada. Several thousand acres of low alluvial plains (pl. 1) that lie to the east of the American Basin were included in this storage unit, because the low plains in this area are underlain at relatively shallow depth by the Laguna formation and related continental sediments which crop out in the dissected alluvial uplands farther east. The deposits underlying the plains in this area are lithologically similar to the Laguna formation exposed farther east and therefore were placed in the same storage unit.

The dissected uplands are gently rolling low hills that merge almost imperceptibly with the foothills of the Sierra Nevada on the east and with undulating low plains on the west. The land within the storage area rises from about 25 feet above sea level near the American Basin to 275 feet near the Sierra Nevada foothills and Folsom in the southeastern part of the area. The altitudes of the hill summits decrease to the west and to the north. The flood plain of the American River, which forms the southern boundary of the unit, has been eroding laterally northward, and the precipitous bluff on the north bank rises to more than 125 feet above the river near Folsom. Several intermittent streams flow westward into the American Basin, and only a narrow territory immediately adjoining the American River is tributary to that stream.

Irrigation development has a long history in the southern part of this storage unit. As early as 1894, water imported from the North Fork of the American River was used to irrigate lands in the Fair Oaks District (Adams, 1929). At the present time the Fair Oaks, Citrus Heights, and Carmichael Irrigation Districts and the Orangevale Mutual Water Co. supply water to the old San Juan land grant. Prior to the construction of Folsom Dam all these agencies obtained water from the North Fork ditch, which diverted water from the North Fork of the American River near Auburn. The Fair Oaks, Citrus Heights, and Carmichael Irrigation Districts also obtain supplemental water from deep wells within their districts, and the Carmichael District pumps water from the north bank of the American River, 3 miles downstream from the Fair Oaks bridge.

In addition to these irrigation districts, large tracts of land extending several miles north of the American River between the American Basin and Carmichael have been developed as suburban residential areas and are supplied with ground water by several public utility water companies.

Most of the irrigation development on the dissected uplands has been limited to the southern area. The district north of the Southern Pacific railroad is devoted largely to pasturage and unirrigated grain farming, although there has been some development of ground-water supplies on the low alluvial plains in the western part of the storage unit and northwest of Lincoln. The Laguna formation, which is exposed over most of the storage unit area, consists of reddish- to yellowish-brown silt and sand and moderately well-bedded indurated siltstone and fine sandstone. Drillers' logs report a predominance of hard silt and clay and a smaller proportion of sand or tight sand and sandstone. Volcanic rocks from the Sierra Nevada crop out to the east of this storage area and are within 200 feet of the surface near the eastern boundary.

Too few well logs were available to treat townships as single units so the logs were combined in four groups. The proportion of sand and gravel as shown by logs indicated that there was no systematic change in water-bearing character with depth but that there was a noticeable lateral change in the northern part of the area. The percentage of sand and gravel in wells in T. 11 N., T. 12 N., and T. 13 N., averaged only 9, 5, and 7 percent, respectively, in the 20- to 50-foot, 50- to 100-foot, and 100- to 200-foot zones. To the south the percentage of sand and gravel from 20 to 200 feet below the surface ranged from 12 to 19 percent, averaging 17 percent for the area. The explanation for this striking difference in amounts of water-bearing materials probably is that the northern plains were remote from any major stream course and that the upper 200 feet of alluvial deposits were laid down by small streams of low competence like those that flow across the area today. The proportion of sand and gravel for the storage unit as a whole is 15, 14, and 14 percent for the 20- to 50-foot, 50- to 100-foot, and 100- to 200-foot depth zones, respectively.

Specific yields computed from well logs reflect the absence of water-bearing deposits in the northern area. Specific yields there were 4.7, 4.6, and 5.1 percent in the 20- to 50-foot, 50- to 100-foot, and 100- to 200-foot zones as compared with averages of 5.5, 5.8, and 6.3 percent in the same zones for the storage unit as a whole. The estimated storage capacity of the deposits in this storage unit (C4) for the shallow, intermediate, and deep zones is 311,000, 543,000, and 1,184,000 acre-feet, respectively, or a total of 2,038,000 acre-feet (table 6).

DEPOSITS SOUTH OF OROVILLE (UNIT C5)

From Oroville south to the Yuba River the dissected uplands lie in two belts, one about 1 to 2 miles wide adjacent to the Sierra Nevada foothills, and the other a series of disconnected hills lying about 1 to 2 miles farther west and separated from the first by a strip of low alluvial plains. This area, including the strip of low plains, comprises the 32,960 acres within storage unit C5. It is about 22 miles long in a general north-south direction and ranges in width from 2 to 6 miles.

Rounded knolls and ridges, rising as much as 100 feet above the surrounding plains and separated by minor intermittent drainages, typify the area of dissected deposits. The drainage is generally southward, parallel to the trend of the outer belt of hills to Honcut Creek and south of Honcut Creek to the Yuba River, and then westward to the Feather River.

Irrigation began in 1888 with the importation of Feather River water to the Palermo Colony, now included in the Oroville-Wyandotte Irrigation District. In addition to the area near Palermo, a small area lying to the east of Trainer Hills, north of the Yuba River, is served with Yuba River water diverted by the Cordua Irrigation District. The land not irrigated with ditch water generally is devoted to cattle grazing on the dissected uplands and to grain farming on the intervening low alluvial plains. The discouraging results from the few wells drilled have deterred ground-water development.

The Laguna formation and related continental deposits crop out in the dissected uplands and underlie the intervening low plains at shallow depth. Beds of tuff, tuffaceous sand, and clay assigned to the volcanic rocks from the Sierra Nevada underlie the Laguna and crop out along the steep bluff south of the Feather River near Oroville. A coarse gravel containing abundant cobbles of quartz and metamorphic rocks in a red silty or sandy matrix caps the ridges, but the lower slopes are underlain by compact silt and sand.

In the upper 200 feet, drillers' logs indicate a generally fine-grained section with a few thin beds of sand and gravel. Proportions of sand and gravel computed from the few available logs average 14, 8, and 6 percent, respectively in the 20- to 50-foot, 50-

to 100-foot, and 100- to 200-foot zones. However, too few logs were available to determine definitely any trends in water-bearing character.

Specific yields computed from drillers' logs generally were lower than the average for the dissected alluvial deposits of the valley as a whole. The estimated storage capacity of the deposits south of Oroville (storage unit C5) for the three zones is 51,000, 103,000, and 148,000 acre-feet, respectively, or a total of 302,000 acre-feet (table 6).

DEPOSITS WEST OF OROVILLE (UNIT C6)

The dissected alluvial deposits west of Oroville include 8,990 acres of low rolling reddish-colored hills, bounded on the north by steep slopes rising to Table Mountain, on the east by the flood plain of the Feather River, on the south by the low plains in the Gridley area, and on the west by the low, poorly drained flat lands of Butte Creek lowland.

Rounded knolls and ridges, separated by small intermittent streams, rise from 100 feet above sea level in the southwestern corner of the area to more than 200 feet near Table Mountain. Local relief in the uplands is 25 to 50 feet. The drainage pattern generally is westward toward Butte Creek lowland; only a narrow fringe of uplands on the east is tributary to the Feather River.

In the past these low hills have been unirrigated and devoted largely to pasturage and grain farming, but recently some of the lower slopes have been leveled and placed under irrigation with ground water from wells drilled in the Laguna formation.

Compact silt, sand, and poorly sorted gravel of the Laguna formation and related continental sediments crop out in road cuts and stream valleys throughout the dissected uplands. A reddish gravelly soil of the Corning series covers most of the ridges and hills.

Logs of water wells drilled in the uplands record a predominance of firm clay or silt with a smaller proportion of sand or consolidated sand. The proportion of coarse material in the section, as shown by well logs, reached 30 percent in the 50- to 100-foot depth zone—a higher proportion of water-bearing deposits than is ordinarily found in the Laguna formation. This may be due in part to the proximity of the area to the Feather River.

Specific yields computed from drillers' logs reflect the high proportion of coarse material in the Laguna in this area, ranging from 7 percent in the 20- to 50-foot interval to 8 percent in the 50- to 100-foot interval, and averaging 7½ percent for all three depth zones. The estimated storage capacity of the deposits in storage unit C6 for the shallow, intermediate, and deep zones is

19,000, 38,000, and 64,000 acre-feet, respectively, or a total of 121,000 acre-feet (table 6).

DEPOSITS NORTH OF CHICO (UNIT C7)

The dissected alluvial deposits north of Chico flank the Cascade Range for 28 miles along the east side of the valley. The band is as much as 6 miles wide in the middle but narrows in both directions like a canoe.

The uplands have the characteristic appearance of coalescing alluvial fans but are deeply trenched by the streams draining the Cascade Range to the east. The larger streams have cut narrow gorges as much as 150 feet below the apexes of the fans. The lower portions of the fans are not as deeply trenched but are cut by numerous small drainages that have developed on the surface of the fans. For several miles the western border of the old fans is marked by a steep bluff as much as 50 feet in height, cut by the Sacramento River at some time in the past.

The average slope of the fan surface is about 50 feet to the mile, rising eastward from the river bluffs to the Chico monocline.

Agriculture on the old fans along the east side of the valley at the present time is limited to grazing. The narrow alluvium-floored valleys of Antelope, Mill, and Deer Creeks, which indent the western margin of the dissected old fan deposits, are irrigated by surface diversions from those perennial streams, but the dissected deposits lie above the canals and are not cultivated.

The dissected fans are underlain by the fanglomerate from the Cascade Range, which rests unconformably on gently westward-dipping beds of the Tuscan formation to the east, and which is believed to be of Pleistocene age. The fan deposits were derived from the fragmental volcanic rocks of the Tuscan formation and are lithologically similar to them. Unlike the Tuscan formation, however, mudflow breccias are lacking, and the tuffaceous materials all show evidence of fluviatile deposition. Volcanic sand, gravel, and tuff are typical of the surface exposures. The deposits are semi-consolidated to consolidated and along stream valleys stand in steep banks 25 to 50 feet high.

Wells in the fanglomerate penetrate a predominantly fine-grained section described by the drillers as yellow, brown, or red clay interbedded with varying amounts of gravel, sand, and cemented gravel and sand. The proportion of sand and gravel in the section, as indicated by drillers' logs, is 10, 6, and 1½ percent for the 20- to 50-foot, 50- to 100-foot, and 100 to 200-foot depth zones, respectively. On the other hand, the proportion of materials in the clay category did not increase with depth as might be expected from the decrease in coarse water-bearing materials. Hence, the difference is represented necessarily by an increase in materials grouped in the fine, hard, and cemented sand category and the clay and gravel and cemented gravel categories. Too few well logs are available to evaluate properly this feature, but it may be related to an increase of cementation with depth.

Average specific yields were calculated to be 5.6, 5.3, and 4.5 percent in the 20- to 50-foot, 50- to 100-foot, and 100- to 200-foot depth zones, respectively, and averaged 4.9 percent for the storage unit as a whole—the lowest average specific yield in any of the 8 units classified as dissected alluvial deposits. The estimated storage capacity of the deposits north of Chico (storage unit C7) for the shallow, intermediate, and deep zones is 103,000, 162,000, and 280,000 acre-feet respectively, or a total of 545,000 acre-feet (table 6).

DEPOSITS ON THE NORTHWEST SIDE OF THE VALLEY (UNIT C8)

Storage unit C8 comprises 52,460 acres of gently rolling, mildly dissected uplands in Tehama County that extend along the west side of the valley for 20 miles from Red Bank Creek to Rice Creek. The area ranges in width from less than a mile to as much as 6 miles and is bordered on the east by the flood-plain deposits of the Sacramento River and Corning Ridge and on the west by dissected uplands for which ground-water storage capacity was not estimated. These western uplands structurally are related to the Coast Ranges; and, although there is no clean-cut physiographic boundary between them and the valley lands between Red Bluff and Stony Creek, they are not usually considered part of the Sacramento Valley. Corning Ridge is the surface expression of an anticline and is an outlier of the deposits to the west; consequently, it also was excluded from the ground-water storage computations.

This storage unit includes the extensive low hills north of Thomes Creek, (geomorphic map, pl. 1) which are the dissected remnants of a once extensive alluvial plain that reached from the Sacramento River to the Klamath Mountains, and a broad area of low alluvial plains in the drainage areas of Thomes, Burch, and Rice Creeks, near Corning. The low hills slope from altitudes of about 320 feet above sea level at the western border of the area to about 260 feet on the east where a well-defined bluff, 20 to 30 feet high, marks the edge of the Sacramento River flood plain. These hills are well drained by several streams that cross the area from west to east, the largest of which are Red Bank, Oat, and Elder Creeks.

The low plains near Corning constitute a moderately east-sloping plain, between Corning Ridge and the uplands to the west, which slopes from more than 300 feet above sea level on the west to 210 feet near Kirkwood. Drainage is eastward toward the Sacramento River through Thomes Creek, which skirts Corning Ridge on the north, and Rice Creek, which skirts the ridge on the south, and Burch Creek, which flows across Corning Ridge through a saddle between its high northern and southern sections.

Irrigation generally is limited to the low plains in the vicinity of Corning and to the El Camino Irrigation District, which occupies parts of the old Las Flores and Sauces land grants west of the Southern Pacific railroad and west and northwest of the town of Tehama. A small portion of Thomes Creek runoff is diverted for irrigation, but ground-water pumpage supports the major part of the irrigated agriculture. The U.S. Bureau of Reclamation estimated the 1947 ground-water pumpage at 14,500 acre-feet in the Corning area and at 24,000 acre-feet in the Proberta area to the north, including the El Camino irrigation district.

The low hills north of Corning are underlain by the Tehama formation and the Red Bluff formation. The Red Bluff formation which at most places is generally less than 50 feet thick, consists of reddish, poorly sorted gravel, sand, and silty clay and caps an old erosion surface cut on the yellow and gray moderately indurated silt, silty clay, sand and gravel of the Tehama formation. In the Corning area the low plains are underlain by unconsolidated alluvial deposits of Pleistocene and Recent age.

Drilled wells in the northern part of the area pass through as much as 60 feet of coarse deposits of the Red Bluff formation above the predominantly fine-grained deposits of the Tehama, where the Red Bluff has not been removed by erosion. The plain west of the Corning Ridge overlies a syncline along which the Tehama formation has been down warped. Coarse unconsolidated Pleistocene and Recent silt, sand, and gravel deposits extend to depths of 50 to 185 feet where they are underlain by moderately indurated yellow clay, sandstone, and cemented gravel of the Tehama formation.

Drillers' logs for unit C8 indicate that in the northern part of the area, where the Red Bluff formation overlies the Tehama, the proportion of sand and gravel in these wells is significantly higher in the 20- to 50-foot depth zone than in the deeper zones where the deposits are generally finer grained. The average percntages of sand and gravel in this area were computed to be 32 percent in the 20- to 50-foot interval, 12 percent in the 50- to 100-foot interval, and 15 percent in the 100- to 200-foot interval. Farther south in the Corning area, where coarse sediments do not make up a significant part of the 20- to 200-foot interval, the proportions of sand and gravel in the overlying unconsolidated alluvium averaged

20, 18, and 25 percent in the 20- to 50-foot, 50- to 100-foot, and 100- to 200-foot zones, respectively. The proportion of coarse deposits is significantly higher in the Pleistocene and Recent alluvial-fan deposits in the Corning area than those in the Tehama formation farther north. The Red Bluff formation, overlying the Tehama in the northern part of the area, contains the highest proportion of coarse materials of any formation in the area and probably accounts for the abnormally high proportion of sand gravel, 25 percent, in the 100- to 200-foot depth interval in the Corning area.

Specific yields computed from well logs reflect the lithologic features described above. Specific yields range from 5.9 percent in the 50- to 100-foot interval of T. 26 N., R. 3 W., to a maximum of 11.2 percent in the 100- to 200-foot zone of T. 24 N., R 3 W., averaging 9.3, 7.4, and 8.1 percent, respectively, in the 20- to 50-foot, 50- to 100-foot, and 100- to 200-foot zones. The computed specific yields are significantly higher than yields computed for the other storage units of the dissected alluvial deposits (group C), reflecting the presence of appreciable thicknesses of coarse-grained materials not generally found in the dissected alluvium. The estimated storage capacity of the deposits on the northwest side of the valley (storage unit C8) for the shallow, intermediate, and deep zones is 147,000, 194,000, and 426,000 acre-feet, respectively, or a total of 767,000 acre-feet (table 6).

BASIN DEPOSITS (GROUP D)

The basin deposits of group D underlie low, nearly flat, poorly drained lands between the natural levees of the Sacramento River and the low plains at the sides of the valley and extend from the Chico fan to the American River on the east and from the Stony Creek fan to the Montezuma Hills on the west. Near the surface the storage group is composed of the geologic unit of Recent age called "flood basin deposits." (See p. 146.)

The flood basin deposits characteristically have a high proportion of clay and silt laid down by flood waters of the Sacramento River and its tributaries. The permeability and specific yield of the deposits are low. The estimated ground-water storage capacity of the basin deposits (group D) between 20 and 200 feet is nearly 5,500,000 acre-feet, or 16 percent of the total for the Sacramento Valley (tables 3 and 4).

YOLO BASIN (UNIT D1)

The Yolo Basin includes 96,610 acres of low, poorly drained land lying between the Sacramento River on the east and the low alluvial fans on the west and extending from the Knights Landing Ridge southward to the Montezuma Hills. Its southern end is below sea level and formerly consisted of a large tidal lagoon that connected with the Sacramento River. At the upper end it is separated from the Colusa Basin by the Knights Landing Ridge, an old channel ridge of Cache Creek.

The Yolo By-Pass, an artificial flood channel for the Sacramento River waters, traverses the basin from north to south, receiving flood waters at Fremont Weir near Grays Bend and discharging them to the Sacramento River near Rio Vista. A cross channel connects the by-pass with the Sacramento River near Bryte, a few miles above Sacramento, permitting water from the river to flow over the Sacramento Weir to the Yolo By-Pass when high stages on the Feather River endanger the levees below the Sacramento-Feather River confluence. Leveed channels conduct the waters of Cache Creek, Willow Slough, and Putah Creek, which formerly drained to the Yolo Basin, to the Yolo By-Pass.

Most of the basin land not included in the by-pass, that is, the land between the by-pass levee and the Sacramento River and between the by-pass and the low plains on the west, is under irrigation. Large acreages devoted for the most part to rice growing are irrigated with surface water and in some areas with ground water. Even some of the land in the Yolo By-Pass is under irrigation despite the annual flood hazard. Temporary pumping plants that may be removed in the winter are used, and at least one deep-well turbine pump was installed on a steel platform several feet above the maximum high-water stage.

Near the land surface the flood basin depsits consist of dark-gray clay and clay adobe soils containing more than 50 percent clay-sized particles at many places. The Recent flood basin deposits have formed from the accumulation of silt and clay carried in suspension by flood waters and deposited from the slowly moving waters in the basin. During the period of deposition of the top 200 feet of materials, it is likely that Cache and Putah Creeks and possibly the Sacramento River have flowed in most parts of the Yolo Basin. As a result, wells drilled in the basin lands pass through some water-bearing materials, but the proportion of sand and gravel found in a given well is generally less than that in the adjoining river lands and low plains. The proportion of sand and gravel in the section, as indicated by drillers' logs, averages 9, 12, and 27 percent in the 20- to 50-foot, 50- to 100-foot, and 100- to 200-foot depth zones. The proportion of clay ranges from 50 to 98 percent but is higher in the 20- to 50-foot zone than in the other depth zones.

Computed specific yields reflect the proportion of water-bearing materials present in the different zones, ranging from 3 to 12 percent. The average specific yields are 4.4, 5.4, and 8.3 percent in the 20- to 50-foot, 50- to 100-foot, and 100- to 200-foot depth zones, respectively. The relatively high yield of the 100- to 200-foot zone is believed to reflect the presence of nonbasin materials in this zone. The estimated storage capacity of the deposits in Yolo Basin (storage unit D1) for the shallow, intermediate, and deep zones is 130,000, 259,000, and 802,000 acre-feet, respectively, or a total of 1,191,000 acre-feet (table 6).

AMERICAN BASIN (UNIT D2)

The American Basin includes 41,270 acres of poorly drained lowland between the Bear River on the north and the American River on the south and bounded by the river deposits of the Feather and Sacramento Rivers on the west and by the low alluvial plains forming the western border of storage unit C4 on the east. The length of the basin is 20 miles and the width ranges from 2 to 7 miles.

Under natural conditions the basin received flood overflows from the Bear, Feather, and Sacramento Rivers and from minor streams tributary to the basin itself. Originally, the basin drained southward into the Sacramento River through a number of deep sloughs, but even before the advent of extensive flood control works, silting of the Sacramento River channel by hydraulic debris made natural drainage of the basin impossible.

At the present time the American Basin is protected from normal flood flows of the Bear, Feather, and Sacramento Rivers by high levees, and drainage of the basin is provided through deep drains of several reclamation districts from which water is pumped over the levees into the Sacramento River.

The surface of the basin is marked by minor relief. Small mounds and irregular elevated areas that appear to be the unburied remnants of an old plain occur at several localities. To the northeast the boundary between the basin lands and low plains is gradual, but south of the Sacramento County line the boundary is marked by a well-defined low escarpment. The altitude slopes from 25 feet above sea level at the north end of the basin to 12 feet at the south end.

The initial irrigation development of the American Basin was under the direction of the Natomas Co., which at one time owned most of the land in the basin; but, following the construction of flood-control works along the Feather and Sacramento Rivers, the company subdivided their property, organized mutual water companies to supply surface water from Sacramento River diversions, drilled wells to supply water where surface supplies were unavailable, and sold their holdings to private owners. In 1949 (California Dept. Public Works, Div. Water Resources, 1950) almost 25,000 acres of American Basin and adjoining river lands was served with Sacramento River water by the Northern, Central, Elkhorn, and Riverside Mutual Water Cos. More than half this area was devoted to rice growing. Surface-water supplies are ample and relatively inexpensive; consequently, few wells have been drilled to supply ground water.

The Recent flood basin deposits, exposed at the land surface, are composed of dark-gray clay and clay adobe soils of the Alamo and Freeport series (Weir, 1950). Small areas of reddish older soils, belonging to the San Joaquin series, occur as isolated patches, usually on mounds and gentle swells that rise above the basin floor. Wells drilled on the basin soils generally pass into yellow or brown clay within a few feet of land surface. Thus, it appears that the flood basin deposits are a thin veneer that overlies extensive alluvial deposits lithologically similar to the Victor and Laguna formations exposed to the east of the American Basin.

Drillers' logs report yellow, red, and brown clay with a minor proportion of sand and gravel, sometimes described as hard or tight, to depths of 40 to 100 feet below the surface. These deposits are generally similar in lithologic and water-bearing character to those found beneath the low plains to the east. Below 100 feet, blue clay with a higher proportion of interbedded sand are generally found in drilling wells. The proportion of sand and gravel, as computed from the few available drillers' logs in the area, is 7, 9, and 25 percent in the 20- to 50-foot, 50- to 100-foot, and 100- to 200-foot zones, respectively.

Specific yields computed from drillers' logs reflect the increase in coarse materials with depth, increasing from 4.6 to 5.1 to 7.7 percent in the three zones, respectively. A similar but less pronounced increase in specific yield with depth occurs in storage unit C4 (table 6) to the east, partly confirming the relationship of the deposits in the 20- to 200-foot interval in the two storage units. The estimated ground-water storage capacity of the deposits in the American Basin (storage unit D2) for the shallow, intermediate, and deep zones is 57,000, 104,000, and 317,000 acre-feet, respectively, or a total of 478,000 acre-feet (table 6).

COLUSA BASIN (UNIT D3)

The Colusa Basin storage unit extends along the west side of the Sacramento Valley from near Willows southward to Knights Landing, a distance of about 55 miles. It ranges in width from 2 to 10 miles, averaging about 4 miles, and includes 194,640 acres of low, poorly drained land between the natural levee deposits of the Sacramento River on the east and a narrow strip of low alluvial fans flanking the Coast Ranges on the west. To the north the

Stony Creek alluvial fan impinges upon the Colusa Basin, and at its southern end the basin is separated from the Yolo Basin by the Knights Landing Ridge, a channel ridge marking a former course of Cache Creek. Sycamore Slough and other distributary channels extend westward from the Sacramento River near Grimes almost bisecting the Colusa Basin. The low areas between these distributary ridges are known locally as basins, the two largest of which are called Mormon Basin and Munson Basin.

All the streams draining the Coast Ranges from Stony Creek south to Cache Creek are tributary to the Colusa Basin. Under natural drainage conditions the waters of these west-side streams and the Sacramento River flowed slowly southward across the basin at times of floods and at other times through Sycamore Slough to its confluence with the Sacramento River at Knights Landing. The flat trough that forms the basin floor slopes gently from 100 feet above sea level at the northern end east of Willows to 25 feet above at the southern end near Knights Landing. Along the Sacramento River the basin is bounded sharply by the natural-levee slope, but on the west side it merges gradually with the low plains constructed by the west-side streams.

Virtually the only crop grown in the Colusa Basin was irrigated grain until 1906, when water deliveries from the Central Canal began in the northern part of the basin. At the present time most of the arable land of the basin that is not affected by high concentrations of alkali is under irrigation by surface water diverted from the Sacramento River. The Glen-Colusa, Jacinto, Provident, Compton-Delevan, and Maxwell Irrigation Districts and Reclamation District 108 supply water to 111,808 acres of land, most of which is in the Colusa Basin.

Availability of surface water and low productivity of wells has limited ground-water development in this storage unit. In fact, only 19 drillers' logs were available from the whole Colusa Basin for computation of specific yields and ground-water storage capacity.

The Recent flood basin deposits exposed at the land surface are characteristically dark, fine-textured, poorly drained clay and clay-adobe soils. They have formed from the accumulation of silt and clay deposited by flood waters of the Sacramento River and the west side streams. During the period represented by the deposition of the upper 200 feet of sediments, it is likely that distributary ridges, such as Sycamore Slough, have extended over most of the area underlying the Colusa Basin. Consequently, wells drilled in the area tap occasional beds of sand or gravel interbedded with brown or yellow silt and clay deposited in a quiet-water environment.

Drillers' logs indicate that the proportion of clay and silt penetrated within 200 feet of land surface is 90, 96, and 82, percent in the 20- to 50-foot, 50- to 100-foot, and 100- to 200-foot depth zones, respectively. The scant data available indicate that no significant changes, either lateral or vertical, are known to occur within 300 feet of the land surface.

Specific yields reflect the high proportion of fine-grained materials in the 20- to 200-foot interval. Average specific yields computed for the basin as a unit are 4.6, 3.4, and 5.7 percent in the 20- to 50-foot, 50- to 100-foot, and 100- to 200-foot depth zones. The specific yields were lower than the average for all the basin deposits in each zone, and the overall value for the 20- to 200-foot interval was only 0.1 percent higher than the minimum for the basin deposits. The estimated storage capacity of the deposits in the Colusa Basin (storage unit D3) for the shallow, intermediate, and deep zones is 272,000, 335,000, and 1,121,000 acre-feet, respectively, or a total of 1,728,000 acre-feet (table 6).

SUTTER BASIN (UNIT D4)

The Sutter Basin storage unit includes 114,510 acres of flat, low poorly drained land between the natural levees of the Feather River on the east and the Sacramento River on the west and is bounded by the alluvial fans surrounding Sutter Buttes on the north. It extends about 30 miles southward from Butte Slough at the upper end to Sacramento Slough at the lower end near the confluence of the Feather and Sacramento Rivers and averages about 8 miles in width. The land slopes gently from about 40 feet above sea level near Butte Slough to less than 15 feet above in the southern part. Saline waters are known to exist at shallow depth in this storage unit; and, accordingly, estimates of storage capacity have been made only for the shallow and intermediate depth zones.

Several distributary channel ridges extend from the Feather and Sacramento Rivers toward the trough of the basin. Under natural drainage conditions the Sutter Basin was filled at every high stage of the Sacramento River with backwater which enters its lower end through Sacramento Slough and other outlet channels. In addition, water entered from Butte Creek lowland and from the Sacramento River through Butte Slough and over the banks from the Feather River. At present a leveed floodway, the Sutter By-pass, traverses the basin from north to south along its eastern side and conducts flood water from the Sacramento River and Butte Slough southward to the Sacramento River at Fremont Weir near the Sacramento-Feather River confluence.

Construction of Sutter By-pass and protective works along the Sacramento River made possible intensive irrigation development in the Sutter Basin. Ground water is of poor quality throughout most of the Sutter Basin (California State Water Resources Board, 1952) and ground-water pumpage is negligible. Most of the basin lands are irrigated with surface water diverted from the Sacramento River, the Sutter By-pass, and Sacramento Slough. The Sutter Mutual Water Co. supplies water to nearly 40,000 acres, most of which is in the southern part of the basin. The northern part of the basin is irrigated with Sacramento River water delivered from ditches of the Meridian Farms Water Co., Newhall Land and Farming Co., and Butte Slough Irrigation Co. In addition, several thousand acres are irrigated from private diversions from the Sacramento River, and more than 14,000 acres are irrigated with water pumped from the Sutter By-pass borrow pits and Sacramento Slough.

Few water wells have been drilled in the basin, but the limited data available indicate that the deposits within 100 feet of the surface consist of varicolored clay and silt interbedded with occasional thin beds of sand or gravel. The proportion of sand and gravel, as computed from drillers' logs, is 12 percent in the 20- to 50-foot zone and 8 percent in the 50- to 100-foot zone. The Recent flood basin deposits exposed at the surface comprise clay and silt deposited by slowly moving flood waters, and sand and gravel deposited upon distributary ridges extending out from the natural levees of the Sacramento and Feather Rivers. It is likely that the deposits within 100 feet of the surface were laid down under similar conditions; the clay and silt represent the slack-water deposits and the sand and gravel represent deposits of distributary streams or, in some cases, the Feather and Sacramento Rivers.

Specific yields computed from drillers' logs are 5.5 and 5.2 percent for the 20- to 50-foot and 50- to 100-foot zones, respectively, and reflect the fact that the proportion of sand and gravel in wells in the Sutter Basin is somewhat higher than average for all the basin deposits in the 20- to 100-foot interval. Because of the presence of saline water, it is considered impracticable to draw down the water level to more than 100 feet below the land surface. Accordingly, the specific yield and storage capacity were computed for only the deposits within 100 feet of the land surface in the Sutter Basin. The estimated storage capacity of the deposits in Sutter Basin (storage unit D4) for the two depth zones, 20 to 50 and 50 to 100 feet, is 189,000 and 295,000 acre-feet, respectively, or a total of 484,000 acre-feet (table 6).

BUTTE CREEK LOWLAND (UNIT D5)

Storage unit D5 comprises 184,500 acres of level, poorly drained but gently sloping land east of the Sacramento River and extends from the Chico fan on the north to Butte Slough, between the Sacramento River and Sutter Buttes, on the south. The length is about 30 miles; the width ranges from 3 miles at the southern end to 12 miles in the northern part.

The land is not as flat as in the other flood basins; it slopes from an altitude of 150 feet in the northeast corner of the storage area to 50 feet at the Butte Slough outlet. Comparison of the map showing ground-water storage units (fig. 4) with the geomorphic map (pl. 1) shows a considerable area of low alluvial plains and fans east of Butte Creek included in this storage unit. The alluvial deposits that underlie this area within 200 feet of the land surface are predominantly fine grained, are lithologically similar to the deposits underlying the basin proper, and are included with the Butte Creek lowland deposits for this reason.

Flood waters of Butte Creek, Little Chico Creek, and Dry Creek as well as floodwaters from the Sacramento River enter the basin. Numerous small distributaries of these streams extend through the basin and form small channels about 5 feet deep. Flood waters drain slowly around the west side of Sutter Buttes through Butte Slough into the Sutter By-pass. The present drainage pattern is little changed from the natural drainage, and the only major flood control works are the levees along the Sacramento River. Most of the land within this storage unit is poorly drained, and during the winter much of it is under water for long periods of time. The soils are heavy clay and clay abode, and the principal crop is rice. Much of the land is uncultivated, some is devoted to pasturage, and large tracts are used for gun club preserves. Further agricultural development in the area awaits the elimination of the flood hazard and the construction of extensive drainage projects.

Ground-water development is limited to small areas north of Pennington and northeast of Nelson. Throughout the remainder of the area, surface waters imported from the Feather and Sacramento Rivers and diverted from Butte Creek are used exclusively. Diversions from the Feather River by the Western Canal Co., the Richvale Irrigation District, and the Biggs-West Gridley Water District supply water to 45,211 acres in the northern part of the Butte Creek lowland. Some 10,413 acres in reclamation district 1004, much of which is in the Butte Creek lowland area, is irrigated with water from the Sacramento River and lower Butte Creek; and 7,650 acres is irrigated with water diverted from Butte Creek (California Division Water Resources, 1949).

The soils are predominantly heavy, dark clay adobe, of the Stockton and Landlow series, and Sacramento clay. Although the soils are closely related to basin soil types, only the areas underlain by the Sacramento clay in the vicinity of Butte Sink were mapped as Recent flood basin deposits (pl. 2). As described in the Oroville area soil survey (Carpenter and others, 1926), the Stockton and Landlow clay adobe soils are underlain at shallow depth by semiconsolidated sediments that bear no relation to the soils, and these sediments are included in the Victor formation and related deposits in this report. The soils in the area between Butte Creek and the natural levee deposits of the Sacramento River belong to the Marvin series, described in the soils report (Carpenter and others, 1926) as being derived from river-terrace deposits; hence, they were mapped in this report as river deposits (pl. 2).

Throughout most of the area the proportion of sand and gravel within 200 feet of the surface is low, ranging from 3 to 13 percent of the section, but in the northeastern part of the area, in T. 20 N., R. 2 E. and T. 20 N., R. 3 E., the proportion of sand and gravel reaches a maximum for the storage unit of 18 percent in the 20- to 50-foot zone. The proportion of water-bearing deposits averages 14, 5, and 7 percent in the 20- to 50-foot, 50- to 100-foot, and 100- to 200-foot depth zones, respectively. Unfortunately, too few well logs are available to attempt any explanation of the lithologic features of the alluvium.

Specific yields computed from well logs reflect the predominance of fine-grained deposits within 200 feet of the surface. The specific yields are 5.5, 4.7, and 4.7 percent in the 20- to 50-foot, 50- to 100-foot, and 100- to 200-foot zones, respectively. These figures agree closely with average specific yields computed for all the basin deposits in the upper two zones, but the yield of the deep zone is significantly lower than the average of 6 percent. The overall average of 4.8 for the 20- to 200-foot interval is lower than that for any of the other basins. The estimated storage capacity of the deposits in Butte Creek lowland (storage unit D5) for the shallow, intermediate, and deep zones is 304,000, 434,000, and 860,000 acre-feet, respectively, or a total of 1,598,000 acre-feet (table 6).

ESTIMATES OF GROUND-WATER STORAGE CAPACITY

A summary and detailed estimates of ground-water storage capacity of the Sacramento Valley are given in the following tables.

Table 3.—Estimated ground-water storage capacity of the Sacramento Valley

[Figures in parentheses indicate acreage for computing storage in zone 100 to 200 feet below the land surface]

Symbol (fig. 4)	Storage group	Area (acres)	Depth zone, in feet: 20–50, Specific yield (percent)	20–50, Storage capacity (acre-feet)	50–100, Specific yield (percent)	50–100, Storage capacity (acre-feet)	100–200, Specific yield (percent)	100–200, Storage capacity (acre-feet)	All zones (20–200), Specific yield (percent)	All zones (20–200), Storage capacity (acre-feet)
A.	River flood-plain and channel deposits	612, 220 (572, 060)	11. 7	2, 150, 000	10. 5	3, 220, 000	8. 2	4, 680, 000	9. 5	10, 050, 000
B.	Low alluvial-plain and alluvial-fan deposits	1, 007, 650	8. 0	2, 460, 000	7. 4	3, 730, 000	6. 8	6, 870, 000	7. 2	13, 060, 000
C.	Dissected alluvial deposits	446, 650	6. 3	840, 000	6. 0	1, 350, 000	6. 2	2, 780, 000	6. 2	4, 970, 000
D.	Basin deposits	632, 530 (518, 020)	5. 0	950, 000	4. 5	1, 430, 000	6. 0	3, 100, 000	5. 4	5, 480, 000
	Total	2, 699, 050 (2, 544, 380)	7. 9	6, 400, 000	7. 2	9, 730, 000	6. 8	17, 430, 000	7. 1	33, 560, 000
	Percent of total			19. 1		29. 0		51. 9		100. 0
	Storage capacity, excluding basin deposits: Total (A+B+C)	2, 066, 520 (2, 026, 360)	8. 8	5, 450, 000	8. 0	8, 300, 000	7. 1	14, 330, 000	7. 6	28, 080, 000
	Percent of total			19. 4		29. 6		51. 0		100. 0

TABLE 4.—*Estimated ground-water storage capacity of the Sacramento Valley*

Symbol (fig. 4)	Storage unit	Area (acres)	Depth zone, in feet							
			20–50		50–100		100–200		All zones (20–200)	
			Specific yield (percent)	Storage (acre-feet)	Specific yield (percent)	Storage (acre-feet)	Specific yield (percent)	Storage (acre-feet)	Specific yield (percent)	Storage (acre-feet)
	Flood-plain and channel deposits (Group A)									
A1	Cache Creek	12,420	18.0	67,000	14.8	92,000	6.8	84,000	10.9	243,000
A2	Cosumnes River	7,970	11.8	28,000	11.2	45,000	7.6	60,000	9.3	133,000
A3	Sacramento River south of Colusa	146,000	9.7	425,000	10.0	729,000	8.6	1,256,000	9.2	2,410,000
A4	Sacramento River north of Colusa	237,100	12.8	911,000	11.2	1,329,000	9.1	2,147,000	10.3	4,387,000
A5	Feather, Yuba, and Bear Rivers	208,730 (168,570)	11.5	718,000	9.8	1,025,000	6.8	1,138,000	8.6	2,881,000
	Total	612,220 (572,060)	11.7	2,150,000	10.5	3,220,000	8.2	4,680,000	9.5	10,050,000
	Low alluvial-plain and alluvial-fan deposits (Group B)									
B1	Putah plain	221,490	7.8	521,000	7.9	875,000	7.8	1,733,000	7.8	3,129,000
B2	Low plains south of American River	127,010	9.9	379,000	7.3	463,000	6.0	759,000	7.0	1,601,000
B3	Low plains south of Bear River	38,090	6.5	74,000	5.2	99,000	4.2	160,000	4.9	333,000
B4	Low plains south of Dunnigan Hills	45,680	6.6	91,000	6.5	149,000	8.1	370,000	7.4	610,000
B5	Low plains east of Dunnigan Hills	91,040	8.3	228,000	8.3	378,000	8.2	749,000	8.3	1,355,000
B6	Alluvial fans, west side, Delevan to Zamora	129,730	5.9	229,000	6.0	392,000	5.9	768,000	5.9	1,389,000
B7	Low plains north of Bear River	47,070	4.7	67,000	4.5	105,000	5.4	253,000	5.0	425,000
B8	Low plains west of Feather River	30,670	5.8	53,000	6.0	92,000	5.2	158,000	5.5	303,000
B9	Alluvial plains enclosing Sutter Buttes	15,930	4.8	23,000	5.8	46,000	3.7	59,000	4.5	123,000
B10	Big Chico Creek alluvial fan	75,100	9.5	213,000	6.5	244,000	5.7	426,000	6.5	883,000
B11	Stony Creek fan	185,840	10.4	583,000	9.6	891,000	7.7	1,438,000	8.7	2,912,000
	Total	1,007,650	8.0	2,460,000	7.4	3,730,000	6.8	6,870,000	7.2	13,060,000

TABLE 4.—*Estimated ground-water storage capacity of the Sacramento Valley*—Continued

Symbol (fig. 4)	Storage unit	Area (acres)	Depth zone, in feet							
			20–50		50–100		100–200		All zones (20–200)	
			Specific yield (percent)	Storage (acre-feet)	Specific yield (percent)	Storage (acre-feet)	Specific yield (percent)	Storage (acre-feet)	Specific yield (percent)	Storage (acre-feet)
	Dissected alluvial deposits (Group C)									
C1	Deposits south of American River	75,330	7.1	160,000	6.2	232,000	7.1	538,000	6.9	930,000
C2	Deposits south of Winters	11,290	5.9	20,000	6.2	35,000	6.1	69,000	6.1	124,000
C3	Plainfield ridge	15,230	5.9	27,000	5.1	39,000	4.9	74,000	5.1	140,000
C4	Deposits between American and Bear Rivers	188,810	5.5	311,000	5.8	543,000	6.3	1,184,000	6.0	2,038,000
C5	Deposits south of Oroville	32,960	5.2	51,000	6.2	103,000	4.5	148,000	5.1	302,000
C6	Deposits west of Oroville	8,990	7.0	19,000	8.5	38,000	7.1	64,000	7.5	121,000
C7	Deposits north of Chico	61,580	5.6	103,000	5.3	162,000	4.5	280,000	4.9	545,000
C8	Deposits on northwest side of valley	52,460	9.3	147,000	7.4	194,000	8.1	426,000	8.1	767,000
	Total	446,650	6.3	840,000	6.0	1,350,000	6.2	2,780,000	6.2	4,970,000
	Basin deposits (Group D)									
D1	Yolo Basin	96,610	4.4	130,000	5.4	259,000	8.3	802,000	6.8	1,191,000
D2	American Basin	41,270	4.6	57,000	5.0	104,000	7.7	317,000	6.4	478,000
D3	Colusa Basin	195,640	4.6	272,000	3.4	335,000	5.7	1,121,000	4.9	1,728,000
D4	Sutter Basin	114,510	5.5	189,000	5.2	295,000	(1)	(1)	5.3	484,000
D5	Butte Creek lowland	184,500	5.5	304,000	4.7	434,000	4.7	860,000	4.8	1,598,000
	Total	632,530 (518,020)	5.0	950,000	4.5	1,430,000	6.0	3,100,000	5.4	5,480,000

[1] Excluded because of high salinity ground water.

TABLE 5.—*Estimated ground-water storage capacity of the Sacramento Valley, by townships*

Location		Area (acres)	Storage, in acre-feet, for indicated depth zone, in feet			
T.	R.		20-50	50-100	100-200	All zones (20-200)
27N	3W	11,400	48,000	58,300	129,000	235,300
27N	2W	1,500	6,600	10,900	14,200	31,700
26N	3W	18,370	67,000	68,800	172,200	308,000
26N	2W	15,210	44,600	75,000	102,100	221,700
25N	3W	20,190	66,500	61,600	125,400	253,500
25N	2W	20,740	66,600	82,500	114,700	263,800
25N	1W	7,470	12,700	19,700	34,700	67,100
24N	4W	2,240	5,200	3,800	11,800	20,800
24N	3W	17,300	36,200	89,800	193,200	319,200
24N	2W	17,980	68,200	91,300	113,100	272,600
24N	1W	21,030	36,300	56,100	98,000	190,400
24N	1E	1,120	1,900	3,000	5,200	10,100
23N	3W	5,440	15,200	22,600	47,000	84,800
23N	2W	19,070	80,000	102,300	191,700	374,000
23N	1W	22,250	64,000	81,600	148,000	293,600
23N	1E	7,800	12,800	21,100	32,400	66,300
22N	4W	1,890	6,900	7,400	12,100	26,400
22N	3W	22,740	82,600	89,400	145,300	317,300
22N	3W	23,490	90,500	152,000	199,800	442,300
22N	1W	22,390	94,800	119,200	137,800	351,800
22N	1E	20,500	48,800	54,500	102,100	205,400
22N	2E	3,610	8,800	12,300	17,600	38,700
21N	3W	22,840	90,300	98,800	155,800	344,900
21N	2W	23,010	84,500	160,100	254,300	498,900
21N	1W	22,730	92,500	143,900	218,000	454,400
21N	1E	23,270	68,000	77,800	124,000	269,800
21N	2E	11,050	28,800	27,800	61,300	117,900
20N	3W	22,830	70,500	116,400	205,200	392,100
20N	2W	22,560	59,600	112,800	217,300	389,700
20N	1W	21,710	69,800	120,300	111,000	301,100
20N	1E	22,290	37,200	55,500	98,200	190,900
20N	2E	20,380	48,200	54,600	142,000	244,800
20N	3E	2,520	6,000	6,700	17,600	30,300
19N	4W	7,770	15,500	23,900	35,000	74,400
19N	3W	23,170	44,600	67,700	107,800	220,100
19N	2W	25,720	63,400	92,700	195,200	351,300
19N	1W	21,700	93,200	145,800	251,700	490,700
19N	1E	23,160	35,400	52,700	100,000	188,100
19N	2E	24,000	36,600	54,600	104,000	195,200
19N	3E	14,660	44,200	78,200	116,300	238,700
19N	4E	5,100	18,300	28,200	40,300	86,800
18N	4W	2,920	5,800	9,000	13,200	28,000
18N	3W	23,260	36,400	48,900	125,100	210,400
18N	2W	23,050	49,400	64,400	187,900	301,700
18N	1W	24,480	81,500	111,400	285,200	478,100
18N	1E	23,560	36,000	53,600	101,800	191,400
18N	2E	23,050	35,200	58,800	120,000	214,000
18N	3E	22,930	87,900	124,800	164,800	377,500
18N	4E	10,480	20,300	28,700	54,500	103,500
17N	4W	2,570	4,200	5,200	11,700	21,100
17N	3W	23,260	34,100	42,200	124,300	200,600
17N	2W	22,950	46,800	65,700	171,100	283,600
17N	1W	23,540	55,400	84,300	174,300	314,000
17N	1E	21,360	32,500	49,900	91,000	173,400
17N	2E	22,010	37,800	62,000	94,200	194,000
17N	3E	23,060	80,800	109,600	142,300	332,700
17N	4E	12,790	25,200	50,800	59,400	135,400
16N	4W	6,400	10,400	13,000	29,200	52,600
16N	3W	22,890	34,600	43,000	117,300	194,900
16N	2W	22,960	39,800	65,200	131,100	236,100
16N	1W	24,670	51,300	99,400	124,300	275,000
16N	1E	3,140	4,700	8,500	12,200	25,400
16N	2E	8,320	18,400	29,100	40,100	87,600
16N	3E	22,930	63,100	90,000	129,300	282,400
16N	4E	21,940	48,300	82,800	109,800	240,900

TABLE 5.—*Estimated ground-water storage capacity of the Sacramento Valley, by townships*—Continued

Location		Area (acres)	Storage, in acre-feet, for indicated depth zone, in feet			
T.	R.		20–50	50–100	100–200	All zones (20–200)
15N	4W	5,130	9,800	16,000	19,700	45,500
15N	3W	21,950	40,700	65,200	88,700	194,600
15N	2W	23,340	34,400	42,100	132,700	209,200
15N	1W	22,740	68,300	74,000	161,700	304,000
15N	1E	17,770	32,500	47,300	43,500	123,300
15N	2E	19,780	40,600	65,000	41,400	147,000
15N	3E	24,040	65,700	99,200	91,800	256,700
15N	4E	24,340	99,900	135,800	169,800	405,500
15N	5E	7,910	19,300	26,700	51,900	97,900
14N	3W	4,440	7,600	13,400	33,600	54,600
14N	2W	22,800	32,900	54,400	146,300	233,600
14N	1W	22,760	38,500	49,600	126,500	214,600
14N	1E	24,500	47,100	88,000	223,300	358,400
14N	2E	23,700	39,300	61,700	5,100	106,100
14N	3E	23,040	56,700	85,300	20,800	162,800
14N	4E	22,860	41,800	98,900	122,000	262,700
14N	5E	20,970	32,600	42,700	129,800	205,100
14N	6E	580	2,400	2,000	3,100	7,500
13N	2W	15,130	32,900	65,700	113,500	212,100
13N	1W	22,770	36,000	75,800	172,800	284,600
13N	1E	24,420	53,400	75,700	171,100	300,200
13N	2E	23,120	41,600	64,600	19,600	125,800
13N	3E	21,270	51,300	63,000	6,700	121,000
13N	4E	22,890	46,300	55,600	97,600	199,500
13N	5E	22,930	53,100	58,500	112,000	223,600
13N	6E	8,580	12,200	19,800	43,500	75,500
12N	2W	990	2,900	2,000	6,300	11,200
12N	1W	15,180	27,600	50,000	98,100	175,700
12N	1E	23,400	38,500	66,200	135,000	239,700
12N	2E	22,670	42,500	85,800	55,100	183,400
12N	3E	23,030	58,000	95,700	67,100	220,800
12N	4E	23,610	45,600	70,900	115,700	232,200
12N	5E	22,180	32,500	52,600	111,100	196,200
12N	6E	7,650	10,800	17,700	38,800	67,300
11N	2W	4,650	5,600	9,700	31,100	46,400
11N	1W	4,140	6,100	12,400	33,000	51,500
11N	1E	18,970	40,600	67,600	127,200	235,400
11N	2E	23,380	37,300	99,900	174,900	312,100
11N	3E	23,460	72,200	125,800	192,600	390,600
11N	4E	22,740	32,800	55,300	135,000	223,100
11N	5E	22,980	32,600	53,100	116,500	202,200
11N	6E	8,030	11,400	18,500	40,700	70,600
10N	2W	5,960	9,800	21,200	48,300	79,300
10N	1W	19,770	77,100	105,500	134,700	317,300
10N	1E	15,300	58,300	74,700	141,200	274,200
10N	2E	22,000	57,100	92,800	189,400	339,300
10N	3E	21,590	42,400	91,100	250,700	384,200
10N	4E	20,790	34,300	62,500	165,200	262,000
10N	5E	21,760	39,300	71,600	156,500	267,400
10N	6E	21,750	41,400	81,000	169,000	291,400
10N	7E	6,100	11,600	22,700	47,600	81,900
9N	1W	17,560	32,100	58,100	148,200	238,400
9N	1E	23,710	60,400	81,700	170,700	312,800
9N	2E	21,510	43,300	72,500	167,100	282,900
9N	3E	24,240	42,700	69,900	199,500	312,100
9N	4E	22,740	53,800	85,800	177,500	317,100
9N	5E	23,300	46,700	73,200	167,500	287,400
9N	6E	22,250	56,400	81,300	163,900	301,600
9N	7E	23,820	66,100	131,800	224,200	422,100
8N	1W	17,300	48,900	87,300	145,800	282,000
8N	1E	23,660	61,100	112,200	146,300	319,600
8N	2E	22,630	35,300	67,900	162,900	266,100
8N	3E	23,170	26,000	70,600	147,400	244,000

TABLE 5.—*Estimated ground-water storage capacity of the Sacramento Valley, by townships*—Continued

Location		Area (acres)	Storage, in acre-feet, for indicated depth zone, in feet			
T.	R.		20–50	50–100	100–200	All zones (20–200)
8N	4E	18,960	51,100	90,700	154,900	296,700
8N	5E	22,510	65,400	102,600	162,300	330,300
8N	6E	22,780	80,900	75,200	146,500	302,600
8N	7E	23,300	48,300	57,900	139,400	245,600
7N	1W	14,850	36,400	54,100	96,600	187,100
7N	1E	23,300	61,500	96,700	179,400	337,600
7N	2E	22,900	72,100	84,700	192,400	349,200
7N	3E	22,640	52,800	70,300	185,700	308,800
7N	4E	21,380	59,100	108,600	179,900	347,600
7N	5E	23,020	50,000	74,700	127,600	252,300
7N	6E	22,900	83,700	74,600	120,000	278,300
7N	7E	23,230	56,800	83,700	166,700	307,200
7N	8E	11,540	24,500	37,000	86,900	148,400
6N	1W	12,190	27,000	42,700	85,300	155,000
6N	1E	23,240	44,600	96,400	190,600	331,600
6N	2E	23,180	46,600	78,800	189,800	315,200
6N	3E	23,140	37,300	62,400	186,100	285,800
6N	5E	23,210	42,800	47,000	102,600	192,400
6N	6E	5,760	13,400	21,600	30,100	65,100
5N	1W	1,000	1,900	4,200	8,200	14,300
5N	1E	20,560	39,600	85,300	168,600	293,500
5N	2E	8,870	18,100	30,600	72,700	121,400
Valley total		2,699,050	6,402,600	9,726,400	17,439,100	33,568,100
Rounded total		2,699,050	6,400,000	9,730,000	17,440,000	33,570,000

TABLE 6.—*Estimated ground-water storage capacity by storage units and townships*

Location		Area (acres)	Depth zone, in feet							
			20–50		50–100		100–200		All zones 20–200	
T.	R.		Specific yield (percent)	Storage (acre-feet)	Specific yield (percent)	Storage (acre-feet)	Specific yield (percent)	Storage (acre-feet)	Specific yield (percent)	Storage (acre-feet)
FLOOD PLAIN AND CHANNEL DEPOSITS										
Cache Creek (unit A1)										
10N	2W	1,090	11.2	3,700	14.9	8,100	7.3	8,000	10.1	19,800
10N	1W	9,510	18.6	53,200	15.6	74,300	7.3	69,600	11.5	197,100
10N	1E	1,820	19.1	10,400	11.1	10,100	3.4	6,900	8.4	27,400
Total		12,420	18.1	67,300	14.9	92,500	6.8	84,500	10.9	244,300
Rounded total			18.0	67,000	14.8	92,000	6.8	84,000	10.9	243,000
Percent of total				28		38		34		100
Cosumnes River (unit A2)										
8N	7E	640	11.8	2,300	11.2	3,600	7.6	4,900	9.3	10,800
7N	6E	6,070		21,400		34,000		46,100		101,500
7N	7E	1,260		4,400		7,000		9,600		21,000
Total		7,970	11.8	28,100	11.2	44,600	7.6	60,600	9.3	133,300
Rounded total			11.8	28,000	11.2	45,000	7.6	60,000	9.3	133,300
Percent of total				21		33		46		100
Sacramento River South of Colusa (unit A3)										
15N	2W	260	10.0	800	6.5	800	7.1	1,800	7.3	3,400
15N	1W	22,740	10.0	68,300	6.5	74,000	7.1	161,700	7.4	304,000
15N	1E	5,590	7.6	12,700	5.5	15,300	6.6	36,900	6.4	64,900
14N	1W	10,240	6.8	21,000	5.3	27,100	5.2	53,700	5.5	101,800
14N	1E	19,190	6.7	38,500	7.8	75,100	11.3	217,200	9.6	330,800
14N	2E	450	6.7	900	7.8	1,800	11.3	5,100	9.6	7,800
13N	1E	11,460	10.3	35,400	9.3	53,500	8.4	96,800	9.0	185,700

13N	2E	2,320	10.3	7,200	9.3	11,000	8.4	19,600	9.0	37,800
12N	1E	4,660	8.5	11,900	14.4	33,500	6.0	27,800	8.7	73,200
12N	2E	6,480	8.5	16,500	14.4	46,600	6.0	38,600	8.7	101,700
11N	2E	3,630	4.9	5,300	12.6	22,900	7.7	28,000	8.6	56,200
11N	3E	10,060	14.1	42,600	14.2	78,800	12.7	127,600	12.9	249,000
10N	3E	8,520	11.4	29,300	12.7	53,900	11.5	98,300	11.8	181,500
10N	4E	1,930	11.4	6,600	12.7	12,200	11.5	22,300	11.8	41,100
9N	3E	2,510	11.0	8,300	10.0	12,500	7.9	19,700	9.0	40,500
9N	4E	11,460	11.0	37,900	10.0	51,100	7.9	90,200	9.0	185,200
8N	4E	9,740	11.1	32,500	12.5	60,700	8.6	83,800	10.1	177,000
7N	4E	14,760	11.1	49,200	12.5	92,000	8.6	126,900	10.1	268,100
Total		146,000	9.7	424,900	10.0	728,800	8.6	1,256,000	9.2	2,409,700
Rounded total			9.7	425,000	10.0	729,000	8.6	1,256,000	9.2	2,410,000
Percent of total				18		30		52		100
Sacramento River North of Colusa (unit A4)										
27N	3W	11,400	14.0	48,000	10.2	58,300	11.3	129,000	11.5	235,300
27N	2W	1,500	14.8	6,600	14.5	10,900	9.5	14,200	11.7	31,700
26N	3W	7,790	14.0	32,600	9.7	37,700	12.3	96,000	11.9	166,300
26N	2W	11,590	11.1	38,500	11.3	65,500	7.4	85,300	9.1	189,300
25N	3W	430	15.0	1,900	10.3	2,200	6.3	2,700	8.8	6,800
25N	2W	11,150	15.0	50,300	10.3	57,200	6.3	70,200	8.8	177,700
24N	2W	16,240	13.4	65,200	10.7	86,700	6.4	105,000	8.8	256,900
24N	1W	270	13.4	1,100	10.7	1,400	6.4	1,700	8.6	4,200
23N	2W	11,870	16.3	58,100	11.7	69,300	10.8	127,800	11.9	255,200
23N	1W	2,720	16.3	13,300	11.7	15,900	10.8	29,300	11.9	58,500
22N	2W	1,790	15.2	8,200	11.3	10,100	6.0	10,600	9.0	28,900
22N	1W	15,770	15.2	71,800	11.3	88.900	6.0	93,800	9.0	254,500
21N	1W	22,730	13.5	92,500	12.7	143,900	9.6	218,000	11.1	454,400
20N	2W	1,040	10.7	3,300	11.1	5,800	5.1	5,300	7.7	14,400
20N	1W	21,710	10.7	69,800	11.1	120,300	5.1	111,000	7.7	301,100
19N	2W	8,820	14.3	37,900	13.4	59,300	11.6	102,300	12.6	199,500
19N	1W	21,700	14.3	93,200	13.4	145,800	11.6	251,700	12.6	490,700
18N	2W	7,680	12.2	28,100	9.9	38,100	13.0	99,800	12.0	166,000
18N	1W	20,720	12.2	75,800	9.9	102,800	13.0	269,000	12.0	447,600
17N	2W	8,430	10.5	26,600	9.7	40,900	10.4	87,900	10.2	155,400
17N	1W	11,900	10.5	37,600	9.7	57,800	10.4	124,000	10.2	219,400
16N	2W	6,710	8.6	17,200	11.1	37,400	5.7	38,000	7.7	92,600
16N	1W	13,140	8.6	33,700	11.1	73,200	5.7	74,500	7.7	181,400
Total		237,100	12.8	911,300	11.2	1,329,400	9.1	2,147,100	10.3	4,387,800
Rounded total			12.8	911,000	11.2	1,329,000	9.1	2,147,000	10.3	4,387,000
Percent of total				21		30		49		100

TABLE 6.—*Estimated ground-water storage capacity by storage units and townships*—Continued

Location		Area (acres)	Depth zone, in feet							
			20–50		50–100		100–200		All zones 20–200	
T.	R.		Specific yield (percent)	Storage (acre-feet)	Specific yield (percent)	Storage (acre-feet)	Specific yield (percent)	Storage (acre-feet)	Specific yield (percent)	Storage (acre-feet)
Feather, Yuba, and Bear Rivers (unit A5) [Figures in parentheses indicate acreage used for computing storage in zone 100 to 200 feet below the land surface.]										
19N	4E	2,930	16.0	14,100	15.2	22,300	9.9	29,000	12.4	65,400
19N	3E	4,970	16.0	23,900	15.2	37,900	9.9	49,200	12.4	111,000
18N	3E	14,190	16.0	67,900	13.6	96,200	8.1	114,800	10.9	278,900
17N	4E	3,640	13.2	14,400	10.4	18,900	6.7	24,300	8.8	57,600
17N	3E	18,740	13.2	74,200	10.4	97,400	6.7	125,000	8.8	296,600
17N	2E	1,640	13.2	6,500	10.4	8,500	6.7	10,900	8.8	25,900
16N	4E	14,210	9.2	39,100	7.8	55,800	5.6	80,100	6.8	175,000
16N	3E	22,930	9.2	63,100	7.8	90,000	5.6	129,300	6.8	282,400
16N	2E	4,780	9.2	13,200	7.8	18,800	5.6	27,000	6.8	59,000
15N	5E	3,080	13.9	12,900	11.3	17,500	7.0	21,700	9.4	52,100
15N	4E	23,670	13.9	98,900	11.3	134,200	7.0	166,900	9.4	400,000
15N	3E	24,040 (15,100)	9.1	65,700	8.2	99,200	6.0	91,800	7.5	256,700
15N	2E	8,100 (3,970)	9.1	22,100	8.2	33,400	6.0	24,000	7.5	79,500
14N	6E	580	13.9	2,400	6.8	2,000	5.4	3,100	7.2	7,500
14N	5E	1,670	13.9	7,000	6.8	5,700	5.4	9,000	7.2	21,700
14N	4E	14,590	6.8	29,900	10.8	78,600	5.9	86,400	7.4	194,900
14N	3E	15,140 (1,010)	9.4	42,600	8.2	62,400	5.2	5,200	8.4	110,200
13N	5E	6,170	13.9	25,700	6.8	21,000	5.4	33,100	7.2	79,800
13N	4E	3,000	13.9	12,500	6.8	10,200	5.4	16,100	7.2	38,800
13N	3E	8,280 (1,050)	12.0	29,800	7.1	29,600	6.4	6,700	8.6	66,100
12N	4E	940	14.1	4,000	14.2	6,700	12.7	11,900	13.7	22,600
12N	3E	7,990 (3,890)	14.1	33,800	14.2	57,000	12.7	49,300	13.7	140,100
11N	3E	3,450 (1,820)	14.1	14,600	14.2	21,600	12.7	23,100	13.7	59,300
Total		208,730 (168,570)	11.5	718,300	9.8	1,024,900	6.2	1,137,900	8.2	2,881,100
Rounded total			11.5	718,000	9.8	1,025,000	6.2	1,138,000	8.2	2,881,000
Percent of total				25		36		39		100

LOW ALLUVIAL-PLAIN AND ALLUVIAL-FAN DEPOSITS

Putah Plain (unit B1)

8N	1W	16,870	9.5	48,100	10.2	86,000	8.5	143,400	9.1	277,500
8N	1E	20,110	8.8	53,100	10.2	102,600	6.4	128,700	7.9	284,400
8N	2E	22,630	5.2	35,300	6.0	67,900	7.2	162,900	6.5	266,100
8N	3E	7,740	5.2	12,100	6.0	23,200	7.2	55,700	6.5	91,000
7N	1W	7,120	10.6	22,600	8.5	30,300	7.6	54,100	8.3	107,000
7N	1E	23,300	8.8	61,500	8.3	96,700	7.7	179,400	8.0	337,600
7N	2E	22,900	10.5	72,100	7.4	84,700	8.4	192,400	8.5	349,200
7N	3E	11,400	10.5	35,900	7.4	42,200	8.4	95,800	8.5	173,900
6N	1W	9,060	8.0	21,700	7.2	32,600	6.8	61,600	7.1	115,900
6N	1E	23,240	6.4	44,600	8.3	96,400	8.2	190,600	7.9	331,600
6N	2E	21,900	6.8	44,700	6.9	75,600	8.2	179,600	7.6	299,900
6N	3E	4,790	6.8	9,800	6.9	16,500	8.2	39,300	7.6	65,600
5N	1W	1,000	6.4	1,900	8.3	4,200	8.2	8,200	7.9	14,300
5N	1E	20,560	6.4	39,600	8.3	85,300	8.2	168,600	7.9	293,500
5N	2E	8,870	6.8	18,100	6.9	30,600	8.2	72,700	7.6	121,400
Total		221,490	7.8	521,100	7.9	874,800	7.8	1,733,000	7.8	3,128,900
Rounded total			7.8	521,000	7.9	875,000	7.8	1,733,000	7.8	3,129,000
Percent of total				17		28		55		100

Low plains south of American River (unit B2)

9N	5E	2,060	9.7	6,000	9.1	9,400	7.2	14,900	8.2	30,300
9N	6E	7,350	12.7	28,000	7.0	25,700	6.5	47,900	7.7	101,600
9N	7E	7,310	11.0	24,100	11.6	42,300	8.0	58,200	9.5	124,600
8N	4E	3,370	9.7	9,800	9.1	15,400	7.2	24,300	8.2	49,500
8N	5E	22,510	9.7	65,400	9.1	102,600	7.2	162,300	8.2	330,300
8N	6E	19,510	12.7	74,500	7.0	68,200	6.5	127,200	7.7	269,900
8N	7E	1,900	11.0	6,300	11.6	11,000	8.0	15,100	9.5	32,400
7N	5E	22,690	7.2	49,400	6.5	74,000	5.5	125,700	6.1	249,100
7N	6E	11,680	17.2	60,100	8.0	46,400	4.5	52,400	7.6	158,900
6N	5E	23,210	6.1	42,800	4.0	47,000	4.4	102,600	4.6	192,400
6N	6E	5,420	7.8	12,700	7.7	20,900	5.2	28,100	6.3	61,700
Total		127,010	9.9	379,100	7.3	462,900	6.0	758,700	7.0	1,600,700
Rounded total			9.9	379,000	7.3	463,000	6.0	759,000	7.0	1,601,000
Percent of total				24		29		47		100

TABLE 6.—*Estimated ground-water storage capacity by storage units and townships*—Continued

Location		Area (acres)	Depth zone, in feet							
			20–50		50–100		100–200		All zones 20–200	
T.	R.		Specific yield (percent)	Storage (acre-feet)	Specific yield (percent)	Storage (acre-feet)	Specific yield (percent)	Storage (acre-feet)	Specific yield (percent)	Storage (acre-feet)
Low plains south of the Bear River (unit B3)										
13N	4E	10,950	6.4	21,000	4.3	23,500	3.9	43,000	4.4	87,500
13N	5E	6,090	6.4	11,700	4.3	13,100	3.9	23,900	4.4	48,700
12N	4E	17,450	6.5	34,200	6.0	52,100	4.4	77,300	5.2	163,600
12N	5E	2,060	6.5	4,000	6.0	6,100	4.4	9,100	5.2	19,200
11N	4E	1,540	6.5	3,000	6.0	4,600	4.4	6,800	5.2	14,400
Total		38,090	6.5	73,900	5.2	99,400	4.2	160,100	4.9	333,400
Rounded total			6.5	74,000	5.2	99,000	4.2	160,000	4.9	333,000
Percent of total				22		30		48		100
Low plains south of the Dnnnigan Hills (nnit B4)										
11N	2W	4,650	4.0	5,600	4.2	9,700	6.7	31,100	5.5	46,400
11N	1W	3,100	4.3	4,000	6.0	9,200	8.3	25,800	7.0	39,000
10N	2W	4,870	4.2	6,100	5.4	13,100	8.3	40,300	6.8	59,500
10N	1W north	6,260	9.1	17,100	6.1	19,200	7.7	48,300	7.5	84,600
10N	1W south	4,000	5.7	6,800	6.0	12,000	4.2	16,800	4.9	35,600
9N	1W	17,560	6.1	32,100	6.6	58,100	8.4	148,200	7.5	238,400
9N	1E	5,240	12.4	19,500	10.5	27,500	11.2	59,000	11.2	106,000
Total		45,680	6.6	91,200	6.5	148,800	8.1	369,500	7.4	609,500
Rounded total			6.6	91,000	6.5	149,000	8.1	370,000	7.4	610,000
Percent of total				15		24		61		100

Low plains east of the Dunnigan Hills (unit B5)

11N	1W	1,040	6.8	2,100	6.1	3,200	6.9	7,200	6.7	12,500
11N	1E	15,560	7.7	35,900	7.9	61,800	6.9	107,700	7.3	205,400
11N	2E	10,660	6.2	19,900	11.0	58,500	8.3	88,100	8.7	166,500
10N	1E	13,030	12.1	47,300	9.8	63,600	10.1	131,600	10.3	242,500
10N	2E	22,000	8.6	57,100	8.4	92,800	8.6	189,400	8.6	339,300
9N	1E	7,240	10.5	22,800	7.1	25,800	8.0	57,700	8.2	106,300
9N	2E	21,510	6.7	43,300	6.7	72,500	7.8	167,100	7.3	282,900
Total		91,040	8.4	228,400	8.3	378,200	8.2	748,800	8.3	1,355,400
Rounded total			8.3	228,000	8.3	378,000	8.2	749,000	8.3	1,355,000
Percent of total				17		28		55		100

Alluvial fans, west side, Delevan to Zamora (unit B6)

17N	4W	2,570	5.4	4,200	4.1	5,200	4.6	11,700	4.6	21,100
17N	3W	7,690	5.4	12,500	4.1	15,600	4.6	35,100	4.6	63,200
16N	4W	6,400	5.4	10,400	4.1	13,000	4.6	29,200	4.6	52,600
16N	3W	11,920	5.4	19,400	4.1	24,200	4.6	54,400	4.6	98,000
15N	4W	5,130	6.4	9,800	6.2	16,000	3.8	19,700	4.9	45,500
15N	3W	19,610	6.4	37,500	6.2	61,200	3.8	75,300	4.9	174,000
15N	2W	2,410	6.8	4,900	5.0	6,000	5.2	12,500	5.4	23,400
14N	3W	4,440	5.7	7,600	6.0	13,400	7.6	33,600	6.8	54,600
14N	2W	18,340	4.9	26,700	5.1	46,800	6.6	120,700	5.9	194,200
14N	1W	1,230	4.9	1,800	5.1	3,200	6.6	8,100	5.9	13,100
13N	2W	15,130	7.2	32,900	8.7	65,700	7.5	113,500	7.8	212,100
13N	1W	17,780	5.4	29,100	7.6	67,300	8.1	144,200	7.5	240,600
12N	2W	990	9.6	2,900	4.1	2,000	6.3	6,300	6.3	11,200
12N	1W	15,180	6.1	27,600	6.6	50,000	6.5	98,100	6.4	175,700
12N	1E	910	6.7	1,800	4.8	2,200	5.7	5,200	5.6	9,200
Total		129,730	5.9	229,100	6.0	391,800	5.9	767,600	5.9	1,388,500
Rounded total			5.9	229,000	6.0	392,000	5.9	768,000	5.9	1,389,000
Percent of total				16		28		55		100

TABLE 6.—*Estimated ground-water storage capacity by storage units and townships*—Continued

Location: T.	Location: R.	Area (acres)	Depth zone, in feet: 20–50: Specific yield (percent)	20–50: Storage (acre-feet)	50–100: Specific yield (percent)	50–100: Storage (acre-feet)	100–200: Specific yield (percent)	100–200: Storage (acre-feet)	All zones 20–200: Specific yield (percent)	All zones 20–200: Storage (acre-feet)
Low plains north of the Bear River (unit B7)										
15N	4E	670	4.8	1,000	4.9	1,600	4.3	2,900	4.6	5,500
15N	5E	4,830	4.4	6,400	3.8	9,200	6.3	30,200	5.3	45,800
14N	3E	3,490	6.5	6,800	6.6	11,500	4.5	15,600	5.4	33,900
14N	4E	8,270	4.8	11,900	4.9	20,300	4.3	35,600	4.6	67,800
14N	5E	19,300	4.4	25,600	3.8	37,000	6.3	120,800	5.3	183,400
13N	4E	8,940	4.8	12,800	4.9	21,900	4.3	38,500	4.6	73,200
13N	5E	1,570	5.9	2,800	4.4	3,400	5.6	8,900	5.3	15,100
Total		47,070	4.8	67,300	4.5	104,900	5.4	252,500	5.0	424,700
Rounded total			4.7	67,000	4.5	105,000	5.4	253,000	5.0	425,000
Percent of total				16		25		59		100
Low plains west of Feather River (unit B8)										
18N	2E	8,370	5.1	12,800	6.1	25,400	3.3	56,800	5.3	94,900
18N	3E	6,270	8.1	15,200	7.0	21,800	5.9	37,200	6.6	74,200
17N	2E	11,970	5.2	18,600	5.6	33,400	4.0	48,000	4.6	100,000
17N	3E	4,060	5.2	6,300	5.6	11,300	4.0	16,300	4.6	33,900
Total		30,670	5.8	52,900	6.0	91,900	5.2	158,100	5.5	302,900
Rounded total			5.8	53,000	6.0	92,000	5.2	158,000	5.5	303,000
Percent of total				18		30		52		100

Alluvial plains enclosing Sutter Buttes (unit B9)										
17N	1E	2,100	4.9	3,100	5.8	6,100	3.7	7,800	4.5	17,000
17N	2E	1,580		2,300		4,600		5,800		12,700
16N	1E	2,240		3,300		6,500		8,300		18,100
16N	2E	3,540		5,200		10,300		13,100		28,600
15N	1E	1,780		2,600		5,200		6,600		14,400
15N	2E	4,690		6,900		13,600		17,400		37,900
Total		15,930	4.9	23,400	5.8	46,300	3.7	59,000	4.5	128,700
Rounded total			4.8	23,000	5.8	46,000	3.7	59,000	4.5	128,000
Percent of total				18		36		46		100
Chico Creek alluvial fan (unit B10)										
23N	1W	11,650	10.7	37,300	7.7	44,900	7.0	82,100	7.8	164,300
23N	1E	440	10.7	1,400	7.7	1,700	7.0	3,100	7.8	6,200
22N	1W	6,620	11.6	23,000	9.2	30,300	6.6	44,000	8.2	97,300
22N	1E	18,640	8.2	45,600	5.3	49,100	5.1	94,000	5.6	188,700
22N	2E	3,610	8.1	8,800	6.8	12,300	4.9	17,600	6.0	38,700
21N	1E	23,270	9.7	68,000	6.7	77,800	5.3	124,000	6.4	269,800
21N	2E	11,050	8.7	28,800	5.0	27,800	5.6	61,300	5.9	117,900
Total		75,100	9.4	212,900	6.5	243,900	5.7	426,100	6.5	882,900
Rounded total			9.5	213,000	6.5	244,000	5.7	426,000	6.5	883,000
Percent of total				24		28		48		100
Stony Creek alluvial fan (unit B11)										
23N	3W	2,860	10.2	8,700	9.2	13,100	8.9	25,400	9.2	47,200
23N	2W	7,200	10.2	21,900	9.2	33,000	8.9	63,900	9.2	118,800
23N	4W	1,890	12.1	6,900	7.9	7,400	6.4	12,100	7.8	26,400
22N	3W	22,740	12.1	82,600	7.9	89,400	6.4	145,300	7.8	317,300
22N	2W	21,700	12.6	82,300	13.1	141,900	8.7	189,200	10.6	413,400
21N	3W	22,840	13.2	90,300	8.6	98,800	6.8	155,800	8.4	344,900
21N	2W	23,010	12.2	84,500	13.9	160,100	11.0	254,300	12.0	498,900
20N	3W	22,830	10.3	70,500	10.2	116,400	9.0	205,200	9.5	392,100
20N	2W	19,680	9.1	53,700	10.6	103,900	10.2	201,500	10.1	359,100
19N	4W	7,770	6.6	15,500	6.2	23,900	4.5	35,000	5.3	74,400
19N	3W	20,500	6.6	40,900	6.2	63,100	4.5	92,500	5.3	196,500
19N	2W	3,240	6.6	6,500	6.2	10,000	4.5	14,600	5.3	31,100
18N	4W	2,920	6.6	5,800	6.2	9,000	4.5	13,200	5.3	28,000
13N	3W	3,[illegible]	6.6	13,[illegible]	6.2	20,500	4.5	30,000	5.3	63,800
Total		185,840	10.5	583,400	9.6	890,500	7.7	1,438,000	8.7	2,911,900
Rounded total			10.4	583,000	9.6	891,000	7.7	1,438,000	8.7	2,912,000
Percent of total				20		31		49		100

TABLE 6.—*Estimated ground-water storage capacity by storage units and townships*—Continued

Location		Area (acres)	Depth zone, in feet							
			20–50		50–100		100–200		All zones 20–200	
T.	R.		Specific yield (percent)	Storage (acre-feet)	Specific yield (percent)	Storage (acre-feet)	Specific yield (percent)	Storage (acre-feet)	Specific yield (percent)	Storage (acre-feet)
DISSECTED ALLUVIAL DEPOSITS										
Deposits south of American River (unit C1)										
9N	7E	11,880	9.3	33,200	12.2	72,200	10.9	130,000	11.0	235,400
8N	6E	3,360	6.4	6,400	4.2	7,000	5.8	19,300	5.4	32,700
8N	7E	20,760	6.4	39,700	4.2	43,300	5.8	119,400	5.4	202,400
7N	5E	330	6.4	600	4.2	700	5.8	1,900	5.4	3,200
7N	6E(W)	4,050	6.4	7,800	4.2	8,400	5.8	23,300	5.4	39,500
7N	6E(NE)	5,500	6.4	10,500	4.2	11,500	5.8	31,600	5.4	53,600
7N	6E(SE)	410	7.1	900	6.4	1,300	7.5	3,100	7.1	5,300
7N	7E(NW)	4,790	6.4	9,200	4.2	10,000	5.8	27,500	5.4	46,700
7N	7E(SE)	12,370	7.1	26,200	6.4	39,700	7.5	93,100	7.1	159,000
7N	8E	11,540	7.1	24,500	6.4	37,000	7.5	86,900	7.1	148,400
6N	6E	340	6.4	700	4.2	700	5.8	2,000	5.4	3,400
Total		75,330	7.1	159,700	6.2	231,800	7.1	538,100	6.9	929,600
Rounded total			7.1	160,000	6.2	232,000	7.1	538,000	6.9	930,000
Percent of total				17		25		58		100
Deposits south of Winters (unit C2)										
8N	1W	430	6.0	800	6.0	1,300	5.5	2,400	5.8	4,500
7N	1W	7,730	6.0	13,800	6.2	23,800	5.5	42,500	5.8	80,100
6N	1W	3,130	5.6	5,300	6.4	10,100	7.6	23,700	6.9	39,100
Total		11,290	5.9	19,900	6.2	35,200	6.1	68,600	6.1	123,700
Rounded total			5.9	20,000	6.2	35,000	6.1	69,000	6.1	124,000
Percent of total				16		28		56		100

Plainfield ridge (unit C3)										
10N	1E	450	4.3	600	4.3	1,000	6.1	2,700	5.3	4,300
9N	1E	11,230	5.4	18,100	5.0	28,400	4.8	54,000	5.0	100,500
8N	1E	3,550	7.6	8,000	5.4	9,600	5.0	17,600	5.5	35,200
Total		15,230	5.8	26,700	5.1	39,000	4.9	74,300	5.1	140,000
Rounded total			5.9	27,000	5.1	39,000	4.9	74,000	5.1	140,000
Percent of total				19		28		53		100
Deposits between American and Bear Rivers (unit C4)										
13N	5E	9,100	4.7	12,900	4.6	21,000	5.1	46,100	4.9	80,000
13N	6E	8,580	4.7	12,200	4.6	19,800	5.1	43,500	4.9	75,500
12N	4E	5,220	4.7	7,400	4.6	12,100	5.1	26,500	4.9	46,000
12N	5E	20,120	4.7	28,500	4.6	46,500	5.1	102,000	4.9	177,000
12N	6E	7,650	4.7	10,800	4.6	17,700	5.1	38,800	4.9	67,300
11N	4E	13,280	4.7	18,800	4.6	30,700	5.1	67,400	4.9	116,900
11N	5E	22,980	4.7	32,600	4.6	53,100	5.1	116,500	4.9	202,200
11N	6E	8,030	4.7	11,400	4.6	18,500	5.1	40,700	4.9	70,600
10N	4E	3,470	6.0	6,300	6.6	11,400	7.2	24,900	6.8	42,600
10N	5E	21,760	6.0	39,300	6.6	71,600	7.2	156,500	6.8	267,400
10N	6E	21,750	6.4	41,400	7.5	81,000	7.8	169,000	7.4	291,400
10N	7E	6,100	6.4	11,600	7.5	22,700	7.8	47,600	7.4	81,900
9N	5E	21,240	6.4	40,700	6.0	63,800	7.2	152,600	6.7	251,100
9N	6E	14,900	6.4	28,400	7.5	55,600	7.8	116,000	7.4	200,000
9N	7E	4,630	6.4	8,800	7.5	17,300	7.8	36,000	7.4	62,100
Total		188,810	5.5	311,100	5.8	542,800	6.3	1,184,100	6.0	2,038,000
Rounded total			5.5	311,000	5.8	543,000	6.3	1,184,000	6.0	2,038,000
Percent of total				15		27		58		100
Deposits south of Oroville (unit C5)										
19N	3E	700	6.5	1,400	5.5	1,900	5.2	3,600	5.5	6,900
19N	4E	2,170	6.5	4,200	5.5	5,900	5.2	11,300	5.5	21,400
18N	3E	2,470	6.5	4,800	5.5	6,800	5.2	12,800	5.5	24,400
18N	4E	10,480	6.5	20,300	5.5	28,700	5.2	54,500	5.5	103,500
17N	3E	260	4.0	300	7.0	900	3.8	1,000	4.7	2,200
17N	4E	9,150	4.0	10,800	7.0	31,900	3.8	35,100	4.7	77,800
16N	4E	7,730	4.0	9,200	7.0	27,000	3.3	29,700	4.7	65,[illegible]00
Total		32,960	5.2	51,000	6.3	103,100	4.5	148,000	5.1	302,100
Rounded total			5.2	51,000	6.2	103,000	4.5	148,000	5.1	302,000
Percent of total				17		34		49		100

TABLE 6.—*Estimated ground-water storage capacity by storage units and townships*—Continued

Location		Area (acres)	Depth zone, in feet							
			20–50		50–100		100–200		All zones 20–200	
T.	R.		Specific yield (percent)	Storage (acre-feet)	Specific yield (percent)	Storage (acre-feet)	Specific yield (percent)	Storage (acre-feet)	Specific yield (percent)	Storage (acre-feet)
Deposits west of Oroville (unit C6)										
19N	3E	8,990	7.0	18,900	8.5	38,400	7.1	63,500	7.5	120,800
Rounded total		8,990	7.0	19,000	8.5	38,000	7.1	64,000	7.5	121,000
Percent of total				16		31		53		100
Deposits north of Chico (unit C7)										
26N	2W	3,620	5.7	6,100	5.3	9,500	4.6	16,800	5.0	32,400
25N	2W	9,590	5.7	16,300	5.3	25,300	4.6	44,500	5.0	86,100
25N	1W	7,470	5.7	12,700	5.3	19,700	4.6	34,700	5.0	67,100
24N	2W	1,740	5.7	3,000	5.3	4,600	4.6	8,100	5.0	15,700
24N	1W	20,760	5.7	35,200	5.3	54,700	4.6	96,300	5.0	186,200
24N	1E	1,120	5.7	1,900	5.3	3,000	4.6	5,200	5.0	10,100
23N	1W	7,880	5.7	13,400	5.3	20,800	4.6	36,600	5.0	70,800
23N	1E	7,360	5.2	11,400	5.3	19,400	4.0	29,300	4.5	60,100
22N	1E	2,040	5.2	3,200	5.3	5,400	4.0	8,100	4.5	16,700
Total		61,580	5.6	103,200	5.3	162,400	4.5	279,600	4.9	545,200
Rounded total			5.6	103,000	5.3	162,000	4.5	280,000	4.9	545,000
Percent of total				19		30		51		100

Deposits on northwest side of valley (unit C8)

26N	3W	10,580	10.8	34,400	5.9	31,100	7.2	76,200	7.4	141,700
25N	3W	19,760	10.9	64,600	6.0	59,400	6.2	122,700	6.9	246,700
24N	4W	2,240	7.7	5,200	3.4	3,800	5.3	11,800	5.2	20,800
24N	3W	17,300	7.0	36,200	10.4	89,800	11.2	193,200	10.2	319,200
23N	3W	2,580	8.4	6,500	7.4	9,500	8.4	21,600	8.1	37,600
Total		52,460	9.3	146,900	7.4	193,600	8.1	425,500	8.1	766,000
Rounded total			9.3	147,000	7.4	194,000	8.1	426,000	8.1	767,000
Percent of total				19		25		56		100

BASIN DEPOSITS

Yolo Basin (unit D1)

11N	2E	1,950	3.3	2,000	5.7	5,500	11.6	22,700	8.6	30,200
10N	3E	13,070	3.3	13,100	5.7	37,200	11.6	152,400	8.6	202,700
9N	3E	21,730	5.3	34,400	5.3	57,400	8.3	179,800	6.9	271,600
9N	4E	1,090	5.3	1,700	5.3	2,900	8.3	9,000	6.9	13,600
8N	3E	15,430	3.0	13,900	6.2	47,400	5.9	91,700	5.5	153,000
8N	4E	5,580	5	8,800	5	14,600	8	46,800	6.7	70,200
7N	3E	11,240	5	16,900	5	28,100	8	89,900	6.7	134,900
7N	4E	6,620	5	9,900	5	16,600	8	53,000	6.7	79,500
6N	2E	1,280	5	1,900	5	3,200	8	10,200	6.7	15,300
6N	3E	18,350	5	27,500	5	45,900	8	146,800	6.7	220,200
Total		96,610	4.5	130,100	5.4	258,800	8.3	802,300	6.8	1,191,200
Rounded total			4.5	130,000	5.4	259,000	8.3	802,000	6.8	1,191,000
Percent of total				11		22		67		100

American Basin (unit D2)

12N	3E	2,320	4.6	3,200	5.1	5,900	7.7	17,800	6.4	26,900
11N	3E	5,450		7,600		13,800		41,900		63,300
11N	4E	7,920		11,000		20,000		60,800		91,800
10N	4E	15,390		21,400		38,900		118,000		178,300
9N	4E	10,190		14,200		25,800		78,300		118,300
Total		41,270	4.6	57,400	5.1	104,400	7.7	316,800	6.4	478,600
Rounded total			4.6	57,000	5.0	104,000	7.7	317,000	6.4	478,000
Percent of total				12		22		66		100

TABLE 6.—*Estimated ground-water storage capacity by storage units and townships*—Continued

Location		Area (acres)	Depth zone, in feet							
			20–50		50–100		100–200		All zones 20–200	
T.	R.		Specific yield (percent)	Storage (acre-feet)	Specific yield (percent)	Storage (acre-feet)	Specific yield (percent)	Storage (acre-feet)	Specific yield (percent)	Storage (acre-feet)
Colusa Basin (unit D3)										
20N	2W	1,840	4.6	2,600	3.4	3,100	5.7	10,500	4.9	16,200
19N	3W	2,670		3,700		4,600		15,300		23,600
19N	2W	13,660		19,000		23,400		78,300		120,700
18N	3W	16,600		23,100		28,400		95,100		146,600
18N	2W	15,370		21,300		26,300		88,100		135,700
17N	3W	15,570		21,600		26,600		89,200		137,400
17N	2W	14,520		20,200		24,800		83,200		128,200
16N	3W	10,970		15,200		18,800		62,900		96,900
16N	2W	16,250		22,600		27,800		93,100		143,500
15N	3W	2,340		3,200		4,000		13,400		20,600
15N	2W	20,670		28,700		35,300		118,400		182,400
14N	2W	4,460		6,200		7,600		25,600		39,400
14N	1W	11,290		15,700		19,300		64,700		99,700
14N	1E	1,070		1,500		1,900		6,100		9,500
13N	1W	4,990		6,900		8,500		28,600		44,000
13N	1E	12,960		18,000		22,200		74,300		114,500
12N	1E	17,830		24,800		30,500		102,000		157,300
12N	2E	2,880		4,000		4,900		16,500		25,400
11N	1E	3,410		4,730		5,800		19,500		30,[illegible]
11N	2E	6,290		8,700		10,800		36,100		55,[illegible]
Total		195,640	4.6	271,700	3.4	334,600	5.7	1,120,900	4.9	1,727,200
Rounded total			4.6	272,000	3.4	335,000	5.7	1,121,000	4.9	1,728,000
Percent of total				16		19		65		100

Sutter Basin (unit D4)

15N	1E	10,400	5.5	17,200	5.2	26,800	(1)	(1)	5.3	44,000
15N	2E	6,990		11,600		18,000				29,600
14N	1E	4,290		7,100		11,000				18,100
14N	2E	23,250		38,400		59,900				98,300
14N	3E	4,410		7,300		11,400				18,700
13N	2E	20,800		34,400		53,600				88,000
13N	3E	12,990		21,500		33,400				54,900
12N	2E	13,310		22,000		34,300				56,300
12N	3E	12,720		21,000		32,800				53,800
11N	2E	850		1,400		2,200				3,600
11N	3E	4,500		7,400		11,600				19,000
Total		114,510	5.5	189,300	5.2	295,000			5.3	484,300
Rounded total			5.5	189,000	5.2	295,000			5.3	484,000
Percent of total				39		61				100

[1] Excluded because of high salinity ground water.

Butte Creek lowland (unit D5)

20N	1E	22,290	5.6	37,200	5.0	55,500	4.3	98,200	4.8	190,900
20N	2E	20,380	7.9	48,200	5.4	54,600	7.0	142,000	6.7	244,800
20N	3E	2,520	7.9	6,000	5.4	6,700	7.0	17,600	6.7	30,300
19N	1E	23,160	5.1	35,400	4.6	52,700	4.3	100,000	4.5	188,100
19N	2E	24,000	5.1	36,600	4.6	54,600	4.3	104,000	4.5	195,200
18N	1W	3,760	5.1	5,700	4.6	8,600	4.3	16,200	4.5	30,500
18N	1E	23,560	5.1	36,000	4.6	53,600	4.3	101,800	4.5	191,400
18N	2E	14,680	5.1	22,400	4.6	33,400	4.3	63,400	4.5	119,200
17N	1W	11,640	5.1	17,800	4.6	26,500	4.3	50,300	4.5	94,600
17N	1E	19,260	5.1	29,400	4.6	43,800	4.3	83,200	4.5	156,400
17N	2E	6,820	5.1	10,400	4.6	15,500	4.3	29,500	4.5	55,400
16N	1W	11,530	5.1	17,600	4.6	26,200	4.3	49,800	4.5	93,600
16N	1E	900	5.1	1,400	4.6	2,000	4.3	3,900	4.5	7,300
Total		184,500	5.5	304,100	4.7	433,700	4.7	859,900	4.8	1,597,700
Rounded total			5.5	304,000	4.7	434,000	4.7	860,000	4.8	1,598,000
Percent of total				19		27		54		100

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