Geologic Control of Mineral Composition of Stream Waters of the Eastern Slope of the Southern Coast Ranges California

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1535-B

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By G. H. DAVIS

GEOCHEMISTRY OF WATER

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GEOLOGIC CONTROL OF MINERAL COMPOSITION OF STREAM WATERS OF THE EASTERN SLOPE OF THE SOUTHERN COAST RANGES, CALIFORNIA

By G. H. Davis

ABSTRACT

Chemical analyses of waters of streams that drain the semiarid eastern slope of the southern Coast Ranges in California demonstrate that differences in the anion composition, especially in the ratio of bicarbonate to sulfate, are related chiefly to the lithologic character of the rocks exposed in the tributary drainage area.

Where more than half the drainage area of a typical eastern-slope stream is underlain by clastic marine sedimentary rocks of Jurassic and Cretaceous age, bicarbonate generally predominates over sulfate; the ratio of bicarbonate to sulfate, both expressed in equivalents per million, in samples of the streams at low-flow stage ranges from 0.8 to 6. Conversely, where more than half the drainage area is underlain by marine and continental deposits of Tertiary age and continental deposits of Quaternary age, sulfate predominates over bicarbonate, and the ratio of bicarbonate to sulfate in samples taken during the low-flow stage ranges from 0.02 to 0.7.

Organic siliceous marine shale of Tertiary age deposited in a reducing environment is probably the primary source of sulfate in the region. Secondary deposits of sulfate minerals, chiefly gypsum, which are abundant in the continental deposits of late Tertiary and Quaternary age, also contribute sulfate to the stream waters.

INTRODUCTION

Chemical analyses of waters of the streams that drain the semiarid eastern slope of the southern Coast Ranges of California indicate that, despite similarities of climate and distribution of precipitation in the several drainage basins, the chemical character of the stream waters differs greatly. Bicarbonate predominates over the other anions in many of the waters and sulfate predominates in other waters; chloride predominates only in the waters of two streams.

This paper shows that, contrary to an assumption commonly made for stream waters, the chemical character of the waters of typical streams in the southern Coast Ranges is determined less by climatic influences than by the lithologic character of the rocks exposed in the drainage basins.

Chemical analyses of samples from most of the principal streams and from many of the minor streams of the eastern slope of the southern Coast Ranges are presented in table 2. Determinations are given of the principal cations—calcium, magnesium, and sodium—and the principal anions—bicarbonate, carbonate, sulfate, and chloride—and for most samples of boron as well.

Silica, potassium, fluoride, nitrate, iron, and aluminum were determined also in many of the analyses. However, these constituents, which were generally present in relatively small concentration, and the pH were omitted from table 2 because they showed little relation to the geology of the drainage basin.

In figure 4, the analyses are compared to the percentages of different geologic units exposed in the respective drainage areas (table 1), which were determined by planimeter from the "Geologic Map of California" (Jenkins, 1938; Kundert, 1955).

ACKNOWLEDGMENTS

The writer wishes to express his gratitude to his colleagues of the U.S. Geological Survey who have offered many helpful suggestions and criticisms. Special thanks are due Messrs. William Back and D. E. White for their constructive advice on the geochemical features. None of these men, however, should be held responsible for the author's interpretations and conclusions.

PHYSIOGRAPHY AND CLIMATE

The southern Coast Ranges comprise the coastal mountains of California extending from San Francisco Bay southward 250 miles where they are terminated by the Transverse Ranges. The southern Coast Ranges are characterized by longitudinal ranges rising 2,000 to 6,000 feet above sea level, and by intervening valleys trending generally N. 30°–40° W. Folding and faulting control the trend of the ranges. The easternmost ranges, which include the area discussed in this report, are the Diablo Range, which extends from San Francisco Bay to Polonio Creek (fig. 1), and the Temblor Range, in echelon to the Diablo Range, which extends southward from Polonio Creek to the Transverse Ranges.

The topography of the Diablo and Temblor Ranges is controlled largely by faulting and folding in rocks of Cenozoic, Cretaceous, and Jurassic age. The drainage basins of the eastern slope of the ranges are characterized by rugged hills and steep stream gradients. Along the east border of the Coast Ranges the sediments dip steeply beneath the San Joaquin Valley, thus forming an abrupt boundary that virtually lacks transitional foothills.

Precipitation in the Coast Ranges and San Joaquin Valley generally decreases southward and with declining altitude in the eastern part of the mountains and adjoining valley areas. The average annual precipitation on the west side of the San Joaquin Valley ranges from about 5 inches at Buttonwillow near the south end of the valley to about 9½ inches at Tracy at the north end. Precipitation in the mountains differs greatly with altitude. At Priest Valley (altitude 2,400 feet) about 22 miles west of Coalinga, the average seasonal (October through September) precipitation is 19.56 inches, but at Buttonwillow (altitude 295 feet) on the floor of the San Joaquin Valley, the seasonal total is only 4.88 inches.

ROCKS OF THE EASTERN SLOPE OF THE SOUTHERN COAST RANGES

The drainage basins of the eastern slope of the southern Coast Ranges are underlain chiefly by sedimentary rocks ranging in age from Late Jurassic to Quaternary. Volcanic rocks are present, chiefly in the Franciscan formation of Jurassic and Cretaceous age; locally, ultramafic intrusive rocks, largely serpentinized, are closely associated with the Franciscan formation. Near the contacts of the intrusive rocks with the Franciscan formation, the Franciscan has been altered into many varieties of metamorphic rocks.

The rocks of the area may be conveniently subdivided into five generalized units as shown in the following table: the Franciscan formation of Jurassic and Cretaceous age, ultramafic rocks intrusive

Generalized geologic unit	Formations and age
Continental deposits of Tertiary and Quaternary age	Older alluvium (Recent? and Pleistocene), terrace deposits (Pleistocene), Tulare formation (Pleistocene? and Pliocene), continental deposits of the McKittrick group.
Marine sedimentary rocks of Tertiary age	San Joaquin, Etchegoin, and Jacalitos formations, (Pliocene); San Pablo formation, Neroly formation, Cierbo sandstone, Santa Margarita sandstone, Temblor formation, Reef Ridge shale, Monterey formation, and Vaqueros sandstone (Miocene); Kreyenhagen shale (Oligocene and Eocene); Domengine sandstone, Avenal sandstone, and Tejon formation (Eocene); Lodo formation (Eocene and Paleocene; and Martinez formation (Paleocene).
Marine sedimentary rocks of Cretaceous age	Moreno shale (Paleocene? and Upper Cretaceous) and Panoche formation (Upper Cretaceous).
Ultramafic intrusive rocks	Serpentine (post-Franciscan)
Franciscan formation	Franciscan formation (Cretaceous and Jurassic), locally includes small bodies of post-Franciscan ultramafic intrusive rocks

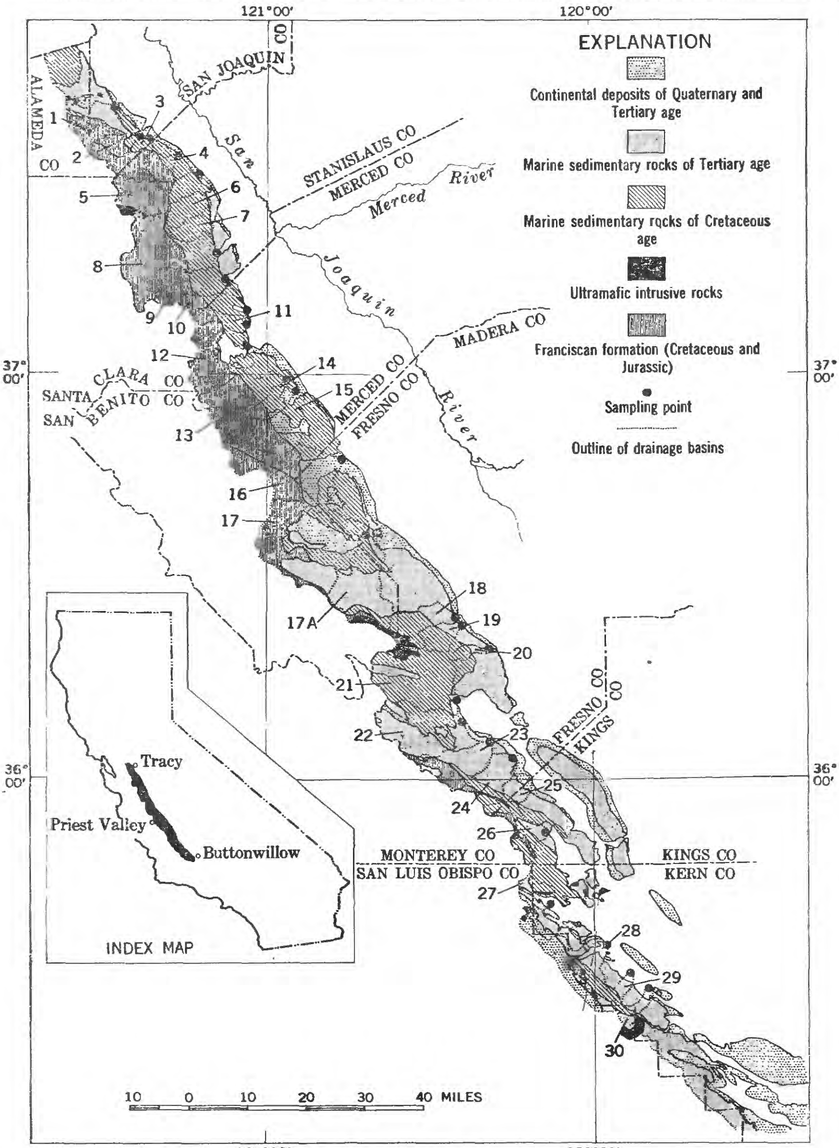
into the Franciscan formation, marine sedimentary rocks of Cretaceous age, marine sedimentary rocks of Tertiary age, and continental deposits of late Tertiary and Quaternary age. The areal distribution of these simplified geologic units in the principal drainage basins is shown on figure 1 and the areas, determined by planimeter, are shown in table 1.

The Franciscan formation and sedimentary rocks of Cretaceous age predominate in the northern part of the area, but younger deposits underlie a greater part of the area from Panoche Creek southward. This distribution influences the geochemistry of the stream waters, determining not only the percentage composition but also the total mineral concentration of the waters.

The Franciscan formation consists of a heterogeneous but characteristic assemblage of shallow marine clastic, chemical, and organic sediments and mafic volcanic rocks. Although composed chiefly of sandstone, shale, and mafic volcanic rocks, it contains also minor amounts of chert, limestone, glaucophane schist, and actinolite schist. According to Taliaferro (1943, p. 123), the lower part of the Franciscan consists largely of arkosic sandstone, thin subordinate shale partings, a few basalt flows, and lenses of radiolarian chert; the upper part consists of the same type of sandstone, but it contains more shale partings, basalt flows, and lenses of chert. The bulk of the formation is sandstone that contains 30 to 60 percent orthoclase and plagioclase feldspar.

The ultramafic rocks intrusive into the Franciscan formation are commonly called serpentine, because they have been almost completely altered to minerals of the serpentine group. In outcrops where the primary textures and minerals are evident, Walker and Griggs (1953, p. 45) have identified peridotite, saxonite, dunite, lherzolite, and pyroxenite among the parent rocks. As these rocks are composed chiefly of magnesium silicates, they constitute a major source of magnesium in the stream waters.

The Cretaceous rocks underlying the eastern slope of the southern Coast Ranges consist chiefly of shale and sandy shale, sandstone containing conglomerate members, and, locally, thin limestone beds most of which were referred to the Panoche formation by Anderson and Pack (1915, p. 39–46). According to Reed (1933, p. 98), the rocks of Cretaceous age are remarkably similar throughout the area. As in the sandstone of the Franciscan formation, the Cretaceous sandstone has a high proportiòn of feldspar. A notable exception to the general lithology of the rocks of Cretaceous age is the Moreno shale (Paleocene? in part), which is predominantly siliceous organic shale and partly diatomaceous. North of Coalinga it ranges in thickness from 1,000 to 2,000 feet and includes the uppermost Creta-



DRAINAGE BASINS

1	Corral Hollow Creek	12	San Luis Creek	21	Los Gatos Creek
2	Lonetree Creek	13	Los Banos Creek	22	Warthan Creek
3	Hospital Creek	14	Salt Creek	23	Jacalitos Creek
4	Ingram Creek	15	Ortigalita Creek	24	Zapato Creek
5	Del Puerto Creek	16	Little Panoche Creek	25	Canoas Creek
6	Salado Creek	17	Panoche Creek	26	Avenal Creek
7	Crow Creek	17A	Silver Creek	27	Polonio Creek
8	Orestimba Creek	18	Cantua Creek	28	Bitterwater Creek
9	Garzas Creek	19	Salt Creek	29	Media Agua Creek
10	Quinto Creek	20	Domengine Creek	30	Carneros Creek
11	Romero Creek				

FIGURE 1.—Generalized geologic map of the eastern slope of the southern Coast Ranges, Calif.

ceous strata that crop out along the east flank of the Diablo Range. The Moreno shale includes clay shale of clastic origin, organic siliceous shale, diatomite, sandstone, and conglomerate.

Anderson and Pack (1915, p. 46), in discussing the Moreno, noted its typically organic character at the type section and in the area from Coalinga northward to Pacheco Pass near San Luis Creek, and concluded that the organic siliceous deposits were formed during a time when physical conditions were different from those prevailing during the rest of Cretaceous time. North of Pacheco Pass the Moreno comprises beds somewhat different lithologically from those south of the pass. Although the beds of the Moreno in the northern area consist of predominantly shaly materials, they contain less organic material, and are more like the argillaceous shale of the Panoche formation. According to Anderson and Pack (1915, p. 55), the shale that appears to be of organic origin north of Pacheco Pass is predominantly carbonaceous clay shale, as distinguished from the typical siliceous organic shale of the Moreno to the south.

The marine sedimentary rocks of Tertiary age include deposits ranging in age from Paleocene to Pliocene. As compared to the older rocks, they are characterized by rapid changes in character over short distances and by a greater proportion, at least in parts of the section, of organic deposits. As shown in figure 1, the Tertiary marine sediments form a narrow discontinuous ribbon of outcrops flanking the east border of the Diablo Range from Little Panoche Creek northward. They are more widely exposed from Panoche Creek southward, and in the Temblor Range the total area in which the younger rocks crop out is greater than that of older rocks.

The marine sedimentary rocks of early Tertiary age are similar in many respects to the sedimentary rocks of Cretaceous age. Arkosic sandstone, commonly containing as much as 50 percent feldspar, and sandy or silty shale, commonly micaceous, make up most of the early Tertiary section. In parts of the area, however, distinctive organic siliceous sediments of the Kreyenhagen shale (Eocene and Oligocene), as much as 2,000 feet thick, constitute fully half the early Tertiary rocks. Von Estorff (1930, p. 1321-1336) reports that the Kreyenhagen, in addition to the preponderant siliceous shale, also contains feldspathic sandstone near the base and quartzitic sandstone interbedded with shale at higher horizons. The siliceous shale contains calcite, very fine quartz and feldspar grains, carbonized wood fragments, and scattered radiolarians. Remains of diatoms, not found at the type section south of Coalinga, are reportedly plentiful north of Coalinga. Foraminiferal tests make up a substantial part of the lower beds of the Kreyenhagen at the type locality; fish scales, mollusk shells, and, rarely, leaf imprints also are found.

TABLE 1.—*Areas*[1] *of generalized geologic units within stream basins*

Drainage basin (fig. 1)	Creek	Drainage area (square miles)	Area, in percent, occupied by indicated geologic unit				
			Franciscan formation	Ultramafic intrusive rocks	Marine sedimentary rocks of Cretaceous age	Marine sedimentary rocks of Tertiary age	Continental deposits of Tertiary and Quaternary age
1	Corral Hollow	59	59	0	3	38	0
2	Lonetree	20	69	0	19	12	0
3	Hospital	33	81	0	19	0	0
4	Ingram	20	69	0	31	0	0
5	Del Puerto	69	67	6	24	3	0
6	Salado	26	5	0	93	2	0
7	Crow	21	0	0	98	2	0
8	Orestimba	125	74	2	24	0	0
9	Garzas	51	51	0	49	0	0
10	Quinto	29	35	0	65	0	0
11	Romero	22	51	0	49	0	0
12	San Luis	85	67	0	17	0	16
13	Los Banos	132	81	0	16	3	0
14	Salt (Merced County)	26	26	0	55	0	19
15	Ortigalita	60	43	0	33	0	24
16	Little Panoche	103	41	0	25	0	34
17	Panoche (includes Silver Creek)	298	17	0	26	42	15
17A	Silver	102	2	5	26	65	2
18	Cantua	48	0	13	52	35	0
19	Salt (Fresno County)	25	0	0	68	32	0
20	Domengine	11	0	0	59	41	0
21	Los Gatos	127	0	6	84	10	0
22	Warthan	110	3	0	34	59	4
23	Jacalitos	60	34	0	5	61	0
24	Zapato	47	5	0	40	50	5
25	Canoas	20	0	0	19	65	16
26	Avenal	45	12	4	61	23	0
27	Polonio	12	0	0	47	53	0
28	Bitterwater	95	0	0	17	31	51
29	Media Agua	12	0	0	32	55	14
30	Carneros	15	0	0	16	66	18

[1] Areas and percentages based on them are approximate; determined by planimeter from "Geologic Map of California" (Jenkins, 1938; Kundert, 1955).

Marked and abrupt lateral lithologic variations and a scarcity of megafossils have complicated the problems of mapping and correlating the Miocene sedimentary rocks of the southern Coast Ranges. In general the lower Miocene consists largely of clastic sediments; arkosic sandstone is dominant near the base, and the rocks decrease in average grain size and become mudstone in the upper part of the lower Miocene. Calcareous shale and mudstone are common in the lower part of the middle Miocene, and siliceous rocks become more common and widespread in the upper part of the middle Miocene and in the upper Miocene. These siliceous rocks, known in the past by local names, were grouped into a single unit, the Monterey formation, by Bramlette (1946, p. 3). The siliceous rocks locally include thick diatomaceous members, more widespread and generally thicker members of hard but not very dense silica-cemented rocks called porcelanite and porcelaneous shale, and larger amounts of hard, dense siliceous rocks classified as chert and cherty shale.

Bramlette (1946, p. 36) reports that strata which may be termed "bituminous shale" because of their high content of organic matter are common in several areas. Thin sections of dark unweathered siliceous rocks show many small areas of dark-brown organic matter either disseminated or concentrated in definite laminae. Black iron sulfide also has been recognized in thin sections, but it is usually less abundant than organic matter, although the two are likely to be associated.

Marine sediments commonly as much as 10,000 feet thick make up much of the Pliocene section in the southern Coast Ranges. The lower part of the Pliocene section consists chiefly of sandstone, conglomerate, and silt of the Jacalitos formation. The sand beds have been described by Bramlette (1934, p. 1570) as being largely of pyroclastic volcanic origin. They contain abundant fresh andesine, altered volcanic glass, and ferromagnesian minerals. Above the Jacalitos formation, the Etchegoin formation consists of sand, sandy silt, and some clay also rich in volcanic detritus. This unit is in turn overlain by the San Joaquin formation, which is generally finer grained than the earlier Pliocene deposits and consists of strata of silt and clay, generally lacking in marine fossils, alternating with strata of silt, sandstone, and conglomerate, commonly containing marine fossils.

No marine beds younger than the San Joaquin formation of late Pliocene age have been recognized. The youngest deposits of Pliocene age in the area are continental deposits in the lower part of the Tulare formation, which in the upper part includes sediments of probable Pleistocene age and exhibits no marked discontinuity of sedimentation (Woodring and others, 1940).

The continental deposits of late Tertiary and Quaternary age include all the deposits above the youngest marine deposits of the eastern Coast Ranges. From Los Gatos Creek south to near Polonio Creek, late Pliocene marine deposits are present; therefore, the overlying continental deposits locally are chiefly of Quaternary age. Elsewhere along the flanks of the Coast Ranges, continental deposits may represent deposition during early Pliocene and even Miocene time. These deposits consist generally of poorly sorted silty materials enclosing lenses of poorly sorted sand and gravel. They are characterized by a high proportion of early Tertiary detritus. At Elk Hills the lower part of the continental sediments (Tulare formation) is characterized by deposits that indicate deposition under reducing conditions suggestive of a swampy or lacustrine environment. Elsewhere the exposed continental deposits usually indicate deposition under oxidizing conditions. Locally, limy or marly beds are present in the nonmarine section, and in some areas the continental deposits contain much reworked gypsum and a few deposits of bedded gysum. Gypsum deposits found in Quaternary continental deposits have been described by Ver Planck (1952, p. 47–59). In most areas the gypsum appears to have been precipitated from lakes or swampy areas, but locally, deposition may have resulted from evaporation of rising ground water.

GEOCHEMISTRY OF THE SURFACE WATERS

The chemical quality of the surface waters of the eastern slope of the Coast Ranges can be closely, though not perfectly, correlated with the geologic units exposed in the drainage basins. Table 1 shows the areal extent of 31 drainage basins and the percentage of the total area of each that is underlain by the 5 generalized rock units. The areas were determined by planimeter from the "Geologic Map of California" (Jenkins, 1938) in the area north of lat 36° N., and from the preliminary edition (Kundert, 1955) of the new "Geologic Map of California" in the area south of lat 36° N.

The writer recognizes that comparison of the chemistry of the stream waters to the areal extent of the simplified geologic units may involve considerable error because of lithologic differences within the generalized units. However, lacking detailed geologic maps of all the areas compared, the writer believes that this treatment gives a more uniform, less statistically biased approach than if detailed geologic information were used in some basins and generalized geologic units in others.

In general, sulfate is the predominant anion in runoff from terranes underlain by deposits of Tertiary and Quaternary age, and the water has a higher total mineral content than water from terranes underlain by Cretaceous and older rocks. The surface waters derived from areas underlain by rocks of Cretaceous age and by the Franciscan formation (Jurassic and Cretaceous) generally are characterized by a high proportion of bicarbonate as compared to sulfate. Where substantial bodies of serpentinized ultrabasic rocks are exposed, the stream waters are characterized by a high proportion of magnesium as compared to the other cations.

RELATION OF MINERAL CONTENT TO DISCHARGE

The waters of the streams of the eastern Coast Ranges are made up of varying proportions of direct runoff and ground-water discharge. At high flow much of the discharge consists of direct runoff, but at low flow the discharge consists chiefly of ground-water discharge.

Rainfall that runs off directly has relatively little opportunity to dissolve mineral matter, and thus to increase the slight chemical content of the rainwater itself. However, water that enters the soil and percolates to the ground-water reservoir reacts with mineral matter in the soil and the underlying rocks and may take much additional mineral matter into solution.

Many of the streams of the eastern slope of the Coast Ranges show a consistent relationship between discharge and the dissolved-solids content of the water. Figure 2 shows semilogarithmic plots of dissolved-solids content, in parts per million (ppm), versus discharge, in cubic feet per second (cfs), for all the streams for which adequate analyses were available. The waters of Corral Hollow, Orestimba, Quinto, San Luis, and Los Banos Creeks contained less than about 800 ppm of dissolved solids and bicarbonate generally predominated over sulfate. The waters of Little Panoche and Panoche Creeks generally contained from 500 to 5,000 ppm of dissolved solids, and chloride and sulfate were the predominant anions, respectively.

The plots of the waters of the streams characterized by high bicarbonate (fig. 2) fell fairly close to the curve for each stream, and the type curves of most of the streams had about the same slope. The waters of Corral Hollow and Los Banos Creeks showed the steepest type curves; that is, the rate of decrease in concentration with increasing discharge was greater than for the other stream waters. In this connection it may be significant that these two streams both contain a higher percentage of sulfate at low flow than the other streams of the group.

The plots of the waters of Little Panoche and Panoche Creeks have a greater scatter and steeper slope than the bicarbonate waters. In general, the plots of the waters of both streams fall fairly close to a type curve, except for two points for each stream that repre-

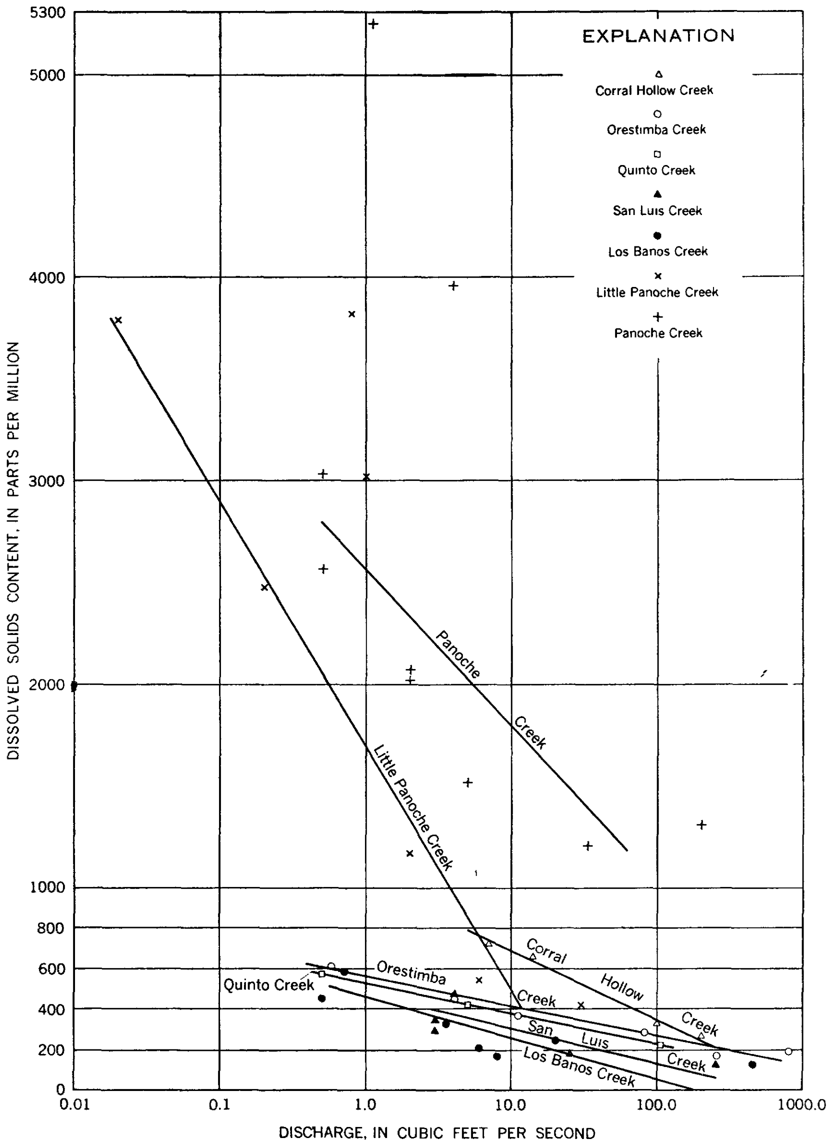


FIGURE 2.—Relation of the mineral content of water to the discharge of several streams, eastern slope of the southern Coast Ranges.

sented concentrations of dissolved solids much higher than the stage warranted. It is possible that these anomalous points represent errors in estimates of discharge; however, it is more likely that the waters were atypical initial flows sampled at the beginning of a period of increased flow when the water was enriched by solution of salts precipitated in the streambed during a previous period of low flow and extensive precipitation of salts by evaporation. Because all the other points for both streams plot fairly close to a straight line on the semilogarithmetic graph, the type curves were drawn without reference to the anomalous points described above.

The water analyses used to show the relationship between discharge and concentration (fig. 2) may be used also to illustrate the relationship between discharge and chemical character of the stream waters. Figure 3 is a geochemical graph that illustrates the chemical character of the waters of three typical streams, Orestimba, Los Banos, and Little Panoche Creeks, at various stages of flow. On these graphs are plotted the percentage of total equivalents per million (percentage reacting values) of the principal constituents of the water; the cations are in the lower left triangle and the anions are in the lower right triangle. The single-point plots in the diamond field indicate the general chemical character of the waters. The diagram is one utilized and described by Piper (1945).

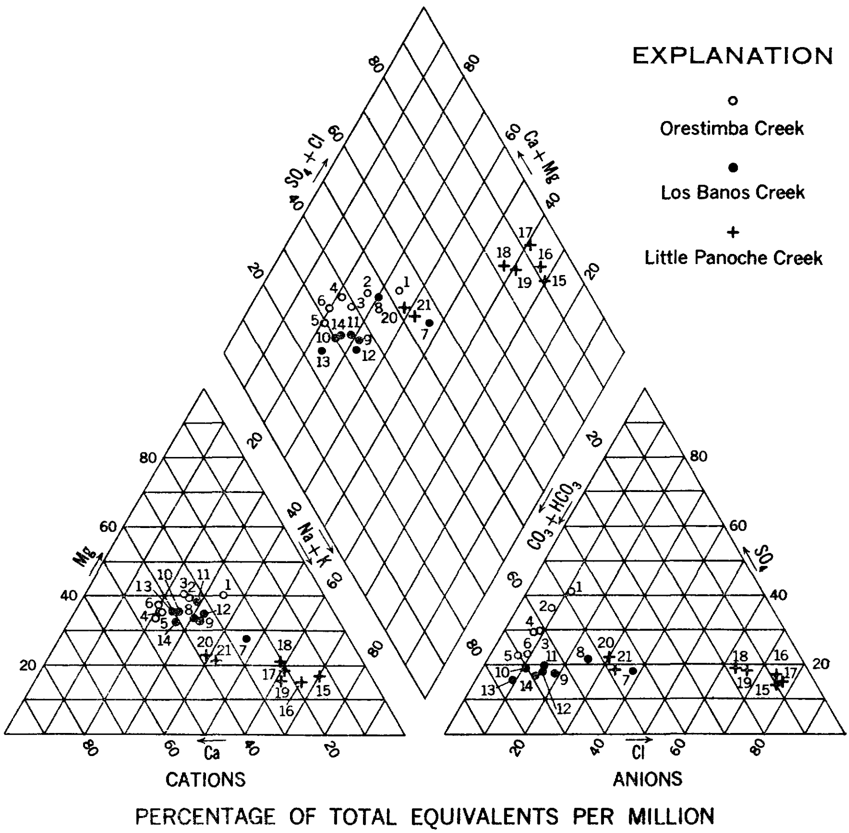


Figure 3.—Chemical character of water from Orestimba, Los Banos, and Little Panoche Creeks at different stages of flow. See also table on following page.

Sample	Date	Dissolved solids (ppm)	Discharge (cfs)
ORESTIMBA CREEK			
1	4-21-54	609	0. 58
2	1-27-53	449	4. 2
3	1- 7-52	363	11. 0
4	1-30-52	286	82. 0
5	1-26-56	195	800. 0
6	12-31-55	174	253. 0
LOS BANOS CREEK			
7	4-20-54	583	0. 72
8	4-11-56	455	. 5
9	1-30-53	335	------------
10	5- 3-55	327	3. 5
11	1-30-52	244	20. 0
12	1- 8-52	204	6. 0
13	3-20-52	164	8. 0
14	12-31-55	128	450. 0
LITTLE PANOCHE CREEK			
15	4-10-56	3, 020	1. 0
16	1-27-54	3, 820	. 81
17	5-22-30	3, 790	. 02
18	2- 9-52	2, 480	. 2
19	1- 7-52	1, 170	2. 0
20	3-19-52	541	6. 0
21	1-26-56	422	30. 0

The streams for which adequate analyses and discharge measurements of representative flows are available indicate significant changes in character as well as concentration with changes in flow. In most of the waters, as the discharge increases the percentage reacting values of bicarbonate and carbonate increase and those of sulfate and chloride decrease. This trend implies that the ground-water contribution to the streamflow has a higher sulfate and chloride content than the contributions of direct runoff. Generally, these systematic changes are more pronounced in the anion composition, but in some streams the cation composition also shows marked changes in proportion. Particularly good examples are the plots for Little Panoche Creek, in which increases in flow result in an increase in the proportion of bicarbonate and a relatively large decrease in the proportion of chloride and, among the cations, a relative increase in calcium and a large relative decrease in sodium.

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RELATION OF CHEMICAL CHARACTER TO GEOLOGY

As described earlier, the streams contain a greater proportion of ground water at low flow than at high flow. The ground water reacts chemically with the rock minerals and is thereby altered in chemical character when it percolates through the ground. Hence, ground water is more influenced by the mineral content of the rocks than is water that runs off directly to the streams. Therefore, analyses of the water at low flow, as available, were used to illustrate the relation of chemical character of the stream waters to the geology of tributary drainage basins.

Table 1 lists the main streams along the east flank of the Coast Ranges and the percentage of the respective drainage areas underlain by the generalized geologic units in each basin. Figure 4, a semilogarithmic plot of 22 stream waters for which low-flow analyses are available, shows the relationship of the percentage of the respective drainage basins underlain by rocks of Jurassic and Cretaceous age to the ratio of bicarbonate (HCO_3) to sulfate (SO_4) in the waters of the streams.

The term "low flow" as used herein is arbitrarily defined as flow of less than 0.15 cfs per square mile of tributary drainage basin. Thus, the 22 plots of figures 4 and 6 include analyses from all streams sampled at flows below this limit. Where several samples were available in the low-flow range, the most concentrated sample was used in figures 4 and 6. Of the 22 plots, 19 are supported by discharge records; 3 are inferred to represent low flows: Salt Creek (Merced County) and Domengine Creek because of their high concentration, and Quinto Creek because the next most concentrated sample nearly qualified as representing the low-flow stage. The 8 streams of table 1 that are not shown on figure 4 were omitted for the following reasons: Salado, Crow, and Ortigalita Creeks because no analyses were available; Jacalitos Creek because the sample was taken downstream from the Jacalitos oil field and therefore was probably contaminated by waste water; and Lonetree, Hospital, Ingram, and Garzas Creeks because the lowest flows sampled all exceeded 0.25 cfs per square mile.

On figure 5 the HCO_3-SO_4 ratios of the samples of figure 4 have been plotted against the yield of the drainage basins in cubic feet per second per square mile. Most of the points lie along the baseline indicating yields of less than 0.01 cfs per square mile; a few other points are scattered in random fashion. The graph indicates that the HCO_3-SO_4 ratio is virtually independent of the yield of the drainage basin.

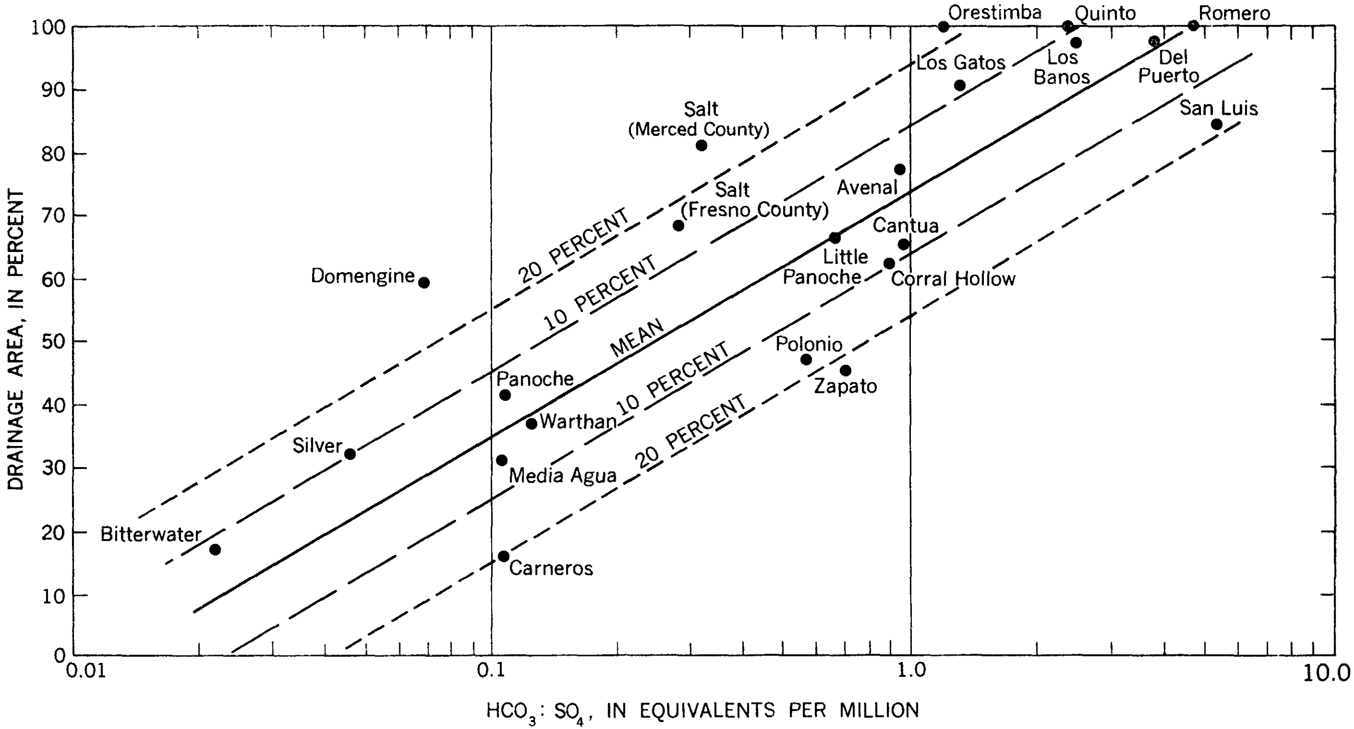

FIGURE 4.—Relation of percentage of drainage basin underlain by rocks of Jurassic and Cretaceous age to the HCO_3-SO_4 ratio in samples from streams at low-flow stage, eastern slope of the southern Coast Ranges.

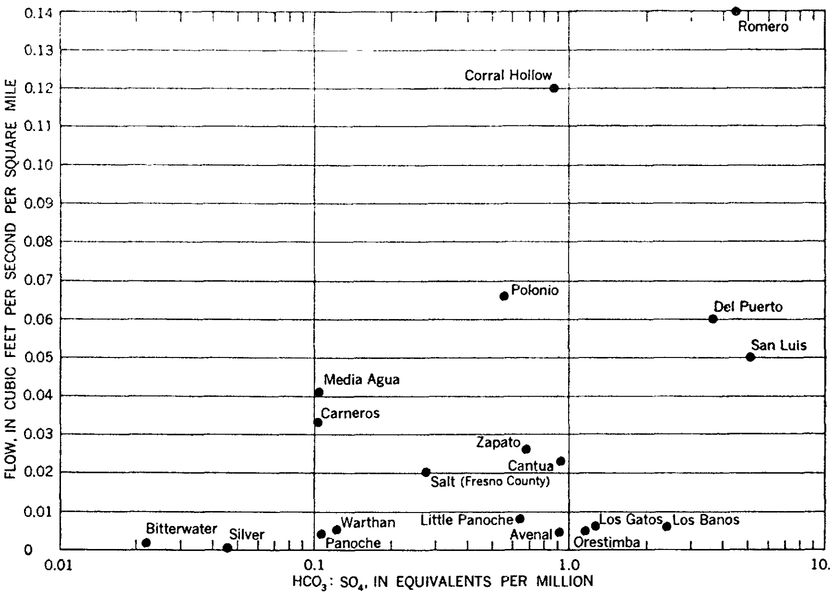

Figure 5.—Relation of flow per square mile to the HCO_3-SO_4 ratio in samples from streams at low-flow stage, eastern slope of the southern Coast Ranges. See also table below.

Area on fig. 1	Creek	Date sampled	Disolved solids (ppm)	Discharge (cfs)
1	Corral Hollow	2-4-56	720	7.0
5	Del Puerto	1-7-52	580	4.0
8	Orestimba	4-21-54	609	.58
10	Quinto	1-7-52	635	-----------
11	Romero	1-23-52	410	3.0
12	San Luis	4-21-54	468	4.2
13	Los Banos	4-20-54	583	.72
14	Salt (Merced County)	3-20-52	5,600	-----------
16	Little Panoche	1-27-54	3,820	.81
17	Panoche	1-27-54	5,250	1.13
17A	Silver	9-9-31	9,000	.03
18	Cantua	5-2-55	1,250	1.13
19	Salt (Fresno County)	1-21-52	2,700	.5
20	Domengine	3-19-52	2,500	-----------
21	Los Gatos	1-28-53	1,510	.7
22	Warthan	1-28-53	3,280	.5
24	Zapato	1-26-54	328	1.23
26	Avenal	1-26-54	306	.22
27	Polonio	1-25-52	540	.8
28	Bitterwater	1-25-52	3,200	.2
29	Media Agua	1-25-52	1,600	.5
30	Carneros	1-25-52	1,900	.5

Figure 6, a geochemical graph similar to figure 3, shows the chemical character of typical samples from 22 streams at low-flow stage along the eastern flank of the Coast Ranges. In the diamond part of the graph, boxes outline the plots of waters derived from drainage basins in which more than and less than 50 percent of the basins are underlain by rocks of Jurassic and Cretaceous age. The plots of three waters strongly affected by contributions of saline marine connate water, as discussed later, are outlined by a separate box.

The relationship between the areal extent of the rocks of Jurassic and Cretaceous age and the HCO_3-SO_4 ratio is evident from the plots on figure 4. Of the 22 samples, 12 (55 percent) lie witbin the 10-percent-deviation envelope, and 18 (about 80 percent) lie within the 20-percent-deviation envelope. All waters in which the HCO_3-SO_4 ratio is greater than 1.0—that is, HCO_3 exceeds SO_4—are from drainage basins in which more than 84 percent of the area is underlain by Jurassic and Cretaceous rocks. Conversely, waters in which the HCO_3-SO_4 ratio is less than 1.0 are from basins where less than 81 percent of the area is underlain by the Jurassic and Cretaceous rocks.

The waters of Little Panoche Creek and Salt Creek (Merced County) are unique in that sodium and chloride are the predominant cation and anion, respectively (fig. 6). The general geology of the tributary drainage areas does not differ greatly from that of nearby

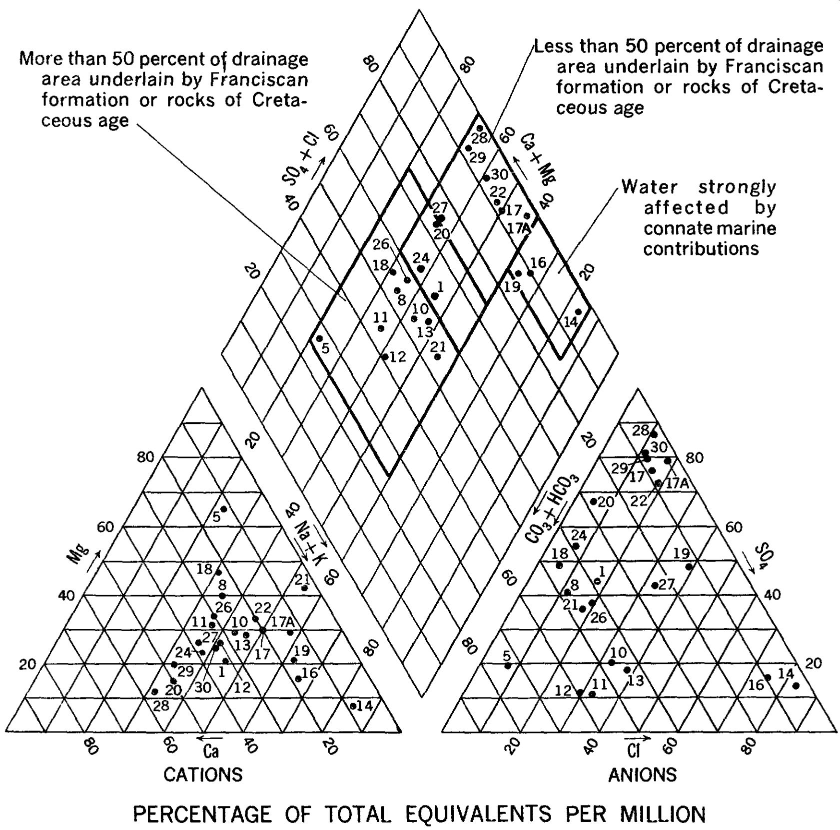

FIGURE 6.—Chemical character of samples from streams at low-flow stage, eastern slope of the southern Coast Ranges.

basins, as indicated by table 1 and figure 1. Therefore, the source of the sodium chloride evidently is unique to these two basins. In this connection, the comparatively high boron content of the water of Little Panoche Creek (table 2), which ranges from 1.4 to 19 ppm, probably is significant. A marked similarity in chemical character exists between the waters of Little Panoche Creek and Mercy Hot Springs (Eaton, 1935, p. 61), a thermal spring in the drainage area that discharges a water with a high chloride and boron content; this fact may indicate a common source. The waters of Salt Creek (Merced County) likewise carry considerable boron, 25 parts of a total 5,600 ppm of dissolved solids (table 2), suggesting a similar source of the mineral content. In waters of several other streams, notably Salt Creek (Fresno County) but also Romero, Quinto, Los Banos, and Polonio Creeks, chloride makes up more than 30 percent of the total equivalent anions per million at low-flow stage (fig. 6). The ratio of boron to chloride in these stream waters corresponds generally to the boron-chloride ratio in Little Panoche Creek and Salt Creek (Merced County), suggesting that boron and chloride have a common source in all the streams. White (1957, p. 1674) considers the water of Mercy Springs to be connate, in part, but rather extensively diluted by meteoric water. A similar explanation seems quite appropriate for the other stream waters with a high boron and chloride content (p. B-22), this report).

The chief systematic differences in cation content are those related to the relative amount of magnesium. In the low-flow waters of Del Puerto, Orestimba, Cantua, and Los Gatos Creeks magnesium characteristically makes up more than 40 percent of the total equivalent cations per million. As shown on figure 1, ultrabasic intrusive rocks crop out in the drainage basins of all streams, ranging from about 2 percent of the area of the drainage basin of Orestimba Creek to about 13 percent in the basin of Cantua Creek (table 1).

Aside from the effect of ultrabasic rocks mentioned above, few systematic differences were found in the proportion of cations in the stream waters of the eastern slope of the Coast Ranges. Sodium slightly exceeds calcium or magnesium in most waters, although in the waters of Bitterwater and Media Agua Creeks calcium exceeds the other cations.

SOURCE OF MINERAL CONSTITUENTS IN THE STREAM WATERS

It has been shown that the relative amount of the mineral constituents in the stream waters along the eastern slope of the southern Coast Ranges is related to the distribution of geologic units in the drainage basins of the streams. The classification of these units, of necessity, is based chiefly on age and depositional environment of the sediments—for example, continental deposits of late Tertiary and Quaternary age. However, the differences in chemical character are directly related to the lithologic features of the rocks, which, in turn, are related chiefly to their source rocks and to the environment in which they were deposited.

The constituents ordinarily reported in chemical analyses of waters are the common cations—calcium, magnesium, sodium, and potassium—and the common anions—carbonate, bicarbonate, sulfate, and chloride—and, in more comprehensive analyses, nitrate, silica, boron, and fluoride. The cations and silica are abundant in the minerals of the sedimentary rocks. Moreover, calcium carbonate precipitated from sea water is a common cementing material in marine sediments. Calcium in the form of gypsum is abundant in many of the sediments of the area, especially the continental deposits of late Tertiary and Quaternary age, presumably as a precipitate from ground or surface waters of an earlier time (p. B–9). The anions in the stream water, however, are not important constituents of igneous rocks but are derived from the atmosphere and the ocean, and where present in sedimentary rocks presumably were derived originally from those sources. The probable sources of some of the constituents of the stream waters are indicated in the following paragraphs.

Calcium is the most common of the alkaline-earth metals in most natural water. Rankama and Sahama (1950, p. 462) have calculated that in igneous rocks approximately half the calcium occurs in minerals of the pyroxene and amphibole groups and about half in minerals of the plagioclase feldspar group. As most of the sediments of the southern Coast Ranges are composed largely of only slightly altered arkosic materials (p. B–3–9), an abundant source of calcium is present in the feldspar and in the pyroxene and amphibole minerals, common constituents of most igneous rocks.

Magnesium is most abundant in the mafic silicate minerals in igneous rocks, characteristically in combination with iron. Locally it occurs abundantly in the ultramafic intrusive rocks (p. B–17), which are made up largely of olivine (magnesium iron silicate) and enstatite (magnesium silicate).

Sodium and potassium are the only alkali metals common in most natural water. In igneous rocks, sodium occurs chiefly in plagioclase feldspar; potassium occurs in microcline and orthoclase feldspar and in minerals of the mica group. In addition, sodium commonly is present in marine sediments in connate water, of which sodium is the principal cation. Potassium normally is found in stream waters only in small quantities, ranging from about 1 to 20 ppm, and for that reason has been omitted from table 2.

The cations in the stream waters of the southern Coast Ranges do not occur in the same relative amounts as in igneous rocks or even roughly in the relative amounts observed in average river waters (Rankama and Sahama, 1950, table 6, 7, p. 274), in which calcium predominates over all the other cations. Instead, as shown on figure 6, most of the waters of the area are characterized by a generally intermediate cation composition, in which the alkaline earths calcium and magnesium together slightly exceed sodium and potassium. Magnesium exceeds calcium in most of the stream waters, and in the waters of Del Puerto, Orestimba, Cantua, and Los Gatos Creeks makes up more than 40 percent of the cations. Ultramafic intrusive rocks are exposed in the drainage areas of all four streams (see fig. 1 and table 1).

The waters with a relatively high magnesium content may be readily explained by the presence of ultramafic intrusive rocks in many of the drainage basins and by the abundance of basic igneous rocks in the Franciscan formation of Jurassic and Cretaceous age. The relative impoverishment of calcium in the stream waters of the area is difficult to account for because abundant sources of calcium are present in the drainage areas of most of the streams. Only in the waters of Bitterwater and Media Agua Creeks, which were among the most concentrated waters shown on figure 6, did calcium predominate strongly over the other cations. The outstanding feature of the distribution of geologic units in these drainage basins is the large proportion of the area underlain by rocks of late Tertiary and Quaternary age, suggesting a possible causal relationship. The gypsiferous sediments present in the continental deposits of this unit may supply sufficient calcium to the streams to obscure the characteristic composition of the waters of the region in which sodium and magnesium ordinarily would predominate.

Of the anions, bicarbonate and carbonate are among the most abundant constituents of natural waters. In normal stream waters most of the carbon is in the form of bicarbonate (HCO_3), although at high pH values carbonate may be present. Meteoric waters contain the typical gases of the atmosphere in solution, principally nitrogen, oxygen, and carbon dioxide. Upon entering the soil, they first incorporate soluble constituents from the soil. Additional cabbon dioxide is derived from organic substances in which it is fixed by bacteria. The ground water, thus charged with carbon dioxide, is a powerful weathering agent, able to break up nearly all minerals and form new compounds. It is especially effective in dissolving calcium carbonate, an important constituent of most marine sediments. The soil and ground waters eventually carry off much of the dissolved mineral matter to streams. The relation of the carbonates to sulfate in the waters of the east flank of the Coast Ranges is of particular geochemical interest because of the control exercised by the lithologic over the chemical character of the waters.

During weathering, sulfide minerals are oxidized to sulfates. Sulfate also is dissolved during the decomposition of minerals containing sulfate ions. Although much sulfate is reprecipitated as poorly soluble compounds, such as gypsum, much is carried off in stream waters.

In the stream waters of the east flank of the southern Coast Ranges sulfate is the principal anion constituent of water derived chiefly from rocks of Tertiary and Quaternary age. It would appear that these rocks generally contain more readily available sulfur compounds than do the rocks of Cretaceous and Jurassic age. The most notable differences between these major groupings is in the presence of organic shale sediments. In the rocks of Jurassic and Cretaceous age only the Moreno shale (of Late Cretaceous age in part) is known to be predominantly organic (p. B–4), and even this unit is predominantly sandy where exposed north of Ortigalita Creek, as indicated by Anderson and Pack (1915, p. 46–48) and Stewart, Poponoe, and Snavely (1944). In most of the area of this report, highly organic shale makes up only a small percentage of the total thickness of the rocks of Jurassic and Cretaceous age, but locally organic shale composes perhaps as much as a third of the rocks of Tertiary and Quaternary age.

In contrast, the marine sediments of Tertiary age are characterized by thick units of organic, siliceous, commonly diatomaceous shale, as, for example, the Kreyenhagen shale of Eocene and Oligocene age (p. B–6) and the Monterey formation of Miocene age (p. B–8). Moreover, the nonmarine deposits of late Tertiary and Quaternary age commonly contain much reworked gypsum and locally some deposits of bedded gypsum.

The organic marine shales are herein considered to be the primary source of sulfate in the area, supplying that sulfate found in solution in the stream waters and also that in the gypsum of younger nonmarine deposits.

The occurrence of sulfur compounds in shale and organic sediments often has been observed. Clark (1924) reported that the amount of sulfur removed from sea water by deposition was 2,600 grams per ton of shale as compared to 1,100 grams per ton of limestone and only 300 grams per ton of sandstone. Sulfate in sea water is reduced to hydrogen sulfide, probably largely by the action of bacteria in closed basins that have shallow outlets to the sea, in which lack of circulation results in a loss of oxygen. Under such conditions, mud rich in organic remains is deposited in stagnant water, and the presence of hydrogen sulfide causes the precipitation of sulfides of iron and other metals in the bottom sediments.

In a study of early diagenesis of Recent marine sediments from California basins, Emery and Rittenhouse (1952, p. 789) reported that sulfate had disappeared from water in cores taken from the sea floor within 87 inches below the surface. The sulfate reduction results in the formation of hydrogen sulfide and sedimentary iron sulfides. Grains of pyrite found as casts in shells of Foraminifera and Radiolaria and in tests of diatoms confirm the relation between organic remains and sulfate reduction.

Bramlette (1946, p. 36), in his comprehensive study of the Monterey formation, reported the presence of black iron sulfide in association with organic matter in dark shale and explained the dark color as being due to the presence of these two materials. Further evidence of sulfur compounds in the Monterey formation is the presence of jarosite (hydros sulfate of potassium and ferric iron) coatings and gypsum (hydrous calcium sulfate) in weathered mudstone and of gypsum crystals in weathered outcrops of bentonite (Bramlette, 1946, p. 19, 26, respectively). Briggs (1951, p. 902) also noted the abundance of jarosite in exposures of Tertiary rocks along the western border of the San Joaquin Valley near Ortigalita Creek.

Chloride is a lesser anion of most of the stream waters of the area but is the predominant anion in Little Panoche Creek and Salt Creek (Merced County) at low-flow stage. It is also a substantial constituent of Salt Creek (Fresno County) and several other streams during low flow (fig. 6). Because of the abundance of marine sediments in the drainage basins of the eastern slope of the Coast Ranges, it is presumed that connate water trapped in marine sediments is the principal source of the chloride in the stream waters. However, simple weathering of the rocks cannot account for the high chloride content of streams like Little Panoche Creek and Salt Creek (Merced County). In fact, the geology of these two basins is substantially different despite the similarity of the waters. A more rational explanation would be that saline marine waters trapped in the sediments since deposition are being flushed out in areas where faults or other fractures permit easy access of the formation waters to the land surface.

In summary, the distribution of anions in the stream waters is consistent with the geologic features of the area. Where the clastic, typically arkose sediments of Cretaceous and Jurassic age underlie most of the drainage area the stream waters contain bicarbonate as the predominant anion. Conversely, where organic sediments, chiefly of Teritary age, or continental deposits derived from these organic sediments underlie most of the drainage area, sulfate generally predominates in the stream waters. The only radical departure from this pattern is found in the high-chloride waters of several streams, which have been described (p. B-22) as connate marine waters possibly discharged from springs.

REFERENCES CITED

Anderson, Robert, and Pack, R. W., 1915, Geology and oil resources of the west border of the San Joaquin Valley north of Coalinga, Calif.: U.S. Geol. Survey Bull. 603, 220 p.

Bramlette, M. N., 1934, Heavy mineral studies on correlation of sands at Kettleman Hills, California: Am. Assoc. Petroleum Geologists Bull., v. 18, p 1559-1576.

——— 1946, The Monterey formation of California and the origin of its siliceous rocks: U.S. Geol. Survey Prof. Paper 212, 57 p.

Briggs, L. I., Jr., 1951, Jarosite from the California Tertiary: Am. Mineralogist, v. 36, p. 902-906.

Clarke, F. W., 1924, The data of geochemistry: U.S. Geol. Survey Bull. 770, 841 p.

Eaton, F. M., 1935, Boron in soils and irrigation waters and its effect on plants, with particular reference to the San Joaquin Valley of California: U.S. Dept. Agriculture Tech. Bull. 448, 131 p.

Emery, K. O., and Rittenberg, S. C., 1952, Early diagenesis of California basin sediments in relation to origin of oil: Am. Assoc. Petroleum Geologists Bull., v. 36, no. 5, p. 735-806.

Jenkins, O. P., 1938, Geologic map of California: California Dept. Nat. Resources, Div. Mines.

Kundert, C. J., 1955, Geologic map of California: California Dept. Nat. Resources, Div. Mines.

Piper, A. M., 1945, A graphic procedure in the geochemical interpretation of water analyses: Am. Geophys. Union Trans. 25th Ann. Mtg., pt. 6, p. 914-928.

Rankama, Kalervo, and Sahama, T. G., 1950, Geochemistry: Chicago Univ. Press, 912 p.

Reed, R. D., 1933, Geology of California: Am. Assoc. Petroleum Geologists, 328 p.

Stewart, Ralph, Poponoe, W. P., and Snavely, P. J., Jr., 1944, Tertiary and late Upper Cretaceous stratigraphy of west border of San Joaquin Valley, north of Panoche Creek, Fresno, Merced, and Stanislaus Counties, California: U.S. Geol. Survey Oil and Gas Inv. Prelim. Chart 6.

Taliaferro, N. L., 1943, Geologic history and structure of the Central Coast Ranges of California: California Dept. Nat. Resources, Div. Mines Bull. 118, p. 119-163.

Ver Planck, W. E., Jr., 1952, Gypsum in California: California Dept. Nat. Resources, Div. Bull. 163, 151 p.

Von Estorff, F. E., 1930, Kreyhagen shale at type locality, Fresno County, California: Am Assoc. Petroleum Geologists Bull., v. 14, p. 1321-1336.

Walker, G. W., and Griggs, A. B., 1953, Chromite deposits of the southern Coast Ranges of California: California Dept. Nat. Resources, Div. Mines Bull. 134, pt. 2, chap. 2, p. 39-88.

White, D. E., 1957, Magmatic, connate, and metamorphic waters: Geol. Soc. America Bull., v. 68, no. 12, p. 1659-1682.

Woodring, W. P., Stewart, Ralph, and Richards, R. W., 1940 Geology of the Kettleman Hills oil field, California; stratigraphy, paleontology, and structure: U.S. Geol. Survey Prof. Paper 195.

TABLE 2.—*Chemical analyses of stream waters of the eastern slope of the southern Coast Ranges*

Sampling point	Flow (cfs)	Date sampled	Dissolved solids (ppm)	Parts per million (upper number) and equivalents per million (lower number) for indicated cations and anions							Boron (ppm)
				Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	
Corral Hollow Creek											
SE¼NE¼ sec. 24, T. 3 S., R. 4 E	14	12-28-55	659	77	26	109	208	0	244	67	2.8
				3.84	2.13	4.74	3.41	.00	5.08	1.89	
NE¼NW¼ sec. 19, T. 3 S., R. 5 E	100	1-25-56	335	45	14	45	168	0	96	24	.94
				2.25	1.14	1.96	2.75	.00	2.00	.68	
Sec. 25, T. 3 S., R. 5 E	200	1-27-56	265	33	13	34	141	0	69	20	.78
				1.65	1.07	1.50	2.31	.00	1.44	.56	
NE¼NW¼ sec. 19, T. 3 S., R. 5 E	7	2- 4-56	720	83	29	118	278	0	250	66	2.6
				4.14	2.35	5.13	4.56	.00	5.20	1.86	
Lonetree Creek											
Sec. 1, T. 4 S., R. 5 E	40	1-27-56	484	52	25	78	202	7	140	48	1.7
				2.59	2.03	3.39	3.31	.23	2.91	1.35	
Hospital Creek											
Sec. 25, T. 4 S., R. 5 E	50	1-27-56	309	39	18	37	172	7	75	20	0.70
				1.95	1.51	1.61	2.82	.23	1.56	.56	
Ingram Creek											
NW¼SW¼ sec. 5, T. 4 S., R. 6 E	24	1-27-56	396	33	21	75	195	6	88	45	2.4
				1.65	1.70	3.26	3.20	.20	1.83	1.27	
Del Puerto Creek											
NE¼SE¼ sec. 15, T. 5 S., R. 7 E	4	1- 7-52	580	29	91	58	458	24	105	29	0.95
				1.45	7.48	2.52	7.51	.80	2.19	.82	
SW¼NW¼ sec. 21, T. 5 S., R. 7 E	21.6	12-29-55	512	34	72	47	374	11	107	28	.80
				1.70	5.91	2.04	6.13	.37	2.23	.79	
Sec. 31, T. 4 S., R. 8 E	180	1-25-56	314	24	45	23	256	9	53	10	.34
				1.20	3.70	1.00	4.20	.30	1.10	.28	

Orestimba Creek											
SW¼SW¼ sec. 17, T. 7 S., R. 8 E	11	1- 7-52	363	45	31	35	244	0	91	19	2.7
				2.25	2.55	1.52	4.00	.0	1.89	.54	
SW¼SW¼ sec. 19, T. 7 S., R. 8 E	82	1-30-52	286	44	22	24	190	0	70	12	.20
				2.20	1.81	1.04	3.11	.0	1.46	.34	
NW¼NW¼ sec. 20, T. 7, S., R. 8 E	----------	3-20-52	----------	----		21	189	0	----------	12	----------
				3.80		.91	3.10	.0	----------	.34	
NW¼, sec. 20, T. 7 S., R. 8 E	4.2	1-27-53	449	54	38	46	275	0	138	24	.26
				2.69	3.12	2.00	4.51	.0	2.87	.68	
SE¼SW¼ sec. 27, T. 7 S., R. 7 E	.58	4-21-54	609	56	52	84	303	0	201	44	.86
				2.79	4.28	3.65	4.97	.0	4.18	1.24	
SW¼SW¼ sec. 17, T. 7 S., R. 8 E	253	12-31-55	174	27	13	13	125	0	34	8	.15
				1.35	1.05	.57	2.05	.0	.71	.23	
SE¼SE¼ sec. 24, T. 7 S., R. 7 E	800	1-26-56	195	31	14	15	139	2	36	7	.15
				1.55	1.13	.65	2.28	.07	.75	.20	
Garzas Creek											
NW¼SE¼ sec. 18, T. 8 S., R. 8 E	12.6	12-29-55	349	46	21	42	184	0	91	30	0.43
				2.30	1.74	1.83	3.02	.00	1.89	.85	
Sec. 18, T. 8 S., R. 8 E	130	1-26-56	231	36	15	21	159	2	47	10	.16
				1.80	1.22	.91	2.61	.07	.98	.28	
Quinto Creek											
SE¼NW¼ sec. 15, T. 9 S., R. 8 E	----------	1- 7-52	635	61	40	108	320	----------	107	117	1.8
				3.04	3.29	4.70	5.24	----------	2.23	3.30	
SE¼NW¼ sec. 15, T. 9 S., R. 8 E	5	1-30-52	424	45	33	59	230	10	77	54	.64
				2.25	2.71	2.57	3.77	.33	1.60	1.52	
SE¼NW¼ sec. 15, T. 9 S., R. 8 E	6	3-20-52	----------	----		36	220	6	----------	34	----------
				4.24		1.57	3.61	.20	----------	.96	
SW¼ sec. 9, T. 9 S., R. 8 E	0.5	1-30-53	573	62	53	70	353	0	141	60	.58
				3.09	4.36	3.04	5.79	.00	2.94	1.69	
SW¼SW¼ sec. 12, T. 9 S., R. 8 E	105	1-26-56	228	29	17	25	160	0	36	17	.27
				1.45	1.37	1.09	2.62	.00	.75	.48	
Romero Creek											
NW¼NW¼ sec. 28, T. 9 S., R. 8 E	3	1-23-52	410	41	24	52	200	8	33	71	1.1
				2.05	1.97	2.26	3.28	.27	.69	2.00	

TABLE 2.—*Chemical analyses of stream waters of the eastern slope of the southern Coast Ranges*—Continued

Sampling point	Flow (cfs)	Date sampled	Dissolved solids (ppm)	Parts per million (upper number) and equivalents per million (lower number) for indicated cations and anions: Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	Boron (ppm)
San Luis Creek											
NE¼SE¼ sec. 15, T. 10 S., R. 8 E	----	1-7-52	267	28	16	36	144	----	42	42	0.16
				1.40	1.32	1.57	2.36	----	.87	1.18	
SW¼SW¼ sec. 32, T. 9 S., R. 9 E	----	1-30-52	283	28	20	43	166	0	37	45	.28
				1.40	1.64	1.87	2.72	.00	.77	1.27	
SE¼SE¼ sec. 31, T. 10 S., R. 8 E	25	3-20-52	181	22	12	23	130	0	20	20	.29
				1.10	.99	1.00	2.13	.00	.42	.56	
SE¼SE¼ sec. 15, T. 10 S., R. 8 E	3	1-27-53	293	32	17	44	176	0	43	42	.16
				1.60	1.40	1.91	2.88	.00	.90	1.18	
SE¼NE¼ sec. 15, T. 10 S., R. 8 E	4.2	4-21-54	468	56	25	79	300	0	46	86	.43
				2.79	2.06	3.44	4.92	.00	.96	2.43	
SE¼SE¼ sec. 31, T. 9 S., R. 9 E	250	12-31-55	122	14	7.1	14	74	0	16	12	.18
				.70	.58	.61	1.21	.00	.33	.34	
SE¼SE¼ sec. 15, T. 10 S., R. 8 E	3	4-11-56	342	36	21	53	188	0	46	60	.29
				1.81	1.69	2.29	3.09	.00	.95	1.68	
Los Banos Creek											
NE¼NE¼ sec. 7, T. 11 S., R. 10 E	6	1-8-52	204	22	14	22	132	0	28	17	0.27
				1.10	1.15	.96	2.16	.00	.58	.48	
NE¼NE¼ sec. 7, T. 11 S., R. 10 E	20	1-30-52	244	27	19	26	158	0	36	20	.32
				1.35	1.56	1.13	2.59	.00	.75	.56	
NW¼SW¼ sec. 5, T. 11 S., R. 10 E	8	3-20-52	164	22	12	14	120	0	19	9	.33
				1.10	.99	.61	1.97	.00	.40	.25	
SE¼SW¼ sec. 32, T. 10 S., R. 10 E	----	1-30-53	335	40	23	41	223	0	47	37	.46
				2.00	1.89	1.78	3.65	.00	.98	1.04	
SE¼NE¼ sec. 12, T. 11 S., R. 9 E	.72	4-20-54	583	52	34	108	272	0	87	135	1.6
				2.59	2.80	4.70	4.46	.00	1.81	3.81	
SE¼NE¼ sec. 12, T. 11 S., R. 9 E	3.55	5-3-55	327	43	24	31	232	0	48	22	.77
				2.15	1.98	1.35	3.80	.00	1.00	.62	
SE¼SW¼ sec. 32, T. 10 S., R. 10 E	450	12-31-55	128	17	8.2	11	87	0	16	8.0	.18
				0.85	.67	.48	1.43	.00	.33	.23	
NW¼SW¼ sec. 5, T. 11 S., R. 10 E	0.5	4-11-56	455	56	32	53	253	0	81	69	.75
				2.81	2.63	2.30	4.15	.00	1.69	1.94	

Salt Creek (Merced County)

sec. 18, T. 11 S., R. 10 E.	----------	3-20-52	5,600	160 7.98	83 6.83	1800 78.27	220 3.61	4.7 .16	550 11.45	2,700 76.15	25

Little Panoche Creek

SE¼SE¼ sec. 19, T. 13 S., R. 11 E.	0.02	5-22-30	3,790	278 13.89	146 12.00	919 39.97	333 5.45	---------- ----------	454 9.46	1,810 50.95	19
SE¼NE¼ sec. 21, T. 13 S., R. 11 E.	2.00	1- 7-52	1,170	93 4.64	36 2.96	275 11.96	186 3.05	0 .00	173 3.60	475 13.40	6.0
SE¼SE¼ sec. 19, T. 13 S., R. 11 E.	.2	1-30-52	2,480	182 9.08	114 9.37	580 25.22	458 7.51	0 .0	375 7.81	960 27.08	15
SE¼SE¼ sec. 19, T. 13 S., R. 11 E.	6	3-19-52	541	73 3.64	27 2.22	83 3.61	248 4.06	14 .47	97 2.02	106 2.99	1.4
NE¼NE¼ sec. 22, T. 13 S., R. 11 E.	.81	1-27-54	3,820	239 11.93	116 9.54	983 42.74	400 6.56	0 .00	486 10.12	1,760 49.64	16
sec. 20, T. 13 S., R. 11 E.	30	1-26-56	422	53 2.64	18 1.52	70 3.04	200 3.28	3 .10	65 35	86 2.43	1.5
SW¼NE¼ sec. 21, T. 13 S., R. 11 E.	1	4-10-56	3,020	116 5.78	102 8.42	856 37.25	291 4.77	0 .00	363 7.56	1,400 39.6	17

Panoche Creek

W½ sec. 27, T. 15 S., R. 11 E.	2	5-22-30	2,020	142 7.11	114 9.36	364 15.83	317 5.20	---------- ----------	1,070 22.25	172 4.85	4.9
W½ sec. 27, T 15 S., R. 11 E.	2	9- 9-31	2,070	112 5.59	110 9.04	423 18.38	311 5.10	---------- ----------	1,070 22.21	202 5.70	6.5
SW¼SE¼ sec. 10, T. 15 S., R. 12 E.	4	1- 9-52	3,960	299 14.92	212 17.43	700 30.43	382 6.26	0 .00	2,210 46.01	305 8.60	6.1
SE¼NE¼ sec. 25, T. 15 S., R. 10 E.	.5	1-30-52	3,030	268 13.37	147 12.09	500 21.74	432 7.08	0 .00	1,680 34.98	170 4.79	4.8
NW¼SW¼ sec. 20, T. 15 S., R. 12 E.	5	3-19-52	1,520	178 8.88	55 4.52	237 10.31	192 3.15	0 .00	882 18.36	48 1.35	1.5
NE¼SW¼ sec. 27, T. 15, S., R. 11 E.	.5	1-28-53	2,570	183 9.13	143 11.76	442 19.22	434 7.11	0 .00	1,330 27.69	220 6.20	3.3
SW¼SW¼ sec. 16, T. 15 S., R. 12 E.	1.13	1-27-54	5,250	332 16.57	296 24.34	935 40.66	410 6.72	0 .00	2,990 62.25	460 12.97	8.6
SE¼SE¼ sec. 10, T. 15 S., R. 12 E.	33	1-26-56	1,210	136 6.79	54 4.41	170 7.40	184 3.02	2 .07	685 14.26	48 1.35	1.6
sec. 15, T. 15 S., R. 12 E.	200	3-17-58	1,310	133 6.64	74 6.06	179 7.79	200 3.28	0 .00	753 15.68	42 1.18	1.5

TABLE 2.—*Chemical analyses of stream waters of the eastern slope of the southern Coast Ranges*—Continued

Sampling point	Flow (cfs)	Date sampled	Dissolved solids (ppm)	Parts per million (upper number) and equivalents per million (lower number) for indicated cations and anions							Boron (ppm)
				Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	
Silver Creek											
NW¼ sec. 32, T. 15 S., R. 12 E.	0.03	5-22-30	6,970	391 19.51	515 42.37	1,090 47.54	348 5.70	----	4,270 88.82	528 14.90	8.8
NW¼ sec. 32, T. 15 S., R. 12 E.	.03	9-9-31	9,000	397 19.83	494 40.66	1,820 78.94	290 4.75	----	5,220 108.78	918 25.90	13
SW¼SE¼ sec. 20, T. 15 S., R. 12 E.	4	3-19-52	1,820	146 7.29	135 11.10	235 10.22	360 5.90	0 .00	1,040 21.65	68 1.92	2.6
SW¼SE¼ sec. 20, T. 15 S., R. 12 E.	2	1-28-53	5,010	227 11.33	397 32.65	790 34.35	396 6.49	0 .00	3,090 64.33	270 7.61	7.0
Cantua Creek											
SE¼SE¼ sec. 34, T. 17 S., R. 14 E.	----	1-26-54	957	79 3.94	121 9.95	82 3.57	584 9.57	0 .00	337 7.02	29 .82	0.74
SE¼SE¼ sec. 34, T. 17 S., R. 14 E.	1.13	5-2-55	1,250	103 5.14	121 9.94	145 6.31	604 9.99	0 .00	511 10.64	44 1.24	1.1
NW¼NW¼ sec. 31, T. 17 S., R. 15 E.	40	1-25-56	286	26 1.30	33 2.74	25 1.09	204 3.34	2 .07	72 1.50	2.0 .06	.30
NW¼NW¼ sec. 31, T. 17 S., R. 15 E.	100	3-17-58	772	55 2.74	87 7.18	86 3.74	386 6.33	14 .47	298 6.20	18 .51	.37
Salt Creek (Fresno County)											
Sec. 6, T. 18 S., R. 15 E.	0.5	1-21-52	2,700	140 6.99	100 8.22	590 25.66	330 5.41	7.0 .23	920 19.15	550 15.51	2.5
Domengine Creek											
Sec. 23, T. 18 S., R. 15 E.	----	3-19-52	2,500	370 18.46	63 5.18	300 13.05	110 1.80	0 .00	1,200 24.98	380 10.72	1.5
Sec. 23, T. 18 S., R. 15 E.	5	1-25-56	1,430	137 6.84	41 3.36	281 12.22	107 1.75	0 .00	605 12.60	281 7.92	4.0

Los Gatos Creek											
SW¼SE¼ sec. 11, T. 20 S., R. 14 E	1.00	1– 8–52	791	28 1.40	128 10.53	83 3.61	544 8.92	55 1.83	160 3.33	52 1.47	0.37
SW¼SW¼ sec. 28, T. 20 S., R. 15 E	----------	3– 7–52	710	38 1.90	64 5.26	124 5.39	380 6.23	0 .00	224 4.66	56 1.58	.78
SW¼SW¼ sec. 28, T. 20 S., R. 15 E	.7	1–28–53	1,510	22 1.10	136 11.18	332 14.44	674 11.05	41 1.37	461 9.60	165 4.65	1.6
SW¼ sec. 29, T. 20 S., R. 15 E	.7	1–28–53	1,530	24 1.20	134 11.02	330 14.35	624 10.23	67 2.23	483 10.06	160 4.51	.17
NW¼SE¼ sec. 5, T. 20 S., R. 14 E	0.1	1–26–54	963	30 1.50	151 12.42	109 4.74	614 10.06	47 1.57	250 5.20	58 1.64	.56
SW¼SW¼ sec. 28, T. 20 S., R. 15 E	375	1–25–56	273	19 0.95	33 2.69	32 1.39	191 3.13	17 0.57	51 1.06	8.5 .24	.29
Warthan Creek											
SW¼ sec. 7, T. 21 S., R. 15 E	6	1– 8–52	1,020	90 4.49	60 4.93	134 5.83	138 2.26	0 .0	568 11.83	59 1.66	1.0
Sec. 7, T. 21 S., R. 15 E	.5	1–28–53	3,280	209 10.43	201 16.53	554 24.09	283 4.64	0 .0	1,810 37.68	340 9.59	2.9
NW¼SW¼ sec. 8, T. 21 S., R. 15 E	2.57	1–26–54	1,580	137 6.84	82 6.74	250 10.87	176 2.88	0 .0	854 17.78	140 3.95	2.8
NE¼NE¼ sec. 4, T. 21 S., R. 15 E	400	1–25–56	350	28 1.40	14 1.14	70 3.04	156 2.56	0 .0	124 2.58	12 .34	.54
SW¼NE¼ sec. 13, T. 21 S., R. 14 E	10	3–14–58	2,850	132 6.59	212 17.41	482 20.97	326 5.34	0 .0	1,540 32.06	290 8.18	4.5
Jacalitos Creek											
SW¼ sec. 31, T. 20 S., R. 16 E	----------	3– 7–52	248	25 1.248	11 .905	41 1.783	115 1.885	0 .0	84 1.749	12 .338	0.37
SE¼NE¼ sec. 14, T. 21 S., R. 15 E	300	1–25–56	194	24 1.20	10 .82	25 1.09	127 2.08	0 .0	49 1.02	2.5 .07	.27
Sec. 32, T. 21 S., R. 15 E	10	3–14–58	1,090	60 2.99	76 6.21	193 8.40	270 4.43	14 .47	515 10.72	85 2.40	.94
Zapato Creek											
SE¼ sec. 27, T. 21 S., R. 16 E	1.23	1–26–54	328	41 2.05	15 1.23	44 1.91	124 2.03	0 .0	140 2.91	10 .28	0.32
SE¼NW¼ sec. 27, T. 21 S., R. 16 E	175	1–25–56	162	28 1.40	7.5 .62	17 .74	136 2.23	0 .0	25 .52	0 .0	.18
SE¼NW¼ sec. 27, T. 21 S., R. 16 E	12	3–14–58	604	20 1.00	60 4.92	98 4.26	270 4.43	4 .13	253 5.27	20 .56	.94

TABLE 2.—*Chemical analyses of stream waters of the eastern slope of the southern Coast ranges*—Continued

Sampling point	Flow (cfs)	Date sampled	Dissolved solids (ppm)	Parts per million (upper number) and equivalents per million (lower number) for indicated cations and anions							Boron (ppm)
				Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Chloride (Cl)	
Avenal Creek											
NW¼SW¼ sec. 10, T. 24 S., R. 17 E	18	1-28-52	530	52	38	62	220	24	130	23	0.8
				2.60	3.12	2.70	3.60	.80	2.71	.65	
NW¼ sec. 14, T. 24 S., R. 17 E	.22	1-26-54	306	31	21	40	132	0	114	14	.54
				1.55	1.73	1.74	2.16	.0	2.37	.39	
Polonio Creek											
Sec. 30, T. 25 S., R. 17 E	0.8	1-25-52	540	50	20	48	100	0	140	42	.4
				2.50	1.64	2.09	1.64	.0	2.92	1.82	
Bitterwater Creek											
NE¼ sec. 13, T. 27 S., R. 18 E	0.2	1-25-52	3,200	500	64	320	79	0	1,800	160	0.9
				24.95	5.26	13.92	1.30	.0	37.47	4.51	
Media Agua Creek											
NE¼ sec. 11, T. 28 S., R. 19 E	<0.5	1-25-52	1,600	210	52	160	110	0	820	90	0.3
				10.48	4.28	6.96	1.80	.0	17.07	2.54	
Carneros Creek											
Sec. 29, T. 28 S., R. 20 E	<0.5	1-25-52	1,900	200	81	260	150	0	1,100	110	0.6
				9.98	6.66	11.31	2.46	.0	22.90	3.10	