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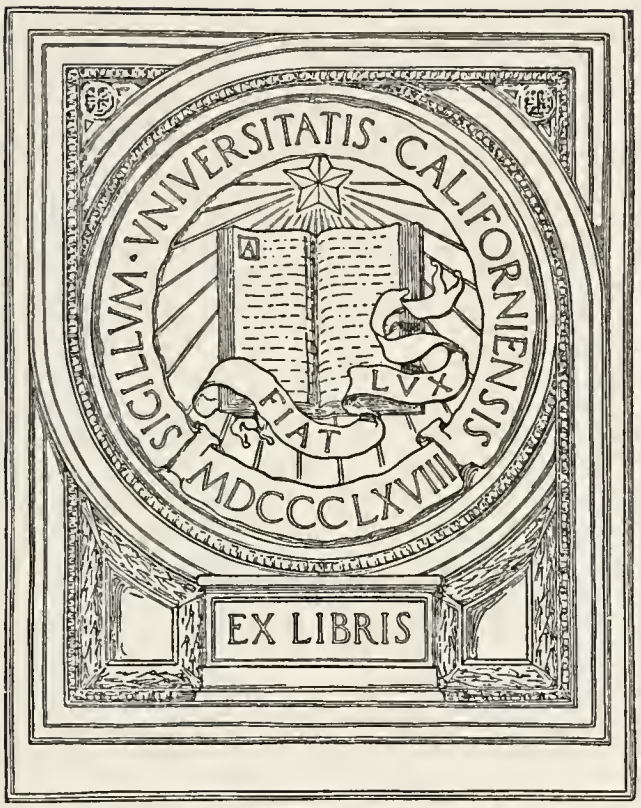
STATE OF CALIFORNIA
DEPARTMENT OF NATURAL RESOURCES

CRYSTALLINE ROCKS OF SOUTHWESTERN CALIFORNIA

BULLETIN 159
1951

DIVISION OF MINES
FERRY BUILDING, SAN FRANCISCO



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EARL WARREN, Governor
DEPARTMENT OF NATURAL RESOURCES
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DIVISION OF MINES
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SAN FRANCISCO BULLETIN 159 JUNE 1951

CRYSTALLINE ROCKS OF SOUTHWESTERN CALIFORNIA

Contributing Authors
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LETTER OF TRANSMITTAL

To His Excellency
The Honorable Earl Warren
Governor of the State of California

Dear Sir: I have the honor to transmit herewith Bulletin 159, *Crystalline Rocks of Southwestern California,* covering parts of Orange, Riverside, and San Diego Counties, prepared under the direction of the Chief of the Division of Mines, Olaf P. Jenkins. The bulletin is accompanied by colored geologic and economic mineral maps. It includes three separate, but technically related reports. The first is of general character, covering the Corona, Elsinore, and San Luis Rey quadrangles, representing the results of many summer field seasons of mapping by Professor Esper S. Larsen, Jr., of Harvard University. The second report is a more detailed geologic treatment of the Cuyamaca Peak quadrangle prepared as a Doctor's thesis at Harvard University by Donald L. Everhart. The third report is on groundwater in the bedrock of western San Diego County prepared by Richard Merriam, a member of the faculty of the University of Southern California.

All three of the reports in this volume treat the subject of basic geology, fundamental to the study of mineral deposition. The bulletin shows the relationship of geology to the study of economic mineral deposits, building stone, sand and gravel, soil, oil and coal, and to the position of underground water reservoirs. The economic mineral deposits of the area include such nonmetallics as gem and lithium minerals, feldspar, quartz, and magnesite, and such metals as gold, silver, lead, zinc, copper, tin, and nickel.

As a cooperative project between research departments of universities, of the United States Geological Survey, and of the State Division of Mines, this volume is an outstanding achievement.

Respectfully submitted,

Warren T. Hannum, Director
Department of Natural Resources

April 9, 1951

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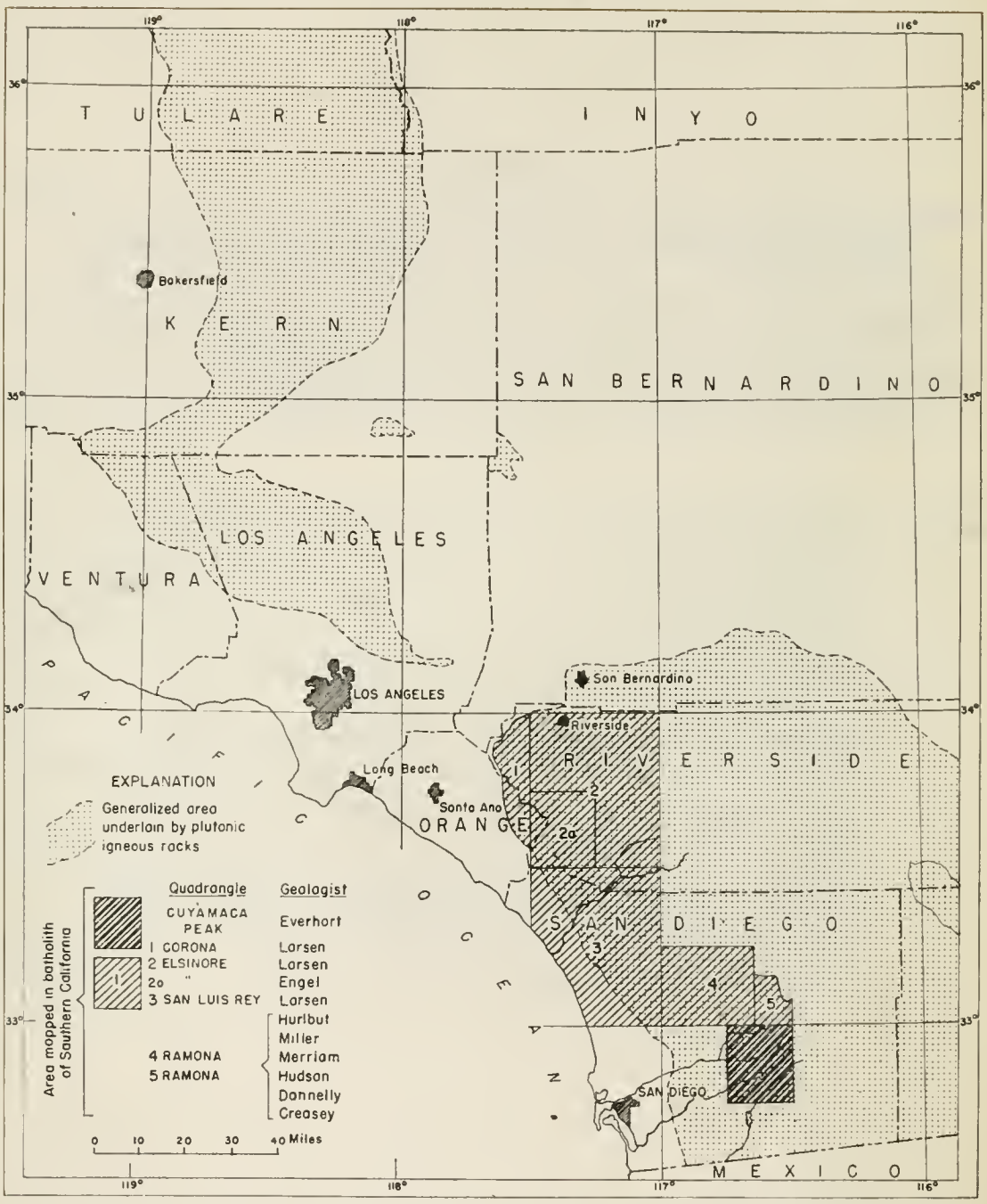

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CRYSTALLINE ROCKS OF THE CORONA, ELSINORE, AND SAN LUIS REY QUADRANGLES, SOUTHERN CALIFORNIA*

By Esper S. Larsen, Jr.**

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* Condensation of the paper *Batholith and Associated Rocks of Corona, Elsinore, and San Luis Rey Quadrangles, Southern California,* by Esper S. Larsen Jr., Geological Society of America Memoir 29, 1948.

** Harvard University, Cambridge, Mass.

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ABSTRACT

The batholith of southern and Lower California is exposed continuously from near Riverside, California, southward for a distance of about 350 miles. In central Lower California it is covered in part by younger rocks, but discontinuous bodies extend to the southern end of Lower California. The batholith is probably over 1000 miles long. Its width is about 60 miles. A strip about 70 miles wide across the northern part of the batholith has been studied; the western half was mapped in detail, and the eastern half was covered in rapid reconnaissance.

In the area studied the batholith intrudes Triassic sediments and Jurassic (?) volcanic rocks along its western border, and Paleozoic sediments along its eastern border. Screens and roof pendants are common within the batholith. The Triassic rocks are mildly metamorphosed in the western part of the area but become progressively more coarsely crystalline toward the east. The Palezoic rocks are rather coarsely crystalline. The metamorphism in large part preceded the intrusion of the batholith, and only locally was there appreciable contact metamorphism. The batholith and older rocks are overlain by Upper Cretaceous and younger sediments. Small bodies of andesite and basalt of Quaternary age are present in the area. The batholith was intruded in early Upper Cretaceous time.

The batholith in the area studied was emplaced by more than 20 separate injections. Most of the resulting rock types are found in only one or a few small bodies which are confined to a small area. In the area studied in detail (pl. 1) five types are present in many large, widely separated bodies, making up about 88 percent of the area underlain by the batholith. In the eastern half of the batholith three more widespread types are present. In the western half of the body the rocks range from gabbro to granite, but in the eastern half several tonalites constitute nearly the whole of the mass. The gabbro is composed of many related rocks. Some have hornblende, some pyroxene; in some the plagioclase is anorthite, in others it is as sodic as andesine-labradorite. Some of the tonalites contain abundant inclusions that have been almost completely reworked by the magma and have been softened and stretched into thin discs. These inclusions are well oriented, and near the contacts with older rocks they parallel the contacts; elsewhere they strike about N. 30° W. and dip steeply to the east. One tonalite, whose feldspar is andesine, has scattered crystals with cores of bytownite, and has well-crystallized hornblende with cores of pale uralitic hornblende and remnants of augite. Hornblende and biotite are the predominant mafic minerals of the tonalites and granodiorites.

The general strike of the structures of the area have been about N. 30° W. from Paleozoic to the present time. The Paleozoic and Triassic sediments, the orientation of the inclusions and other structures of the batholith, the elongation of the batholith and the mountain ranges, and the strike of the major faults are in about the same direction. In the batholith and the older sediments the dips are steep to the east.

The batholith must have been emplaced by stoping and not by forceful injection. The different rocks of the batholith were formed from the intermediate gabbro by crystal differentiation and assimilation in depth.

In early Upper Cretaceous time diastrophism folded the older rocks and formed, in depth, a strip of gabbroic magma about 1000 miles long. A small amount of this magma was intruded nearly to the surface. The deep magma differentiated quietly until its upper part attained the composition of a tonalite. Earth movements then occurred at least five times in rapid succession and caused the injection of the different tonalites. Some of these carry abundant inclusions, indicating a widespread shattering of the wall rock shortly before final emplacement. From time to time local movements caused the injections of the different granodiorites. When the deep-seated magma reached

the composition of a light-colored granodiorite, widespread diastrophism moved the main granodiorite upward. Further local movement caused the emplacement of the many local granodiorites and granites.

INTRODUCTION

Location and Topography. The area described in this report is in southern California and includes a part of the group of mountains known as the Peninsular Ranges. It lies southeast of Los Angeles and north of San Diego. The area is about 70 miles from north to south and somewhat less from east to west. It includes parts of Orange, Riverside, and San Diego Counties. The two quadrangles east of the area mapped in detail have been covered in reconnaissance.

Much of the area is mountainous or hilly. Santiago Peak (elevation 5480 feet) is only 20 miles from the ocean, and in a distance of less than 10 miles, on its southeastern slopes, it reaches an elevation of about 5000 feet. East of the area the mountains rise much higher. San Jacinto Peak has an elevation of 10,805 feet. The largest area of flat land is near the coast in the northwestern part of the area, around the city of Santa Ana. Smaller areas of terraces are present to the south, but in many parts of the area the hills extend nearly or quite to the ocean. Another large area of flat land lies around Riverside in the northern part of, and to the north of, the area. Many smaller valleys lie in the mountain area.

Climate and Vegetation. The area is characterized by little rainfall, most of which falls from December to April. The average annual rainfall at Riverside is about 11 inches, at Santa Ana about 12 inches, and at Fallbrook about 17 inches. In the valleys the winters are mild, and there are few killing frosts. The lowest temperature recorded at Riverside is 21°, at Elsinore 17°, and at Escondido 13°. The summers are hot and dry. The highest temperatures recorded are 118° at Riverside, 113° at Escondido, and 106° at Oceanside. In the higher mountains the rainfall is greater, and both the lowest and the highest temperatures are lower. Snow is unknown in the valleys, but some snow falls on the higher mountains, and the crest of the San Jacinto Mountains, west of the Elsinore quadrangle, is covered with snow during the winter. Thunderstorms are rare in the summer. Occasionally, however, they result in extremely high precipitation in the higher mountains.

Thick brush covers most of the area. On the lower slopes this is low and scattered enough so that it is commonly possible to find a way through it. In the Santa Ana and other high mountains the brush is so thick and tall that it is commonly difficult or impossible to traverse. In the Santa Ana Mountains, the Forest Service has built many trails and roads and has cleared fire breaks along most of the main ridges. The thick brush is a serious handicap to detailed field work.

Field Work and Acknowledgments. The first field work by the author on the pre-Cretaceous rocks of the Corona quadrangle was done in 1906 when Dr. W. C. Mendenhall, assisted by W. O. Clark and E. S. Larsen, made a partial survey of the Corona quadrangle. Much of the geological map of the Corona quadrangle is taken from the field maps of Mendenhall's survey of 1906, though the area was restudied in 1936 and 1938, and the map somewhat modified. Little further work was done until the summer of 1930, when the author mapped a part of the Elsinore

quadrangle. Active field work was carried on during the spring and summer of 1931, when the author was assisted by C. S. Hurlbut Jr. and T. A. Dodge. During the summer of 1932, R. S. Moehlman, H. E. Quinn, and R. H. Svendsen were assistants. Further field work was done during the summer of 1936 with the assistance of A. W. Postel. The field work was completed during the spring of 1938. In all, about 22 months of field work were devoted to the area by the author.

In preparing the map of the part of the Elsinore quadrangle included in the Perris block, the map by Dudley [1] was used, but the formations were checked, and some revision was made. For the area west of the Elsinore Valley and south of Elsinore, the then unpublished map of René Engel [2] was used with some adjustments. The author is grateful to Doctor Engel for the use of this map and for permission to publish it.

The field work was in part financed by the United States Geological Survey and in part by the Department of Mineralogy and Petrography of Harvard University. The author expresses his thanks for this financial support for the loyal and effective help rendered him by his field assistants.

The laboratory work was done at Harvard University. A full petrographic report already has been published.[3]

PHYSIOGRAPHY

Introduction. There are many surfaces of low relief at different elevations. The surfaces within most of the San Luis Rey quadrangle can be correlated, and their relative elevations can be determined with reasonable assurance, as can those in the Santa Ana Mountains and those of the Perris block, which includes the area northeast of the Elsinore-Temecula trough. Correlation of the surfaces of one of these areas with those of the others offers more difficulties. Therefore, the surfaces within each of the areas mentioned above will be described first, then an attempt will be made to correlate the surfaces of the three areas.

San Luis Rey Quadrangle. The lower basins described by Ellis [4] are herein called the Fallbrook surface. This surface is well preserved near Fallbrook and from Vista to Green Valley. The larger streams cross this surface in shallow valleys, but are in canyons both above and below the surface.

Remnants of a surface about 300 feet above the Fallbrook surface are present near Rainbow, south of Red Mountain, and north of Monserate Mountain.

A surface about 200 feet below the Bear Valley surface is present west of Lake Wolford, on Cerro de las Posas, and north of Richland.

The intermediate surface described by Ellis is best preserved in Bear Valley and near Ramona, and is also present southeast of Burnt

[1] Dudley, Paul H., Geology of a portion of the Perris block, southern California: California Jour. Mines and Geology, vol. 31, pp. 487-506, 1935.

[2] Engel, René, Geologic map of Lake Elsinore quadrangle, scale 1:62,500, California Div. Mines, 1949.

[3] Larsen, E. S. Jr., Batholith and associated rocks of the Corona, Elsinore, and San Luis Rey quadrangles, southern California: Geol. Soc. America Mem. 29, 182 pp., 1948.

[4] Ellis, A. J., and Lee, C. H., Preliminary geologic map of San Diego County; geology and ground waters of the western part of San Diego County: U. S. Geol. Survey Water-Supply Paper 446, 321 pp., 1919.

Mountain and west of Oat Hills. On leaving these valleys the streams plunge in canyons over steep slopes.

Perris Block. The name Perris block was applied by English [5] to the structural block that occupies a large part of the Elsinore quadrangle and lies between the Elsinore-Temecula trough on the southwest and the San Jacinto fault on the northeast. An excellent paper on the physiography of this block has been published by Dudley,[6] and much of the discussion follows his ideas.

Topographically this great block is characterized by three features: (1) Great flat valleys, more or less connected, and at a uniform elevation of about 1500 feet, occupy an area of about 200 square miles. They are underlain in most places by young sediments, have many hills of crystalline rock within them, and are bordered on nearly all sides by similar hills. The relief of the bedrock surface on which were deposited the sediments that fill the valleys was at least 1500 feet, as shown by deep wells drilled in the valley.[7] (2) The Perris surface,[8] a mature surface at an elevation of about 1,700 feet, is cut on crystalline rocks and has monadnocks rising about it. (3) The Lakeview surface [9] is a mature surface at an elevation of about 2,100 feet. It is best developed on Lakeview Mountains (Juniper Flat) east of Perris and in the Gavilan, west of Perris. It is also present south of the Gavilan, in Steele Valley, on both sides of the head of Arroyo del Toro, east of Estelle Mountain, and at the head of Rawson Canyon in the southeastern part of the block.

Santa Ana Mountains. Erosion surfaces are well preserved in the southern part of the Santa Ana Mountains, but not in the northern part. The following statement is largely taken from the manuscript of Dr. René Engel. He found four erosion surfaces which are listed and described below, from the lowest to the highest.

(1) The Santa Rosa surface is shown only north of Mesa de Colorado, a few miles southwest of Murrieta, where it has an average elevation of 1,900 feet. It is a surface of very low relief with some mounds or low hills of bedrock. It is underlain chiefly by decomposed rock.

(2) La Cienaga surface is about 300 feet higher than the Santa Rosa surface, where the two are near together north of Mesa de Colorado. It occupies large areas on both sides of Los Alamos Canyon, around El Potrero del Tenaja, south of Sutton Peak, around La Cienaga, and around El Cariso. It, too, is a surface of low relief made up chiefly of decomposed bedrock.

(3) Los Pinos surface is about 500 feet higher than La Cienaga surface. It is present on the crest of the Elsinore Mountains, around Potrero los Pinos, Sutton Peak, and some small areas to the northwest.

(4) The Trabuco surface is about 1,300 feet above Los Pinos surface and is found on Los Pinos Peak and near the crest of the range in the neighborhood of Trabuco Peak.

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[5] English, Walter A., Geology and oil resources of the Puente Hills region, California: U. S. Geol. Survey Bull. 768, 110 pp., 1926.

[6] Dudley, Paul H., Geology of a portion of the Perris block, southern California: Jour. Geology, vol. 44, pp. 358-378, 1936.

[7] Waring, G. A., Ground water in the San Jacinto and Temecula basins, California: U. S. Geol. Survey Water-Supply Paper 429, 113 pp., 1919.

[8] Dudley, P. H., op. cit. 1936, p. 363.

[9] Dudley, P. H., op. cit. 1936, p. 363.

*Table 1. Correlation of the major erosional surfaces.**

Area	Fallbrook	Rainbow	Santa Rosa	Perris	Lakeview	Santa Margarita
San Luis Rey quadrangle	Fallbrook —900	Rainbow —600	Valley —200 Center	Bear Valley 0	300 400	Santa Margarita 1000
Perris Block				Perris 0	Lakeview 500	900
Santa Ana Mountains			Santa Rosa —300	Cienaga 0	Los Pinos 500	Trabuco 1800

* Figures give the elevations above or below the Perris surface.

Summary of Pysiographic History. About the beginning of the Pliocene, the surface of the Perris area and probably of the large surrounding area was mature, and higher than at present. The drainage of the Perris area was toward the northeast, relief was at least 300 feet. The Temecula-Elsinore trough and the valley around Riverside were lowlands, as at present. This landmass sunk at least 3,000 feet, and Pliocene and early Pleistocene sediments buried most of the old mountains and attained a maximum thickness of over 3,000 feet. The land then remained stable long enough for the carving of the mature Trabuco surface. It was later elevated in stages about 1,000 to 1,500 feet and remained stable there long enough to develop the Lakeview surface. Further elevation of about 500 feet was followed by a stable period long enough to form the Perris surface.

Further erosion removed some of the soft sediments from the Perris block and may have developed the Santa Rosa surface. Up to this time the drainage of the Perris block was chiefly to the northeast.

Movement along the San Jacinto fault blocked the drainage of the Perris basin and caused a lake to form there. Sediments deposited in the lake leveled the sedimentary floors of the valleys of this area to about their present form. The outlet of the lake was near the present course of the San Jacinto River. At this time the river probably flowed across the sediment-filled Elsinore Valley and across the Santa Ana Mountains.

There followed renewed faulting along the borders of the Temecula-Elsinore trough which was so rapid that the San Jacinto River could not maintain its course across the Santa Ana Mountains. Lake Elsinore was formed at about this time.

The Fallbrook surface was probably formed at about the same time as the present topography of the Temecula-Elsinore trough.

Several later uplifts and depressions of the land caused the terraces, and filled valleys, and other features of the area near the coast.

If the interpretation of the physiography presented above is correct, it follows that since the Lakeview surface was formed, there has been little differential movement or extensive tilting within the area except in the Elsinore-Temecula block, which may have dropped, and the Agua Tibia Range and the mountains to the southeast which may have been raised as a horst about 4000 feet in the northwestern part and tilted to the southeast.

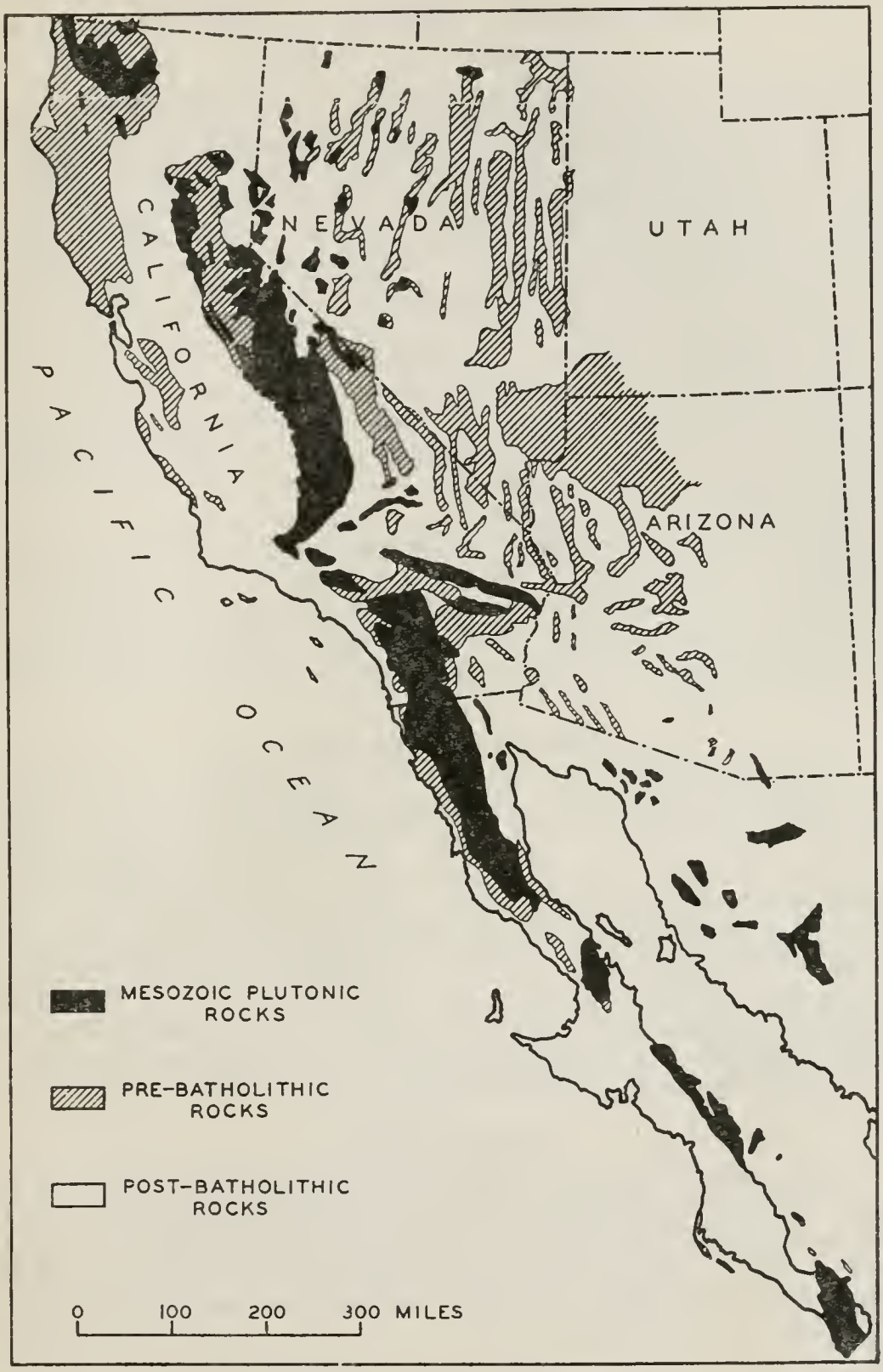

FIG. 1. Outline map of California and Lower California, showing distribution of Mesozoic plutonic rocks.

PRE-BATHOLITH SEDIMENTARY ROCKS

Paleozoic Schists and Quartzites

The schists exposed north and south of Domenigoni Valley, in the southeastern part of the Elsinore 30 minute quadrangle, have been shown to be Carboniferous by Webb,[10] who found Carboniferous (Mississippian) fossils in the interbedded limestone near the old magnesite quarry, southeast of Winchester. The typical schists are rather coarsely crystalline, well laminated rocks in which mica is a prominent constituent. They grade from quartz schists to mica schists, but nearly all have much quartz. In addition to quartz and mica, they contain more or less feldspar and locally amphibole, andalusite, sillimanite, garnet, epidote, and other silicates. Amphibolite and amphibole schist are present in the schists in the extreme northeastern part of the Elsinore quadrangle, and elsewhere. Southeast of Winchester sills of diabase, now altered to amphibolite, intrude the schists. The thickness of the schists could not be estimated accurately, but it must be great.

South of Domenigoni Valley in the southeastern part of the Elsinore quadrangle, a thick series of quartzites appears to overlie slates of the Bedford Canyon formation conformably, but the beds are believed to be separated by a fault. These quartzites are probably Paleozoic. No evidence of repetition of these beds was found, and the apparent thickness is about 12,000 feet.

Bedford Canyon Formation

The Bedford Canyon formation is a group of mildly metamorphosed slates and argillites with some quartzites and very few thin lenses of limestone, which lies west of the main batholith and underlies much of the Santa Ana Mountains. Somewhat similar, but more intensely metamorphosed, rocks are present to the southeast and east, within the batholith. Fossils of Triassic age have been found in these rocks at a number of places in the Santa Ana Mountains. The slates of the Santa Ana Mountains form a uniform lithologic unit, and are believed to be Triassic. Probably 20,000 feet are exposed in the Santa Ana Mountains. The grade of metamorphism of these rocks is very low in the western part of the area, and becomes progressively higher toward the east.

Jurassic (?) Slates

In the extreme southern part of the San Luis Rey quadrangle, just west of La Jolla Valley, some thin beds of slate much like those of the Bedford Canyon formation are interbedded with the Santiago Peak volcanics. A thicker section of slates overlies the main exposure of the volcanic rocks. This latter slate body has been mapped. These sediments strike N. 42° W. and dip 45° NE.

SANTIAGO PEAK VOLCANICS

Outcrops of the Santiago Peak volcanics form a strip, broken in a few places by younger sediments or by younger granitic rocks, from south of La Jolla quadrangle, northward in the Santa Ana Mountains nearly to the Santa Ana River. They have an exposed length of about 80 miles and extend for an unknown distance both to the south and north, beneath

[10] Webb, Robert W., Evidence of the age of a crystalline limestone in southern California: Jour. Geology, vol. 47, pp. 198-201, 1939.

the younger sediments. Their exposed width is nowhere much over 10 miles. In the three mapped quadrangles they underlie an area of about 120 square miles.

The thickness of the volcanic rocks cannot be measured, but it must have been thousands of feet and probably many thousands of feet. This must have been, therefore, a very large mass of andesitic rock.

The Santiago Peak volcanics overlie the Bedford Canyon formation unconformably. In lower Silverado Canyon, just south of the creek, the contact is well exposed. Here the bevelled edge of the Bedford Canyon formation is overlain by 30 feet of conglomerates which have abundant andesitic fragments and are overlain conformably by volcanic rocks. The conglomerates strike N. 75° W. and dip 50° S. The underlying slates do not show very good structure near the contact; they appear to strike in nearly the same direction as the conglomerates, but dip steeply in the opposite direction. To the north, in the drainage area of Ladd Canyon, these conglomerates are several hundred feet thick. East of the conglomerates the slates strike N. 30° E. and dip 40° E. No good structures were seen in the conglomerates near the contact, but a quarter of a mile below the contact the strike is N. 30° W., the dip 35° W. There appears to be an angular unconformity between the slates and the conglomerates. As fragments of the slates are present in the conglomerate, the slates were mildly metamorphosed before the deposition of the conglomerate.

The bodies of volcanic rocks within the slates, such as that of Santiago Peak, do not all appear to be bodies that are infolded but rather seem to occupy their present position as a result of the topographic relief in the surface over which they were spread. Some of the contacts may be faults. The structure in the mountains is not well known, as poor exposures and impenetrable brush make a detailed study of the sediments extremely difficult.

In the canyon below La Jolla Valley, in the southern part of the San Luis Rey quadrangle, rocks of the Santiago Peak volcanics are interbedded with, and conformably overlain by, a considerable thickness of argillites whose age is not known.

The Santiago Peak volcanics overlie the Triassic rocks unconformably; they have undergone nearly the same amount of metamorphism as the Traissic rocks and are intruded by all the batholithic rocks. Their age is therefore believed to be Jurassic.

Andesites and quartz latites predominate, and there are some rhyolites and probably some basalts. These form a pile of alternating flows, tuffs, and breccias, but no great areas of well-bedded clastic rocks or of volcanic conglomerates were found, indicating that the mass was in the main part of the volcanic pile and not at its borders. A little slate and quartzite was found, apparently interbedded with the volcanics, especially in the southern part of the area. The rocks are all mildly metamorphosed, and flow structures, glassy layers, and vesicles have been obscured or obliterated. The breccias break across fragments as easily as between fragments, and the brecciated character of the rocks is best seen on the weathered surfaces. In general, the metamorphism is mild in the western part of the mountains at a distance from the batholith, and especially in the western part of the Corona quadrangle. The highest-grade metamorphism, in which pyroxene had developed, was found only in small inclusions in the granitic rocks, such as near the mouth of Gopher

Canyon in the central part of the San Luis Rey quadrangle. The rocks are dense and compact, and most of them are dark gray to greenish gray or black; a few are light colored. Many show phenocrysts of feldspar in the hand specimens but no other phenocrysts. The groundmasses in most of the rocks are aphanatic. Some of the rhyolites and quartz latites carry phenocrysts of quartz as well as those of feldspar.

Intrusive Rocks. Small bodies of fine-grained granodiorite and related rocks, that are believed to be about the same age as the volcanic rocks, are shown on the geologic map, and some other smaller masses were seen but not mapped. The area underlain by these rocks is about 13 square miles, not including the Temescal Wash quartz latite porphyry.

The rocks included in this group in the San Luis Rey quadrangle have much in common. They are for the most part fine-grained gray rocks, and many carry peculiar long irregular prisms of amphibole. Most of the stocks show some variation from place to place, chiefly a variation in the proportion of dark minerals. In several places a light-colored rock intrudes a darker rock, but the two types differ chiefly in the proportion of minerals present.

A fine-grained granodiorite that forms the backbone of the Santa Margarita Mountains in the northwestern part of the San Luis Rey quadrangle is about 6 miles long. Other bodies of this rock were found in several places in the northwestern part of the quadrangle, north of Deluz Station, the western body in the drainage of the east work of Deluz Creek, and on the ridge between Deluz Creek and Santa Margarita Canyon. The rock gives ragged, angular, somber outcrops, breaks into small angular fragments, and in these respects resembles the Santiago Peak volcanics. Nowhere does it yield boulders of distintegration. In places it carries so many inclusions of the volcanic rocks, dark amphibolite, and other rocks, as to be a puddingstone. It is resistant to weathering and erosion and forms the high ridge and steep slopes of Santa Margarita Mountains. The sharp change in slope on both sides of the mountains is very near the boundary of this rock, which is typically gray and shows a few millimeter-sized white feldspar crystals and more or less long, ragged hornblende crystals in a very fine, light-colored groundmass. There is usually some pyrite and pyrrhotite in the fresh rock.

The strip south of Roblar Canyon, and west of the strip of gabbro, is much darker than the rock just described and carries more biotite and amphibole.

METAMORPHISM

The Santiago Peak volcanics and the Bedford Canyon formation have been subjected to about the same metamorphic processes. The slates were mildly metamorphosed before the extrusion of volcanic rocks, but later metamorphism changed both rocks. The main parts of these formations are rather uniform in their metamorphism and belong to the green schist facies of Eskola. Some small inclusions in the granitic rocks have undergone much more intense metamorphism and belong to the amphibolite and hornfels facies. In some of the screens lamellar injection has taken place.

For the most part there is little contact metamorphism where the granitic rocks intrude large bodies of the older schists, slates, and quartzites. Some of the screens and inclusions in the granitic rocks, however,

have been greatly metamorphosed. The textures have been made coarser, and many of the rocks have been completely recrystallized.

The Paleozoic limestones have been thermally and, locally, hydrothermally metamorphosed near their contacts with the granitic rocks. The famous mineral occurrence at Crestmore, only about a mile north of the Elsinore quadrangle, is in such a hydrothermal contact zone. Such contact zones are present around the Bonsall tonalite, the San Marcos gabbro, and the serpentine south of Winchester. Both the thermal and hydrothermal contact metamorphism around the tonalite, gabbro, and peridotite are much alike, and they are similar to the metamorphism commonly found around granite and granodiorite.

TEMESCAL WASH QUARTZ LATITE PORPHYRY

This nearly black porphyritic rock underlies an area of about 24 square miles, chiefly east of Temescal Wash, southeast of Corona. It intrudes the slates, as it carries inclusions of the slates and cuts across their bedding. It is older than the Woodson Mountain granodiorite, since near the contacts of these two rocks, as seen on the west side of Temescal Wash, it is cut by numerous dikes of aplite and porphyritic aplite which are usually parallel to the contact and which in places cross for short distances into the quartz latite porphyry.

In the hand specimen the greater part of this latite is uniform and shows numerous white or glassy feldspars, up to 3 millimeters across, and more or less quartz in a groundmass that makes up the major part of the rock; it is aphanitic and dense black in mass but gray and translucent in splinters. In some parts, the quartz phenocrysts are more prominent. Locally, near the contacts, the rock is lighter colored and the groundmass is finely granular.

DARK GRANODIORITE PORPHYRY EAST OF CORONA

A granodiorite porphyry of somewhat variable character, and probably made up of several small, closely related intrusive bodies, forms a number of small bodies on both sides of Temescal Wash, east of Corona, and two bodies to the northeast of Corona. The largest is about 3 miles east of Corona and underlies an area of about a square mile, chiefly in the Corona quadrangle. The total area of outcrop of this rock is about 2 square miles.

The outcrops are relatively poor, and small, poorly developed dark boulders of disintegration are strewn over the surface. Some of the outcrops are rugged and subangular.

This granodiorite porphyry is older than the Woodson Mountain granodiorite. The rocks of the dark granodiorite porphyry are medium gray to nearly black. Many show tabular plagioclase in a fine matrix, and some are granular.

SERPENTINE

Two small bodies of serpentine were observed in the area studied. The largest is only half a mile long and is situated in the eastern part of the Elsinore quadrangle, about 3 miles east of Winchester. It intrudes the Paleozoic schists, and its relation to the schists and its lack of metamorphism indicate that it is younger than the metamorphism of the Paleozoic rocks. A small body of serpentine is associated in space with a small

plug of granodiorite porphyry belonging to the Santiago Peak volcanics, and is located in the Corona quadrangle, near the crest of the Santa Ana Mountains at the head of Hagador Canyon.

The serpentine east of Winchester has been briefly described by Hess [11] and Gale,[12] and the associated pegmatites have been described by Murdoch.[13] This serpentine contains abundant remnants of olivine and enstatite and was probably derived from a peridotite. The rock is now made up essentially of serpentine with much anthophyllite and talc, some actinolite, carbonate, iron ore, spinel, chromite, and rutile, and locally tourmaline. In parts of the serpentine, secondary veinlets of magnesite cut the altered rock. Some magnesite has been mined.

A number of small, irregular, coarse-grained dikes of pegmatite cut the serpentine. They are made up chiefly of quartz and microcline microperthite and contain some black tourmaline, iron-poor biotite, and a little muscovite, garnet, coarse crystals of pinkish andalusite, and some needles of sillimanite. The tourmaline, andalusite, and sillimanite are concentrated near the borders of the dikes and extend for a short distance into the walls. They replace the other minerals of the pegmatite and were introduced hydrothermally, the tourmaline first, then the andalusite, and finally the sillimanite. Separating the pegmatite from the serpentine is a layer, an inch or two across, made up of anthophyllite in rather coarse subparallel prismatic aggregates that extend across the layer. Similar layers of anthophyllite or tremolite are common between albitite or plumasite dikes and the enclosing serpentine.

SAN MARCOS GABBRO

The San Marcos gabbro occurs in the San Luis Rey, Elsinore, and Corona quadrangles in about a hundred separate mappable bodies. Many of these are very small. The largest is southeast of Lake Elsinore on the Elsinore quadrangle and underlies an area of about 25 square miles; the body in the San Marcos Mountains in the San Luis Rey quadrangle underlies an area of about 11 square miles. In the three mapped quadrangles the gabbro occupies an area of about 120 square miles.

The San Marcos gabbro intrudes the Bedford Canyon formation of Triassic age and rocks of the overlying Santiago Peak volcanics. It is older than the Green Valley tonalite and the Lakeview Mountain tonalite and appears to be the oldest rock of the Cretaceous (?) batholith.

In the field one of the most noticeable features of the rock is its variability. In places good-sized bodies of one kind of rock are found, but in others the rock varieties are a few tens of feet or less across. Nearly every large body of the rock shows this variability. It is well shown on the southeast slope of the hill (elevation 2434 feet) which is 3 miles northeast of Wildomar in the Elsinore quadrangle. Here there are streaks and patches of fine-grained gabbro, others of coarse grain, some with very large poikilitic hornblende, some that are rich in dark minerals, and others that have sparse dark minerals. In places it is made up of alternate layers half an inch thick of rock rich in hornblende and rock that

[11] Hess, F. L., The magnesite deposits of California: U. S. Geol. Survey Bull. 355, 67 pp., 1908.

[12] Gale, Hoyt S., Late developments of magnesite deposits in California and Nevada: U. S. Geol. Survey Bull. 540, pp. 483-520, 1912.

[13] Murdoch, Joseph, Andalusite in pegmatite: Am. Mineralogist, vol. 21, pp. 68-69, 1933.

FIG. 2. Photo showing granodiorite associated with Bonsall tonalite, on north side of hill about a mile northwest of Lakeview, northern part of Elsinore quadrangle. Inclusions more abundant than usual and less flattened and oriented.

FIG. 3. Photo showing Green Valley tonalite in road cut one mile west of Vista: boulders of disintegration imbedded in gruss.

is nearly all plagioclase. These variations in most cases represent actual differences in mineral content, grain size, and texture. The most widespread and marked type of variation results from abrupt changes in the amount or character of the hornblende. At other places the rock appears to be made up of two distinct phases, with one intimately penetrating the other.

The rocks range from troctolite, made up chiefly of anorthite and olivine, to quartz norites, made up chiefly of calcic andesine and pyroxene with some quartz and biotite. Hornblende is a late mineral in all the rocks and it replaces the other dark minerals. It may be absent from a rock or it may be the only dark mineral present.

GREEN VALLEY TONALITE

A number of bodies of this tonalite of rather uniform character form a discontinuous strip just east of the main mass of the Triassic sedimentary and Jurassic volcanic rocks in the San Luis Rey quadrangle. This tonalite is not very different chemically and mineralogically from the Bonsall tonalite, but it lacks the abundant streaked inclusions of that tonalite. The Green Valley tonalite underlies an area of about 68 square miles in the San Luis Rey quadrangle. It intrudes the Triassic sediments, the Jurassic volcanics, and the San Marcos gabbro, and is intruded by the Woodson Mountain granodiorite and several other granodiorites.

The rock is gray, medium-grained, and rather uniform in character. The minerals, especially the dark minerals, do not show a sharp granularity in the hand specimens. The plagioclase crystals are gray from inclusions. Under the microscope, the average rock shows a variable grain size, ranging from half a millimeter to 3 millimeters.

LAKEVIEW MOUNTAIN TONALITE

The Lakeview Mountain quartz diorite or tonalite is a rather uniform rock, which resembles the typical Bonsall tonalite but lacks the abundant inclusions that characterize that latter rock. In places it shows a streaking of dark and light layers. Within the area mapped in detail, it is found only in the Elsinore quadrangle and to the east. Its contact with the Bonsall tonalite is sharp in most places. The two rocks are nearly identical, but as the contact is approached from the side of the Bonsall tonalite, streaking becomes more conspicuous, and inclusions are more abundant and "streaked out." At the contact they stop abruptly. The contact is well shown east of Lakeview and in many places northeast of Double Butte. Everywhere the streaking and orientation of the flat inclusions in the Bonsall are parallel to the contact. The poorly developed structure of the Lakeview Mountain tonalite also appears to be nearly parallel to the contact. The general character of the contact indicates that the Bonsall tonalite intrudes the Lakeview Mountain tonalite, but the two rocks are probably not very different in age.

West of Lakeview, the Lakeview Mountain tonalite is in contact with a coarse-grained granodiorite related to the Bonsall tonalite. Here, the two rocks are separated by a strip, a few hundred feet across, of a fine-grained streaked rock that appears to be younger than either of the adjoining rocks.

The Lakeview Mountain tonalite shows nearly white outcrops and the usual huge boulders of disintegration. In the Lakeview Mountains it is cut by many pegmatites, some of which have been prospected for gem minerals and for feldspar.

Some of the rocks are a little lighter colored than the common rock, and these have biotite as the chief mafic mineral and calcic oligoclase as the feldspar. The rock of the San Jacinto Mountains is chiefly of the light-colored kind. Local patches contain a large amount of hornblende. In some places the hornblende is rather well oriented.

THE BONSALL TONALITE

The most prominent characteristics of the Bonsall tonalite are the abundant oriented inclusions and the streaking. The rock differs greatly in the proportion and distribution of the inclusions, in the extent of the streaking and schistosity, in the proportion of the minerals present, and in the average grain size. It represents more than one injection, probably with little difference in age. The dominant rock varies within moderate limits. Many of the streaked, fine-textured, and gneissoid rocks are near contacts, but others are not near any known contacts.

The Bonsall tonalite is younger than the San Marcos gabbro, as it carries abundant inclusions of the gabbro, which in some places are drawn out and altered almost beyond recognition; in other places they retain their characteristic features. The flow lines of the tonalite bend around inclusions of gabbro, and the tonalite sends many apophyses into the gabbro.

The Bonsall tonalite is younger than the Lakeview Mountain tonalite. The Bonsall tonalite is intruded by the Woodson Mountain granodiorite and the Indian Mountain granodiorite, as the latter rocks carry inclusions of the Bonsall and send apophyses into it in many places. The fluidal structure of the granodiorites parallels the contacts with the tonalite, while those of the tonalite are truncated at the contacts.

The Bonsall tonalite is a medium-grained rock ranging from light to dark gray depending on the proportion of dark minerals present. Hornblende is the chief dark mineral, and it is present in elongated grains up to a centimeter in length or in large patches, poikilitically enclosing the feldspar. This poikilitic type is the main rock of the eastern part of Bear Valley, and of the large mass east of the San Luis Rey quadrangle. Biotite is present in moderate amount and locally it is more abundant than hornblende. White to gray plagioclase and quartz are easily seen in the hand specimen. Locally this tonalite contains few dark minerals and essential amounts of orthoclase; some specimens would be called granodiorite. These bodies of light-colored rock may be separate related intrusives. Such light-colored rock underlies many square miles south of Morro Hill, another area in the basin about 2½ miles east of Mt. Ararat, and a third area about 1½ miles southeast of Lilac, all in the San Luis Rey quadrangle. A still lighter-colored rock makes up much of the hills east of Reche Canyon in the northeastern part of the Elsinore quadrangle. It may not belong to the Bonsall. It is gneissoid and has about 25 percent orthoclase and much quartz; biotite is the only important mafic mineral. It contains scattered small inclusions but has many large flat inclusions of amphibolite, schist, and quartzite.

GRANODIORITE WEST OF LAKEVIEW

Two small bodies of granodiorite have been mapped, one east of Riverside and one west of Lakeview, and some other small outcrops were seen. The central and eastern parts of the lone hill north of Egan are made up of a similar rock which is somewhat gneissoid. East of Riverside, in the small gulch with the mapped road, stringers of granodiorite cut the tonalite, showing that the granodiorite is younger. West of Lakeview the Bonsall tonalite and the granodiorite are separted by a screen of schist.

The granodiorite carries abundant elongated inclusions, especially in the body west of Lakeview. The typical rock is flesh-colored to nearly white and is characterized by very large, flat, glassy orthoclase crystals, some of which are several centimenters in length. The rocks are rather coarse-grained and are richer in quartz and orthoclase than the Bonsall tonalite. They are believed to be closely related to the Bonsall tonalite.

The orthoclase tends to be glassy. It is in tablets up to several centimeters long and only a few milimeters thick, and these tablets tend to be oriented. The orthoclase contains little or no microperthite, but it carries irregular patches of quartz and andesine. It has much the appearance of sanidine. There is some myrmekite on the borders of the orthoclase. Allanite is present in the rock.

STREAKING AND INCLUSIONS

The Lakeview Mountain tonalite contains only scattered inclusions which are not well oriented. In many places this tonalite shows a streaking, with dark layers as much as a foot across; in others it shows some orientation of the dark minerals, and locally the rock has a faint schistosity. In a few places the hornblende has a good linear orientation that is mostly along the dip of the other structures, but in a few places appears to be at an angle to the dip.

Nearly every good outcrop of the Bonsall tonalite and the associated granodiorite west of Lakeview shows inclusions. The inclusions are concentrated in streaks parallel to the structure, and streaks rich in inclusions run across the hills like dikes of dark rocks. In a few outcrops the inclusions are spherical or angular, but for the most part they are much-flattened ellipsoids of revolution, and in some places they are streaked out into thin dark layers in the host. Where the flattened inclusions are observed on a surface cutting their long dimensions, they appear as long narrow parallel strips ranging from half an inch to 2 feet in length. Locally, as in the hills east of Reche Canyon in the northeastern part of the Elsinore quadrangle, they are hundreds of feet in length.

The granodiorite west of Lakeview has very abundant flat, oriented inclusions and the orthoclase tablets are well oriented.

In the Bonsall tonalite and associated rocks the orientation of the inclusions and mineral crystals results in a regional structure. Near the contacts with older rocks the structure is parallel to the contact.

In many places the dark minerals are oriented and concentrated in layers, and in some places the rock has a faint gneissoid structure. This is more common in the rocks in which biotite is the chief mafic mineral, as in the rocks east of the Riverside-Perris road. In some places the hornblende and other minerals have a linear orientation. The rocks near contacts and the fine-grained varieties commonly have a pronounced

streaking with thin layers of different minerals or textures, even when fine-textured rocks are not associated with known contacts. In places the rock near the contacts is in good gneiss with abundant biotite in layers.

The orientation of the inclusions and of the minerals is believed to have taken place before the magma was completely crystalline. Some of the streaking of the mica along nearly plane surfaces to give the rock a rude schistosity may have taken place after the rock was sufficiently crystalline to fracture. In general, the texture is typically igneous, and there is little fracturing or straining of the crystals, indicating that most of the orentation was brought about before the crystal mesh was strong enough to fracture. The orientation is thus essentially a flow phenomenon, and the crystals and inclusions were oriented according to shape. The actual movement during this stage must have been small, as otherwise the thin plastic inclusions would have been streaked out still more, torn apart, and elongated.

GRANITIC ROCKS OF THE SAN JACINTO AND RAMONA QUADRANGLES

The San Jacinto quadrangle lies east of the Elsinore quadrangle and has been mapped by Fraser,[14] but he did not make a detailed study of the granitic rocks. The Ramona quadrangle lies east of the San Luis Rey quadrangle. In this latter quadrangle the area near the mining camps of Julian and Banner have been mapped by Hudson [15] and Donnelly [16] and the southwestern part has been recently mapped by Merriam.[17]

A reconnaissance study of the area north of the Ramona-Kane Springs road as far as Banning was made for the purpose of comparing the granitic rocks of this area with those to the west. The area contains bodies of older rocks, chiefly sedimentary schists, gneisses, quartzites, and marbles, but in part amphibolites and gneissoid granodiorite. The latter rock underlies much of the large area from Ballena for about 15 miles to the east and northward, nearly to Lake Henshaw. It was also seen north of Warner Hot Springs. This is probably related to the Stonewall quartz diorite which Hudson [18] and Donnelly [19] found to be older than the Cuyamaca basic intrusive (San Marcos gabbro). It is older than the Cretaceous batholith and is probably pre-Triassic.[20]

Granitic rocks related to the Cretaceous batholith underlie the greater part of the area, and tonalite grading to granodiorite poor in orthoclase makes up by far the greater part of these granitic rocks.

The tonalites are of several kinds, most of them much like those to the west, although they appear to have more quartz, less mafites, and a more sodic plagioclase. Some of them are much like the granodiorites to the west but have little or no potash feldspar. In the southern part of the

[14] Fraser, Donald M., Geology of the San Jacinto quadrangle south of San Gorgonio Pass, California: California Div. Mines Rept. 27, pp. 494-540, 1931.

[15] Hudson, F. S., Geology of the Cuyamaca region of California, with special reference to the origin of the nickeliferous pyrrhotite: Univ. California, Dep. Geol. Sci. Bull., vol. 13, pp. 175-252, 1922.

[16] Donnelly, Maurice, Geology and mineral deposits of the Julian district, San Diego County, California: California Div. Mines Rept. 30, pp. 331-370, 1934.

[17] Merriam, R. H., Igneous and metamorphic rocks of the southwestern part of the Ramona quadrangle, San Diego County, California: Geol. Soc. America Bull., vol. 57, pp. 223-260, 1946.

[18] Op. cit., pp. 191-193.

[19] Op. cit., pp. 340-341.

[20] Op. cit.

area the large body of Green Valley tonalite in the San Luis Rey quadrange extends to the east nearly to Ramona, a distance of about 8 miles. The Bonsall tonalite, carrying abundant dark inclusions, extends with some interruptions from the Pala area eastward to Lake Henshaw. The Lakeview Mountain tonalite is the most abundant granitic rock of the San Jacinto and Ramona quadrangles. Much of this rock has fewer mafic minerals than the Lakeview Mountain tonalite to the west. In the Ramona quadrangle this rock was found in small amount a few miles east of Ramona and west of Santa Ysabel. A large body extends from Lake Henshaw eastward to Warner Hot Springs and the mountains to the east.

DOMENIGONI VALLEY GRANODIORITE

In the southeastern part of the Elsinore quadrangle there are a number of small bodies of rock that range from tonalite to granodiorite which resemble the Bonsall tonalite, but are lighter-colored and finer in grain size. The rock underlies an area of about 13 square miles. The name Domenigoni Valley granodiorite is proposed for this rock as it is well exposed on both sides of Domenigoni Valley.

The Domenigoni Valley granodiorite crops out as light-colored boulders of disintegration. It has abundant oriented dark inclusions, but they are somewhat fewer than those in the Bonsall tonalite. The rock is made up of grains 1 millimeter to 5 millimeters long.

Along the north contact of the body south of Domenigoni Valley there are several hundred feet of a rock that is coarser in grain, richer in dark minerals and poorer in orthoclase than most of the rock.

ESTELLE TONALITE

The name Estelle quartz diorite was applied by Dudley [21] to the body of tonalite that occupies the basin southeast of Estelle Mountain. It underlies an area of about 2 square miles and intrudes the Temescal Wash quartz latite porphyry which surrounds it on all sides. It is less resistant to erosion than the quartz latite and occupies a basin that is surrounded by steep hills of the latite. It yields the usual huge boulders of disintegration. It lacks the abundant large dark inclusions that are found everywhere in the Bonsall tonalite and is finer textured and a little darker in color than that rock.

The rock is light gray, with grains up to a few millimeters in length. It contains biotite and grains of a green hornblende that shows poorly developed cleavage in contrast to the cleavable black hornblende of the Bonsall tonalite. This rock resembles the Green Valley tonalite more than it does the Bonsall tonalite.

LA SIERRA TONALITE

La Sierra tonalite occurs in several small bodies in the hills of La Sierra, north and northeast of Corona. The contacts of La Sierra tonalite with the Woodson Mountain granodiorite appear to be sharp, as the two rocks in typical development were found within 50 or 100 feet of each other in many places, and the actual sharp contact is exposed on the slopes north of the peak (elevation of 1505 feet) about 4 miles northeast of Corona. The contact is extremely sharp and very irregular in detail. La

[21] Op. cit., 1935, p. 502.

Sierra tonalite is clearly intruded by the Woodson Mountain granodiorite as the latter sends apophyses into and carries inclusions of the tonalite. There is no change in texture of either rock near the contact.

La Sierra tonalite is a little darker gray than the associated granodiorites, and in the hand specimen it shows many prominent stout tablets of plagioclase that are commonly 2 to 4 millimeters in length and about three-fifths as thick. The dark minerals are not in good grains, and little or no quartz can be seen.

In most specimens this tonalite shows bending of the biotite, and some show fracturing of the plagioclase crystals. Secondary uralite is present in all the specimens; it replaces more or less of the pyroxene and in some specimens it replaces some of the plagioclase, generally along fractures across the plagioclase tablets. In some of these specimens the plagioclase is in part albitized.

Veinlike bodies of more intense alteration cut the tonalite, especially in the area northeast of Auburndale. The most conspicuous of these forms the crest of the low ridge N. 15° W. of Hill 1020. This mass is up to 100 feet across and forms the ridge for 100 yards east of the alluvium; from there it is faulted about 100 yards to the north and continues to the alluvium on the east. In this vein the tonalite is completely replaced by a mixture of quartz and epidote with some uralite, fine-grained scapolite, and in some parts a little tourmaline, sphene, and carbonate.

A replacement vein along the road just west of the aplite hill contains much bluish-green uralite, some birefracting garnet, epidote, and some secondary quartz, fine-grained anorthite, sphalerite, galena, chalcopyrite, and pyrite. In this replacement silica and soda must have been lost; calcium, zinc, sulfur, and probably iron and magnesia, gained.

MISCELLANEOUS TONALITES

A number of small bodies of mafic rocks, chiefly tonalites, are present in the area mapped. Some of the smaller bodies have not been mapped, others are designated by a single pattern on the geologic maps. Some of the more important of these bodies are described below. Most of them are older than the adjoining rocks, and some may be related to the Santiago Peak volcanics.

The tonalite near San Juan Hot Springs, in the southeastern part of the Corona quadrangle lacks the conspicuous cleavable hornblende and biotite of the Bonsall tonalite. It is medium to dark gray, medium-grained and under a pocket lens shows tabular plagioclase, biotite, femic minerals of doubtful identity, and quartz. The rock of the dike-like body about 3 miles west of Valverde is fine-grained.

In the San Luis Rey quadrangle, the mass in Reedy Canyon, northwest of Escondido, is fine-grained and much decomposed. The body west of Merriam Mountain, San Luis Rey quadrangle, is variable and is probably a complex. The tonalite south of El Salto, about 7 miles southeast of Oceanside, has plagioclase phenocrysts in a micrographic matrix of quartz and oligoclase, resembles some of the intrusives related to the Santiago Peak volcanics and may belong to them.

The body south of San Marcos is chiefly a tonalite porphyry. That west of Battle Mountain, in the southern part of the quadrangle, is a tonalite with a groundmass made up of micrographic intergrowths of

quartz and sodic plagioclase. The small body to the west of the one last described is a gabbro.

In the Corona quadrangle much altered rock is associated with some of the intrusive bodies. The dike east of Santiago Peak is a milimeter-grained tonalite. The larger body south of Santiago Peak is lighter colored and is a granodiorite. The stock at the head of the West Fork of Ladd Canyon is a tonalite.

Bodies of hornblende gabbro and hornblende tonalite are present in many places, chiefly associated with the metamorphosed sediments.

WOODSON MOUNTAIN GRANODIORITE

This granodiorite is present in many large masses in the western part of the Peninsular range. In the eastern part of the batholith typical Woodson Mountain granodiorite is not found, but a similar and probably related rock, white and lacking potash feldspar, is widespread.

The Woodson Mountain granodiorite intrudes the Green Valley and Bonsall tonalites, as in many places it carries inclusions of these rocks. It is darkest or finest-grained near the contact, but in most places there is no appreciable change. It clearly intrudes the Temescal Wash quartz latite porphyry and the mafic granodiorite east of Temescal Wash, as it carries inclusions of these rocks and sends apophyses into them, but it does not become finer-grained at the contact. It also intrudes La Sierra tonalite, as it sends many dikes into that tonalite and carries inclusions of it. The Woodson Mountain granodiorite is cut by the dike of granodiorite porphyry in Temescal Wash. It is older than the Roblar leucogranite, the Mt. Hole granodiorite, and the micropegmatite northeast of Corona.

The Woodson Mountain granodiorite shows lighter-colored outcrops than any other large body of the crystalline rocks. Near the contact of the granodiorite where it intrudes older rocks, it commonly has a more or less banded or even gneissoid structure. In several places this is very marked for a few feet next to the contact, but gradually becomes less prominent, and in the main mass of the rock is entirely lacking. This banding parallels the contact and is everywhere nearly vertical. This gneissoid border zone is more common and wider in some of the smaller bodies and is well shown in the elongated body that is about 2½ miles east of Auld, in the southeastern part of the Elsinore quadrangle. The Woodson Mountain granodiorite everywhere carries scattered inclusions of a dark, fine-grained rock. They are mostly irregular in shape and only a few inches across. They are much less abundant than in the Bonsall tonalite, are smaller, and are rarely drawn out into discs. An outcrop 20 feet across will usually show a few such inclusions.

The typical Woodson Mountain granodiorite is a rather coarse-grained rock, nearly white to pale brownish gray in color in the fresh rock, and flecked with scattered black grains. In hand specimens, large grains of quartz in places with a bluish color, white plagioclase, and flesh-colored microcline are the chief constituents, and black biotite and hornblende are present in small amounts.

A number of relatively small bodies of a fine-grained granodiorite have been mapped with the Woodson Mountain granodiorite.

LAKE WOLFORD LEUCOGRANODIORITE

This formation differs considerably from place to place in each of the main masses, and it was probably not emplaced as a single injection but as several injections, closely related in time and character. The rocks are characteristically light-colored and fine-grained. They are very light gray on fresh fractures and yellowish on the weathered surface. They all show abundant quartz and a few percent of biotite in the hand specimens.

In part, the formation is closely sheeted and shows poor outcrops that resemble those of quartzite or schist. Where the sheeting is more widely spaced the nearly white outcrops are rounded but not like the boulders of disintegration of the Woodson Mountain granodiorite and other rocks of the area. Where the texture is coarser, as around Burnt Mountain, boulders are developed.

The rock tends to intimately inject and react with the wall rock. North of Lake Wolford and in many other places it contains abundant inclusions of all sizes of amphibolite, especially near the amphibolite contacts. In such places there is obvious contamination of the leucogranodiorite which may carry as much as 20 percent of the amphibole and calcic plagioclase. Elsewhere inclusions of schist are abundant. Locally, as on Burnt Mountain, the rock shows a streaking of the mica as if replacing mica schist.

The Lake Wolford leucogranodiorite is younger than the San Marcos gabbro, as it carries abundant inclusions of the gabbro. It is believed to be older than the Woodson Mountain granodiorite. The contact just east of Lake Wolford in the Ramona quadrangle is well exposed along a small gulch which follows the contact. The Lake Wolford rock for 50 feet from the contact is a fine-grained gneiss. The two rocks are tightly welded. The Woodson Mountain rock for a few inches near the contact is finer grained and shows a gneissoid streaking into the finer-grained Lake Wolford rock.

INDIAN MOUNTAIN LEUCOGRANODIORITE

Two bodies of granodiorite southwest of Pala in the northern part of the San Luis Rey quadrangle are much alike and are believed to be closely related. The one body underlies Indian Mountain, about 2 miles southwest of Pala, the other underlies Lancaster Mountain and the area to the north, about 6 miles southwest of Pala.

On Indian Mountain, the contact of this light-colored rock with the darker Bonsall tonalite can be seen in places from the saddle south of Indian Mountain northwestward for 1½ miles to the allivium of the San Luis Rey River. It dips gently to the north nearly to the river and there plunges rather steeply. An examination of this contact shows that in the gently dipping part the two rocks are separated by a screen of micaceous amphibolite gneiss that is in most places less than 50 feet in thickness. Where the slope of the contact changes, the contact cuts across the gneiss and tonalite. This screen is well shown on the northern slopes of Indian Mountain where the gneiss is about 50 feet thick. The Bonsall tonalite follows the layering of the gneiss, but in detail it has eaten into the gneiss in rounded bays. The contact is sharp. The tonalite is finer grained near the contact and carries many inclusions of the gneiss. The gneiss near the contact is half-millimeter grained and is more than half labradorite with quartz, hornblende, and biotite. It was probably derived from a basaltic

rock. The contact of the gneiss and the Indian Mountain leucogranodiorite is gradational for a few feet. The granodiorite replaces and impregnates the gneiss and has apparently reacted on it to a small extent. The Bonsall tonalite is clearly cut by the leucogranodiorite near the San Luis Rey River and is the older rock.

The gneiss of the screen and the contacts of the two rocks strike about west and dip 30° N. on the south shoulder of Indian Mountain. On the northeast flank, they strike about N. 20° E. and dip 35° NW. Just to the east, the layering of the granodiorite of the eastern arm dips about 30° NE. The banding of the granodiorite is everywhere parallel to the contact. On Indian Mountain, the banding of the granodiorite is marked near the contact, and the rock might be called a gneiss. Away from the contact the banding gradually becomes less prominent, and in the main part of the body it is distinctly but faintly visible.

The form and structure of the body shows that it is steeply crosscutting near the San Luis Rey River, and at the gently dipping gneiss it follows along the schistosity as the surface of easiest fracture, and in this part might be called a batholith or sill. The body to the southeast of Indian Mountain appears to be steeply crosscutting.

This leucogranodiorite is nearly white in color, rather fine-grained, and contains very little biotite. The rock of the upper part of the mass shows a faint streaking due to the orientation of the dark minerals, and this becomes more prominent as the lower contact is approached. For some feet above the base, the rock is a well-banded micaceous gneiss with much more mica than usual.

The granodiorite that underlies a large area around Lancaster Mountain and for some miles northwest across the San Luis Rey River is much like the rock of Indian Mountain. Nearly everywhere it carries abundant inclusions of the older rocks and is cut by many aplite dikes. These dikes and inclusions are especially numerous in the mass north of the river. The aplites form better outcrops than the bordering granodiorite, and casual examination gives one the impression that the hills are made up mostly of aplite, although aplites actually make up only a small proportion of the mass. The hills have a peculiar appearance from the light-colored emergent aplite dikes, separated by the darker soil-covered slopes. The aplites carry some garnet and have streaks, mostly less than an inch wide, of pegmatitic material that carries tourmaline. These streaks resemble streaks of fat and lean in fat bacon.

The host rock tends to have a gneissoid texture in many places, and the numerous small inclusions are oriented with the streaking. The strike of the schistosity and inclusions is approximately east-northeast, and the dip is moderate to the north in the area south of the river and to the south in the northern part. The rocks are nearly white with scattered dark patches a few millimeters across. The dark areas are biotite and amphibole, and in most places can be seen with the naked eye to carry poikilitically numerous inclusions of the light constituents.

The Indian Mountain leucogranodiorite south of the San Luis Rey River has a sheeting that is nearly flat and parallel to the lower contact of the body. This results in sheeted outcrops rather than the typical boulders of disintegration.

ESCONDIDO CREEK LEUCOGRANODIORITE

Two large masses of this fine-grained, light-colored rock that ranges in composition from a leucogranodiorite to a leucotonalite and averages granodiorite are exposed in the mountains west of Escondido. Along most of its contact it intrudes the Santiago Peak volcanics, but in Escondido Creek, near Harmony Grove, it intrudes both the Green Valley tonalite and the San Marcos gabbro. It sends many dikes into the surrounding rocks.

This granodiorite is younger than the Green Valley tonalite, and this relation is well shown a little above the new highway in the small gulch north of Hodges Lake. The granodiorite sends several dikes into the Green Valley tonalite, and it carries inclusions of the tonalite. For an inch or two next to the contact the granodiorite contains more mafic minerals than usual, and they are irregularly distributed; but otherwise there is little change next the contact.

The Escondido Creek leucogranodiorite shows nearly white outcrops with meager soil. The outcrops tend to be blocky or subangular with some small well-rounded blocks but no good boulders of disintegration. As in most of the fine-grained and porphyritic rocks of the area, the closely spaced sheeting seems largely to control the weathering.

This granodiorite commonly carries abundant dark inclusions, erratically distributed. In some outcrops, few inclusions can be seen, while in some areas, hundreds of yards across, especially near the contacts but not confined to contacts, the rock is a puddingstone.

The rock is fairly uniform except for the variableness of the inclusions. Near the contacts, it is finer grained and tends to be distinctly porphyritic, richer in orthoclase, and poorer in dark minerals. In a few places the rock appears to be richer in mafic minerals near the contact.

MT. HOLE GRANODIORITE

Several bodies of a rock that is intermediate in appearance between the Woodson Mountain granodiorite and the coarse varieties of the dike of granodiorite porphyry are mapped in the hills northeast of Corona. Nearly all of the old quarries for paving blocks were in boulders of disintegration of this rock, and nearly every body of this rock contains scattered quarries. The name Mt. Hole granodiorite is proposed for this rock from its characteristic outcrops on Mt. Hole.

The contact of the Mt. Hole and Woodson Mountain granodiorites is exposed about three quarters of a mile north of BM 687 on Magnolia Avenue in the extreme eastern part of the Corona quadrangle. Here the former rock carries inclusions of the Woodson Mountain up to several feet across, and dikelets of the Mt. Hole cut the Woodson Mountain. The Mt. Hole granodiorite is therefore younger than the Woodson Mountain.

The rock weathers into huge light-colored boulders of disintegration much like those of the Woodson Mountain granodiorite, but it is probably somewhat more resistant than the Woodson Mountain, and less commonly forms a friable gruss. In the hand specimen the rock carries abundant, thick tablets of white feldspar in large part smaller than 8 millimeters long, and some biotite in a fine granular groundmass. As compared with the granodiorite porphyry the rock shows fewer and less conspicuous plagioclase phenocrysts and a less distinct groundmass. It is more distinctly porphyritic than the Woodson Mountain granodiorite, although

both have white plagioclase tablets, and where the rocks are weathered it is difficult to tell the two apart.

GRANODIORITE PORPHYRY

A dike of granodiorite porphyry in Temescal Wash ranges in width from less than 100 feet to 1000 feet or more, and in places breaks up into several smaller dikes. The direction of this dike corresponds closely to that of the contacts of the Woodson Mountain granodiorite, especially in the southern and central portions where for a considerable distance the porphyry occupies the center of a rather narrow band of the Woodson Mountain granodiorite. The porphyry crops out in prominent hard, gray boulders of disintegration in contrast to the pinkish color and poorer outcrops of the surrounding Woodson Mountain granodiorite. Where the dike is narrow and porphyritic, it weathers into small angular fragments.

The rock is uniform in composition but varies greatly in texture. In the wider parts of the dike the rock is nearly uniform in grain and shows prominent tablets of white plagioclase from 5 to 8 millimeters across and 3 to 5 millimeters thick, considerable quartz and irregular feldspar, and a little biotite and hornblende. In the narrower parts of the dike the plagioclase tablets are nearly as large and abundant as in the broad parts of the dike, but the other constituents form a fine-grained, dark-gray groundmass, yielding a porphyry with abundant prominent white plagioclase phenocrysts in a nearly black matrix. At the actual contacts with the Woodson Mountain granodiorite the rock is dark gray, and away from the contact the plagioclase phenocrysts appear first as small crystals, then increase in size until the normal rock appears. Where the dike is wide, this aphanitic, nonporphyritic contact zone is an inch or less wide, but in the narrower parts it is a foot across.

MISCELLANEOUS GRANODIORITES

The spindle-shaped mass, cutting the Green Valley tonalite about a mile north of Hodges Lake, south of Escondido, gives conspicuous, nearly white outcrops of large boulders of disintegration in sharp contrast to the darker colored and less prominent boulders of the Green Valley tonalite. The rock is light gray, pepper and salt colored, and 1 millimeter grained. It is darker colored and finer grained than the Woodson Mountain granodiorite.

The granodiorite forming the hills about 3 miles east of Escondido is in an area of deep weathering. It gives somewhat better and lighter colored exposures than does the Green Valley tonalite. The typical rock is light gray and has a seriate texture with grains 0.3 of a millimeter to 4 millimeters across. The rock nearly everywhere carries abundant inclusions of a fine-textured, dark diorite, of volcanic rocks, schist, and other rocks. Some of the inclusions are of mappable size. The contact with the Green Valley tonalite along the Escondido-Ramona highway is much weathered and is not sharp; in places there is a gradational zone of 10 to 100 feet between the two rocks; and in others there are several feet of light-colored rock with large poikilitic biotite plates and some tourmaline.

The small body of granodiorite south of Red Mountain, 8 miles north of Escondido, is darker than the surrounding Woodson Mountain granodiorite.

The small body of granodiorite on the slopes north of San Dieguito River, about 2½ miles east of Bernardo, in the southern part of the San Luis Rey quadrangle, is darker and less even textured than the Woodson Mountain granodiorite. It gives much lighter-colored boulders of disintegration than does the surrounding Green Valley tonalite.

The two small bodies of granodiorite in the Green Valley area in the extreme southeastern part of the San Luis Rey quadrangle are much like the Lake Wolford leucogranodiorite but have large poikilitic microcline crystals. The rock is light gray or light flesh colored, fine-grained, and resembles an aplite.

The body of granodiorite just south of the mouth of Deluz Creek, in the northern part of the San Luis Rey quadrangle, resembles the Woodson Mountain granodiorite, is seriate in texture, and in places is gneissoid. It carries abundant inclusions of schist.

A small body of fine-grained quartz monzonite is present at the southeast base of Mt. Hole, northeast of Corona. This rock is sheeted into slabs about a foot thick and thus gives no large boulder of disintegration, in contrast to the neighboring Mt. Hole granodiorite and Woodson Mountain granodiorite. The sheeting is about N. 20° W., and parallels the structure of the region. This quartz monzonite is crossed by shear zones along which pyrite, chalcopyrite, pyrrhotite, and molybdenite have been deposited, mostly impregnating the quartz monzonite. It has been prospected. Except for its finer texture the rock resembles the Woodson Mountain granodiorite.

A light pink aplite underlies an area about half a mile across about 2½ miles north of Corona. It intrudes the Sierra tonalite and Woodson Mountain granodiorite.

The granodiorite on both sides of Agua Hedionda Creek about 1½ miles southwest of Bueno is dark on the fresh fracture but weathers to a light color. It is about millimeter grained and contains the dark minerals augite and hypersthene, and some hornblende and biotite.

The granodiorite in the southern part of the Corona quadrangle and adjoining parts of the Elsinore quadrangle, chiefly east of Hot Spring Creek, is light gray in color and of medium grain. It is deeply weathered and gives smaller and poorer boulders of disintegration than the adjoining Woodson Mountain granodiorite.

ROBLAR LEUCOGRANITE

In the northern part of the San Luis Rey quadrangle, chiefly in Roblar Canyon but extending for some distance to the north and east, is a body of light-colored leucogranite, called the Roblar leucogranite. In most places it shows poor outcrops, and the exposures are of a friable sandy nature; where better exposed, it yields small, angular blocks due to the closely spaced sheeting. Rarely it gives boulders of disintegration. In the uplands it forms small, rounded hills with few rock outcrops; in canyons it shows angular, blocky, or sheeted outcrops that are nearly white in color. This is in marked contrast to the huge boulders of disintegration that characterize the outcrops of the Woodson Mountain granodiorite, and in many places the contact can be easily located from the character of the outcrops. East of Deluz Creek the Roblar crops out in boulders of disintegration.

The Roblar leucogranite is younger than the granodiorite of the Santa Margarita Mountains, as it has a fine-grained border zone less than an inch wide where the contact was seen in road cuts a quarter of a mile north of the head of Roblar Canyon. It is younger than the Woodson Mountain granodiorite as dikes of the Roblar cut the Woodson Mountain. This granite is cut by many aplite dikes and carries some large inclusions of quartzite and volcanic rocks.

The rock is rather uniform in character. It is flesh colored and aplitic in appearance and shows a litte biotite and white feldspar. The texture is seriate with grains varying from about 0.1 of a millimeter to 4 millimeters. Some of the biotite is in fairly large flakes, but some is in streaks of smaller flakes that cut across the other minerals, and clearly filled fractures in the feldspar and quartz. The perthite is nearly half albite.

MICROPEGMATITE GRANITE

A pink, indistinctly granular rock forms the low hills about a mile northeast of Corona where it underlies an area of about a square mile. This micropegmatite is younger than the Woodson Mountain granodiorite, as in the old quarry south of the railroad it carries inclusions of the Woodson Mountain and sends dikelets into it.

The micropegmatite crops out as reddish, sheetlike masses with rounded corners, but it does not yield boulders of disintegration. Megascopically the rock is pink in color and shows a few white striated feldspar crystals up to 3 millimeters long imbedded in a rather indistinctly crystalline mass of pink feldspar and quartz with a very little fine-grained dark mineral and some pyrite.

TWO LEUCOGRANITES OF RUBIDOUX MOUNTAIN

Rocks with a greater amount of alkalic feldspar than of plagioclase are present in very small amounts in the area described in this report. Two such rocks, with very different textures and with sharp contacts, form Rubidoux Mountain and some other small hills near Riverside. Both rocks crop out in the usual boulders of disintegration and are deeply decomposed. The coarse rock has some inclusions, and the fine variety has very few. The contact of the two granites was seen in a number of places, and the coarse rock appeared to intrude the fine rock, although the relations were not proved. Large inclusions (?) of the fine rock are rather common in the coarse variety near the contact, and dikelike bodies of the coarse rock cut the fine rock.

The coarse-grained leucogranite underlies the eastern slopes of Rubidoux Mountain and a similar rock cuts the Bonsall tonalite northeast of Quarry Hill. It is pale greenish gray and in the hand specimen shows abundant stout tablets of orthoclase a centimeter or more in length, large quartz grains, and some biotite.

A somewhat similar granite makes up the small granite mass northeast of Quarry Hill, near Riverside. It is pinkish and has a little more biotite than the rock of Rubidoux Mountain (about 5 percent) but no pyroxene.

The fine-grained leucogranite forms the crest and western part of Rubidoux Mountain, some hills to the northeast of Rubidoux Mountain, and Pachappa Hill, to the south of Riverside. It underlies an area of

about a square mile. The rock is nearly white, has few dark minerals, some feldspar as long as 5 millimeters, and looks much like an aplite.

APLITE AND PEGMATITE

Dikes and less regular bodies of aplite and related rocks are widespread and are very abundant in some areas. They are numerous near contacts and commonly are parallel to the contacts. Many of the dikes carry tourmaline and some east of Corona carry dumortierite.

Pegmatites are scattered throughout the area, but they are especially abundant near Pala, where they cut the San Marcos gabbro. From a distance, the many parallel nearly white pegmatites in the dark gabbro resemble alternating beds of sandstone and shale. The dikes dip about 20° W. and are approximately parallel to the Tertiary sediments a few miles to the west. The pegmatites must have been nearly horizontal when formed. Most of the pegmatites are less than a few tens of feet thick. Many of them are made up of three layers—an upper layer of coarse graphic granite, a lower layer of banded aplitic rock, and an irregular central part that contains pockets and most of the rare minerals. The lower banded rock is made up chiefly of quartz and albite and has layers rich in garnet or tourmaline. As to the origin of these pegmatites Schaller [22] says:

> "They were at one time in their history solid graphic granite composed essentially only of microcline and quartz, from top to bottom, and that all the other minerals now present—albite, the micas, the garnets, the tourmaline, all the flourine, phosphorus, water, and lithia-bearing minerals—were not original crystallizations from a magma but were introduced later and are the result of replacement processes."

MAFIC DIKES

Mafic dikes are widely scattered in most of the region, but in a few small areas they are collected in swarms. A great swarm is well shown along the truck trail of the United States Forest Service south of Indian Canyon in the western part of the Elsinore quadrangle, where it intrudes the Woodson Mountain granodiorite. In a distance of about 3 miles along the truck trail, 85 dikes were counted. The black dikes are conspicuous in the nearly white granodiorite. Some of these dikes are less than a foot across, others are 10 feet across. Their general course is about due east, and the dips are about 30° N.; but some strike in other directions and branch in places. They appear to have been intruded along fracture planes in the granodiorite, and have a chilled border next to the granodiorite. The main part of the larger dikes is made up of a dark microtonolite, which has grains about half a millimeter in size.

Another swarm was observed in the eastern part of the San Luis Rey quadrangle along the road from Escondido Valley to Lake Wolford. The dikes are less abundant in this area and intrude the Woodson Mountain granodiorite and the Triassic sediments. These dikes are much decomposed. A thin section of one showed it to be a porphyritic diorite that originally had abundant phenocrysts of zoned plagioclase 2 millimeters across in a finer matrix. The rock has much green hornblende and a little biotite. The cores of the plagioclase are completely altered to a clay mineral, but the sodic rims and the groundmass feldspar are fresh.

[22] Schaller, W. T., The genesis of lithium pegmatites: Am. Jour. Sci., 5th ser., vol. 10, p. 276, 1925.

QUARTZ LATITE PORPHYRY

The tonalite both north and south of Domenigoni Valley and as far north as Double Butte in the eastern part of the Elsinore quadrangle is cut by many dikes of quartz latite porphyry and by fewer dikes of a dark, fine-grained rock related to andesite porphyry or microgabbro rich in hornblende. Most of the dikes are less than 25 feet wide, but a few are as much as 100 feet across. Most of the dikes are in the granodiorite, but a few are in the slates, where they are parallel to the bedding. The dikes are more numerous in the eastern half of the granodiorite, and in several places more than 100 were counted in a distance of a mile. A few similar dikes were found in other parts of the quadrangle.

Nearly all the dikes have platy schistose layers next to the contacts, due to shearing and orientation of the mica. Away from the contacts the shearing planes are less regular and are spaced farther apart, and the main part of many of the dikes is massive with little shearing. In some, even in the center, the mica is collected in thin subparallel patches, and in some the whole dike is more or less schistose or gneissoid. This schistosity is certainly a primary structure, as the intruded tonalite is massive. The elongation of the biotite streaks is nearly along the dip.

Occasional dikes of gray quartz latite porphyry cut the slates in various parts of the San Luis Rey quadrangle. A common type has millimeter- or larger-grained white plagioclase, quartz, and orthoclase in a gray to nearly black aphanitic groundmass.

TERTIARY VOLCANIC ROCKS

Tertiary and Quaternary volcanic rocks underlie only a small part of the area included in the three mapped quadrangles, but they differ greatly in their petrographic character and probably also in their geologic age. Pyroclastic rocks, lava flows, dikes, and plugs are all represented. The total area underlain by these rocks is only a few square miles.

Miocene Ash Northwest of Murietta. A hundred yards northeast of the Inland Highway and about 2¼ miles northwest of Murietta, in the southern part of the Elsinore quadrangle, a bed of white rhyolite ash has been prospected. It is exposed for only a few hundred feet. It is underlain by a blue clay and overlain by clay and sandstone. It is Tertiary and strikes and dips about with the slope of the hill, N. 32° W., 35° SW. It is about 3 feet thick. The tuff bed is made up almost entirely of glass shards.

Mesa-Forming Basalt. Several small mesas, underlain by basalt, are present west of Temecula in the northern part of the San Luis Rey and southern part of the Elsinore quadrangles. Remnants of similar basalt are present 10 miles to the northeast, west of the head of Warm Springs Creek. These basalts underlie an area of only a few square miles, but they were probably originally much more widespread. In most places they overlie a mature erosional surface of pre-Cretaceous rocks, but northeast of Potrero del Teneja they are both overlain and underlain by thin beds of sandstone and gravel, probably of Tertiary age. Their topographic position indicates a late Tertiary age.

The basalt mesas are underlain by a number of thin, rather regular flows. There is little clastic rock or red scoria associated with the flows.

In places these basalts reach a thickness of a little over 100 feet, but most of them are much thinner. The present mesas are only remnants of the original flows, and they must originally have underlain a good many square miles, especially if, as seems probable, the remnants east of Murietta in the Elsinore quadrangle connected with them.

Basalt of the San Joaquin Hills. Several small bodies of basalt are present in the San Joaquin Hills, in the southwestern part of the Corona quadrangle. They cut or overlie Miocene sedimentary rocks. A small flow is present east of Newport Bay and small dikes on French Hill and on the prominent point northwest of Two Rock Point.

The black lava east of Newport Bay has about 20 percent small labradorite crystals, 15 percent hypersthene, and 5 percent augite in a dark glass that contains a dust of iron ore and a few feldspar microlites.

The rock of the dike northwest of Two Rock Point is dense, black, and has a few feldspar phenocrysts. It is made up of thin tablets of labradorite about a millimeter long and interstitial augite, now largely altered to chlorite and epidote. The dike of French Hill is made up of a rock similar to that just described but with a better-developed diabase texture.

English [23] reports a small patch of intrusive rock on the south side of Burrnel Ridge, about 3 miles east of Olive, along the contact between the Topango and the lower shale of the Puente.

English [24] also says,

> "There are several areas of igneous rocks in the vicinity of the old Puente oil field. The largest is a double sill of rock classified by Eldridge as a diabase. The sill is about 2 miles long and not much over 100 feet thick at any point. It appears to show two lithologic types—one having diabasic texture and the other porphyritic texture with feldspar phenocrysts in a dense dark-colored groundmass. About 2 miles northwest of the old Puente field there is an irregular mass of softer rock similar to the intrusive rock found in the hills near Tustin."

Pyroxene Andesite East of El Modena. East of El Modena, near the center of the Corona quadrangle, several hundred feet of andesitic rocks are interbedded with the Miocene sediments. Lava flows, clastic beds, and intrusives are present. The rocks are much altered, and contain abundant secondary chlorite, carbonate, and serpentine. The freshest rocks are dark porphyritic pyroxene andesites. They were extruded during and just after the deposition of the Topango formation (middle Miocene).[25]

Typical specimens of the freshest rocks are black and carry abundant small feldspar phenocrysts. The microscope shows that nearly half is made up of phenocrysts about a millimeter long. Stout tablets of labradorite are the chief phenocrysts, augite is the chief dark mineral, and olivine is present in some of the rocks. The groundmass is very fine-textured and contains abundant very small feldspar laths.

Dacite Stock of Cerro de la Calavera. The stock of Cerro de la Calavera east of Oceanside in the San Luis Rey quadrangle intrudes both

[23] English, Walter A., Geology and oil resources of the Puente Hills region, California: U. S. Geol. Survey Bull. 768, pp. 46-47, 1926.
[24] Op. cit., pp. 46-47.
[25] English, W. A., op. cit., p. 46.

the Jurassic granitic rocks and the Tertiary sediments. It is rudely circular in outcrop and underlies an area of about a quarter of a square mile. Its contacts are not vertical but tend to flare out and upward, as shown by the quarrying operations. It very probably represented the crater and throat of a volcano that has been eroded to only a moderate depth. Jointing is prominent and tends to yield prismatic blocks which are about normal to the contacts.

In large part the rock is free from visible vesicles, but in places some large vesicles are present and are partly filled with the zeolite, stellerite. This zeolite is also found along fractures. The rock is fine-grained and light greenish gray. It is being quarried on a large scale for crushed rock by the Calavera Rock Company.

The quarrying operations have exposed an inclusion of the Green Valley tonalite of about 60 by 40 feet. This inclusion has been uniformly partly melted to a rock that resembles an obsidian with abundant phenocrysts. It is now made up of partly resorbed crystals of plagioclase and quartz, and small grains of augite in a glassy matrix.

Tridymite Dacite of Morro Hill. Morro Hill, located about 6 miles south of Fallbrook, in the northern part of the San Luis Rey quadrangle, is a small volcanic neck of tridymite dacite. It intrudes the Jurassic granitic rocks and also remnants of Tertiary sediments. To the east and south of Morro Hill there are some flows and pyroclastic beds of rock similar to that of Morro Hill. The latter is probably a stock and crater filling and has suffered no great erosion. Waring and Waring [26] have described these volcanic rocks and concluded that they are probably pre-Tertiary. There is no clear evidence of their age, but they are believed by the author of this report to be related to the other Tertiary volcanics of the area.

The rock of the Morro Hill stock is light gray, dense, and finely microgranular in texture. It contains many stout tablets of andesine and much tridymite in part as streaks and in part as needles (probably thin tablets) up to a millimeter long in the mass of the rock. Tridymite makes up about a quarter of the rock.

The rock of the flows is very similar but is a little more irregular in texture; the plagioclase is in thinner laths and is fluidal in habit and the tridymite is commonly in patches and streaks rather than in tablets. This whole group of lavas and the associated stock are of unusual character, especially in the form and abundance of the tridymite. Among the many tridymite rocks studied, these have the largest and best-formed thin laths of tridymite.

A sill on the southwest slope of Morro Hill is made up of quartz latite. It is a dense black banded rock showing in the hand specimen a few small quartz grains. No tridymite is present.

Quartz Latite Stock of San Onofre Creek. A small stock near the head of the south fork of San Onofre Creek in the northwestern part of the San Luis Rey quadrangle cuts the granitic rocks and the sediments. It is an andesite or quartz latite with a composition much like that of the stock of Cerro de la Calavera but probably a little nearer a quartz latite. It contains about 5 percent light-brown hornblende phenocrysts and a

[26] Waring, G. A., and Waring, C. A., Lavas of Morro Hill and vicinity, southern California: Am. Jour. Sci., 4th ser., vol. 44, pp. 98-104, 1917.

few of augite. Much stellerite is present in the stock, and irregular veins of stellerite were found on the ridge near the northeast contact of the stock.

QUATERNARY BASALT

In the extreme northeastern part of the San Luis Rey and the southwestern part of the San Jacinto quadrangles, on both sides of the Temecula River, remnants of basalt lie upon an irregular surface underlain by the pre-Cretaceous rocks and sands of late Pliocene or early Pleistocene age. South of the Temecula River they cap hills 600 feet higher in elevation than the river and plunge down the slopes beneath the alluvium of the river. They also form an eroded cinder cone that rises above the alluvium on the edge of the gabbro hills south of the river. North of the river in the San Jacinto quadrangle a small flow caps a dipping mesa, and on the higher slopes directly overlies the San Marcos gabbro; but on the lower slopes it overlies late Pliocene or early Quaternary sands and gravels. The basalt is therefore believed to be of Quaternary age. It must have been deposited in a canyon much like the present canyon.

On the lower slopes near the cinder cone the rock is made up chiefly of clastic beds in which basalt fragments up to a foot across are imbedded in a matrix of white mud. Many of the fragments are of volcanic bombs. Some of the material is a highly vesicular and scoriaceous breccia—in part a flow breccia or welded breccia. The basaltic fragments are in large part brick red.

On the east bank of Murietta Creek about 1.9 miles north of Murietta, a basalt similar to that just described crops out for 100 yards along the creek. It may be a dike. It has a rude platy structure N. 30° W. and is nearly vertical. It contains scattered crystals of glassy oligoclase up to 3 centimeters long and some small granular nodules made up of olivine and a little augite.

Abundant float of a black vitreous basalt with prominent olivine and large feldspar crystals occurs on the low hill, 100 yards west of the gate into the Santa Rosa ranch, in the large gulch about 2 miles southwest of Wildomar. It is almost identical with the rock described in the preceding paragraph. This float may be related to the flow described by Waring [27] as follows: "One tongue of lava extends part way down the side of the mountain about 1½ miles south of Wildomar." This flow was not seen by the author. In these rocks the large glassy oligoclase crystals must be foreign inclusions.

A few small remnants of a basalt much like the other basalts described in this section are present in the southern part of the Elsinore Mountains, west of Elsinore Lake. The rock is black, very fine-grained, and contains about 5 percent of fresh olivine crystals up to a millimeter across, in a submicroscopic to glassy mass.

WEATHERING

General Character. The slates of the area yield a clayey soil and rounded slopes with a few prominent outcrops and no boulders of disintegration. The schists and quartzites are more resistant than the slates and yield a soil with more sand. In places the quartzites are deeply weathered to a friable, sandy material. The andesitic rocks weather to

[27] Op. cit., 1919, p. 83.

a dark clayey soil. They yield somewhat better and more massive outcrops than do the slates. The rhyolitic rocks yield more prominent outcrops than the slates. The massive Temescal Wash quartz latite porphyry yields a scant soil and gives prominent subangular outcrops. The gabbro yields a scant, red soil. In most places it shows subangular to rounded outcrops, and the norite locally gives good boulders of disintegration. The tonalites and granodiorites yield a thin soil underlain by a great thickness of disintegrated rock. Imbedded in the gruss and rising above the surface are boulders of disintegration.

The relative resistance to weathering and erosion of the different formations can be determined in a general way. The Temescal Wash quartz latite porphyry is the most resistant of the larger rock formations. It yields steep, rugged canyons and high mountains. The Santiago Peak volcanic rocks form high mountains and are more resistant than most of the granular rocks. The gabbro is, in general, the most resistant of the granular rocks. It underlies many of the mountains of the area. In some areas of low relief it is less resistant than the granitic rocks as in places it underlies low hills or fields, while dikes of aplite and granodiorite show the chief outcrops of the area, and the surrounding bodies of granodiorite and tonalite yield good boulders of disintegration. The Triassic slates appear to be less resistant to erosion than the granitic rocks.

Contrast of Weathering in the Mountains and Lower Areas. There is a distinct difference between the weathering in the high mountains—the Santa Ana, Agua Tibia, and San Jacinto—and that in the lower rolling hills about Perris, Fallbrook, and Escondido. In the mountain areas, even on the steep slopes and deep canyons facing young faults, the weathering is very deep and the tonalites and granodiorites yield little fresh rock. Even the boulders of disintegration are friable. Fresh rock is difficult to find. In the low country the same formations yield fresh rock in most of the small gulches and they yield hard, fresh boulders of disintegration.

The explanation of this difference in weathering is somewhat obscure. The rainfall and the length of time the soil is moist are much greater in the mountains than in the lower hills, and these may contribute to the rapid weathering in the mountains. The mountains are covered with taller and thicker brush than are the lower hills, and this may furnish organic matter for rock decomposition and may prevent rapid removal of the disintegrated rock.

Boulders of Disintegration. Nearly all the quartz-bearing rocks of the area yield boulders of disintegration and these boulders furnish most of the outcrops of fresh rock. Nearly all the quarrying of granitic rocks has been on these boulders. The boulders are large and well-formed where made of coarse-grained rocks and small and poorly formed where made of fine-grained rocks.

The boulders of disintegration rise above the surface as much as 20 feet. In areas of low relief they are scattered and in some places are tens or even hundreds of feet apart. On mountain slopes they are commonly closer together, and many mountains, such as Woodson Mountain, just east of the southern part of the San Luis Rey quadrangle, look like piles of huge boulders. On the steep slopes the disintegrated rock has been washed from between the boulders. On steep slopes many of the boulders

have turned and rolled, as shown by the discordant structure of their inclusions, but in the rolling country most of the boulders are in nearly their original positions.

In addition to the boulders that are exposed there are similar boulders imbedded in the gruss below the surface. In road cuts and other excavations the gruss is 10 feet or more thick and has boulders scattered through it.

STRUCTURE

In is remarkable that the trend of the general structure of the area here described has been approximately the same from pre-batholithic time to the present. The following list shows the general strike of the chief structural and physical features of the area:

Crest of the Santa Ana Mountains	N. 37° W.
Coast line in Corona quadrangle	N. 55° W.
Coast line in San Luis Rey quadrangle	N. 30° W.
Temecula-Elsinore trough	N. 51° W.
San Jacinto fault	N. 45° W.
Strike of the Triassic sediments	N. 30° W.
Strike of the Paleozoic sediments	N. 35° W.
Average strike of Upper Cretaceous beds	N. 26° W.
Average strike of inclusions in Bonsall tonalite	
Elsinore quadrangle	N. 30° W.
San Luis Rey quadrangle	N. 65° W.

The regional structure of the Paleozoic, Triassic, and Jurassic (?) sediments is nearly the same. The regional strike is about N. 30° W., and this is the general structural trend for most of the area except the Santa Ana Mountains. In the northern part of the Santa Ana Mountains the general strike is N. 30° E. This changes toward the south, and in the southwestern part it is N. 45° W. South of Murietta it is N. 15° W. The regional dip is everywhere toward the east and greater than 45°. In the Santa Ana Mountains it ranges from 45° to 60°; elsewhere it is about 70°.

The Triassic and Paleozoic rocks appear to be in part overturned. In the Santa Ana Mountains and to the south the younger Santiago Peak volcanics are to the west of the older Triassic rocks, yet the dips are to the east. In the southern part of the Elsinore quadrangle the Paleozoic rocks are to the east of the Triassic rocks, and the dips of both formations are to the east.

The structural data are mostly simply interpreted as indicating that the Triassic and Paleozoic rocks are on one limb of a great fold.

Faulting

Some faults are shown on the geological map, and there are no doubt other faults that have not been located. In general, faults have been mapped only where the evidence for them is reasonably convincing. Little attempt was made to locate faults by physiographic features, as no detailed study of the physiography was made. A study of the sediments might also result in locating some faults. In areas of crystalline rocks, such as are here described, faults are difficult to locate, especially where the general elongation and structure of the rock bodies tend to parallel the fault pattern. In general, exposures are good in the area, but impenetrable brush makes it impracticable to follow many of the contacts in detail.

San Jacinto Fault. The San Jacinto fault, on the northeast border of the Perris block, is indicated by the straight boundary between the flat valleys and the mountains to the northeast. The throw of this fault is large in the southeast part of the Elsinore quadrangle and the southeast side is upthrown. The throw decreases rapidly to the northwest and north of Moreno it hinges so that northwest of the hinge the upthrown side is to the southwest.

Faults of Temecula-Elsinore Trough. The Temecula-Elsinore trough is a narrow, fairly straight depression, underlain in most places by Tertiary or younger sediments, and bordered on both sides by steep slopes that are made up chiefly of pre-Cretaceous rocks. This valley is about 40 miles long and 2 miles wide. Elsinore Lake is a large lake near the center of the trough. Part of the trough is drained to the northwest through Temescal Creek, and part to the southeast into Temecula Creek. The divide between the two drainages is very low and inconspicuous. To the southeast of Temecula the valley floor rises about 200 feet and granodiorite comes out from under the valley fill. Beyond this the valley gives place to a canyon which is a short tributary of the San Luis Rey River. The latter river is about 500 feet lower than the divide at the southeast end of the Temecula-Elsinore trough.

Two major streams enter the trough from the northeast. The San Jacinto River enters the trough at the south end of Lake Elsinore and empties into the lake whose outlet is to the northwest along the trough through Temescal Creek. Temecula River rises in the mountains west of the trough, flows across the trough in a shallow trench, and cuts through the mountains on the southwest side of the trough in a deep canyon.

All the features of the trough indicate a graben. The faulting of this graben has not been studied in detail by the author. In the Corona quadrangle mapping by Mendenhall (unpublished) has been used. For the area near Lake Elsinore, Mr. René Engel kindly permitted the use of data then unpublished.

The major fault of the Elsinore-Temecula trough bounds the trough on its southwest side and is continuous from the Santa Ana River to the southeastern end of the trough, nearly to the San Luis Rey River. The general course of this fault is N. 55° W., but it has several sharp turns and offsets, and it has been modified by cross faulting. Displacement along this fault is more than 1500 feet west of Elsinore; it decreases southward, is 400 feet near the southern boundary of the Elsinore quadrangle, and probably ends a few miles to the south.

Faulting along the northeastern border of the Elsinore-Temecula trough is not certain in most places, and it is probably not continuous. In the southern part of the trough even the topographic break between the trough and the hills to the northeast is not abrupt. The straight northeastern shore of Lake Elsinore indicates a fault there.

Agua Tibia Fault. A great fault near the southwestern base of the Agua Tibia Mountains is indicated by the straight, abrupt mountain front, hot springs, and a broad zone of brecciated rock. This fault appears to displace the Bear Valley erosion surface as much as 4000 feet. The displacement decreases both to the southeast and northwest. The fault is probably older than the early Pleistocene sediments as it does not appear to displace them south of Temecula River.

Origin of the Structures

Present knowledge of the structures of southern California is so incomplete that any attempt to work out the forces that caused the structures must be only a working hypothesis and subject to modification or complete abandonment.

The batholith is believed not to have been the source of the forces that brought about the structures, but rather to have been a result of them. Probably the formation of the magma, the general location of the intrusions, the time at which successive injections were made, the chemical composition and textural character of the different injected masses, and the magmatic differentiation, were determined by those forces. Older structure determined the contacts of the bodies in detail.

The explanation offered by Miller [28] seems to be the most probable so far proposed. He says:

> "It is believed that the principal force or pressure has come from the south and that it is still active. Direct action of this force, combined with its resolution into important northwesterly and northeasterly directed components, has produced both the fault and fold structures of the general region of Southern California, including the San Andreas fault. Resistance of counter pressure from the north has been more or less effective."

However, the author believes that the possibility that the forces originated to the west, under the Pacific Ocean, should not be overlooked. The fact that structures similar to those of southern California are present along a strip next the Pacific Ocean along most of North America indicates a clear relation between the structures and the basin of the Pacific Ocean.

GENERAL CHARACTER OF THE BATHOLITH

Size. The batholith of southern and Lower California, a small part of which is described in this report, has been mapped as a continuous strip from near Riverside, California, southward into Lower California for a distance of about 350 miles. It averages about 70 miles in width and narrows between older rocks toward its southern end. The area underlain by this body is about 20,000 square miles. Beyond its southern outcrops it is covered by younger rocks, and several bodies of a similar batholith crop out to the southern tip of Lower California. The batholith probably has a total length of about 1000 miles and has an area of over 50,000 square miles. It is much larger than the batholith of the Sierra Nevada.

Complexity. The area described in this report is believed to be a fairly good sample of the batholith. A few trips across the batholith to the south show this; and the chief rocks of the northern area—the San Marcos gabbro, the Lakeview Mountain tonalite, the Bonsall tonalite, and the Woodson Mountain granodiorite—can be recognized as well as some types not found to the north. The work of Böse and Wittich,[29] Hirschi and Quervain,[30] and Woodford and Harriss [31] indicates similar rocks and a similar complexity in the batholith in Lower California.

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[28] Miller, W. J., Some features of faulting in southern California: Jour. Geology, vol. 48, p. 417, 1940.

[29] Böse, E., and Wittich, E., Informe relativo a la exploracion de la region norte de la costa occidental de la Baja California: Inst. Geol. Mexico Parergones, vol. 4, pp. 307-429, 1913.

[30] Hirschi, H., and Quervain, Fr. de, Beiträge zur Petrographie von Baja California (Mexiko): Schweiz. Mineralog. Petrograph. Mitt., vol. 7, pp. 142-164, 1927 . . . vol. 8, pp. 323-356, 1928 . . . vol. 13, pp. 232-277, 1933.

[31] Woodford, A. O., and Harriss, T. F., Geological reconnaissance across Sierra San Pedro Martir, Baja California: Geol. Soc. America Bull., vol. 49, pp. 1297-1336, 1938.

The batholith is made up of many distinct rock types, each representing a separate injection. Over 20 such types were recognized in the area studied in detail and in the region to the east, which was examined only in reconnaissance. About three-fourths or more of the batholith is made up of about six rock types. The main types are present in many separated bodies, and most of them are present along the whole length of the batholith in California. Some types are confined to the eastern, some to the western part of the batholith.

Age. The batholith of southern California is no doubt related to that of the Sierra Nevada which is of late Jurassic age. However, evidence from Lower California [32] indicates that it is somewhat younger and is middle or early Upper Cretaceous in age.

Zoning. The part of the batholith studied is divided into three zones. The rocks of the western zone, which includes all of the area mapped in detail, are moderate in content of K_2O, those of the San Jacinto Mountains are lower in K_2O, and those of the scattered granitic bodies of the desert area east of the San Jacinto Mountains are very rich in K_2O.

Sequence of Intrusions. The gabbros were intruded first, then the tonalites, then the granodiorites, and finally the granites. This is the succession commonly found in batholiths.

For the most part, the older intrusions were nearly or entirely crystalline when the next intrusion was emplaced. This is indicated by the sharp contacts the presence of inclusions of the intruded rock in the intruding rock, and the presence of small dikelets. In only a few places were gradational contacts found.

Areas Underlain by the Different Rocks. The approximate areas that each of the mapped subdivisions of the batholith directly underlies in the Elsinore, San Luis Rey, and Corona quadrangles are given in the first column of table 2, and the percentage of the batholith which they make up in the second column of table 2. The percentage of the batholith made up of the different rock types is given in column 1 of table 3 for the three areas included in the Corona, Elsinore, and San Luis Rey quadrangles and in column 2 of table 3 for these three quadrangles, with the Ramona and San Jacinto quadrangles added. Most of the granodiorite in the San Jacinto and Ramona quadrangles is low in orthoclase, and some of the tonalites are low in femic minerals.

Relation Between Orogenesis, the Primary Magma, and Successive Intrusions. The batholith forms the core of the Peninsular Ranges for their known length of over 1000 miles. The major part of the folding and metamorphism of the pre-batholith rocks of this range took place before the intrusion of the gabbro, the oldest exposed rock of the batholith. The batholith was not forcefully injected and was not a major cause of the folding. The primary magma was essentially the same throughout that part of the batholith which is known.

The primary, relatively homogeneous, gabbroic magma is believed to have formed at a considerable depth along the length of the mountain

[32] Böse and Wittich, op. cit.; Woodford and Harriss, op. cit.

Table 2. Approximate areas directly underlain by the mapped members of the batholith and percentages of the outcrop of the batholith which each one occupies in the Corona, Elsinore, and San Luis Rey quadrangles.

	Area in sq. miles	Percentage of batholith
San Marcos gabbro	120	14.0
Green Valley tonalite	68	8.0
Bonsall tonalite	325	38.0
Granodiorite west of Lakeview	2	0.2
Lakeview Mountain tonalite	30	3.5
Estelle tonalite	2	0.2
La Sierra tonalite	3	0.4
Miscellaneous tonalites	3	0.4
Domenigoni Valley granodiorite	13	1.5
Woodson Mountain granodiorite	220	25.5
Indian Mountain leucogranodiorite	20	2.3
Lake Wolford leucogranodiorite	15	2.0
Escondido Creek leucogranodiorite	9	1.0
Mt. Hole granodiorite	2	0.2
Miscellaneous granodiorite	9	1.0
Roblar leucogranite	15	2.0
Micropegmatite granite	1	0.1
Aplite granite	2	0.2
Leucogranites of Rubidoux Mountain	1	0.1
Total	860	----

range during the later stages of folding. The same forces and movements that folded the rocks determined the layer in the crust that furnished the magma and thereby the composition of the magma. The new magma was slowly differentiated by crystal fractionation, modified by assimilation.

Before differentiation had progressed far, diastrophic forces acted on the crustal rocks and moved some of the magma toward the surface, thus emplacing the gabbro bodies.

Most of the large, mapped units are present in many separate bodies which have been seen along the northernmost 100 miles of the batholith and continue for an unknown distance to the south. The rocks of the different masses of these units are remarkably similar and can be identified with little difficulty. There are strong similarities in general appearance, texture, structure, character of inclusions, mineral and chemical composition, and age relations.

The origin of the rocks of the batholith is believed to have been as follows: A magma of relatively uniform gabbro was formed at depth in the core of the ranges. This gabbro was slowly differentiating, having at any given time in its history an upper part essentially the same throughout the length of the batholith as to chemical composition and

Table 3. Percentage of rock types making up the batholith.

	1	2
Gabbro	14	7
Tonalite	50	63
Granodiorite	34	28
Granite	2½	2

kind and amount of suspended crystals. From time to time diastrophism moved the magma toward the surface. This diastrophism may have been local and may have furnished local bodies of magma or it may have been widespread and have emplaced many bodies. The magma resulting from any such movement would be uniform in composition throughout the area. Such features as texture and character of inclusions would be determined by details of the movement—whether brief, prolonged, intermittent, with extensive brecciation, et cetera.

After the emplacement of the gabbro, little further movement took place until the upper part of the magma had the composition of a tonalite. Then many local and several widespread movements emplaced the several tonalites. The earliest of these movements did not greatly shatter the wall rock, or any shattering that took place was sufficiently early to allow most of the included blocks to be dissipated in the magma. This movement emplaced the Lakeview tonalite. Several of the tonalites to the east of the mapped area and some of the local bodies of tonalite were emplaced under similar conditions and at about the same time.

A later movement emplaced the Bonsall tonalite, and the last stages of this movement shattered the wall rock and mixed abundant inclusions in the magma. Any siliceous inclusions were probably dissolved, but inclusions of gabbro were reacted on, softened, and flattened by flow shortly before movement of the magma ceased. The Domenigoni granodiorite and the granodiorite near Lakeview contain similar inclusions, and were probably intruded under similar conditions, possibly at about the same time.

Another widespread movement during the tonalite stage shattered the walls and imbedded inclusions throughout the moving magma. The gabbroic inclusions were softened and then, by later movement, disintegrated, and crystals were rather uniformly scattered throughout the magma. Cooling then brought about crystallization before these crystals were completely reworked. Thus the Green Valley tonalite was produced.

After the intrusion of the tonalites no widespread earth movement took place until the upper part of the remaining magma reached the composition of a granodiorite. The Woodson Mountain granodiorite was then injected over much of the length of the mountain range.

The small volume of granite in the batholith may result from a scarcity of residual granite liquid or from the fact that during the granite stage diastrophism discouraged movement of the magma toward the surface.

NATURAL RESOURCES

Soil and Water

The chief natural resources of the area herein described are soil and water for agriculture. The rainfall is deficient for most crops, but some grain and similar crops are raised without irrigation. The chief crops are citrus, avocados, and other fruits, and they require irrigation. Part of the water for irrigation comes from the normal flow of streams heading in the mountains, but to provide for the long dry summers many large dams have been constructed to conserve the flood waters. Some water is pumped from sands and gravels.

Hot Springs

Many hot springs are scattered over the area, and they support a large industry, as hotels and resorts have been built at most of them. These springs may be related to igneous activity but are believed to be fed for the most part by surface waters that have penetrated deeply into the hotter part of the earth's crust and risen to the surface along faults. The northernmost of the hot springs is Eden hot spring, situated in the northeastern part of the Elsinore quadrangle. The Bernasconi hot spring is situated a few miles southwest of the Eden hot spring, about 2 miles west of the town of Lakeview. Successively farther south are the Glen Ivy hot spring (formerly called Temescal hot spring), siuated in the eastern part of the Corona quadrangle near the mouth of Coldwater Canyon; Elsinore hot springs, Elsinore, now furnishes the town with hot water; Murietta hot springs, situated a few miles northeast of Murietta, in the southern part of the Elsinore quadrangle; San Juan hot springs, situated in the southeastern part of the Corona quadrangle, near the mouth of San Juan Canyon; and Agua Tibia spring, a very large spring of warm water a few miles east of Pala in the northeastern part of San Luis Rey quadrangle. Water from the latter is used for irrigation.

Oil, Clay, and Coal

A large amount of oil is produced from the Tertiary beds in the northwestern part of the area, and excellent clay for many clay products is produced on a large scale from the Tertiary beds near Alberhill, in the northwestern part of the Santa Ana Mountains, and elsewhere.[33] A small amount of lignitic coal has been mined from the Tertiary beds near Alberhill and on the western slopes of the Santa Ana Mountains. Goodyear[34] said that the Chaney mine near Alberhill "produces 500 to 600 tons (of coal) a month, for local use." Coal is no longer mined.

Sand and Rock

Some sand and gravel is used locally, and the sandy disintegrated granitic rock (gruss) is used extensively for surfacing secondary roads and for similar purposes. High-grade sand for glass making is quarried a few miles east of Oceanside, and also from the Tertiary beds a few miles southeast of Corona.

Granitic rocks are quarried on a small scale. About 40 years ago they were more generally quarried for paving stones near Corona and elsewhere. A large quarry on the east side of Temescal Wash a few miles northeast of Corona, in the eastern part of the Corona quadrangle, supplied crushed rock from the Temescal Wash quartz latite porphyry, but it has been idle for some years. Another quarry, on Cerro de la Calavera about 4 miles east of Carlsbad, in the San Luis Rey quadrangle, supplies crushed rock from a dacite plug of Tertiary age. Large quarries near Riverside are in limestone, probably of Paleozoic age. Locally the Triassic slates are quarried for flagstones and similar purposes. Limestone has been quarried near Riverside and elsewhere for burnt lime and for cement.

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[33] Southerland, J. C., Geological investigation of the clays of Riverside and Orange Counties, southern California: California Div. Mines Rept. 31, pp. 51-87, 1935.

[34] Goodyear, W. A., San Diego County: California Min. Bur. Rept. 9, p. 152, 1890.

Pegmatites

Near Pala in the northern part of the San Luis Rey quadrangle and in the Lakeview Mountains, in the eastern part of the Elsinore quadrangle, pegmatite dikes have produced gem minerals and lithia. Feldspar and quartz have been produced from pegmatites in many places.

Magnesite

Magnesite has been mined from a body of serpentine about 4 miles south of Winchester, in the southeastern part of the Elsinore quadrangle. The mine has been described by Hess,[35] Gale,[36] and Bradley.[37] The main rocks of the area are Carboniferous schists and quartzites, and some limestone. The beds strike about northwest and dip steeply to the northeast. The serpentine is an irregular, elongate body a few hundred yards across.

The magnesite was mined from the crest of the ridge near the northern part of the serpentine body. It is present in a network of thin veins in serpentine, and it is said that about a tenth of the rock mined was recovered as magnesite. The mining was done in an open cut about 85 yards long, as much as 25 yards wide, and from 60 to 75 feet deep.

Metals

Gold is the chief metal produced in the area, but some tin and other metals have been produced on a small scale. Some placer gold has been produced, but most of the gold has come from lode mines. Gold mining was begun during the Spanish occupation. About 50 years ago gold mining was active, but for more than 40 years the work has been on a few scattered small-scale prospects.

The Good Hope mine, situated in the Elsinore quadrangle about 4 miles southwest of Perris, has probably been the chief producer of gold. It is said to have produced about $2,000,000.[38]

During the period from 1876 to 1885 much prospecting was carried on in the hills to the west of Perris, and many shafts were sunk and tunnels driven. Some of these prospects produced some gold, but none operated for long. The Gavalin mine, about 5 miles north of the Good Hope mine, is said to have produced some gold. It is on a vein in the Bonsall tonalite that strikes almost due east and dips about 40° S. In 1938 some gold was being produced from the Ida Leona mine, about 250 yards south of the Gavalin mine. The Ida Leona mine has an inclined shaft down more than 100 feet on a vein said to average 3 feet in width, striking N. 67° W. and dipping 72° S. The ore is iron-stained quartz. Some altered tonalite is said to be good ore; some is reported to be rich. The ore is treated in a small mill consisting of a jaw crusher, Huntington mill and plates. The country rock is Bonsall tonalite.

Several groups of men have worked the gravel of a buried stream channel on the flat a few miles northwest of the Gavalin mine. The miners sunk shallow shafts to the bedrock, raised, and washed the gravel that rested on bedrock.

Most of the prospects of this area are in the Bonsall tonalite, and few are in the San Marcos gabbro or slates of the Bedford Canyon formation.

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[35] Op. cit., p. 389.

[36] Op. cit., pp. 516-519.

[37] Bradley, Walter W., Magnesite in California: California Min. Bur. Bull. 79, pp. 61-65, 1925.

[38] Sampson, R. J., Mineral resources of a portion of the Perris block, Riverside County, California: California Div. Mines Rept. 31, p. 509, 1935.

This district southwest and west of Perris is called the Pinacate mining district, and is said to have produced about $2,500,000 chiefly in gold.[39]

Some prospecting has been done in the drainage of Arroyo del Toro, about 5 miles north of Elsinore. The prospects are in the Woodson Mountain granodiorite, the Triassic slates, and the Temescal Wash quartz latite porphyry.

Much prospecting was done many years ago at and near the Leon mine, situated about 12 miles southeast of Perris. The main prospecting was on a quartz vein 1 foot to 2 feet thick. The vein is in slates of the Bedford Canyon formation, parallels the bedding, strikes about N. 30° W., and dips about 70° NE.

Some mining and prospecting has been done near Escondido. Irelan [40] describes the Cravatt mine, about 2 miles southeast of Escondido, as on a vein from 6 to 18 inches wide that strikes about magnetic north, and dips from 20° to 40° W. Twenty years before Irelan's visit (about 1868) the mine was worked for a distance of one-half to three-quarters of a mile along the strike. Most of the stoping was less than 80 feet in depth, but one stope extended to 275 feet along the dip. The vein is said to have been narrow, but very rich. The vein is in the Green Valley tonalite.

In the last few decades of the last century extensive prospecting was done in the Santa Ana Mountains. This has continued on a smaller scale to the present time, and has been chiefly for silver and gold; but also for lead, zinc, copper, antimony, and tin. Nearly all of the veins are in the Bedford Canyon formation or the Santiago Peak volcanics, or in small intrusive bodies enclosed in these formations.

In and near Tin Mine Canyon, a few miles southwest of Corona, some prospecting has been carried on for tin, antimony, and other metals.

Farther south, in and near Silverado Canyon, a large amount of prospecting has been done. Fairbanks [41] visited the area while it was still active, and most of the data here given are taken from his descriptions of the mines of the area. The Quincy mine is near Silverado Creek at an elevation of about 2300 feet. The vein cuts andesite, is 2 feet wide, and is made up essentially of calcite with some argentiferous galena in thin flakes. At the time of Fairbanks' visit the mine was opened for a length of 500 feet. Much prospecting and some mining has been done in the drainage of the south fork of Silverado Creek that reaches the main creek about 3¼ miles east of the mouth of Ladd Canyon. According to Fairbanks [42] the ores of this area contain much sphalerite, pyrite, and some lead. Just preceding 1906 much prospecting for tin was carried on near the head of this canyon, but little was found. In the last 10 years some mining has been done at a mine west of this canyon and about 200 feet above the creek bed. A good small mill was on the property when it was visited in 1938. The ore is quartz with much pyrite. The mine was not in operation at the time it was visited.

The area south of Silverado has some prospects, and in Santiago Canyon, just below the sharp turn in the canyon, prospecting was being

[39] Sampson, R. J., op cit., p. 507.

[40] Irelan, W., Eighth report of the State Mineralogist: California Min. Bur. Rept. 8, pp. 524-525, 1888.

[41] Fairbanks, H. W., Geology of San Diego County, also of portions of Orange and San Bernardino Counties: California Min. Bur. Rept. 11, pp. 114-117, 1893.

[42] Op. cit.

carried on during Fairbanks'[43] visit, and some was being done in 1938. The country rock is chiefly argillite and quartzite of the Bedford Canyon formation, with some intrusive rock and some Santiago Peak volcanics. According to Fairbanks, the veins strike a little east of south and dip a little less than 45° E. The veins are in crushed rock, and the vein matter consists of quartz and calcite with galena, pyrite, sphalerite, and some antimony.

In Trabuco Canyon, farther south, some prospecting for tin, copper, gold, and silver was carried on many years ago.

A new prospect on the north bank of San Juan Creek, in the southwestern part of the Elsinore quadrangle, about 1½ miles east of the western boundary of the quadrangle, is in an irregular replacement streak in the Triassic sediments. In places the vein is several feet wide. The ore is said to be fairly rich in gold. It is made up of quartz with dark sphalerite, pyrrhotite, and some chalcopyrite.

Near the beginning of the present century much excitement was aroused over placer gold found in Lucas Canyon, which is a south fork of San Juan Creek. The placer gold was found partly in the Corona and partly in the Elsinore quadrangles, just east of the boundary of Mission Viejo grant. The prospectors are said to have seldom made more than $1 a day, although two men panned out about $40 an hour in one place. Barren gravel 10 to 20 feet thick covered the pay dirt, and was worked in the last few years.

In lower San Mateo Canyon and the area to the south, in both the Elsinore and San Luis Rey quadrangles, prospecting was carried on, during 1906 and 1907, chiefly in the Santiago Peak volcanics.

In 1937 and 1938 a new gold vein was found 100 yards south of Deluz Creek and about half a mile west of the boundary of the Santa Rosa grant. The vein is in a brecciated zone in the Woodson Mountain granodiorite and strikes about southwest. The ore at Whaley mine is made up of quartz, coarse spherulites of muscovite, much pyrite, and some black sphalerite.

About 9 miles west of Elsinore near the crest of the Santa Ana Mountains, the Old Dominion mine at the head of Long Canyon is in metamorphic sedimentary rocks, probably belonging to the Bedford Canyon formation but more intensely metamorphosed than usual. The vein is in a shear zone with streaks of vein material. Fresh sulfides are present very near the surface. The vein strikes N. 16° W. and dips very steeply to the west. The ore is made up of siderite and quartz with pyrrhotite, pyrite, and galena. There is some copper stain. The ore is said to contain gold with some silver, lead, zinc, nickel, and tin.

In 1853[44] tin was discovered in the Temescal deposit about 5 miles south of Arlington, in the northwestern part of the Elsinore quadrangle. From time to time thereafter some work was done on the deposit, and in 1890 an English syndicate acquired the property, erected a smelter, and worked it until 1892. They mined about 10,000 tons of ore and produced 251,289 pounds of tin valued at $59,964. The tin is found in veins of quartz and tourmaline that cut the Woodson Mountain granodiorite. There are said to be 65 such veins on the property of the Temescal tin mine (the old Cajalco tin mine) and many more in the adjoining area.

[43] Op. cit.
[44] Sampson, R. J., op. cit., pp. 515-518.

The veins strike about northeast and dip 55°-75° NW. Some irregular bodies of the tourmalinized granite are tens of feet across. Some of the veins have blue dumortierite partly altered to sericite.[45] This tourmalinized rock is found as far west as Temescal Wash and for some miles south of the Temescal mine. The Temescal property was carefully prospected from 1927-30. Much of the tourmaline rock of the area is said to carry a little tin, but only one body of workable ore has been found. A description of the district is given by Sampson.[46]

Some prospecting for tin was carried on in Tin Mine Canyon, southwest of Corona, and in the early part of this century prospecting for tin was carried on at the Silverado tin mine, near the head of the basin south of Silverado Canyon and about 2½ miles east of the mouth of Ladd Canyon. About 1936 several prospectors were searching for tin in the hills of Triassic slates a few miles east of Elsinore. Little or no tin was found in any of these prospects.

A small amount of molybdenite has been found about 3½ miles northeast of Corona, just east of the small gulch that heads east of Mt. Hole. The molybdenite is in the sheeting planes of an aplitic granite.

Cinnabar was discovered about 50 years ago 2 miles east of Tustin, in the Corona quadrangle in a low hill of sandstone a few miles south of a body of Tertiary volcanic rocks.

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[45] Murphy, F. Mac, Dumortierite in Riverside County, California: Am. Mineralogist, vol. 15, pp. 79-80, 1930.

[46] Op. cit., pp. 515-518.

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GEOLOGY OF THE CUYAMACA PEAK QUADRANGLE, SAN DIEGO COUNTY, CALIFORNIA*

By Donald L. Everhart**

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* Begun in partial fulfillment of the requirements for Ph.D. degree at Harvard University; completed as part of the cooperative program of the California State Division of Mines and U. S. Geological Survey; published by permission of the Director, U. S. Geological Survey. Manuscript submitted for publication in January 1950.

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6. Vertical aerial photograph showing primary joint pattern in a massif of Woodson Mountain granodiorite in southwestern corner of the Cuyamaca Peak quadrangle ..... In pocket

ABSTRACT

The Cuyamaca Peak quadrangle is in the central part of the Peninsular Ranges about 30 miles from the Pacific Coast in south-central San Diego County, California. Most of its area of 250 square miles is underlain by a part of the batholith of southern California. The economic mineral resources of the quadrangle include gold, feldspar, and silica.

The rocks of the area have been grouped into 15 mappable units on the basis of characteristic topographic expression, individual outcrop form, primary structures, and petrographic and chemical properties. The oldest of these rocks, the Julian schist of Triassic (?) age, forms septa and pendants in the batholith. Part of it is intruded by the Jurassic (?) Stonewall granodiorite, which in some areas has intimately injected and locally granitized the Julian rocks to form extensive areas of mixed rock. The main sequence of batholithic rocks is believed to be Upper Cretaceous in age, and the probable order of intrusion is as follows: Cuyamaca gabbro, diorite, Green Valley tonalite, Bonsall tonalite, Woodson Mountain granodiorite, leucogranodiorite, Rattlesnake granite, and late granite pegmatite, aplite, and vein quartz. Quaternary alluvium overlies the batholithic rocks in several of the stream valleys of the area.

The bedding and schistosity of the Julian schist have a dominant northwest trend and a near-vertical dip to the northeast. The primary structures of the igneous masses include flow layers, platy parallelism of inclusions and mineral grains, and primary fractures. Most of these have the same general attitude as the schistosity, but locally the primary structures of successive intrusions are crosscutting. These primary structures are shown on plate 5 and have proved to be of value in determining the significant rock units and age sequence. Although joints are dominant structural features in parts of the area, there apparently are no mappable faults.

Some of the late quartz veins contained sufficient gold to have been mined profitably.

The interesting features of the topography include gently rolling, well-developed erosion surfaces, abrupt changes of gradient along major streams, and meadowlands.

INTRODUCTION

Location. The Cuyamaca Peak 15-minute quadrangle occupies about 250 square miles of the south-central part of San Diego County, California. The western edge of the area is about 29 miles east of the Pacific Ocean, and the southern edge is 12 miles north of the Mexican border. The quadrangle is in the center of the northwest-trending Peninsular Ranges, which lie between the Pacific Coast and the Salton Sea trough. Access from the east or west is by transcontinental U. S. Highway 80, and from the north by State Highway Route 79 which joins U. S. 80 near the center of the area. No railroads serve the area itself, although the San Diego and Eastern Arizona Railway system passes a few miles to the west and south of it.

Topography. The topography of the Cuyamaca Peak quadrangle is moderately rugged. The highest point in the area is 6,515 feet above sea level on Cuyamaca Peak; the lowest, 770 feet, is on the San Diego River where it leaves the quadrangle. The region exhibits a variety of land forms distributed without regularity or simple pattern. These features include broad tablelands above which rise both rugged steep-sided bouldery peaks like Descanso Peak, and broad-based cone-shaped mountains with gentle smooth slopes like Viejas Mountain. Deep gorges and youthful canyons, such as Pine Valley Creek canyon, locally cut below the extensive upland surfaces, but in places the major streams flow through broad, mature valleys, such as Descanso Valley.

Precipitation in the Cuyamaca Peak region.

Location of station	Elevation, in feet above sea level	Wettest month, and average preceipitation, in inches	Driest month, and average precipitation, in inches	Average annual precipitation, in inches
El Cajon 14 mi. W. of Ilidden Glen	560	February 3.04	July 0.07	14.12
Barret Dam 7 mi. S. of Japatul Valley	1,600	February 4.16	July 6.06	19.36
Campo 16 mi. S. of Pine Valley	3,000	February 4.16	June 0.08	19.22
Descano	3,350	January 6.76	June 0.06	24.47
Julian 5 mi. NW. of Cuyamaca Reservoir	4,222	January 6.20	June 0.19	33.26*
Cuyamaca Reservoir	4,677	February 8.07	June 0.35	39.36*

* Part of the annual precipitation is in the form of snowfall.

The three major streams and tributaries that drain the area flow southwest into the Pacific Ocean. The San Diego River, originating north of the quadrangle, cuts across the northwest quadrant of the area, and three of its tributaries drain a large region on the west slope of Cuyamaca Peak. The Sweetwater River rises in the northeast part of the area and, flowing southwest, drains the central region. Pine Valley Creek originates a short distance east of the quadrangle, and, nearly parallel to the Sweetwater River, cuts across the southeast quadrant.

Climate. The climate of the Cuyamaca Peak quadrangle varies markedly according to elevation. In the higher sections adjacent to Cuyamaca Peak, temperatures are generally lower and precipitation is greater than in the low valley lands along the west edge of the area. The summers are usually rainless over the whole region. The following tables show the precipitation and temperature at U. S. Weather Bureau stations in or near the Cuyamaca Peak quadrangle.

Temperatures in the Cuyamaca Peak region.

Location of station	Elevation, in feet above sea level	Average annual maximum temperature and range, in degrees F.	Average annual minimum temperature and range, in degrees F.	Average annual temperature in degrees F.
El Cajon	560	77.2 88.7–67.2	47.5 58.5–37.6	62.3
Barret Dam	1,600	77.0 93.8–63.2	44.8 57.7–34.4	60.9
Cuyamaca	4,677	63.7 83.7–47.3	41.0 56.7–29.5	51.6

Vegetation. The vegetation in the Cuyamaca Peak quadrangle includes a variety of conifers, deciduous trees, bushes, shrubs, and grasses. These plants have been grouped by the U. S. Forest Service [1] into the five vegetation types or plant communities shown in the following table.

Plant communities in the Cuyamaca Peak quadrangle.

Community	Characteristic plants	Elevation, range in ft. above sea level	Topographic location	Precipitation	Drainage
Trees (with brush)	Conifers, alder, manzanita, oaks	Above 4,000	Uplands, peaks, and high valleys	Abundant. Rain and snow	Good
Woodland-grass	Oaks, buckwheat, lilac, sage, chess, oats, and brome	Above 4,000 (at lower elevations along streams)	Tablelands	Abundant. Rain and snow	Fair
Brush	Chamise, oaks, manzanita, lilac deerweed, and sage	Below 4,000	Uplands and slopes of canyons	Low rainfall	Good
Open grasslands	Alfilaree, clover, lupine, chess, brome, and wild oats	4,000-5,000	Rolling hills of low relief	Moderate rainfall	Fair
Meadows	Sedges, deergrass, wire grass, chess, and wild oats	Below 5,000	Along streams and in "low level pockets"	Moderate rainfall	Poor

This classification is based on the plant assemblages, but the assemblage in turn is partly controlled by the topography and the land forms. The vegetation types depend only indirectly on the underlying rock formations insofar as the formations have determined the topography and land forms. The soils developed from the various rock formations apparently do not support distinctive plant species, but in general the mafic igneous rocks support the most vegetation.

Culture. The geology of the Cuyamaca Peak quadrangle has had a marked effect upon the use that the few permanent residents make of the land. Agriculture is of minor importance, but the range land is suitable for grazing cattle, and some of the higher country supports a small lumber industry. The rugged peaks and open meadow lands developed on the crystalline rocks have considerable scenic beauty, which attracts large numbers of vacationists. Cuyamaca Rancho State Park, on State Highway 79, about 6 miles north of Descanso, is an area of more than 20,000 acres set aside by the state for public use. The park includes Cuyamaca and Stonewall Peaks.

The mineral deposits of the quadrangle include gold-bearing quartz veins and quartz and feldspar deposits that formerly supported a small mining industry. In the summer of 1946, however, only a few prospectors were developing small gold properties by hand methods.

[1] Oral communication from Roy W. Saarni of the Forest Service, U. S. Department of Agriculture at Descanso, California.

Previous Geologic Work. Brief notes on geologic observations made in the Cuyamaca Peak quadrangle are published in at least three of the early Annual Reports of the State Mineralogist.[2] A few rock units were described and named in these reports, but the first geological mapping in the district was by Hudson.[3] Although much of the area that he mapped lies in the vicinity of Julian to the north of the Cuyamaca Peak quadrangle, nearly 40 square miles of it is in the northeastern part of the Cuyamaca Peak quadrangle. Donnelly,[4] in 1934, published a report on nearly the same area studied by Hudson, with emphasis on gold deposits instead of the nickeliferous deposits. Donnelly's map includes 21 square miles in the northeastern part of the Cuyamaca Peak quadrangle, but the report largely deals with areas lying to the north. None of the nickeliferous deposits discussed by Hudson and Donnelly are within the Cuyamaca Peak quadrangle.

Early in 1935, W. J. Miller [5] published a geologic section and a reconnaissance map along U. S. Highway 80 through the middle of the Cuyamaca Peak quadrangle. He described and named several of the igneous rocks.

Later in 1935, several student members of "The Delvers",[6] the honorary geologic society at San Diego State College, completed a preliminary report on the geology in the vicinity of the Cuyamaca Rancho State Park. Mimeographed copies of this report, which are available at the college, contain several excellent photographs and a reconnaissance geologic map of about 70 square miles in the northeast quarter of the Cuyamaca Peak quadrangle.

Two other geologists have mapped areas that lie adjacent to the Cuyamaca Peak quadrangle to the north. S. C. Creasey [7] made a strategic minerals study of the Julian-Cuyamaca area, with special emphasis on the nickel deposits, and his geologic map includes a mile-wide strip extending to the north edge of Cuyamaca Reservoir. Richard Merriam [8] mapped a part of the Ramona quadrangle; his map borders the western half of the north edge of the Cuyamaca Peak quadrangle.

Two geologists have made regional studies of the crystalline rocks of parts of southern California, and include a few observations in the Cuyamaca Peak quadrangle. W. J. Miller [9] has discussed the rocks of the quadrangle in his study of the crystalline rocks of southern California,

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[2] Goodyear, W. A., San Diego County, California: California Min. Bur. Rept. 9, pp. 516-528, 1890.

Fairbanks, H. W., Geology of San Diego County (and also portions of Orange and San Bernardino Counties): California Min. Bur. Rept. 11, pp. 81-83, 1893.

Merrill, F. J. H., Geology and mineral resources of San Diego and Imperial Counties, California: California Min. Bur. Rept. 14, pp. 653-662, 1914.

[3] Hudson, F. S., Geology of the Cuyamaca region of California, with special reference to the origin of the nickeliferous pyrrhotite: Univ. California, Dept. Geol. Sci. Bull., vol. 13, pp. 175-252, 1922.

[4] Donnelly, Maurice, Geology and mineral deposits of the Julian district, San Diego County, California: California Jour. Mines and Geology, vol. 30, pp. 331-370, 1934.

[5] Miller, W. J., A geologic section across the southern Peninsular Range of California: California Jour. Mines and Geol., vol. 31, pp. 115-142, 1935.

[6] Chilcott, F. M., Johnson, Ray, Payton, Don, Simmonds, Harry, and others, Preliminary report on the geology of the southern half of the Cuyamaca State Park and adjacent districts, San Diego County, California: Delvers Quarterly (mimeographed), vol. 1, no. 4, San Diego State College, 28 pp., 1936.

[7] Creasey, S. C., Geology and nickel mineralization of the Julian-Cuyamaca area, San Diego County, California: California Jour. Mines and Geology, vol. 42, pp. 15-29, 1946.

[8] Merriam, Richard, Igneous and metamorphic rocks of the southwestern part of the Ramona quadrangle, San Diego County, California: Geol. Soc. America Bull., vol. 57, pp. 223-260, 1946.

[9] Miller, W. J., Crystalline rocks of southern California: Geol. Soc. America Bull., vol. 57, pp. 485-486, May 1946.

and E. S. Larsen, Jr.,[10] who has worked largely in the San Luis Rey Elsinore, and Corona quadrangles, has made a general study of the petrology of the southern California batholith.

Purpose and Scope of the Study. The geologic study of the Cuyamaca Peak quadrangle was begun by the writer in June 1941 as partial fulfillment of the requirements for a Ph.D. degree at Harvard University. The object of the study was to extend to the southwest the petrologic and geologic studies of the southern California batholith made by Prof. Esper S. Larsen, Jr.,[11] and his students.[12]

During the 1941 summer field season the igneous and metamorphic rocks of the area were mapped in reconnaissance on a part of the old Cuyamaca topographic sheet enlarged to a scale of 1:63,360. About two-thirds of the quadrangle was thus mapped and an attempt was made to correlate the rock units with those described by Larsen and others. During the winter and spring of 1941-42 the rocks were studied in thin section, and the optical properties of the key minerals were determined by the oil-immersion method.

In March 1946 the study of the Cuyamaca Peak quadrangle was resumed as a part of a cooperative program of the California State Division of Mines and the U. S. Geological Survey. The 1944 edition of the Cuyamaca Peak quadrangle provided an excellent new base map, and Army aerial photographs of the entire quadrangle were used for plotting the geology in the field. To map the quadrangle efficiently, all roads, truck trails, trails, and stream beds were followed, and intermediate traverses were made where the complexity of the local geology required them. By the end of June 1946 the field work, including revision of the 1941 mapping, was completed. During the ensuing 6 months laboratory studies were completed and the manuscript was prepared.

The principal purpose of this report is to contribute a geologic map of the Cuyamaca Peak quadrangle, and to supply information on the petrography, igneous sequence, and primary structures of a part of the southern California batholith. The mineral deposits of the area were examined, but, owing to the limitations imposed by the lack of time and the inaccessibility of most of the mine workings, the study is not exhaustive. The physiography of the quadrangle is discussed without benefit of having studied the development of the Peninsular Ranges as a whole.

Acknowledgments. The study of the Cuyamaca Peak quadrangle was suggested by Prof. Esper S. Larsen, Jr., of Harvard University, who has shown constant interest in it and has offered many valued suggestions during visits to the field, in the laboratory, and in a critical review of the

[10] Larsen, E. S., Jr., The batholith of southern California: Science, new serv., vol. 93, pp. 442-443, 1941.

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Larsen, E. S., Jr., Batholith and associated rocks of Corona, Elsinore, and San Luis Rey quadrangles, southern California: Geol. Soc. America Mem. 29, 182 pp., 1948.

[11] Larsen, E. S., Jr., op. cit. 1948.

[12] Hurlbut, C. S., Dark inclusions in a tonalite in California: Am. Mineralogist, vol. 20, pp. 609-630, 1935.

Miller, F. S., Petrology of the San Marcos gabbro, southern California: Geol. Soc. America Bull., vol. 48, pp. 1397-1426, 1937.

Miller, F. S., Hornblendes and primary structures of the San Marcos gabbro: Geol. Soc. America Bull., vol. 49, pp. 1213-1232, 1938.

manuscript. C. S. Hurlbut and the late Harry Berman of Harvard University visited the writer during the 1941 field season and made helpful suggestions. Equally valuable was the visit of Edgar H. Bailey and Ward C. Smith of the U. S. Geological Survey in June 1946. For critical review of the manuscript the writer is grateful to Edgar H. Bailey, C. S. Ross, and F. M. Chace of the Survey, and Marland P. Billings of Harvard University.

The writer wishes to thank E. William Heinrich for assistance during the 1941 field season, and for the use of an unpublished manuscript on the gabbroic rocks.

Generous grants from the Holden Fund of Harvard University made possible the work done in 1941-42.

Olaf P. Jenkins, chief, California State Division of Mines, gave the writer personal and official encouragement and support.

GENERAL GEOLOGY

Geologically, the Cuyamaca Peak quadrangle is nearly in the middle of a large complex body of plutonic igneous rocks. This body has been called by Larsen the great batholith of southern and Lower California. Its full extent and exact limits are not known, but it extends northwest at least to the Santa Ana River in the vicinity of Riverside and southeast as far as the central part of Lower California, Mexico. It appears to be much narrower from east to west, for it is exposed only between the Salton Sea trough and the Pacific coastal plain. During the early part of Upper Cretaceous time, the batholith intruded a thick series of sedimentary rocks, which were probably already metamorphosed.

The pre-batholithic rocks of the Cuyamaca Peak quadrangle include: (1) a group of metamorphosed sediments, (2) granodioritic to quartz dioritic rock that intrudes the sediments, and (3) a mappable unit of mixed rock formed by intermixing of the metamorphic rock and the granodiorite magma. The batholithic rocks in the quadrangle are probably representative of the batholith as a whole, or at least its western part, and they comprise a normal sequence of 11 igneous rock units that range from olivine-rich gabbro through granite to pegmatite dikes and gold-bearing quartz veins. The only post-Cretaceous formation in the area is Quaternary alluvium. All the rock units mapped in the Cuyamaca Peak quadrangle are listed in the accompanying table.

The structural features of the rocks in the Cuyamaca Peak quadrangle generally trend northwest and dip steeply to the northeast. This dominant attitude in the Julian schist has had a strong influence on the alinement and form of most of the individual igneous intrusives, and their structures generally reflect those of the schist. Local variations from the general trend are common, however, owing to the influence of the intrusive forces. The Julian schist is locally contorted adjacent to contacts with the intrusive rocks, and the flow structures in the igneous rocks deviate to conform with the walls of the intrusive bodies. Successive rock units locally crosscut older structures, usually at a low angle.

Late fractures, produced by forces acting on the region as a whole, apparently are confined to a few prominent sets of joints. The most prominent of these fractures strike about N. 30° E.; they are essentially vertical. No mappable faults have been recognized in the area by the writer.

Rock units mapped in the Cuyamaca Peak quadrangle.

Rock unit	Dominant rocks	Age	Areal extent in sq. mi.
Alluvium	Unconsolidated rounded fragments of all other rocks of the area	Quaternary	
Quartz veins	Quartz vein rock	Upper Cretaceous	Less than 0.1
Aplite	Aplite	Upper Cretaceous	Less than 0.1
Pegmatite	Granitic pegmatite	Upper Cretaceous	Less than 0.1
Rattlesnake granite	Granite	Upper Cretaceous	3
Leucogranodiorite	Granodiorite	Upper Cretaceous	0.5
Woodson Mountain granodiorite	Granodiorite	Upper Cretaceous	38
Bonsall tonalite	Quartz diorite	Upper Cretaceous	65.5
Green Valley tonalite	Quartz diorite	Upper Cretaceous	50
Diorite	Diorite	Upper Cretaceous	2
Cuyamaca gabbro	Gabbro, norite, and other mafic rocks	Upper Cretaceous	41
Mixed rock	Julian schist, granodiorite, and migmatite of Stonewall formation	Jurassic (?)	25
Stonewall granodiorite	Granodiorite	Jurassic (?)	12
Julian schist	Quartz-mica schist, quartzite, and amphibolite	Triassic (?)	12.5

ROCK UNITS

Julian Schist

General Characteristics. The Julian schist consists essentially of two metamorphic rocks—quartz-mica schist and quartzite. The former is by far the more abundant, for it underlies at least 90 percent of the area of Julian schist. Three very small bodies of amphibolite also have been noted in the Julian schist. The quartz-mica schist is extremely schistose and generally very fine-grained. It is well exposed in most places, commonly forming small ribs that trend across country parallel to its bedding and schistosity. It is typically brownish gray. The usual mineral content is: quartz, 35 to 65 percent; biotite, 5 to 25 percent; muscovite, 1 to 20 percent; plagioclase, 5 to 20 percent; and magnetite, red garnet (almandite?), zircon, orthoclase, zoisite, and ilmenite, less than 1 percent each. Unusual varieties contain several percent garnet and lesser amounts of sillimanite and andalusite.

All the rock identified as quartzite contains more than 90 percent quartz, and most of it contains about 98 percent quartz. This gray to white quartzite is locally interbedded with quartz-mica schist in the form of zones or lenses a few feet in thickness and hundreds of feet in length. It is a fine-grained, homogeneous aggregate of interlocking, subangular grains of clear quartz, feldspar, and minor constituents. The latter occur as crushed fragments between the quartz and feldspar grains.

Name and Former Description. The Julian schist was first described in the literature by Fairbanks [13] as a metamorphic series; however, Merrill [14] first named the schists of San Diego County the Julian group and designated the area near Julian as the type locality. Hudson [15] later changed the name to the "Julian schist series" and subdivided the metamorphic rocks in the Cuyamaca-Julian district into five types. Donnelly [16] shortened the name to Julian schist, and subsequent workers in the area have followed his usage.

Distribution. The Julian schist underlies about 12½ square miles of the Cuyamaca Peak quadrangle. Most of the schist lies in the extreme northeast corner, but several areas of the same rock, totaling about 3 square miles, occur as elongate roof pendants or septa scattered through the batholithic rocks along a zone extending from the southeast corner of the quadrangle northwest through the central area. The extension of the zone to the northwest of the quadrangle is shown on Merriam's map.[17] The schist area in the northeast corner of the quadrangle is but a part of an extensive area of Julian schist, shown by the geologic map of California [18] to be at least 75 square miles in extent, that trends northwest into the Ramona quadrangle. Reconnaissance trips by the writer into the unmapped Laguna Mountains area east of the Cuyamaca Peak quadrangle indicate that this schist area is at least twice as large as indicated by the State map. Although extensive, this body of metamorphic rocks appears to be surrounded by the granitic rocks of the batholith.

Petrography. The dominant mineral of the typical quartz-mica schist is quartz in the form of small subrounded inequigranular grains which are commonly fractured and granulated. Locally, larger irregular areas of clear unbroken quartz take the place of granular quartz. Both biotite and muscovite occur in the quartz-mica schist, although biotite is generally the more abundant. Both mica minerals show marked planar orientation of their small flakes and cause the well-developed foliation so characteristic of the schist. Subhedral grains of plagioclase, which occur with the quartz in most of the schists in the whole area, are predominantly oligoclase in composition, but grains as calcic as labradorite were observed. Euhedral crystals of magnetite, red garnet (probably almandite), and zircon are present in small amounts, and also a few grains of orthoclase, zoisite, and ilmenite were identified. Edges of the biotite flakes are in places altered to iron oxides.

Quartz in clear subangular grains is the dominant mineral in the quartzite. Mixed with the quartz grains are subhedral grains of plagioclase which are generally oligoclase in composition. Small shreds of biotite, and to a less extent muscovite, fill in between the grains in small amounts. Small euhedral crystals of magnetite are commonly associated with the biotite. In some places the biotite is extensively altered to limonite.

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[13] Fairbanks, H. W., op. cit., p. 118.
[14] Merrill, F. J. H., op. cit., p. 12.
[15] Hudson, F. S., op. cit., p. 182.
[16] Donnelly, Maurice, op. cit., p. 337.
[17] Merriam, Richard, op. cit., pl. 1, opp. p. 223.
[18] Jenkins, O. P., Geologic map of California, scale 1 inch equals approx. 8 miles, California State Div. Mines, 1938.

The types of Julian schist described by the writer in the Cuyamaca Peak quadrangle correspond in general to those described by Merriam [19] in the Ramona quadrangle to the northeast and by Donnelly [20] in the Julian district to the north. They also correspond to the rock types described by Hudson [21] except that his fifth classification, injection gneiss, is absent. Such mixed rocks formed from Julian schist injected by later magma are very common and widespread in the area. Because they deserve independent consideration, they have been mapped as a lithologic unit, and will be described in the section on mixed rock of the Julian schist and the Stonewall granodiorite.

Origin. On the basis of its mineralogic composition, its microscopic texture, and its bedding and relict textures, most of the Julian schist in the Cuyamaca Peak quadrangle is believed by the writer to have formed by the metamorphism of sedimentary rocks. The quartzites were derived from fine- to medium-grained sandstones, and the quartz-mica schist, either with or without sillimanite and andalusite, represents shaly sandstones and siltones in varying degrees of metamorphism. The amphibolites are probably the metamorphic products of the only nonsedimentary rocks of the Julian schist, for they are presumed to be metamorphosed andesitic or basaltic flows or tuffs.

On the basis of the mineral assemblage of the rocks, most of the Julian schist is mesozonal in grade of metamorphism. Those phases carrying sillimanite and andalusite are more highly metamorphosed, and their general association with intrusive rocks suggests that they may be the result of contact metamorphism. The regional extent and uniformity of the schists indicate that the metamorphism of the area as a whole may have been dynamic.

Age assigned to the Julian schist by previous geologists.

Geologist	Age
H. W. Fairbanks	Lower Triassic (?)
F. J. H. Merrill	Carboniferous
F. S. Hudson	Triassic
Maurice Donnelly	Juratriassic
S. C. Creasey	Triassic
Richard Merriam	"Possibly several ages" in the Paleozoic and Triassic
W. J. Miller	"Most likely" late Paleozoic and Triassic
E. S. Larsen, Jr.*	Probably late Paleozoic and extending into the Triassic

* Oral communication, September 1946.

Age. The Julian schist is clearly older than the intrusive rocks in the Cuyamaca Peak quadrangle because its structures are cut off by all the igneous rocks in contact with it. No fossils were discovered in the area by the writer, despite diligent search. Thus the dating of the schist must rest upon the findings of other geologists in areas where correlative rocks have been dated. The following table lists the several geologists who have mapped or described the Julian schist and their conclusions as to its age. It should be noted that only Hudson's conclusions are based on fossil evidence (a single ammonite imprint on a piece of quartzite float); the conclusions of the others are based on lithologic similarity to dated rocks. All except Donnelly agree that the age is not younger than Triassic, but it seems impossible to place a lower limit to the age of the Julian schist.

[19] Merriam, Richard, op. cit., pp. 227-230.
[20] Donnelly, Maurice, op. cit., pp. 337-338.
[21] Hudson, F. S., op. cit., pp. 182-186.

Stonewall Granodiorite

General Characteristics. The Stonewall granodiorite as it occurs on Stonewall Peak is a typical granodiorite. It crops out boldly in large white to light-gray masses of irregular shape measuring several scores of feet in largest dimension. Unlike the younger granodiorites of the region, most of the Stonewall does not weather out in separate rounded boulders, but is exposed on subdued surfaces nearly even with the ground level. The rock is homogeneous and massive and is not closely jointed and sheeted. Many of the large weathered surfaces are slightly curved.

Megascopically the granodiorite is medium- to coarse-grained, with a subhedral granular texture. The rock is normally equigranular, although locally it has phenocryst-like euhedral crystals of potassium feldspar that are appreciably larger than the rest of the mineral grains. In places, where prominent flakes of biotite are oriented in bands, a gneissic texture is well developed.

Modes of various phases of the Stonewall granodiorite in the Cuyamaca Peak quadrangle.

	1	2	3	4	5	6
Number of sections	5	1	1	1	1	1
Quartz	40	25	45	20	20	10
Plagioclase	19	40	5	50	50	50
K feldspar	29	----------	----------	13	----------	----------
Orthoclase	----------	25	----------	----------	5	----------
Microcline	----------	----------	40	----------	----------	----------
Biotite	9	5	8	10	5	20
Muscovite	----------	----------	2	----------	----------	----------
Hornblende	2	3	----------	5	----------	20
Augite	----------	----------	----------	----------	5	----------
Hypersthene	----------	----------	----------	----------	15	----------
Apatite	----------	----------	<1	<1	<1	<1
Magnetite	----------	----------	----------	1	<1	<1
Zircon	<1	<1	<1	<1	----------	<1
Ilmenite	----------	----------	<1	<1	----------	----------
Sphene	----------	----------	----------	<1	----------	----------
Total	99+	98+	100+	100	100+	100+
Percent of An in the plagioclase	20	20	18	24–50	50–55	30

1. Specimen No. Des. 41-18. Rosiwal analysis of gneissic Stonewall granodiorite near State Route 79 at the northwestern base of Stonewall Peak.
2. Des. 41-18. Estimated mode.
3. CP-91. Estimated mode of abnormally felsic Stonewall granodiorite. Rancho Alegria.
4. Des. 41-57. Estimated mode of the injection gneiss in the Stonewall granodiorite. Ridge south of Stonewall Peak.
5. Des. 41-66. Estimated mode of a charnockite phase of the Stonewall granodiorite. East Mesa.
6. Des. 41-19. Estimated mode of a dioritic phase of the Stonewall granodiorite. Eastern shore of Cuyamaca Reservoir.

Name and Former Description. The name Stonewall was first applied to certain "granitic rocks of the Cuyamaca region" by Hudson [22] after Stonewall Peak, which he designated as the type locality. Hudson's petrographic descriptions of the rocks are generalized, but he recognized that some of the rocks that he called Stonewall quartz diorite actually had the composition of a granodiorite.

Later Donnelly [23] in his study of the same general area adopted the name Stonewall granodiorite because he found that the formation contained only minor amounts of quartz diorite. Donnelly's complete and detailed petrographic description of the Stonewall rocks shows the important and interesting role of orthoclase in the petrology, especially in those porphyritic phases (as in Oriflamme Canyon) that carry orthoclase phenocrysts. He suggested that the granodiorite may have been derived in part by assimilation of the Julian schist by a quartz diorite magma.

Subsequent workers in areas underlain by the Stonewall rocks have differed in their naming of them. Creasey [24] followed Hudson in calling the rock Stonewall quartz diorite; Miller,[25] with Donnelly, used the term Stonewall granodiorite. Merriam [26] introduced Stonewall formation and emphasized the variability of the rocks. He separated quartz diorite from granodiorite on his geologic map, and in the Ramona quadrangle the quartz diorites apparently predominate. Merriam concluded that the two rocks were "probably intruded separately."

The Stonewall granodiorite mapped by the writer is restricted to typical igneous rocks. Hudson's choice of a type locality is appropriate, for the rock underlying Stonewall Peak and the adjacent areas seems to have a minimum of inclusions and would probably be called igneous rock by most geologists. The writer has attempted to assign to the Stonewall granodiorite only those rocks that definitely correspond to those of Stonewall Peak, that is, relatively uncontaminated granodioritic rocks with the definite characteristics described in the section on petrography.

Distribution. The Stonewall granodiorite, as mapped in this study, occurs in the Cuyamaca Peak quadrangle in one main body approximately 12 square miles in area, and three smaller bodies with a total area of no more than half a square mile (pl. 2). The large mass underlies Stonewall Peak in the northeastern part of the quadrangle and extends southeast into the southern part of East Mesa. One of the smaller masses lies on the northeast flank of Cuyamaca Peak, and the other two are at the east edge of the Anhuac School upland just north of Sill Hill in the north-central part of the quadrangle.

As an extension of the above areas, a large zone of mixed rock formed from Julian schist and Stonewall magma stretches from the extreme northwest corner of the map area to the vicinity of Noble Canyon at the middle of the east boundary of the quadrangle. One large and important break occurs where the zone is crossed by the gabbroic rocks underlying Cuyamaca and Middle Peaks. The total area underlain by mixed rock in the Cuyamaca Peak quadrangle is approximately 25 square miles. It thus exceeds the areas underlain by the Julian schist or Stonewall granodiorite.

[22] Hudson, F. S., op. cit., p. 191.
[23] Donnelly, Maurice, op. cit., p. 340.
[24] Creasey, S. C., op. cit., p. 19.
[25] Miller, W. J., op. cit., p. 486, and table 4, opp. p. 530, 1946.
[26] Merriam, Richard, op. cit., pp. 230-231.

Merriam's map [27] shows that the Stonewall granodiorite, with scattered inclusions of Julian schist, extends northwest from the Cuyamaca Peak quadrangle into the Ramona quadrangle as far as Lake Henshaw, following the same general trend as the Stonewall granodiorite and mixed rock zone in the Cuyamaca Peak quadrangle. According to Hudson,[28] the Stonewall also occurs to the north at least as far as San Felipe Valley on the eastern edge of the Ramona quadrangle.

Characteristic Primary Structural Features. Flow layering is the dominant structural feature in the Stonewall granodiorite, and platy parallelism of biotite flakes is less prominent. In the large areas of mixed granodiorite and Julian schist, the schistosity of the schist and the foliation of the igneous rock are parallel and difficult to distinguish from each other.

Petrography. Feldspars are the dominant minerals in the Stonewall granodiorite. Plagioclase exceeds the potassium feldspar, and its composition, as determined optically, is remarkably uniform; all determined plagioclase is in the oligoclase range. Some of the oligoclase is in slightly zoned phenocrysts as large as 5 by 10 millimeters. Many of these are twinned according to the carlsbad law, but a few are twinned polysynthetically. The oligoclase also is in smaller grains interlocking with the other minerals in the groundmass of the rock; in these grains polysynthetic albite twinning is common. Both orthoclase and microcline occur in the Stonewall granodiorite. The two are not found together in the same specimen, so far as the writer has observed, but they seem to have formed interchangeably in different parts of the rock mass. The potassium feldspars, like the plagioclase, tend to form large phenocrysts in certain phases of the granodiorite. As a general rule, the large phenocrysts are orthoclase; but the smaller subhedral to anhedral grains of potassium feldspar that form part of the groundmass are microcline with prominent cross hatching. The orthoclase is commonly sericitized and to a lesser degree argillized. Quartz occurs only in the groundmass. It is invariably anhedral, and most of it is granulated. In some thin sections small granules of quartz fill in between the plagioclase grains. The quartz also makes small rounded windows in some of the orthoclase phenocrysts, and the intergrowth of quartz and plagioclase in the form of myrmekite is common. Biotite is the most abundant dark mineral, and in most of the specimens examined it is the only ferromagnesian mineral that could be considered a major constituent of the rock. It occurs in flakes that are several millimeters across, irregular in outline, and frayed at the edges. Some of the biotite flakes show pleochroic halos around small crystals of zircon, and many of them are partly altered to limonite.

Rather large isolated grains of very pleochroic green to brown hornblende are in places associated with the biotite. All the hornblende appears to be older than the biotite, and the edges of the grains are invariably frayed and altered as though by replacement. It is probable that at least some of the biotite was derived by reaction with the hornblende. Another alteration product of the hornblende is chlorite, and small amounts of epidote are associated with a few of the biotite-hornblende clots. Common accessories are apatite, spinel, and magnetite.

[27] Merriam, Richard, op. cit., pl. 1, opp. p. 223.
[28] Hudson, F. S., op. cit., map opp. p. 182.

Within the bodies of granodiorite are rocks in which the proportion of the various minerals departs widely from the average. The minerals and general textures of these rocks are essentially the same as those of the typical granodiorite, but the rocks are more mafic and commonly have subhedral equigranular textures rather than the slightly porphyritic, inequigranular texture of the granodiorite. The hornblende and biotite may each make up 20 percent of the rock, and the plagioclase (oligoclase to andesine) as much as 50 percent. The quartz content averages less than 10 percent. These dioritic and quartz-dioritic rocks occur only in very small bodies in the Cuyamaca Peak quadrangle, and the contacts with the main granodiorite are extremely vague and ill-defined. The writer believes that the dioritic or quartz-dioritic phases merely represent erratic concentrations of dark minerals and more calcic plagioclase within the main granodiorite mass, rather than separate intrusions. These rocks have been included with the Stonewall granodiorite.

Another unusual variation of the Stonewall granodiorite in the Cuyamaca Peak quadrangle is classified as hypersthene-quartz diorite. This rock underlies several small knolls on the gently undulating upland surface of East Mesa in the east-central part of the quadrangle. Megascopically the rock is gray, fine-grained, equigranular, and massive. Study of thin sections of this rock shows that it is made up of about 65 percent plagioclase. The plagioclase is zoned; the large, euhedral grains have a composition of about Ab_{50} on the outside, but slightly more calcic cores. Both hypersthene and augite occur in small broken fragments that are somewhat rounded and apparently fractured. The hypersthene makes up about 15 percent of the rock and the augite about 5 percent. Nearly 5 percent is made up of small broken fragments of partly altered biotite. Quartz is a comparatively minor constituent (about 10 percent), and a little orthoclase is present (as high as 5 percent of the rock). Accessory minerals are apatite (in very small euhedral crystals) and magnetite. This unusual rock is probably the product of the reworking by granodiorite magma of a considerably more mafic rock, as it appears to be out of equilibrium. That is, relatively sodic plagioclase and considerable quartz occur in the same rock with a high content and variety of mafic minerals. However, the process of digestion has gone so far, and the rock is so closely identified with the Stonewall granodiorite, that the hypersthene-quartz diorite has not been mapped as a separate unit.

Mixed Rock of Julian Schist and Stonewall Granodiorite

The Stonewall magma intimately injected, included, and in places probably replaced the Julian schist over large areas in the Cuyamaca Peak quadrangle. The writer believes that the mixed character of the rock should be emphasized, and where it underlies an appreciable area it has been mapped as mixed rock (pl. 2). The rocks mapped under this reclassification include gradations from Julian schist that has been only slightly injected, mostly lit-par-lit, to coarsely granular gneiss that may be of igneous or sedimentary origin. Several of the rocks recognized and described by other geologists as parts of either the Julian schist or the Stonewall granodiorite have been called mixed rock by the writer. These include certain of the paragneisses, coarse schists, the injection gneiss

in the Julian schist, the gneissic phases of the quartz diorite of the Stonewall as described by Hudson,[29] the gneissic phase of the quartz diorite of the Stonewall, and the injection gneiss described by Donnelly[30] and Merriam.[31]

The most typical and widespread mixed rock is a medium- to coarse-grained granular gneiss with a comparatively high content of well-oriented biotite flakes. The biotite is commonly altered in part to iron oxide, which stains the clear quartz and white feldspar of the rock a pinkish-brown on the weathered surfaces. Outcrops of mixed rock are generally subdued in form, and boulders are rare. The appearance of the rock is variable. Some parts of it are coarse-grained and granitic, but they change abruptly to very fine-grained schistose rocks. In the injection rock, schist and granitic rock alternate in bands that range from a fraction of an inch to to several inches in width. In some outcrops it is possible to trace the schistosity of quartz-mica schists into gneissic granitic rocks with oriented biotite flakes without interruption and with complete gradation between the two. In other places the bands of the injection rock show an extreme degree of contortion and intricate folding, resembling marble cake.

The mineralogic composition of the mixed rock varies widely. In rock that is about half quartz-mica schist of the Julian and half granodiorite of the Stonewall, quartz is the dominant mineral, amounting to about 40 percent. In thin section, the quartz commonly shows strain and forms irregular, granulated masses between larger euhedral grains of plagioclase and biotite flakes. The plagioclase, which is subordinate to the quartz but commonly makes up 20 to 25 percent of the rock, occurs in large euhedral grains that are polysynthetically twinned. They are only slightly zoned and average about Ab_{25} in composition. The biotite, which also may make up as much as 20 to 25 percent of the rock, is in the form of large strongly pleochroic flakes that occur in long lenticles. It commonly contains small zircon grains surrounded by well-developed pleochroic halos, and as much as 2 percent of magnetite in scattered grains of less than a millimeter in diameter. Apatite is another minor constituent.

The most prominent feature of the mixed rock in thin section is the texture. The large euhedral plagioclase grains are surrounded on all sides by crushed granules of quartz and feldspar and curved shreds of biotite. The crushed quartz and feldspar seem to be inherited from the older metasedimentary rocks, but the large euhedral grains of plagioclase and biotite and some of the quartz appear to have formed from granitic solutions that soaked the older rocks, causing partial replacement or granitization. Donnelly[32] pointed out secondary textures caused by deformation and replacement in some of the Stonewall granodiorite he described. As replacing minerals he listed quartz, myrmekite (quartz and albite), and fine-grained intergrowths of quartz and alkalic feldspar. He also stated that at least part of the gneissic texture in the granodiorite is inherited from the schist.

[29] Hudson, F. S., op. cit., pp. 183-186, 191-192.
[30] Donnelly, Maurice, op. cit., pp. 337-340.
[31] Merriam, Richard, op. cit., pp. 231-232.
[32] Donnelly, Maurice, op. cit., pp. 340-341.

Cuyamaca Gabbro

General Characteristics. In appearance of their outcrops and characteristic land forms, the mafic rocks of the Cuyamaca gabbro are remarkably uniform, but in texture, mineral content, and chemical composition, they vary widely. Mountains underlain by the rocks of this gabbroic group have distinctive, broad-based, somewhat conical forms that give rise to local radial drainage. Their smooth slopes are covered by a residual soil of deep reddish-brown color, and they support a dense growth of brush.

The outcropping rocks are generally massive and gray to black; on close inspection most of them show a mottling, banding, or veining of white or clear grains of feldspar and dark-green to black grains of ferromagnesian minerals. The textures range from fine-grained ophitic to coarse-grained pegmatitic, but most of them are typical medium-grained gabbroic textures. Gabbro pegmatites containing individual crystals measuring several inches in longest dimension are locally abundant.

The dominant minerals of these rocks are calcic plagioclase, olivine, augite, diallage, hypersthene, and hornblende. They occur in various combinations to form several kinds of rocks. The five most prominent of these rocks—troctolite, olivine gabbro, gabbro, hypersthene gabbro (norite), and hornblende gabbro—are described in this report.

Name and Correlation. The widespread gabbroic rocks in the southern California batholith form one of its most interesting and important lithologic units, and they have been given at least five names in four type localities by the several geologists who have studied them. The table on page 67 summarizes the essential data on their nomenclature.

There now seems to be little doubt that the gabbroic rocks are distinctive and widespread and should be correlated under one name. The writer has followed Creasey [33] in referring to the rocks as the Cuyamaca gabbro, thereby retaining the original locality name given by Hudson, but substituting the more appropriate gabbro for the term basic intrusive.

Because of the diversity of rocks included in the gabbro, and also in any one gabbroic mass as exposed in the field, the mapping and describing of the group presents unusual problems. Hudson,[34] on the basis of field and petrographic work, broadly grouped the gabbroic rocks of the Cuyamaca Peak-Julian area into gabbros, norites, and basic diorites. He subdivided these into 15 separate types, representing a gradation from quartz norite and hypersthene diorite to peridotite. However, he found the field relations to be so complex and intricate that he made no attempt to separate the types in mapping. Donnelly [35] followed Hudson in briefly describing the Cuyamaca basic rocks as largely norite and gabbro. Creasey [36] worked with the same rocks as some of those studied by Hudson and Donnelly, but subdivided them according to the estimated content of feldspar. He is the only geologist who has attempted to map subdivisions within the gabbro. His arbitrary and generalized units include those rocks that contained: (1) less than 15 percent feldspar (including mafic norites and gabbros, pyroxenites, and peridotites); (2) from 15 to 40 percent feldspar (including the intermediate types of gabbro); (3) more

[33] Creasey, S. C., op. cit., p. 19.
[34] Hudson, F. S., op. cit., pp. 193-207.
[35] Donnelly, Maurice, op. cit., p. 341.
[36] Creasey, S. C., op. cit., pp. 19-22.

Names applied to the gabbroic rocks of the southern California batholith.

Name	Geologist	Year published	Type locality	Area studied
Cuyamaca basic intrusive	Hudson	1922	Cuyamaca Peak	Cuyamaca region
Cuyamaca basic intrusive	Donnelly	1934	Cuyamaca Peak	Julian district
Viejas gabbrodiorite	Miller, W. J.	1935	Viejas Mountain	Section along U. S. Highway 80
Virginia quartz-hypersthene norite and gabbro	Dudley, P. H.	1935		Perris block
San Marcos gabbro	Miller, F. S.	1937	San Marcos Mountains	San Luis Rey quadrangle
Gavilan Peak gabbro	Osborn	1939	Gavilan Peak	Perris block, Riverside quadrangle
Cuyamaca gabbro group	Creasey	1946	Cuyamaca Peak	Julian-Cuyamaca area
San Marcos gabbro	Merriam	1946	San Marcos Mountains	Ramona quadrangle, southwestern part
Cuyamaca and San Marcos gabbro	Miller, W. J.	1946	See above	Central and northwestern San Diego county
San Marcos gabbro	Larsen	Unpubl. manuscript	San Marcos Mountains	San Luis Rey, Elsinore, and Corona quadrangles

All data are from previously cited references except:
Dudley, P. H., Geology of a portion of the Perris block, southern California: California Jour. Mines and Geology, vol. 31, no. 4, p. 501, 1935.
Osborn, E. F., Structural petrology of the Val Verde tonalite, southern California: Geol. Soc. America Bull., vol. 50, pp. 921-950, 1939.

than 40 percent feldspar (including norites, hornblende gabbro, and hybrid rocks near contacts with the Julian schist and Stonewall granodiorite); and (4) more than 40 percent feldspar, and olivine as the predominant ferromagnesian mineral.

The most detailed and extensive petrographic and chemical studies of the gabbroic rocks have been made by Larsen [37] and F. S. Miller [38] on the San Marcos gabbro of the San Luis Rey quadrangle. Although they have not differentiated the rocks in mapping, they have classified them petrographically into seven types: (1) olivine rock, (2) norite [39] and hypersthene gabbro, (3) hornblende gabbro, (4) calcic hornblende gabbro, (5) quartz-biotite norite, (6) noritic hornblende gabbro, and (7) quartz-biotite-hornblende gabbro. Merriam [40] described essentially the same range of rocks from relatively small, scattered gabbroic bodies in the southwestern part of the Ramona quadrangle.

Distribution. The rocks of the Cuyamaca gabbro group in the Cuyamaca Peak quadrangle crop out in six large masses and twelve smaller ones, collectively underlying about 41 square miles. The masses form some of the highest and most distinctive mountain peaks in the Peninsular

[37] Larsen, E. S., Jr., op. cit., pp. 41-53, 1938.
[38] Miller, F. S., op. cit., pp. 1397-1426.
[39] Only those rocks with a hypersthene-augite ratio greater than 2:1 are termed norites by Miller.
[40] Merriam, Richard, op. cit., pp. 234-240.

Ranges, and four of the six large bodies in the Cuyamaca Peak quadrangle make up mountains sufficiently outstanding to be named: (1) Cuyamaca and Middle Peaks in the north-central part of the map area, (2) Viejas Mountain in the west-central sector, (3) Poser Mountain in the west-central sector, and (4) Guatay Mountain in the east-central sector. Both the large and small gabbro bodies are scattered throughout the area mapped for this study and form no obvious pattern. However, a very definite broad zone of gabbro is evident throughout the batholith as a whole if gabbro bodies of the Cuyamaca Peak quadrangle are considered with those mapped by Merriam [41] and Larsen [42] in the Ramona, San Luis Rey, and Elsinore quadrangles to the northwest and those noted by the writer to the south and southeast. The zone is nearly 20 miles wide in places and trends about N. 40° W. from the Mexican border to the valley of the Santa Ana River between Riverside and Corona. The gabbro bodies are most concentrated along the northeast edge of the zone and include Los Pinos Mountain (just south of the southeast corner of the Cuyamaca Peak quadrangle), Guatay Mountain and the Cuyamaca Peaks (in the Cuyamaca Peak quadrangle), the Mesa Grande gabbro body (in the Ramona quadrangle), Pala Mountain (in the San Luis Rey quadrangle), and Gavilan Peak (in the Elsinore quadrangle). The southwest edge of the gabbro zone is marked by Little Tecate Mountain (near the Mexican border south of the Cuyamaca Peak quadrangle), Viejas Mountain (in the Cuyamaca Peak quadrangle), the small gabbro bodies west of the town of Ramona and south of Escondido, and the San Marcos Mountains (in the San Luis Rey quadrangle).

Characteristic Primary Structure. Primary structural features in the rocks of the Cuyamaca gabbro are developed only locally and show no consistent attitudes. The best-developed feature is banding of light- and dark-colored layers that are only a few inches thick and pinch out within a few feet in all directions. This banding most commonly occurs in the hornblende gabbro where the layers are formed by concentrations of either hornblende or plagioclase grains. The strikes of the layers are erratic, but the dips are generally steep.

Another structural feature called auto-injection structure by Larsen [43] and Merriam [44] is common in some of the gabbroic bodies. It consists of interpenetration of very coarse-grained gabbro pegmatites and fine-grained gabbro in highly irregular small bodies. Generally the pegmatites intrude the fine-grained rock, but in a few places the intrusive relationships are reversed.

Petrography. Mineralogically and chemically the gabbroic rocks in the Cuyamaca Peak quadrangle are classed as mafic rocks, but some of them contain appreciable amounts of felsic minerals. One of their most striking features is the degree to which the main constituent minerals appear to have undergone reaction during the late magmatic stages. The hornblende-bearing rocks show these reaction effects best, for much of the hornblende itself is the product of reaction; the accompanying plagioclase is strongly zoned, with the cores of the grains considerably more calcic than the rims. The norites and normal gabbros appear to have

[41] Merriam, Richard, op. cit., pl. 1, opp. p. 223.
[42] Larsen, E. S., Jr., op. cit., unpublished map.
[43] Larsen, E. S., Jr., op. cit., p. 52, 1948.
[44] Merriam, Richard, op. cit., pp. 238-240.

undergone less reaction, and the mafic olivine rocks, pyroxenites, and anorthosites still less. The quantities of the various rocks are apparently somewhat proportional to the degree of reaction, with those showing the most reaction effects being the most abundant.

Modes of the major rock types of the Cuyamaca gabbro, Cuyamaca Peak quadrangle.

	1	2	3	4	5	6	7	8
Number of sections	1	1	1	1	1	1	1	1
Quartz	--------	tr	--------	--------	--------	--------	--------	--------
Plagioclase	85	65	62	85	60.3	78	50	60
Biotite	--------	--------	--------	--------	2.3	--------	2	--------
Actinolite	--------	2	--------	--------	--------	--------	--------	--------
Hornblende	3	5	--------	3	21.3	--------	46	39
Diopside	--------	--------	22	--------	--------	--------	--------	--------
Augite	--------	15	--------	12	--------	2	--------	tr
Hypersthene	--------	2	5	--------	15.5	20	--------	--------
Olivine	5	5	8	--------	--------	--------	--------	--------
Iddingsite	5	4	<1	--------	--------	--------	--------	--------
Magnetite	<1	<1	<1	<1	0.2	<1	<1	<1
Ilmenite	--------	--------	--------	--------	--------	--------	--------	<1
Apatite	--------	--------	--------	--------	0.3	--------	<1	tr
Pyrite	--------	--------	--------	--------	--------	--------	<1	--------
Pyrrhotite	--------	<1	--------	--------	--------	--------	--------	--------
Total	99	100	99	100+	99.9	100+	100—	100
Percent of An in plagioclase	82	70	66	78	60	78	57	58

1. Specimen No. CP-7. Troctolite (olivine gabbro) from Poser Mountain. Estimated mode.
2. CP-80. Estimated mode of augite-olivine gabbro. One mile north of Laguna Junction.
3. CP-75. Estimated mode of diopside-olivine gabbro. Between Corte Madera and Pine Valley Creek.
4. CP-33. Estimated mode of augite gabbro. Western slope of Viejas Mountain.
5. Des. 41-24. Rosiwal analysis of norite. Cuyamaca Peak, one-third mile west of the Cuyamaca Guard Station.
6. CP-14. Estimated mode of norite. Eastern slope of Viejas Mountain.
7. CP-97. Estimated mode of hornblende gabbro. Southern edge of East Mesa.
8. CP-84. Estimated mode of hornblende gabbro. Brenner Ranch, 2½ miles northwest of Hulburd Grove.

Troctolite, an olivine gabbro containing essentially only olivine and calcic plagioclase and very little pyroxene, is abundant in parts of the Cuyamaca Peak quadrangle, and is especially plentiful on Poser Mountain in the west-central part. The rock is coarse-grained with interlocking laths of gray feldspar and grains of dark-green to black ferromagnesian minerals. Very calcic plagioclase, averaging around An_{90} and only slightly zoned, is the dominant mineral, making up in some places as much as 85 percent of the rock. The olivine is in altered rounded grains up to 2 or 3 millimeters in diameter, entirely surrounded by plagioclase. The main alteration product is iddingsite, in halos rimming and replacing the olivine grains so extensively as locally to make up 5 percent of the

rock. More subordinate pleochroic, brown to dark-green hornblende, probably formed by deuteric alteration, occurs along cracks in the olivine. Small euhedral grains of magnetite are common in cracks in the olivine and in bodies around the olivine grains. A few euhedral grains of augite are scattered throughout the rock as cores in the hornblende.

Olivine gabbro, as defined by Johannsen,[45] is common in a few of the gabbro bodies of the quadrangle, notably north of Laguna Junction, northwest of Corte Madera, and on Cuyamaca Peak. It is a medium- to coarse-grained, nearly equigranular, dark-gray to black rock with ophitic texture. The approximate mineral composition is about 65 percent labradorite, 20 to 25 percent clinopyroxene, 2 to 5 percent hypersthene, 8 to 10 percent olivine, up to 5 percent hornblende, 1 or 2 percent actinolite, and minor amounts of magnetite, iddingsite, pyrite, pyrrhotite, chlorite, and limonite.

In thin section, olivine appears to have been the first mineral to crystallize, followed by augite, diallage, and hypersthene; plagioclase probably formed simultaneously with all the other minerals. The plagioclase (An_{65-70}, and only slightly zoned) is the most abundant mineral in the rock and is in large, polysynthetically twinned euhedral grains. Surface alteration of the plagioclase to clay minerals is not common. Olivine is present in large, euhedral grains and generally is at least slightly altered to iddingsite. Both augite and diallage form stout euhedral prisms, and hypersthene, if present, is greatly subordinate to these minerals. The pyroxenes are locally affected by deuteric reaction, with the formation of numerous rims and pockets of pleochroic, light-green to brown hornblende. Similarly formed fibrous actinolite is common, and small euhedral grains of magnetite are invariably scattered throughout the reaction rims. Pyrite and pyrrhotite are present in small amounts, apparently as primary minerals, and chlorite and limonite are common secondary minerals.

Gabbro, as defined by Johannsen,[46] is not one of the most common gabbroic rocks in this area. More of it is exposed on the west side of Viejas Mountain than at any other place, and some of it, intimately associated with other mafic rocks, underlies the western slope of Cuyamaca Peak. Generally the gabbro is coarse-grained and subhedral-granular in texture. It is distinguished by the abundance of heterogeneously oriented feldspar laths. Plagioclase in large almost euhedral grains, averaging An_{78}, is the dominant mineral, comprising as much as 85 percent of the rock. The rest is clinopyroxene—augite in some places and diallage in others—and minerals derived from the pyroxenes. The pyroxene grains are prismatic and subhedral, commonly showing reaction rims of light- to dark-green hornblende. Many of the pyroxene-hornblende aggregates carry rather large patches of magnetite, and in at least one specimen the aggregates include small amounts of phlogopite. Spinel, pyrite, and pyrrhotite are common accessories.

Norite (hypersthene gabbro) is one of the two most widespread types of gabbroic rock in the Cuyamaca Peak quadrangle, for it makes

[45] Johannsen, Albert, A descriptive petrography of the igneous rocks, University of Chicago Press, Chicago, Illinois, vol. 1, p. 271, 1939. "Olivine-gabbro (2312P). A gabbro which contains essential olivine in addition to the usual minerals of this rock" (i.e. calcic plagioclase and pyroxene).

[46] Johannsen, Albert, op. cit., p. 252. "Gabbro (2312P). Plutonic rocks composed essentially of laboradorite (or bytownite) and pyroxene. Olivine may be an accessory, and magnetite is seldom absent." The pyroxene in this definition is generally understood to be clinopyroxene.

up part of nearly every major body. The norite varies considerably in mineral content if it is defined, following Miller,[47] as a gabbro in which the ratio of hypersthene to clinopyroxene is greater than 2:1. In norites studied, this ratio varies widely, and in addition, the clinopyroxenes are augite, or diallage, or rarely diopside. The textures also show variation from coarse to fine grain. Most of the norites are medium-grained, subhedral-granular or ophitic rocks that show equidimensional interlocking crystals of pyroxene, hornblende, and glassy plagioclase. The approximate mineral composition is 60 to 75 percent labradorite-bytownite, 15 to 25 percent hypersthene, up to 20 percent hornblende, 2 to 5 percent augite, about 1 percent magnetite, and minor amounts of actinolite, biotite, chlorite, and apatite.

The plagioclase ranges in composition from An_{50} to An_{78} and is commonly zoned, with cores of the grains containing as much as 10 percent more anorthite molecules than the rims. In some norites the plagioclase is stained by iron oxides, and as a result the rocks are pinkish. The diagnostic hypersthene is generally very prominent in thin section, for as a rule it forms large euhedral grains. Most of it is highly pleochroic (from brownish-pink to green), indicating a relatively high iron content. Augite is commonly present but is subordinate to the hypersthene. Nearly all the grains of both pyroxenes have reaction rims of hornblende which is pleochroic dark green to brown or blue-green to dark green. Aggregates of actinolite also occur, and minor amounts of late biotite and chlorite have been observed. As in all the other gabbros, magnetite in euhedral grains and blobs is common; most of it is believed to be a reaction product because it is in the reaction rims around the pyroxene grains. Apatite in crystals up to a millimeter in cross section is a persistent accessory.

Hornblende gabbro, in which the ferromagnesian mineral is hornblende rather than pyroxene, is the most abundant kind of gabbroic rock in the Cuyamaca Peak quadrangle, and the hornblende it contains is one of the most interesting of the rock-forming minerals. The hornblende rocks seem to be concentrated in the gabbro bodies in the eastern and central part of the quadrangle, and they are especially well developed in the intrusive near the junction of Route 80 and Pine Valley Creek, on East Mesa, and on the eastern slopes of Cuyamaca Peak. This general distribution and Merriam's statement that " * * * hornblende gabbro is the most abundant rock type * * * "[48] in the Ramona quadrangle suggests that the hornblende rocks are principally along the northeast edge of the gabbro zone in the batholith.

The texture of the hornblende gabbros is more variable and complex than that of any other gabbroic rocks, although most of them should be classified as medium-grained and ophitic. Some of the rocks are extremely coarse-grained or pegmatitic, whereas others are as fine-grained as any in the batholith. Where rocks with the two textures occur side by side, the coarser generally appear to have formed from magma or solutions that intruded the finer-grained rocks. The hornblende gabbro is gray-green to black.

The principal mineral is zoned plagioclase, which generally makes up 50 to 60 percent of the rock and ranges from An_{55} to An_{65} in composition. Many of the plagioclase grains are partly altered to clay minerals

[47] Miller, F. S., op. cit., p. 1405.
[48] Merriam, Richard, op. cit., p. 235.

Hornblende makes up most of the remaining volume of the rock. Small to moderate amounts of hornblende formed by late magmatic reaction have been described as part of the other rocks of the Cuyamaca gabbro, but in the hornblende gabbros, hornblende is present to the exclusion of other ferromagnesian minerals. It appears to have been formed as a primary mineral in some places and as the result of essentially complete conversion from pyroxene in others. Most of the subhedral hornblende grains interlock with those of plagioclase, but huge poikilitic crystals of hornblende are also generally present. The pleochroic colors in thin section are largely green to brown and less commonly dark to light green. In some of the rocks a few small flakes of biotite and minute euhedral grains of magnetite are associated with the hornblende. A remnant of an augite core in a hornblende grain was noted in one thin section, and epidote (?) in small amounts was also seen in a few sections. Accessories include apatite in crystals up to a millimeter in cross section, ilmenite with leucoxene rims, euhedral pyrite which is locally in considerable quantity, and pyrrhotite.

Chemical Composition. One analysis of a rock of the Cuyamaca gabbro from the Cuyamaca Peak quadrangle has been made for W. J. Miller.[49] The rock occurs at the southern base of Viejas Mountain and appears to be in the third or normal gabbro type described in the foregoing section on petrography. This analysis, together with three others of gabbroic rocks from the San Luis Rey quadrangle,[50] is given in the accompanying table. The modes of the rocks from the San Luis Rey quadrangle suggest that they may be correlated with three of the other types of gabbroic rock described in the foregoing section on petrography.

Some of the significant features brought out by these analyses are a very low Na_2O and K_2O content and, as pointed out by Merriam,[51] the high Al_2O_3 content and the high percentage of CaO in the olivine-bearing rocks.

Diorite

Plutonic igneous rocks similar to the Green Valley tonalite, but differing from it in texture and structure and lacking the quartz essential in a tonalite, underlie two sizable areas within the Cuyamaca Peak quadrangle. Because of their limited extent these rocks have not been given a formation name but are referred to only as diorite.

One diorite body, covering about a square mile, lies in the southwest part of the quadrangle near the places at which the Sweetwater River leaves the mapped area (pl. 2). It is entirely surrounded by Green Valley tonalite, from which it differs in several respects, notably in its lack of abundant elliptical inclusions and in its moderate degree of weathering. It further differs in that the rock contains very large poikilitic flakes of biotite which give it a faint foliation. This foliation, which is taken to be primary, is cut by the Green Valley tonalite, and further, the primary structures of the tonalite bend around the diorite mass.

The diorite of this body is subhedral-granular in texture and medium- to coarse-grained. The groundmass consists of plagioclase laths interlocked with somewhat larger pyroxene grains. The plagioclase, averaging An_{50} in composition, makes up nearly 80 percent of the rock.

[49] Miller, W. J., op. cit., pp. 522-523, 1946.
[50] Larsen, E. S., Jr., op. cit., pp. 50-51, 1948.
[51] Merriam, Richard, op. cit., p. 238.

Analyses, modes, and norms of Cuyamaca gabbro.

Analyses	I	II	III	IV
SiO_2	42.86	48.16	52.12	44.66
TiO_2	0.18	0.76	0.33	0.96
Al_2O_3	24.94	19.66	20.88	22.85
Fe_2O_3	2.13	1.53	0.34	3.88
FeO	6.14	5.06	6.52	6.44
MnO	0.06	0.14	0.09	0.11
MgO	9.28	7.59	6.90	5.22
CaO	13.08	13.46	10.14	14.56
Na_2O	0.76	1.88	2.40	1.08
K_2O	0.09	0.31	0.25	0.07
H_2O-	0.78	1.48	0.22	0.24
P_2O_5	----	0.11	----	tr
S	0.03	0.08	----	----
	100.33	100.22	100.19	100.07

Modes		Volume		Weight
Plagioclase	67	47	65	66.0
Hornblende	11	46	0.9	4.0
Pyroxene	2	6	33	8.0
Olivine	18	----	----	21.0
Fe ore	0.2	1.9	1.7	1.3
	100.4	101.0	100.6	100.3

Norms				
Quartz	----	----	1.26	----
Orthoclase	0.56	1.67	1.11	0.56
Albite	6.29	16.24	20.44	8.91
Anorthite	64.22	44.20	45.59	57.27
Diopside	0.68	17.39	3.76	12.06
Hypersthene	4.09	9.18	26.53	11.56
Olivine	20.09	6.01	----	1.90
Magnetite	3.02	2.09	0.46	5.57
Ilmenite	0.46	1.52	0.61	1.82
Pyrite	----	0.12	----	----
Apatite	----	0.34	----	----

I. Olivine norite, San Luis Rey quadrangle.*
II. Noritic hornblende gabbro, San Luis Rey quadrangle.*
III. Typical norite (hornblende free), San Luis Rey quadrangle.*
IV. Gabbro, Cuyamaca Peak quadrangle (south base of Viejas Mountain). Analysis made for W. J. Miller by L. C. Armstrong, analyst.

* The olivine norite (I) is roughly equivalent to the writer's olivine gabbro, noritic hornblende gabbro (II) to certain phases of the hornblende gabbro, and the typical norite (III) to norite. All three analyses made for E. S. Larsen, Jr., by F. A. Gonyer, analyst. Norm calculated by Larsen.

Hypersthene in euhedral prisms comprises another 10 percent, and it has reaction rims of hornblende which may make up as much as 2 percent of the rock. Augite also is present to the extent of about 2 percent, and biotite in poikilitic flakes several centimeters in dimension occurs throughout the groundmass making up 5 percent of the rock. Scattered euhedral grains and blobs of magnetite, apatite, and a little quartz are minor minerals in this diorite.

The other body of diorite is near the eastern edge of the quadrangle in the vicinity of Deer Park. Although somewhat less than a square mile of this body is within the Cuyamaca Peak quadrangle, it extends east of the quadrangle for an undetermined distance. The area underlain by the diorite contains very subdued outcrops and thus differs from the areas underlain by the Green Valley tonalite, which are characterized by huge boulders.

The diorite is medium- to coarse-grained ophitic in texture and very homogeneous. In mineral content it is more closely related to the Green Valley tonalite than to any other major rock unit of the area, but it is quite different from the aforedescribed diorite or any other rock in the area. It appears to be largely composed of plagioclase tablets and shreds of hornblende and biotite. The plagioclase, amounting to about 45 percent of the rock, is somewhat zoned but averages An_{54}. The hornblende shreds and fragments comprise about 25 percent, and the large broken flakes of biotite total about 20 percent. Granular intertsitial quartz ordinarily amounts to less than 5 percent but locally may exceed 10 percent. Associated with both the hornblende and the biotite is less than 1 percent of epidote; apatite, tourmaline, and sphene are the common accessories.

Green Valley Tonalite

General Characteristics. Green Valley tonalite is a rock unit that is easily identified. Outcrops are distinctive in appearance, and large bodies tend to erode to characteristic land forms. Because the rock is unusually susceptible to weathering, much of the area of tonalite is covered with gruss, or deeply disintegrated, rotten rock. Scattered liberally throughout the gruss, however, are numerous, comparatively small boulders of hard, homogeneous, fresh rock. These boulders are black to dark gray, ellipsoidal, and commonly no more than 6 feet in maximum dimension. Apparently because of its low resistance to weathering and erosion, the Green Valley tonalite in the Cuyamaca Peak quadrangle underlies lowland areas.

Megascopically, most of the Green Valley tonalite in the Cuyamaca Peak quadrangle is a light- to dark-gray, medium- to coarse-grained, granular rock with prominent euhedral plagioclase crystals that are larger than most of the other minerals. In some places, large biotite flakes poikilitically enclose other mineral grains, and hornblende prisms measuring several centimeters in length are less common.

The approximate mineral makeup of the Green Valley tonalite as estimated in thin sections is: generally 50 to 70, and rarely as much as 85 percent plagioclase; 5 to 10 percent hornblende; about 10 percent biotite; 1 to 10 percent pyroxene (both augite and hypersthene); 10 to 20 percent quartz; 2 percent or less orthoclase; and less than one percent each of magnetite, ilmenite, epidote, chlorite, limonite, sericite, apatite, zircon, sphene, and tourmaline.

Elliptical dark inclusions, generally no more than a foot or two in any dimension, are fairly abundant in the Green Valley tonalite, but streaked-out inclusions are rare. The inclusions have only slightly smaller grain size than the rest of the rock, and their mineral content is the same except for an appreciably greater concentration of dark minerals.

Name and Correlation. Green Valley tonalite [52] is the name applied by Larsen [53] and F. S. Miller [54] to a rock exposed in extensive outcrops around Green Valley in the southeast corner of the San Luis Rey quadrangle. The unit was traced eastward and northeastward by Merriam [55] and mapped in parts of the Ramona quadrangle. An identical rock from the vicinity of Alpine, 1 mile west of the Cuyamaca Peak quadrangle, was described by W. J. Miller,[56] who named it the Alpine quartz diorite; later in 1946,[57] he correlated it with the Green Valley tonalite mapped by Merriam in the Santa Teresa Valley of the Ramona quadrangle. Although the Alpine quartz diorite term of W. J. Miller was the first to be published, the writer follows Larsen, F. S. Miller, and Merriam in the use of the name Green Valley tonalite because the rock has been so mapped throughout the San Luis Rey and Ramona quadrangles just to the north and northeast of the Cuyamaca Peak quadrangle.

Distribution. Green Valley [58] tonalite underlies about 50 square miles of the mapped area and most of it is confined to two very large bodies, one of which has been invaded by younger intrusives. One large body, occupying parts of the southwestern and south-central areas of the quadrangle, underlies a rolling surface of low relief in which sharp canyons several hundred feet in depth have been carved, and above which rise rugged mountains and highlands underlain by younger, more silicic intrusives. The other large body of Green Valley tonalite, in the northwestern corner of the quadrangle, underlies an area of great relief where the San Diego River and its youthful tributaries cut canyons far below the general upland surface.

The deep weathering of the Green Valley tonalite is best observed in several large roadcuts on U. S. Highway 80 between Viejas Valley and Descanso Junction. Here the rock is weathered at least 25 feet below the surface, and through the weathered zone the characteristic boulders are encased in shells of progressively more weathered rock.

The bodies of Green Valley tonalite in the Cuyamaca Peak quadrangle, like those of the Cuyamaca gabbro together with bodies of correlated rocks in the Ramona and San Luis Rey quadrangles, form a discontinuous belt which, in a general way, lies along the southwest edge of the gabbro zone and in places overlaps it. Reconnaissance southward as far as the Mexican border indicates that the Green Valley tonalite underlies a large area along the southeastern extension of the belt, but none has been recognized in the northern or northeastern part of the batholith.

Characteristic Primary Structures. Elliptical inclusions, platy parallelism of dark minerals, and flow layers or schlieren are in order the dominant primary structures of the Green Valley tonalite. Where two or three of these planar elements are observed together in the same outcrop, they appear to be essentially parallel and therefore probably give a true

[52] Tonalite is defined by Johannsen (op. cit., p. 284) as "strictly . . . a hornblende-biotite-quartz diorite; but Brögger, Spurr, and others have used the term for quartz diorites in general, and it is so used here."

[53] Larsen, E. S., Jr., op. cit., p. 53, 1948.

[54] Miller, F. S., op. cit., p. 1399, 1937.

[55] Merriam, Richard, op. cit., pp. 240-243.

[56] Miller, W. J., op. cit., p. 126, 1935.

[57] Miller, W. J., op. cit., pp. 485-486, 1946.

[58] The Green Valley in the San Luis Rey quadrangle, after which the tonalite is named, should not be confused with the Green Valley in the northeast part of the Cuyamaca Peak quadrangle.

picture of the last flow movement of the magma before consolidation. The structures are abundant throughout most exposures of the Green Valley tonalite except in two rather large areas—one around Las Bancas in the south-central part of the quadrangle and the other in the northwest corner. In these places, inclusions and schlieren are generally absent, and the large biotite flakes are not oriented.

Petrography. Plagioclase, occurring as large rectangular euhedral grains in random orientation, is the dominant mineral of the Green Valley tonalite. For the most part it is An_{40} to An_{50} in composition, but locally it is as sodic as An_{30}. It is almost invariably zoned, with cores several percent more calcic than rims. Polysynthetic twinning according to the albite law is general, and carlsbad twinning is only a little less common. Orthoclase in minor amounts fills between the euhedral grains of plagioclase and occurs in anhedral masses.

Estimated modes of Green Valley tonalite in the Cuyamaca Peak quadrangle.

	1	2	3	4	5	6	7	8
Quartz	20	5	20	12	20	10	20	13
Plagioclase	56	79	65	70	67	80	70	75
Muscovite	--------	--------	--------	<1	tr	--------	--------	--------
Biotite	8	7	5	3	5	3	2	5
Hornblende	10	3	3	12	5	5	5	2
Diopside	--------	--------	--------	tr	--------	--------	--------	--------
Augite	5	5	--------	--------	--------	--------	--------	3
Hypersthene	--------	--------	5	--------	--------	--------	2	--------
Apatite	<1	<1	<1	1	<1	--------	<1	<1
Magnetite	--------	<1	<1	<1	1	1	1	0.3
Zircon	<1	<1	--------	--------	<1	--------	tr	tr
Total	100	100+	99	100—	100—	99	100	99
Percent of An in plagioclase	30	30-70	50	42	46	54-80	46	42

1. Specimen No. Des. 41-40. Typical Green Valley tonalite from near the junction of Route 80 and Japatul Road.
2. CP-69. Massive Green Valley tonalite. Las Bancas.
3. CP-30. Dark phase of the Green Valley tonalite. Northern flank of Bell Bluff.
4. CP-1. Green Valley tonalite. Section 36, Bell Bluff truck trail.
5. CP-93. Green Valley tonalite. El Capitan truck trail.
6. CP-42. Green Valley tonalite. North of Japatul Road-Barrett truck trail junction.
7. CP-85. Green Valley tonalite. Section 2 on eastern side of the San Diego River.
8. CP-65. Green Valley tonalite. Horsethief Ridge at Las Bancas Road.

Dark minerals that either are, or once were, pyroxenes occur in subhedral grains interlocked with the plagioclase grains. The cores in some places are augite and in other places are hypersthene. The rims, which commonly are wide enough to make up most of the grain, are light- to dark-green or brownish hornblende. Large flakes of frayed biotite occur in clumps with the hornblende masses and may have formed from the hornblende by deuteric reaction.

Quartz, another of the essential minerals, occurs in anhedral grains between the other minerals. The amount of quartz varies considerably, but only locally does it make up more than 25 percent of the rock.

Euhedral magnetite is generally associated with the hornblende and biotite. Ilmenite grains with leucoxene rims are locally abundant. Persistent apatite and zircon, and rarer sphene and tourmaline are accessories. Minerals formed from the main dark minerals by hydrothermal

Analyses, modes, and norms of Green Valley tonalite.

Analyses	I	II
SiO_2	63.70	64.88
TiO_2	0.57	0.74
Al_2O_3	15.32	15.31
Fe_2O_3	1.58	1.45
FeO	4.25	3.83
MnO	0.09	0.09
MgO	3.18	2.35
CaO	5.68	5.16
Na_2O	3.00	3.25
K_2O	1.92	2.11
H_2O+	0.04	0.05
H_2O-	0.47	0.50
P_2O_5	0.06	0.14
ZrO_2	----	0.01
S	0.02	----
	99.86	99.87

Modes	I (Vol.)	II (Approx. wt.)
Andesine	48.0	47.0
Quartz	24.0	24.0
Orthoclase	----	6.0
Amphibole	13.0	6.0
Biotite	10.0	11.0
Pyroxene	4.0	5.0
Magnetite	0.9	0.7
Apatite	----	0.3
Zircon	----	0.1
	99.9	100.1

Norms		
Quartz	20.82	22.68
Orthoclase	11.12	12.23
Albite	25.15	27.25
Anorthite	23.63	21.13
Diopside	3.40	2.97
Hypersthene	11.88	9.09
Magnetite	2.32	2.09
Ilmenite	1.22	1.37
Apatite	0.19	0.34
	99.73	99.15

I. From type locality in the San Luis Rey quadrangle. Roadcut 2 miles west-northwest of southwest corner of Ramona quadrangle. Analysis made for E. S. Larsen, Jr., by F. A. Gonyer, analyst. Norm calculated by Larsen.
II. From near Alpine, about 1 mile west of the west edge of the Cuyamaca Peak quadrangle on U. S. Highway 80. Analysis made for W. J. Miller by L. C. Armstrong, analyst. Norm calculated by Miller.

alteration or weathering of the rock include small amounts of epidote, chlorite, and limonite.

Chemical Composition. Two analyses of Green Valley tonalite from localities near the Cuyamaca Peak quadrangle are given in the accompanying table; no analyses have been made of specimens from within the quadrangle.

These two analyses are similar, although the rock from Alpine is seen to be slightly more felsic than the Green Valley rock. The former is part of a mass that extends into the Cuyamaca Peak quadrangle, but much of this tonalite in the quadrangle is more mafic than that around Alpine and probably falls closer to the type rock in composition. The rock appears to be remarkably uniform over large areas.

Bonsall Tonalite

General Characteristics. The Bonsall tonalite is a light-gray, massive, plutonic igneous rock that underlies large areas in the quadrangle. It is very resistant to erosion and much of the area that it underlies is upland; however, in spite of its over-all resistance, it weathers about as readily as the Green Valley tonalite. Most of the rock observed on the surfaces is gruss, but scattered through it are very large residual boulders of more irregular shape and greater dimension than the typical boulders of gabbro or the Green Valley tonalite. They may be as much as 25 or 30 feet in longest dimension and commonly protrude 6 to 10 feet above the surface, giving rise to a landscape characterized by large light-colored boulders studding brush-covered slopes.

Undoubtedly the outstanding feature of the Bonsall tonalite is the abundance of generally streaked-out dark inclusions or schlieren[59] that are so uniformly distributed and widespread as to provide the best means of recognizing the rock in the field. The inclusions differ from those of the Green Valley tonalite in having finer grain and a shape like a much-elongated pancake. They commonly measure tens of feet along their greatest length but are no more than a few feet thick.

The typical Bonsall tonalite is a light-gray, medium- to coarse-grained, nearly equigranular rock. The texture is subhedral-granular, formed by interlocking plagioclase laths and hornblende prisms, with abundant interstitial quartz, some orthoclase, and prominent biotite. In the medium-grained varieties the white color of the feldspar and quartz and dark color of the other minerals combine to give the rock a coarse salt and pepper appearance.

The mineral content of the rock is not everywhere the same throughout the extensive bodies, but in a general way the Bonsall tonalite is more felsic than is the Green Valley tonalite. The approximate mineral ranges are: andesine, 50 to 70 percent; orthoclase, 10 to 15 percent; quartz, 15 to 25 percent; hornblende, 5 to 15 percent; biotite, 8 to 12 percent; and less than 1 percent each of enstatite, clinozoisite, apatite, sphene, zircon, magnetite, schorlite, sericite, and limonite.

[59] Schlieren, as defined by Johannsen (op. cit., p. 196), are "irregular streaks of more or less lenticular form and with blended outlines, which appear in some igneous rocks. . . . In some cases they may represent partially or completely assimilated fragments of included rocks, in others differentiated portions of a homogeneous mass, or injections of a different kind of rock magma."

Name and Correlation. The Bonsall tonalite was named in 1935 by Hurlbut[60] who described the plutonic rocks around Bonsall in the northern half of the San Luis Rey quadrangle. A large body of Bonsall tonalite that Larsen[61] mapped in the San Luis Rey quadrangle was traced eastward into the Ramona quadrangle by Merriam.[62] The writer has examined the Bonsall tonalite in the San Luis Rey and Ramona quadrangles and makes the correlation with the Bonsall tonalite of the Cuyamaca Peak quadrangle on the basis of the field characteristics as well as the petrographic study.

Other rocks that are probably correlative with the Bonsall tonalite in the southern California batholith are included in the table below.

Names of formations correlated with the Bonsall tonalite.

Name	Geologist	Year published	Area studied
Perris quartz diorite	Dudley, P. H.*	1935	Perris block, Elsinore quadrangle
Bonsall tonalite	Hurlbut, C. S.	1935	Part of the San Luis Rey quadrangle
Val Verde tonalite	Osborn, E. F.**	1939	Part of the Riverside quadrangle
Bonsall tonalite	Larsen, E. S., Jr.	1948	San Luis Rey, Elsinore, and Corona quadrangles

* Dudley, P. H., op. cit., p. 501.
** Osborn, E. F., op. cit., p. 926.

Distribution. The Bonsall tonalite underlies about 65 square miles of the Cuyamaca Peak quadrangle—more than is underlain by any other rock. All of it, except for a medium-sized body in the south-central part, occurs in a strip of irregular outline that trends northwest across the quadrangle. The strip is narrow in the central part of the quadrangle where the tonalite shares with younger intrusives a corridor between older gabbro and Green Valley tonalite bodies, but it is very wide to the west and southeast.

Throughout all of the batholith that has been mapped, the Bonsall tonalite, or rock correlated with it, is by far the most widespread formation. Unlike the Cuyamaca gabbro and the Green Valley tonalite, the Bonsall tonalite does not occupy restricted zones, but is distributed through nearly all of the southern California batholith.

Petrography. Plagioclase, which is invariably andesine but ranges in composition from An_{35} to An_{45}, is the chief mineral in the typical Bonsall tonalite. Most of it occurs as euhedral crystals slightly larger than the other mineral grains, but some of it is in small broken grains which, with other minerals, fill in between the larger well-formed crystals. Zoning in the plagioclase is rare, but some of the large crystals show the usual calcic to sodic gradation from core to rim. Orthoclase occurs in small subhedral grains that are generally a part of the interstitial material.

[60] Hurlbut, C. S., op. cit., p. 611.
[61] Larsen, E. S., Jr., op. cit., pl. 1, 1948.
[62] Merriam, Richard, op. cit., pp. 243-247.

Estimated modes of Bonsall tonalite in the Cuyamaca Peak quadrangle.

	1	2	3	4	5	6
Quartz	35	15	16	15	40	8
Plagioclase	55	70	70	46	32	83
Orthoclase	----------	----------	----------	----------	20	----------
Biotite	7	8	8	18	5	5
Muscovite	----------	<1	----------	----------	----------	----------
Hornblende	2	5	5	10	3	----------
Tremolite	----------	----------	----------	----------	----------	0.3
Augite	----------	----------	----------	2	----------	3
Apatite	<1	<1	<1	<1	<1	----------
Magnetite	----------	----------	1	<1	<1	0.5
Zircon	<1	----------	----------	----------	tr	----------
Sphene	----------	<1	----------	8	----------	----------
Schorlite	----------	1	----------	----------	----------	----------
Total	100—	100	100+	99+	100+	100—
Percent An in the plagioclase	----------	42	42	----------	----------	42

1. Specimen No. CP-81. Bonsall tonalite. Southern edge of section 19, southeast corner of quadrangle.
2. CP-70. Bonsall tonalite. South of Harbaugh Ranch headquarters, central southern part of quadrangle.
3. CP-87. Bonsall tonalite. Goudic truck trail.
4. Des. 41-30. Gneissic Bonsall tonalite (containing assimilated schist). West of Guatay.
5. CP-77. Felsic phase of the Bonsall tonalite. Half a mile southeast of Guatay.
6. CP-62. Mafic phase of the Bonsall tonalite. Horsethief Ridge.

Clear quartz, an essential mineral in the Bonsall tonalite, occurs invariably in anhedral masses between feldspar and hornblende grains. Under the microscope much of it appears sutured and shows wavy extinction.

Hornblende, as large but commonly fractured and fragmented grains, occurs in trains and clumps throughout the Bonsall tonalite. Although most of the grains are free from inclusions, some of them enclose other minerals and form a poikilitic texture. In thin section the hornblende shows dark-green to brown pleochroism.

Biotite is prominent as flakes and shreds that tend to be concentrated in bunches; some flakes are large and poikilitic, but others that are smaller and more irregular fill in between quartz and feldspar grains. Part of the biotite is associated with hornblende and doubtless was formed from it by deuteric reaction.

Epidote is a characteristic though not abundant mineral in much of the tonalite. Commonly it takes the form of shreds and small grains associated with biotite and hornblende, but rarely it forms rims around magnetite grains. In at least one locality it occurs as well-developed crystals several centimeters in length on the walls of a joint in the tonalite.

Unusually felsic and mafic phases of the Bonsall tonalite are present in a few places, but these phases differ only in the quantities of the

various minerals rather than in the kind of minerals. For example, in the felsic phase of the Bonsall tonalite about half a mile southeast of Guatay in the east-central part of the quadrangle, quartz composes about half of the rock, and orthoclase is so prominent that it possibly exceeds the plagioclase in amount. In addition, the plagioclase is somewhat more sodic than normal, falling into the oligoclase range. Distinctive intergrowths of quartz and orthoclase in the form of micropegmatite are common. The dark minerals are subordinate with biotite, hornblende, and magnetite making up about 5, 3, and less than 1 percent, respectively. In contrast, a dioritic phase of the Bonsall tonalite cropping out on Horsethief Ridge in the south-central part of the quadrangle contains locally as much as 85 percent plagioclase averaging An_{42}. Other approximate mineral percentages are: quartz, 7 to 8 percent; biotite, 5 percent; augite, 2 to 3 percent; and magnetite a few tenths of one percent.

Hybrid rocks of the Bonsall tonalite near the contacts with older formations also contain mineral assemblages that are different from the typical Bonsall tonalite. Near the gabbro contacts the tonalite usually has as much as 20 percent biotite and a few percent of augite in grains that are rimmed with hornblende. Sphene, in broken grains and euhedral crystals associated with the hornblende, is exceptionally abundant, locally amounting to several percent. Quartz and plagioclase of the usual andesine composition are the other minerals.

Three kinds of inclusions have been observed in the Bonsall tonalite: tenuous dark inclusions, lighter-colored inclusions with a high content of quartz, and inclusions of Julian schist. The dark inclusions are by far the most widespread and uniformly distributed of the three types. They are typically black or dark green and fine to medium granular in texture, resembling gabbro in hand specimen. The following were observed in only a few thin sections but are believed to be characteristic. Plagioclase, with a composition of about An_{45}, comprises about 60 percent of the rock; part of it is in euhedral grains nearly a centimeter in length, and the rest occurs in smaller interstitial grains. Quartz, occurring in a few large granulated masses, constitutes about 10 percent. Pyroxene, partly augite and partly hypersthene, occurs in broken grains that comprise 15 to 20 percent of the inclusions. Most of these pyroxene grains have broad reaction rims of hornblende, which in thin section shows dark-green to brown pleochroism. The hornblende also occurs in scattered clusters and altogether amounts to 12 to 15 percent of the rock. Associated with both the hornblende and the pyroxene is approximately 3 percent of magnetite in small grains. Apatite and pyrite are common accessories.

The dark inclusions occur throughout the Bonsall tonalite bodies and have no special relationship to the Cuyamaca gabbro in the quadrangle; however, similar dark inclusions in the Bonsall tonalite in the San Luis Rey quadrangle have been attributed by Hurlbut [63] to the reworking of inclusions of gabbro by the Bonsall magna.

The lighter-colored inclusions have a dioritic texture and contain a large amount of quartz, locally as much as 50 percent, as well as 20 percent biotite, 20 percent hornblende, and as little as 10 percent plagioclase. The accessory minerals are magnetite and apatite. These inclusions occur in limited amounts near contacts with the Green Valley tonalite

[63] Hurlbut, C. S., op. cit., pp. 609-630.

and are thought to represent inclusions of Green Valley tonalite partly assimilated by the Bonsall magna.

The only inclusions of recognized metasediments are little-altered schists in the Bonsall tonalite close to its contact with the Julian schist. Some of the other inclusions, however, may be fragments of schist so completely assimilated as to be unrecognizable.

Woodson Mountain Granodiorite

General Characteristics. The Woodson Mountain granodiorite is a light-colored granitic rock that underlies about one-sixth of the quadrangle and forms a lithologic unit that is distinctive in appearance, structural behavior, and petrographic detail. In resistance to erosion the Woodson Mountain granodiorite is second only to the Cuyamaca gabbro, and as a result it forms many of the prominent peaks in the quadrangle. Although it is resistant, the Woodson Mountain granodiorite weathers along joint planes on the slopes of the mountains to form huge white rounded knobs most of which are attached to the bedrock on the lower side, but some are completely detached and may properly be called residual boulders. Some of the weathered boulders have a pinkish hue. The general aspect of a mountain of Woodson Mountain granodiorite is that of an enormous rock pile in which the rocks are insulated by disintegrated rock. In some localities, however, the boulders are not present and the mountains are virtually a continuous massive outcrop. Platy or linear orientation of mineral grains or contrasting rock units are rare in the Woodson Mountain granodiorite, and jointing and sheeting are the distinctive structures.

The Woodson Mountain granodiorite exhibits two distinct phases. The phase that is by far the more widespread or normal is coarse-grained and granular, with phenocrysts of feldspar. The other, which appears to be confined to borders of the masses, is fine- to medium-grained, homogeneous, and equigranular. Rosiwal analyses and estimated modes of representative specimens of coarse-grained Woodson Mountain granodiorite are given in the accompanying table.

Other minerals that occur in the coarse-grained Woodson Mountain granodiorite in very small amounts are apatite, zircon, muscovite, hypersthene, hornblende, magnetite, allanite (?), epidote, and chlorite. The fine- to medium-grained phase of the Woodson Mountain granodiorite, which differs somewhat in the proportion of minerals, has a higher quartz content (generally 37 percent and rarely up to 60 percent of the rock) and an abnormally high ratio of potash feldspar to plagioclase.

Name and Correlation. The Woodson Mountain granodiorite was named by Larsen (in a paper by F. S. Miller [64]) after Woodson Mountain, which is in the southwest corner of the Ramona quadrangle and is designated as the type locality. Larsen [65] has applied the name to certain rocks throughout the San Luis Rey, Elsinore, and Corona quadrangles, and Merriam [66] has used the name Woodson granodiorite in describing and mapping similar rocks in parts of the Ramona quadrangle. Although

[64] Miller, F. S., op. cit., p. 1399.
[65] Larsen, E. S., Jr., op. cit., pp. 76-82, 1948.
[66] Merriam, Richard, op. cit., pp. 250-253.

Modes of the Woodson Mountain granodiorite in the Cuyamaca Peak quadrangle.

	1	2	3	4	5	6	7	8
Quartz	35	35	40	38	30	45	37	60
Plagioclase	43	25	20	30	43	40	15	30
Orthoclase	15	35	--------	25	8	--------	--------	3
Microcline	5	--------	37	5	3	10	48	--------
Muscovite	tr	--------	<1	--------	--------	--------	tr	--------
Biotite	1	4	1	<1	10	5	tr	<1
Hornblende	--------	--------	--------	<1	5	--------	--------	2
Hypersthene	--------	--------	--------	tr	--------	--------	--------	--------
Apatite	--------	--------	--------	tr	tr	--------	--------	<1
Magnetite	<1	--------	1	tr	--------	--------	tr	2
Zircon	--------	--------	--------	tr	tr	tr	--------	tr
Epidote	--------	<1	--------	--------	--------	--------	--------	--------
Allanite	--------	1	--------	--------	--------	--------	--------	--------
Total	99+	100	99−	100	99	100	100	99
Percent of An in plagioclase	--------	--------	--------	29	--------	25	--------	20

1. Specimen No. CP-49. Coarse-grained Woodson Mountain granodiorite. Knoll west of Japatul Valley (southwest part of quadrangle).
2. Des. 41-70. Estimated mode of medium-grained Woodson Mountain granodiorite. East Mesa.
3. CP-17. Estimated mode of medium-grained Woodson Mountain granodiorite. North of Petersen Canyon (southwest part of quadrangle).
4. CP-31. Estimated mode of coarse-grained Woodson Mountain granodiorite. Bell Bluff (southwest part of quadrangle).
5. Des. 41-11. Estimated mode of coarse-grained gneissic Woodson Mountain granodiorite. North end of Rattlesnake Valley (northeast part of quadrangle).
6. Des. 41-31. Estimated mode of coarse-grained Woodson Mountain granodiorite. Descanso Junction (center of quadrangle).
7. CP-60. Estimated mode of medium-grained Woodson Mountain granodiorite (southwestern corner of quadrangle).
8. CP-37. Estimated mode of medium-grained Woodson Mountain granodiorite. Barrett truck trail (southwestern part of quadrangle).

W. J. Miller [67] had previously given some of the rocks of this formation in the Cuyamaca Peak quadrangle the name Descanso granodiorite, the writer follows F. S. Miller and Larsen in using the term Woodson Mountain granodiorite. This choice is made in order to extend into the Cuyamaca Peak quadrangle the term used for these rocks in contiguous areas, as well as throughout much of the outcrop area of the batholith. Other rocks that appear from their description to be either similar or closely related petrographically and chemically, and of a parallel position in the igneous sequence, are included in the accompanying table.

Distribution. All the Woodson Mountain granodiorite in the Cuyamaca Peak quadrangle lies southeast of a line from the northeast corner to the point at which U. S. Highway 80 intersects the western edge (pl. 2). The granodiorite crops out in 10 irregularly shaped masses that trend northwest, crosscutting the Julian schist. Stonewall granodiorite.

[67] Miller, W. J., op. cit., pp. 127-128, 1935.

Names of formations correlated with the Woodson Mountain granodiorite.

Name	Geologist	Year published	Area studied
Descanso granodiorite	Miller, W. J.	1935	Section along U. S. Highway 80
Steele Valley granodiorite	Dudley, P. H.	1935	Perris block
Cajalco quartz monzonite	Dudley, P. H.	1935	Perris block
Woodson granodiorite	Merriam, Richard	1946	Ramona quadrangle
Woodson Mountain granodiorite	Larsen, E. S., Jr.	1948	San Luis Rey, Elsinore, and Corona quadrangles

Cuyamaca gabbro, Green Valley tonalite, and Bonsall tonalite. The total area of these exposures is about 38 square miles, but the rock exposed along the southern edge of the quadrangle crops out extensively as far south as the Mexican border. According to Larsen [68] the Woodson Mountain granodiorite is widespread throughout the western part of the southern California batholith.

Characteristic Primary Structures. The only well-developed primary structures in the Woodson Mountain granodiorite are primary fractures in the form of concentric arcuate sheeting and radial vertical joints in some of the masses. Most of the granodiorite is very massive, and, except for the planar orientation of biotite flakes near the borders of the masses, few significant planar or linear elements were observed.

Petrography. The coarse-grained phase of the Woodson Mountain granodiorite is characterized by interlocking grains of white feldspar from 1 to 2 centimeters in greatest dimension and equally large irregular interstitial masses of light-gray quartz. Both potash and soda-lime feldspars are prominent, and, although the proportions of the two vary widely, their total amount is fairly constant. The potash feldspars include both orthoclase and microcline, but in specimens containing both, microcline is subordinate. Sparsely scattered throughout the rock are flakes of biotite, the most abundant dark mineral in the granodiorite. Some of the biotite has been slightly altered to iron oxides by weathering, and where the latter have stained the clear plagioclase grains the rock has a pinkish cast.

The plagioclase occurs both as phenocrysts and to a lesser degree as smaller subhedral grains interlocked with quartz and microcline in the groundmass. The plagioclase is commonly twinned according to the albite law and more rarely according to the pericline law, but some of the large grains show no twinning. The composition is remarkably uniform, ranging only from An_{24} to An_{30} in the specimens examined in thin sections. Some of the grains are slightly zoned, and the cores tend to be more cloudy than the rims. The grains generally have irregular borders that are embayed by the quartz masses; this feature is taken to indicate possible replacement by the quartz. A few specimens showed plagioclase intergrown with orthoclase in the form of microperthite. The plagioclase in places encloses flakes of muscovite and crystals of epidote.

The orthoclase is in large cloudy phenocrysts and smaller subhedral grains that are generally tabular, although their outlines are very irregular and commonly embayed. Some of the orthoclase is intergrown with

[68] Larsen, E. S., Jr., op. cit., p. 76, 1948.

quartz and forms graphic granite, and in one thin section the orthoclase is partly replaced by another untwinned feldspar, probably plagioclase. Both the orthoclase and microline are slightly altered to sericite, but sericite is much more common in the orthoclase.

Microcline occurs in relatively small subhedral or euhedral grains interlocked with quartz and plagioclase in the groundmass. The sections of the grains are generally rectangular with nearly straight edges. In general the microcline crystals show clear cores, but cloudy borders.

Quartz, which consistently makes up at least one third of the coarse-grained Woodson Mountain granodiorite, is invariably anhedral in form. It shows in section incipient fractures and generally includes minute needles of a prismatic mineral that is thought to be rutile. In some specimens the quartz appears to replace the feldspars to a slight degree.

Biotite, making up only a few percent of the rock, occurs mostly in frayed flakes that are several millimeters in size and grouped in long tenuous bunches. In most places in the area individual flakes of the biotite contain small zircon crystals.

Most of the accessory minerals occur in distinctive forms. The apatite is in small stout prisms with rounded ends. Zircon occurs in minute crystals included in the biotite. Muscovite is in frayed flakes a millimeter or two in dimension. Hornblende forms prismatic crystals with highly irregular borders. Magnetite is generally in very small euhedral grains with square outlines. Rare allanite occurs in large euhedral crystals rimmed with irregular aggregates of epidote. Epidote also is commonly associated with biotite.

The fine- to medium-grained phase of the Woodson Mountain granodiorite differs from the normal coarse-grained phase not only in grain size but also in being equigranular and more homogeneous and in having a high quartz and potash feldspar content. Most of the typical fine-grained Woodson Mountain granodiorite occurs adjacent to the contacts with other rocks, and generally it contains accessory minerals that are uncommon in the coarse-grained phase. The most characteristic of these accessories is sphene, but also included are red garnet (spessartite ?), clinozoisite, and monazite (?), as well as the other minor minerals of the coarse-grained phase.

An unusual type of the coarse-grained Woodson Mountain granodiorite containing very little potash feldspar crops out in two small roughly elliptical areas that are entirely surrounded by normal Woodson Mountain granodiorite into which this type grades imperceptibly. It is a coarse-grained hypersthene-bearing type of the Woodson Mountain granodiorite, which resembles the granite of Rubidoux Mountain near Riverside, California. It has been mapped separately. One area of this type, underlying about 25 acres, occurs near the top of Descanso Peak adjacent to the Chiquito truck trail in the central part of the quadrangle, and the other, comparable in size, is at the north end of Horsethief Ridge in the south central part of the quadrangle.

The hypersthene-bearing type of the Woodson Mountain granodiorite differs from the normal type by being equigranular and homogeneous in texture, greenish gray, and lacking appreciable amounts of othroclase or microcline. It contains large irregular interpenetrating grains of quartz and glassy plagioclase, with comparatively few scattered patches of dark minerals. Most of the plagioclase, which is invariably twinned

Analyses, modes, and norms of the Woodson Mountain granodiorite.

Analyses	I	II	III
SiO_2	72.58	74.72	77.25
TiO_2	0.30	0.16	0.14
Al_2O_3	14.12	13.72	12.71
Fe_2O_3	0.65	0.41	0.29
FeO	2.36	1.32	1.00
MnO	0.02	0.01	0.03
MgO	0.07	0.23	0.22
CaO	2.44	1.62	0.84
Na_2O	3.91	3.76	4.24
K_2O	2.84	3.40	2.95
H_2O	0.32	0.33	0.14
S	0.07	0.04	----
ZrO_2	0.05	----	0.01
P_2O_5	----	0.03	0.03
	99.73	99.73	99.85

Norms	I	II	III
Quartz	32.10	35.16	38.82
Orthoclase	16.68	20.02	17.24
Albite	33.01	31.96	35.63
Anorthite	12.23	8.06	4.17
Corundum	----	0.82	1.12
Hypersthene	3.50	2.32	2.05
Magnetite	0.93	0.70	0.46
Ilmenite	0.61	0.30	0.15
	99.06	99.34	99.64

Modes	I (Vol.)	II	III (Approx. wt.)
Quartz	30	44	39.0
Microperthite	13	24	----
Orthoclase	--	--	4.5
Microcline	--	--	12.0
Oligoclase	52	28	39.0
Biotite	3	2	3.3
Hornblende	1	1	1.5
Magnetite	--	--	0.2
Sphene	--	--	0.2
Apatite	--	--	0.1
Zircon	--	--	0.1
	99	99	99.9
Percent An in norm	27	20	
Percent An in mode	24	22	

I. Woodson Mountain granodiorite from the type locality; south slope of Woodson Mountain, sec. 34, T. 13 S., R. 1 W., Ramona quadrangle. Analysis made for E. S. Larsen, Jr., by F. A. Gonyer, analyst. Norm calculated by E. S. Larsen, Jr.

II. Woodson Mountain granodiorite from cut on highway half a mile east of Rainbow, San Luis Rey quadrangle. Analysis made for E. S. Larsen, Jr., by F. A. Gonyer, analyst. Norm calculated by E. S. Larsen, Jr.

III. Woodson Mountain granodiorite (Descanso granodiorite) from near Descanso Junction in the central part of the Cuyamaca Peak quadrangle. Analysis made for W. J. Miller by L. C. Armstrong, analyst. Norm calculated by W. J. Miller.

according to the albite law, is in euhedral grains as long as a centimeter; it averages about An_{30} in composition, and makes up about 50 percent of the rock. Quartz, in large anhedral masses interstitial to the feldspar, makes up another 40 percent. Irregularly shaped grains of hypersthene occurring in clusters comprise about 2 percent of the rock. Also in clumps, and amounting to as much as 5 percent of the rock, are rather large flakes of biotite, which are locally altered to epidote and chlorite. Microperthite is a very minor constituent of the rock.

Chemical Composition. A chemical analysis of a sample of Woodson Mountain granodiorite collected near Descanso Junction, in the central part of the Cuyamaca Peak quadrangle, has been published by W. J. Miller, who first described the rock as the Descanso granodiorite. This analysis is given below along with analyses of the Woodson Mountain granodiorite from the type locality in the Ramona quadrangle and from a second locality in the northern part of the San Luis Rey quadrangle.

Comparison of the analyses shows that the rock from the Cuyamaca Peak quadrangle has appreciably more silicon, magnesium, and sodium, and less aluminum, iron, and calcium than the rock at the type locality. The rock in the San Luis Rey quadrangle occupies an intermediate position in these respects. The norms and modes show the same features observed in the field—rather wide range in the amounts of quartz, plagioclase, and potash feldspar. However, notwithstanding the widespread variation in chemical composition and mineral proportions, the appearance and structural behavior of the rock are remarkably uniform.

Leucogranodiorite

Four small bodies of a rock designated only as leucogranodiorite are shown on the west central part of the map (pl. 2), and a few others too small to delineate were observed. Collectively these rocks underlie no more than half a square mile. In general the rock is light-colored, fine-grained equigranular and granitic in texture. Certain varieties, however, are inequigranular with large grains of feldspar, quartz, and mica embedded in a fine-grained groundmass of subrounded quartz and feldspar grains.

The mineral content of the leucogranodiorite varies slightly from place to place, but in all bodies anhedral quartz makes up from 30 to 50 percent of the rock. Plagioclase, about An_{20} in composition, is twice as abundant as orthoclase, and with quartz these minerals comprise all but a few percent of the rock. Both feldspars generally occur in euhedral grains, and those of the orthoclase are extensively altered to sericite. Neither muscovite, nor the generally less abundant biotite, comprise more than 5 percent of the rock. Most of the muscovite is in large flakes that poikilitically enclose other minerals, whereas the biotite is in bunches of small flakes, largely altered to limonite. A garnet, which is light gray in thin section and possibly is grossularite, is prominent in some of the rock, but in amount it nowhere exceeds 1 percent. Other accessory minerals are zircon and apatite.

Rattlesnake Granite

One coarse-grained, white, plutonic rock that apparently has not been found elsewhere in the southern California batholith crops out over an area of nearly 3 square miles in the vicinity of Rattlesnake Valley in

the northeast corner of the Cuyamaca Peak quadrangle. This rock was first described by Hudson [69] who named it the Rattlesnake granite.

In appearance of outcrop the Rattlesnake granite resembles the Woodson Mountain granodiorite, from which, however, it differs considerably in mineral content and texture. It has a granitic texture characterized by large euhedral feldspar grains, interstitial gray quartz, and smaller broken grains of feldspar and quartz. The average composition of the rock is: orthoclase, slightly altered to sericite, 35 percent; quartz, 35 percent; and oligoclase, 25 percent. Perhaps the most distinctive mineral of the Rattlesnake granite is the prominent muscovite, although in amount it rarely exceeds 3 percent of the rock. Biotite is also present, but in very minor quantities. Euhedral crystals of reddish garnet (almandite ?) up to 3 millimeters in dimension are commonly a prominent constituent, especially near contacts, but apparently they do not exceed 1 percent of the total volume.

Rosiwal analysis of Rattlesnake granite, Specimen CP-120 north end of Rattlesnake Valley, Cuyamaca Peak quadrangle.

	Percent
Quartz	40.4
Plagioclase	16.1
Orthoclase	36.0
Biotite	00.1
Muscovite	07.0
Garnet	00.2
	99.8
Percent of An in the plagioclase	18

Granite Pegmatite

Distribution and Form. Light-colored granitic pegmatites containing potash feldspars and quartz occur throughout the Cuyamaca Peak quadrangle as dikelets or veins only a few inches wide and as dikes several feet wide. Only a few of the dikes are large enough to be mappable on the scale used in the field work, but even on a much larger scale it would be difficult to portray their erratic distribution and abrupt changes in attitude. The pegmatites are abundant in all the rocks older than the Woodson Mountain granodiorite, especially in the Green Valley and Bonsall tonalites, but are much scarcer in the Woodson Mountain granodiorite, leucogranodiorite, and Rattlesnake granite.

Most of the pegmatite in the area is in veins or dikelets that are only 1 to 2 inches in width and pinch out in all directions within a few feet. In the Julian schist and the mixed rock of Julian schist and Stonewall granodiorite, the pegmatites generally parallel the bedding, schistosity, or foliation, but a few of the larger ones cut directly across these structures. In the igneous rocks they occupy narrow, straight, steeply dipping joints from which they branch off into nearly flat-lying joints with arcuate strikes. In many localities they occur as swarms filling fractures that strike in all directions and dip from vertical to horizontal. Excellent examples of swarms of erratic pegmatite veins can be seen in the roadcuts along U. S. Highway 80 throughout the first 2 miles east of Viejas Valley.

The few moderately large pegmatite bodies that have been mapped are several feet wide, scores of feet long, and consistent in form and

[69] Hudson, F. S., op. cit., pp. 207-208.

occurrence. The three largest bodies—at the Spanish Bayonet claim, Decker claim, and Deer Park—trend north, dip steeply, and are somewhat bulbous in form; several other mapped pegmatites have similar shapes but differ in strike.

In a general way more of the pegmatites are developed close to the Woodson Mountain granodiorite bodies than at some distance from them, but this space relationship is not marked and pegmatites may be expected in any of the igneous rocks and in the Julian schist within a few miles of the igneous intrusions. The rare occurrence of pegmatites within the Woodson Mountain granodiorite itself, although pegmatites may be traced to its border in many places, suggests that they were formed almost contemporaneously with the granodiorite, and that probably the granitic pegmatite rocks were derived from the same magmatic sources as the Woodson Mountain granodiorite and the other younger felsic rocks of the batholith.

Petrography. The granitic pegmatites are coarse grained, with feldspar crystals and quartz masses that measure several centimeters in their greatest dimension. Graphic intergrowths of quartz and feldspar are characteristic. Some of the pegmatite veins and most of the dikes are much finer grained near their borders than in their centers. Garnet, tourmaline, and mica are confined to the coarse-grained central zone and in many places exhibit well-developed crystal faces.

The pegmatites contain little besides potash feldspar and interstitial quartz. The white to flesh-colored feldspar may be either microcline or orthoclase, but the former is slightly the more abundant. The quartz in some bodies is glassy and gray, but in others it is milky. Other minerals that occur with the quartz and feldspar in varying abundance, depending on the locality, include muscovite, biotite, schorlite, garnet, and albite. Muscovite, which is the most widespread, occurs in flakes and books that locally are a few centimeters across but are too small and scattered to be of commercial value. Biotite is rather rare in the pegmatites. Schorlite is conspicuous in many of the dikes, where it occurs in typical radiating columnar aggregates or sunbursts, or in individual unoriented prisms. Some of these prisms are as much as 8 inches long and an inch thick, but well-terminated crystals are rare. Euhedral crystals of red garnet, probably almandite, also are common. Albite can be found along the borders of some of the pegmatites, but in the Cuyamaca Peak quadrangle it is much more subordinate than in the more famous pegmatite localities of the batholith at Mesa Grande and Pala.

Concerning the well-known lithium pegmatites to the northwest, Schaller [70] has written, ". . . . they were at one time in their history solid graphic granite composed essentially only of microcline and quartz, from top to bottom, and . . . . all the other minerals now present—albite, the micas, the garnets, the tourmaline, ... were not original crystallizations from a magma but were introduced later and are the result of replacement processes." The Cuyamaca Peak quadrangle pegmatites apparently have much the same origin and early history as those studied by Schaller.

[70] Schaller, W. T., The genesis of lithium pegmatites: Am. Jour. Sci., 5th ser., vol. 10, p. 276, 1925.

Aplite

Distribution and Form. Aplite dikes are distributed throughout the quadrangle in much the same way as the pegmatite dikes: however, because the aplites are on the average even smaller than the granitic pegmatites, only a few of them are shown on the geologic map (pl. 2). They have no uniform trend or attitude, and they are more abundant near the Woodson Mountain granodiorite. These relationships are best illustrated about 1½ miles south of Japatul Valley in the southwestern part of the quadrangle where a swarm of aplite dikes intruding Green Valley tonalite bridges the gap between two intrusives of Woodson Mountain granodiorite.

Petrography. The aplites are fine-grained and have the distinctive saccharoidal texture of most aplites and the mineral composition of a typical alaskite. Quartz makes up 35 percent of the rock, orthoclase 35 percent, and albite nearly 30 percent. Veinlets of comparatively coarse-grained quartz in thin section may be seen to cut a finer-grained groundmass of quartz and feldspar. Orthoclase tablets, somewhat larger than most of the other grains, are in patches throughout the groundmass. Biotite in elongate shreds generally is present but constitutes less than 1 percent of the rock. A few scattered small euhedral grains of magnetite are characteristic, and other accessories include zircon, apatite, and a little schorlite.

Vein Quartz

Distribution and Form. Almost pure white bull quartz occurs in scattered localities in the Cuyamaca Peak quadrangle in veins and pod-like masses, but they are considerably less common than the granitic pegmatites and aplites. These deposits are probably genetically related to the aplites and pegmatites, but they differ in being most abundant in the Woodson Mountain granodiorite. They also differ in having a little more constant attitude, for most of them strike between north and N. 45° W. and dip steeply.

Mineralogy. The quartz veins of the area may be divided mineralogically into two types. The first type contains milky bull quartz and virtually nothing else. The quartz is massive, and apparently single crystal units are very large, although it is not possible to determine their exact boundaries. The quartz is extensively cut by straight fractures several feet in length, and contains other straight planar structures that look as if they had been wide cracks, but are probably healed fractures containing numerous microscopic bubbles. The quartz breaks into large pieces along imperfect rhombohedral (1011) cleavage planes and the fairly continuous straight fractures. Two of the quartz veins of this type have been mined for silica. At the Ajax prospect, the quartz is transected by a few seams of large biotite flakes.

The second type of quartz vein contains small amounts of various sulfides and rare free gold in myriads of cracks and small vugs and in adjacent replacement zones. Because of the concentration of metals in both open-space fillings and replaced masses, these veins appear to represent the last phase of hydrothermal mineralization in and around the batholith. They are discussed in some detail in the section on economic geology.

STRUCTURE

The dominant northwest-trending structural grain of the rocks of the Cuyamaca Peak quadrangle has been mentioned. The various elements that make up this grain have resulted from the combined effect of the structural features of the Julian schist and the structural features of the igneous rocks that are intrusive into it. In general, the attitudes of the structural features of the igneous rocks parallel the contacts with older rocks, but away from the contacts, the general northwest structural trend of the batholith prevails. The detailed relationships of the primary structures of the igneous rocks indicate several separate intrusions, as shown by successive crosscutting of the structural features. Superimposed on the older structural grain are minor structures that involve all the rocks of the area.

Structures of the Julian Schist

The Julian schist contains geologic structures of both sedimentary and metamorphic origin. The sedimentary features that it exhibits are well-developed bedding, drag folding, and in some places a crude cross-bedding. The single metamorphic feature is schistosity.

The original sediments have been regionally folded and now have a comparatively uniform northwest strike; the dips generally range from vertical to steeply northeast. From rather inconclusive evidence—cross-bedding in sandy phases and graded bedding in a few places—the top sides of all of the beds appear to be to the northeast. With the exception of local crumpling adjacent to the intrusions, the bedding in the large schist body in the northeast corner of the quadrangle strikes from north to about N. 25° W. It dips steeply northeast or southwest, but mostly northeast, from vertical to about 60°. The schist contains a few minor drag folds whose axes plunge gently north at angles less than 40°, but lineation is generally absent. In the schist body south of Guatay Mountain, the surface trace of the bedding is somewhat sinuous, for the strikes are N. 40° W. in the southern part, due north in the central part, and N. 30° W. at the northwest end. The dips are all vertical or steeply northeast, the lowest recorded being about 75°. In general, the other smaller schist bodies also show bedding that strikes northwest and dips vertically to steeply northeast.

The schistosity[71] and foliation of the Julian schist generally are parallel to the bedding. Probably the continuation of the compressive forces that folded the rocks induced the original metamorphism of the Julian schist, and certainly the intrusion of the Stonewall magma caused further changes such as the local development of sillimanite and andalusite and the extensive areas of mixed rock.

Primary Structures of the Igneous Rocks

Primary structures in igneous rocks, as defined by Balk,[72] are those that developed during the consolidation of the rocks; they include flow

[71] Schistosity is defined here following the usage of the term schist by E. B. Knopf (Knopf and Ingerson, Structural Petrology: Geol. Soc. America Mem. 6, p. 7, November 1938). "Foliation is used here to denote a parallel arrangement of minerals. A foliated rock will split more or less readily into thin slabs parallel to the foliation plane. Where the rock splits into thin layers, it is called a schist."

[72] Balk, Robert, Structural behavior of igneous rocks: Geol. Soc. America, Mem. 5, p. 7, July 1937.

structures, both linear and platy, and certain kinds of fractures. Such structures are abundant in many of the igneous rocks underlying the Cuyamaca Peak quadrangle, but during the mapping it became obvious that some of them are much more definite and persistent than others. Some measurable attitudes apply consistently throughout several hundred feet of outcrop and others apply only for a few inches, if that much. As it would be impractical to employ all the methods described by Balk[73] if the work was to be completed on an appropriate scale and in a reasonable time, a workable compromise was effected. Those structures that are definite and obvious to the unaided eye, and that prevail over an area large enough to be recorded on a 1:62,500 scale appear on plate 5. Others that are less reliable or more local were only noted and used as a guide in sketching the probable flow lines, which are shown on the map by a different symbol. In this way the broad structural features of the igneous rocks were obtained, and these were used in conjunction with the petrography and intrusive relationships to decipher the development of the batholith.

Types of Primary Structures Recorded

The following types of primary structures, listed in order of usefulness, have been recorded in the intrusive bodies of the quadrangle and used in varying degrees in interpreting the major structure:

(1) Flow Layers (Schlieren). Flow layers, or schlieren, are defined by Balk[74] as follows: "Sheet-like bodies, in which certain minerals appear in abnormal proportions, are called flow-layers or schlieren." Flow-layering and the accompanying foliation constitute one of the most important structural features of the igneous rocks in the Cuyamaca Peak area. They are fairly constant in attitude over considerable distances and form definite structural patterns. The strikes and dips of the flow layers, and the foliation within them, have been extensively plotted and are represented by the usual symbols on plate 5.

(2) Platy Parallelism of Inclusions and Segregations. The widespread inclusions in the igneous rocks are another important structural feature. They are generally planar rather than linear features with attitudes parallel to whatever foliation is present. Definite segregations are somewhat rarer but do occur, modified by apparent flowage, in the gabbroic rocks, and seem to be reliable primary planar structures. Many strikes and dips of inclusions are plotted on the map, and a few segregations are shown.

(3) Platy Parallelism of Minerals. In several of the intrusives, schlieren and inclusions are so rare that the only distinctly planar elements throughout the rock are those formed by the planar orientation of certain minerals. In many places the parallelism of the biotite flakes is so marked that they are a dependable planar element, and their attitudes have been plotted. Parallelism of other tabular mineral grains, such as feldspar crystals, was not so widely observed and only in the rocks of the gabbro group does it form usable flow structure. The flow layers in these gabbros contain plagioclase grains that are well oriented only insofar as they all lie on their side pinacoids. Prismatic hornblende

[73] Balk, Robert, op. cit., pp. 139-155.
[74] Balk, Robert, op. cit., p. 25.

crystals, which are generally considered as linear elements, lie in the plane of flow layering in some of the tonalite, but orientation of the prisms in a preferred direction is not apparent.

(4) Primary jointing and sheeting. Fracture systems in plutonic masses may be numerous and may be the result of a variety of forces. Some of these forces were active during the final consolidation of the intrusive, and gave rise to primary joints. In the Cuyamaca Peak quadrangle, in common with many other batholithic areas, it is difficult to determine which fractures were of primary origin and which were formed by tectonic forces acting after the complete cooling of the batholith. Several kinds of joints are present in the various formations that have been described, but the only ones that seem from their distribution to be unequivocal primary features are similar to Balk's [75] so-called flat-lying joints. These joints are strikingly developed in certain of the granodiorites, where they form concentric layers somewhat similar to the successive layers of an onion. Their strikes curve markedly about central cores that are commonly asymmetric to the intrusive outline, and where best developed their dips vary from rather steep in the border zones to nearly horizontal over the cores. The individual patterns are confined to a single intrusive mass, and the joints do not extend across formation boundaries. Because the joint patterns and the individual joints are much more satisfactorily observed on the aerial photographs (pl. 6) than in the field the traces of the primary flat-lying joints seen in the photographs have been plotted on the structural map (pl. 5), and their dips have been indicated only as either flat or steep.

(5) Linear Parallelism of Minerals. The only common primary mineral that crystallizes in primary grains that could show marked lineation in outcrop is hornblende. It appears to be only slightly aligned in the igneous rocks of the Cuyamaca Peak quadrangle, except in a few local areas. Perhaps statistical methods could be used to determine dominant lineation, but such procedures were not attempted. Although locally linear elements were noted, they are not shown on the map.

(6) Linear Parallelism of Inclusions or Segregations. The ellipsoidal inclusions in both the Green Valley and Bonsall tonalites have been described. As ellipsoids they theoretically have one axis that is longer than the other two and thus might be treated as linear elements. However, most of these inclusions are shaped like pancakes, thus approximating ellipsoids of revolution greatly flattened along the axis of rotation, and the few that are spindle-shaped are so distributed as to be of little use in determining lineation. Therefore most of the inclusions are regarded as planar elements, and the attitudes of the few scattered linear inclusions have not been plotted on the structural map.

Structural Form and Grain of Igneous Rock Units

Each of the igneous rock units of the Cuyamaca Peak quadrangle occurs in plutons having a typical form and characteristic structure that result from the combination of various primary structural features. These features are described in the following paragraphs.

Plutons of Stonewall granodiorite in the Cuyamaca Peak quadrangle are highly irregular in shape, particularly along contacts that

[75] Balk, Robert, op. cit., pp. 39-40.

trend across the bedding of the Julian schist. The magma of the Stonewall intricately injected and partly replaced the schist along the bedding, forming mixed rock of Stonewall granodiorite and Julian schist. Everywhere the contacts are very steep, and although they generally appear to follow the bedding planes of the schist, they cut across the structure of the older rocks at low angles on the sides of the masses and form tongues on the ends.

The structure of the Stonewall granodiorite is largely shown by flow layering and oriented biotite flakes. These features and the schistosity of the Julian schist in the mixed rock are the elements of the structural pattern in the northern and northeastern parts of the quadrangle. These parallel features strike north and are vertical or dip steeply east at the eastern edge of the quadrangle in the vicinity of Noble Canyon. They generally have the same trend throughout the exposures to the northwest as far as Cuyamaca Reservoir, except in two local areas along the western edge of the zone where they deviate to the northwest. The same zone of Stonewall granodiorite and mixed rock continues to the northwestern corner of the mapped area, but it is interrupted by the Cuyamaca gabbro. In the extensive continuation of the zone west of the gabbro mass the foliation swings to the northwest, averaging about N. 60° W. in strike. The dips are both to the northeast and the southwest, generally at steep angles. A local plication in the structures occurs at the north edge of the quadrangle just west of the Inaja Indian Reservation.

Cuyamaca Gabbro. The individual zones of gabbroic rocks in the Cuyamaca Peak quadrangle, like those in the rest of the batholith, are relatively small in areal extent. The Cuyamaca gabbro mass which measures about 9 by 2½ miles and lies in part to the north of the quadrangle, is one of the largest gabbroic masses in the batholith, but in comparison with the continuous exposures of some of the other major igneous rocks it is small. The outlines of the gabbro bodies are in general rounded and elliptical, and the relatively few apophyses or dikes projecting from the masses are blunt and have rounded ends. Most of the observed contacts dip steeply. The mass at Viejas Mountain has contacts that appear to be vertical or to dip outward on all sides, but the contacts of some of the others appear to dip steeply inward (pl. 4). Where the gabbro is the younger rock, it is commonly fine-grained adjacent to the contacts.

The primary structures developed in the gabbros are so local, erratic in attitude, and poorly exposed that it seems impossible to form from them an orderly or coherent pattern for even a single body. The two primary structural features that are locally prominent are banding of light- and dark-colored minerals and evidence of auto-injection. The banding is thought to represent local segregations that have been drawn out by flowage. The complex auto-injection probably developed late in the consolidation of the gabbro when partly solidified rock was intruded and broken by magma differentiates containing active mineralizers. Numerous pulsations of injection are indicated by the incongruous intrusive relations observed between coarse- and fine-grained phases. Because this auto-injection structure is characterized by heterogeneity it is of no value in deciphering the over-all structural grain of the gabbroic masses.

Diorite. The two relatively small bodies of diorite in the Cuyamaca Peak quadrangle have few distinctive structural characteristics. In form, both are apparently elliptical, although each extends beyond the limits

of the mapping. The diorite in the southwest part of the area exhibits large biotite flakes oriented in preferred directions, and the resultant foliation appears to be cut by the surrounding Green Valley tonalite. The diorite at the eastern edge of the quadrangle does not exhibit a definite orientation of planar or linear elements.

Green Valley Tonalite. The Green Valley tonalite occurs in extensive continuous masses that have no distinctive shape. Along the few miles of contacts with older rocks in the quadrangle—those that occur south of Guatay Mountain, around Viejas Mountain, and in the northwest corner of the quadrangle—the tonalite has an irregular outline with somewhat erratic embayments and protrusions. As is true of many of the other rock masses, the contacts are commonly vertical or steeply dipping.

The planar structures of the Green Valley tonalite consist of inclusions, parallel biotite flakes, and schlieren. Near the contacts with older rocks, these structural features locally parallel the contacts in attitude, but away from the contacts, the features tend to assume a regional trend. From the massive body in the vicinity of Las Bancas to the west edge of the quadrangle the structural features strike west and dip steeply north, but local deviations from the general trend are abundant. In the part of the same body that extends from Bell Bluff to Japatul Valley, the structures trend more irregularly, are more sinuous, and dip both northeast and southwest. The structures wrap around the gabbro mass at Viejas Mountain near the west edge of the quadrangle, and west of the mountain depart widely from their regional trend. In the body that lies in the northwestern corner of the quadrangle the primary structures bend in strike from approximately N. 30° W. at the southern tip to N. 15° E. a few miles north of the tip. Their dip is consistently to the east. The structural grain of the Green Valley tonalite as a whole therefore executes a crude 90° arc, concave to the northeast, from the south-central part of the area to the northwest corner. Two large areas of massive Green Valley tonalite containing no mappable flow structures occur at the ends of the arc, one in the south-central part of the quadrangle and the other in its northwestern corner.

Bonsall Tonalite. The Bonsall tonalite masses are similar in shape to those of Green Valley tonalite, except that the Bonsall masses are even more extensive, continuous, and irregular. Like the Green Valley tonalite, the Bonsall tonalite has very irregular contact with older rocks. These contacts, though generally steep, are somewhat less consistent than those of some of the other intrusives, and the Bonsall tonalite appears to have been emplaced from directly below its present position.

The primary structures of the Bonsall tonalite consist of abundant strung-out inclusions and schlieren that are everywhere well developed. They have a fairly constant strike of about N. 20° W. across the area, except in the many places where they deviate as much as 90° in curving around masses of other rocks. Most of the structures dip steeply to the northeast. The manner in which the primary structures wrap around the mixed rock of the Julian schist and Stonewall granodiorite (south of Mineral Hill), the rocks of the Cuyamaca gabbro (Poser Mountain), and the Green Valley tonalite (north of Viejas Mountain) is taken as evidence that the Bonsall tonalite was emplaced after their consolidation.

Woodson Mountain Granodiorite. The Woodson Mountain granodiorite occurs in isolated masses erratically distributed among the older rock bodies. In general the size of the granodiorite intrusives is comparable to the size of the gabbro bodies, although the average is somewhat larger. No granodiorite mass within the Cuyamaca Peak quadrangle is as extensive as the large Cuyamaca gabbro body, but directly south of the area are Woodson Mountain granodiorite intrusives that are considerably larger. The bodies of Woodson Mountain granodiorite are much more irregular in outline than are the gabbros for, as is best shown in the southwest quadrant, they are typified by small outliers and long, tenuous, tonguelike projections that extend out from the main masses. The general elongation of the granodiorite is northwesterly, but the west-trending mass at Bell Bluff in the southwestern part of the quadrangle is a notable exception. The mass at Bell Bluff is also exceptional in that its shape is strongly controlled by structures in the older rock, whereas most of the granodiorite intrusive crosscut older structures and rock masses. The majority of the granodiorite contacts dip steeply outward, and it is therefore assumed that the granodiorite bodies widen in depth.

The character of the contacts of the Woodson Mountain granodiorite with the older rocks is variable and rather interesting. Along many of the contacts the Woodson Mountain magma intimately intermixed with older rocks to form zones of injection gneiss locally as much as 50 feet wide and containing ptygmatic folds. A particularly good exposure of such a contact zone can be seen in the stream bottom about 200 yards below the Japatul School in the southwestern part of the area. In contrast, the Woodson Mountain granodiorite tongues that protrude into the Julian schist have sharp contacts that indicate a lack of widespread intermixing with the invaded rock, although similar tongues of Stonewall magma appear to have reacted with the schist over broad areas.

Another interesting characteristic of the contact zones is the widespread presence of schist "screens" along the edges of the igneous masses parallel to the contacts. Similar tabular schist bodies locally are found within the masses, and they apparently represent pieces of country rock caught up in the intrusions. A few of these are shown on the map, but most of them are so small, measuring only a few feet in thickness and a few scores of feet in length, that they cannot be shown. A well-exposed cross section of one of the contacts separated by such a schist screen may be observed in a large road cut on U. S. Highway 80 about 4 miles west of Descanso Junction.

Apparently the only significant structural patterns in the Woodson Mountain granodiorite bodies are primary fractures. Most of these fractures are in sets that divide the rocks into imperfectly formed concentric shells about cores asymmetrically located with respect to the outlines of the bodies. Sympathetically developed with the concentric fractures are a few vertical joints that are roughly radial from the cores. These structures are not uniformly developed in all of the Woodson Mountain granodiorite masses; in some, particularly that at Bell Bluff, the granodiorite is massive and devoid of a readily recognizable structure of any kind.

Younger Granitic Rocks. The relatively small masses of young felsic rocks—the hypersthene-bearing type of the Woodson Mountain granodiorite, leucogranodiorite, and Rattlesnake granite—are not wide-

spread or important enough as structural units to have any regional characteristic forms. In general they are massive and homogeneous and show very few planar or linear primary structures.

Through-Going Fractures

Sizable and relatively continuous fractures that strike in almost every direction have been observed in all the igneous rocks, and some of these have been filled in places with pegmatite, aplite, and gold-bearing quartz veins of economic importance. The most common veins, fractures, and dikes strike about N. 30° E. As these have a rather uniform trend through all the igneous rocks they doubtless were formed by regional forces rather than by forces related to individual intrusives, but as they are locally filled with dikes or veins, they must have been developed only shortly after the cooling of the igneous rock and prior to the complete consolidation of the magma at depth. It is suggested by the writer that these prominent northeast-striking vertical joints may be tension fractures complementary to predecessors of the important northwest-trending faults of the Peninsular Ranges, one of which—the Elsinore fault zone—passes just to the northeast of the Cuyamaca Peak quadrangle.

At several places in the quadrangle these northeast-trending fractures appear to have influenced the development of the topography. The effect of the fractures is discussed in greater detail in the section on physiography.

Faults

It is very difficult, as is pointed out by Larsen,[76] to find faults in the igneous rocks of a batholith, especially where they tend to parallel the general structural grain of the igneous rocks. Mylonite, gouge, or breccia, and straight-line contacts or major offsets of contacts are good evidence for faults, but physiographic features, unsupported by other evidence, seem unconvincing. Faults large enough to be mapped have not been recognized by the writer in the Cuyamaca Peak quadrangle. Breccia, gouge, or mylonite were not observed. Straight-line contacts that might be faults have not been mapped; indeed, nearly all the igneous contacts observed are text-book examples of sinuous intrusive contacts. No displacement, except for minor normal slips of a few inches to 2 feet in some of the beds of the Julian schist, was observed.

Certain nearly straight troughs in the topography, which are noticeable on the topographic sheet but somewhat less impressive in the field, might be considered to be the result of faulting. However, these troughs are believed by the writer to be a result of differential erosion along zones of closely spaced, nearly vertical, northeast-trending joints. An additional physiographic feature possibly indicating faults is the offset of a single erosion surface to various levels. W. J. Miller [77] has postulated a number of faults in the Cuyamaca Peak quadrangle to account for several relatively flat surfaces at different altitudes in the belief that these are parts of a once continuous surface. The writer believes that these surfaces may be more satisfactorily explained in other ways, as will be discussed in the section on physiography, and that the areal mapping does not support the faults postulated by Miller.

[76] Larsen, E. S., Jr., op. cit., p. 121, 1948.
[77] Miller, W. J., Geomorphology of the southern Peninsular Range of California: Geol. Soc. America Bull., vol. 46, pp. 1535-1562, 1945.

AGE AND SEQUENCE OF THE IGNEOUS ROCKS

The exact age of the igneous rocks in the Cuyamaca Peak quadrangle cannot be determined from the field relationships because of the lack of datable sediments. However, relative ages can be determined, and, at least in part, the rocks can be tentatively correlated with dated igneous rocks found elsewhere.

Age of the Stonewall Granodiorite. The age of the Stonewall granodiorite is debatable, but no serious problem is met in setting its lower limit. All geologists who have mapped and described the rocks have agreed that the Stonewall magma intruded the Julian schist, which is Triassic (?) or older in age. Donnelly [78] has enumerated evidence for the intrusive relationship between the Stonewall granodiorite and the Julian schist, and the development of the widespread Stonewall and Julian mixed rock is compelling evidence. The placing of the upper limit for the time of the intrusion of the magma is more difficult and must be made on less direct evidence, for the Stonewall granodiorite is overlain only by Quaternary alluvium in the Cuyamaca Peak quadrangle. Its upper age limit must therefore be deduced from its relationship to the other igneous rocks of the area, which fortunately comprise a regular sequence of rocks intruded during the Upper Cretaceous. The oldest rocks of this main batholithic sequence are considered to be those of the Cuyamaca gabbro; therefore, the relationship of the Stonewall granodiorite to the gabbro is of prime importance.

The geologic map shows that the structural grain of the Stonewall granodiorite and the related Stonewall and Julian mixed rock is cut across and probably intruded by the gabbro mass of Cuyamaca Peak; thus the gabbro must be the younger rock. However, detailed study of the contact between the rocks in the field did not lead the writer to any conclusive proof as to which rock intruded the other. Because the rocks interfinger, F. S. Hudson and W. J. Miller, even though observing the same contacts, have held different views as to the relative ages of the two rock units. Hudson,[79] in his original description of the rocks, stated that the "Cuyamaca Basic Intrusive cuts across the structures of schist," and Donnelly, Creasey, and Merriam held similar views. Miller,[80] however, in the most recent discussion of these rocks, proposes the different idea that the Stonewall granodiorite is equivalent to the Woodson Mountain granodiorite—one of the later intrusives of the batholithic series—and, therefore, the Stonewall is younger than the gabbro. His idea is based on the belief that the Stonewall granodiorite intrudes the gabbro and can be traced directly south into the "Descanso" (Woodson Mountain) granodiorite.

The writer, on the basis of the structural pattern of the two rocks, dates the Stonewall granodiorite as pre-gabbro in age, which means that it is post-Triassic and pre-Upper Cretaceous. How much time elapsed between the deposition of the sediments of the Julian schist and the intrusion of the Stonewall magma is conjectural. The interval was large enough to include the tilting of the Julian rocks and their regional metamorphism, and Hudson came "to the conclusion that the Stonewall quartz

[78] Donnelly, Maurice, op. cit., p. 341.
[79] Hudson, F. S., op. cit., p. 192.
[80] Miller, W. J., op. cit., pp. 486-487, 1946.

diorite is pre-Cretaceous and post-Triassic, probably corresponding in age to the post-Mariposa granitic masses of the Sierra Nevada." As the major intrusive activity in this period elsewhere in California is considered to have occurred late in the Jurassic, the time of intrusion of the Stonewall magma also may be dubiously placed as late Jurassic.

Age of the Batholithic Rocks. The age of the igneous rocks of the main batholithic sequence in the Cuyamaca Peak quadrangle may be limited only to post-Jurassic and pre-Quaternary, for the rocks intrude the Julian schist and Stonewall granodiorite and are overlain only by Quaternary alluvium. However, Böse [81] and Wittich [82] found that in the northern part of Lower California the granitic rocks intrude metamorphosed formations containing early Upper Cretaceous fossils and are unconformably overlain by late Upper Cretaceous sedimentary rocks. Woodford and Harriss [83] confirmed the conclusions of Böse and Wittich, in general, and concluded the "San Pedro Mártir intrusives are . . . . probably of Upper Cretaceous age." Because this batholith is probably an extension of the batholith that includes the rocks of the Cuyamaca Peak quadrangle, the batholithic rocks of the quadrangle are considered to be of Upper Cretaceous age.

Sequence of Igneous Rocks in the Batholith. The general concept of other geologists who studied the batholith has been that the main igneous sequence, exclusive of the older Stonewall granodiorite, has been from mafic to felsic rocks. This concept has been based largely on petrographic evidence and the relations observed at the intrusive contacts. The writer has supplemented these observations and ideas by using the evidence afforded by the primary structures of the various rock units.

The tentative dating of the Cuyamaca gabbroic rocks as younger than the Stonewall granodiorite has been discussed. Further, the writer considers the gabbroic rocks to be the oldest of the batholithic rock sequence, and specifically older than the Green Valley tonalite for the following reasons: (1) the primary planar structures within the Green Valley tonalite bend around the gabbro at Viejas Mountain, locally deviating markedly from their regional attitude; (2) some of the inclusions in the Green Valley tonalite closely resemble certain of the gabbroic rocks and may have been derived from gabbro; [84] (3) the number of dark inclusions in the Green Valley tonalite apparently increases near the gabbroic bodies, but this evidence is not strong or conclusive; and (4) geologists who mapped these two units in other areas have pointed out the almost imperceptible gradation between them as indicating a nearly continuous crystallization from gabbroic rocks to quartz diorite. In the Cuyamaca Peak quadrangle, however, the writer has not found these contacts to be particularly gradational.

Certain features that suggest that the gabbro could be late in the sequence are the following: (1) the gabbro occurs in isolated rounded

[81] Böse, E., and Wittich, E., Informe relativo alla exploracion de la region norte de la costa occidental de la Baja California: Parergones del Inst. Geol. de Mexico, vol. 4, pp. 307-529, 1913.

[82] Wittich, E., über Eisenlager an der Nordwest-küste von Nieder-Kalifornia: Centralb. f. Mineral., pp. 389-395, 1915.

[83] Woodford, A. O., and Harriss, T. F., Geological reconnaissance across Sierra San Pedro Mártir, Baja California: Geol. Soc. America Bull., vol. 49, pp. 1297-1336, 1938.

[84] Hurlbut (op. cit.) has developed petrographic and chemical evidence for considering the dark inclusions in the Bonsall tonalite in the San Luis Rey quadrangle as derived from the gabbro, and the same evidence might be applied here.

masses which could indicate either scattered late intrusions, or rounded remnants of older bodies; (2) in a few places the gabbro may seem to transect contacts between other igneous rocks, but the younger contacts may merely have been deflected into the gabbro contacts; and (3) a few of the primary fractures of the Woodson Mountain granodiorite appear to be cut off at gabbro contacts. The gabbro apparently was not susceptible to widespread fracturing, however, and it is not surprising that the fracture patterns of the Woodson Mountain granodiorite do not extend into the gabbro.

One of the two diorite bodies in the quadrangle contains planar primary structures that are cut by the Green Valley tonalite, and the primary structures within the tonalite bend around the diorite mass, indicating that the diorite is older than the Green Valley tonalite. The age of the other diorite body can be determined only as younger than the Stonewall granodiorite which it cuts, and into which a small diorite dike extends. The diorite body is therefore younger than the Stonewall granodiorite and older than the Green Valley tonalite.

The Green Valley tonalite clearly is older than the Bonsall tonalite in the Cuyamaca Peak quadrangle, although the relationship between these two units apparently is very vague in other areas of the batholith. The contacts are generally gradational, and detailed study of them has failed to yield conclusive proof as to which rock intruded the other. In the Cuyamaca Peak quadrangle, however, the well-defined primary structures of the Green Valley tonalite are cut on a regional scale by the equally well-defined primary structures of the Bonsall tonalite (pl. 2). In addition, near its contacts the Bonsall tonalite carries quartz diorite inclusions that are thought to have been derived from the Green Valley tonalite.

The primary structures of the Bonsall tonalite, which wrap around some of the Green Valley tonalite and gabbroic bodies, are crosscut in several places by Woodson Mountain granodiorite, and on this evidence the Bonsall tonalite is placed between the older Green Valley tonalite and the younger Woodson Mountain granodiorite in the sequence.

The Woodson Mountain granodiorite is the younger of the major intrusive rocks of the batholithic sequence. Its masses cut the primary structures of the older rocks, and tongues and apophyses of Woodson Mountain granodiorite extend into the older formations. A few inclusions of darker rocks, which might have been derived from the older rocks, occur along some of the borders of the Woodson Mountain granodiorite, but inclusions are not as widespread and conspicuous features as in the tonalites.

The small leucogranodiorite intrusions cut across the prominent flow structure of the Bonsall and Green Valley tonalites, and therefore are younger. Dikes and apophyses of leucogranodiorite occur along the planes of weakness in the tonalites, as is best exemplified by the large mappable projection from the leucogranodiorite body that is northeast of Poser Mountain.

The Rattlesnake granite clearly intrudes the surrounding Julian schist, for its contacts generally cut the schistosity of the schists and small apophyses extend out into the host rock. The granite is considered by the writer to be part of the main batholithic sequence because of its petrologic similarity to the Woodson Mountain granodiorite, but no upper age can be established.

Dikes or veins of granite pegmatite, aplite, and quartz fill fractures in all the igneous rocks of the quadrangle and are thus younger than the other rock units. The solutions that deposited them are believed to have been a late phase of the batholithic igneous activity.

The intrusive sequence in the batholithic rocks of the Cuyamaca Peak quadrangle, based on the above evidence, is as follows: Cuyamaca gabbro, diorite, Green Valley tonalite, Bonsall tonalite, Woodson Mountain granodiorite, leucogranodiorite, Rattlesnake granite, and granite pegmatite, aplite, and vein quartz.

PHYSIOGRAPHY

The land forms in the Peninsular Ranges of southern California and their evolution have been discussed, with some differences of opinion, by several geologists including Ellis,[85] Sauer,[86] Bryan and Wickson,[87] W. J. Miller,[88] Dudley,[89] and Larsen.[90] All these men studied areas of much greater extent than the Cuyamaca Peak quadrangle, and they took a comprehensive view of the broad physiographic problems of the region. The writer believes that before the geomorphology of the area will be entirely understood the areal geology of the whole region must be mapped and the problems of physiography and geomorphology attacked as objectives in themselves. The following discussion is based on observations made within the Cuyamaca Peak quadrangle and is intended only as a description of the land forms and as a possible suggestion for their evolution. The forms discussed include those resulting from the varying resistance of the rock units to weathering and erosion, surfaces of erosion, and meadowlands. The stream pattern of the area, including evidence for significant stream piracy, is also considered.

Relation of Rock Types to Weathering and Erosion. The rather marked difference in resistance to weathering and erosion exhibited by the various major rock units is impressive in the field. Nearly all the rocks in the area are deeply weathered, however, and differences in weathering depend more on such factors as topographic position, temperature, range, and abundance of moisture than on rock types. In regard to the degree of erosion the various rocks behave in peculiarly characteristic ways when subjected to running water and the slope-forming processes that operate in this area subjected to winter rains and summer droughts.

The shape and character of the resulting land forms have been described in the foregoing sections on the topography and rocks of the area. They appear to be directly attributable to the resistance of the rocks, which are here listed in order from most to least resistant; only those rock units that crop out over more than 10 square miles in the area are listed, so that their relative resistance may be more fairly appraised:

[85] Ellis, A. J., and Lee, C. H., Geology and ground waters of the western part of San Diego County, California: U. S. Geol. Survey Water-Supply Paper 446, 1919.

[86] Sauer, Carl, Land forms in the Peninsular Ranges of California: Univ. California, Dept. Geol. Sci. Bull., vol. 5, pp. 199-290, 1929.

[87] Bryan, Kirk, and Wickson, G. G., The W. Penck method of analysis in southern California: Zeitschr. Geomorphologie, Band 6, pp. 287-291, 1931.

[88] Miller, W. J., Geomorphology of the southern Peninsular Range of California: Geol. Soc. America Bull., vol. 46, pp. 1535-1562, 1935.

[89] Dudley, P. H., Physiographic history of a portion of the Perris block, southern California: Jour. Geology, vol. 44, pp. 358-378, 1936.

[90] Larsen, E. S., Jr., op. cit., pp. 5-15, 1948.

(1) Cuyamaca gabbro, (2) Woodson Mountain granodiorite, (3) Stonewall granodiorite, (4) Bonsall tonalite, (5) Julian schist, and (6) Green Valley tonalite. These relative resistances are well shown on the geologic and topographic map, the three cross sections of the area, and to a less extent on the longitudinal profiles of the Sweetwater River and Pine Valley Creek. On the cross sections, as well as on the geologic map, the Cuyamaca gabbro, the Woodson Mountain granodiorite, and the Stonewall granodiorite are seen generally to underlie the mountain peaks and uplands. The Bonsall tonalite is eroded away to a greater extent, although in places it has considerable relief. The Green Valley tonalite especially, and the Julian schist somewhat less consistently, underlie low parts of the area as shown by the cross section, profiles, and topographic map. Relationship of the shapes of the longitudinal profiles of the two most important streams in the area to the rock formations is a little more obscure. Although apparently normal nick-points are present in the streams, changes in gradient seem to be effected by the resistance of the rocks over which the streams flow. In a general way the gradient flattens as the stream flows over zones of resistant rock, such as the Woodson Mountain granodiorite, and steepens perceptibly below them. Certainly the steepest gradients are developed in the low-resistance rocks—the Green Valley tonalite, the Julian schist, and the schistose Stonewall and Julian mixed rock, and to a lesser degree the Bonsall tonalite.

Erosion Surfaces and Their Correlation. Several erosion surfaces occur within the Cuyamaca Peak quadrangle. They are isolated and dissected at their edges, and are individually of no great extent. However, when considered together with similar surfaces studied by Merriam and Larsen in the areas to the northwest, they are seen to fall into groups of rather uniform altitude and may be correlated over large areas. If studied on a regional scale throughout the Peninsular Ranges, they should be of great assistance in interpreting the late geologic history of southern California. The surfaces are gently undulating and as a general rule have a total relief of no more than 300 feet. They are apparently carved on the bedrock and have only a relatively thin soil cover. With very few exceptions, no transported pebbles or gravel and sand deposits underlie the erosion surfaces. The rare rounded pebbles that are found are derived from the bedrock except for one occurrence of basalt pebbles. The basalt may come from the Black Mountain volcanics, described by Hanna, which crop out in other parts of the Peninsular Ranges.

The highest group of undulating erosion surfaces of low relief is in the northeastern part of the quadrangle and is represented by East Mesa, West Mesa, and the area around Cuyamaca Reservoir. These surfaces are separated by deep stream valleys, but upon field examination it seems plausible to project them across to each other. The altitudes over most of the surface range from approximately 4,750 to 5,000 feet above sea level, with the highest areas lying in the southern part of East Mesa. The overall slope of the reconstructed surface is to the north.

Another pair of similar surfaces with nearly the same altitude is in a wide swath from Las Bancas in the east-central part of the quadrangle southeastward to the southeastern corner. This general surface, everywhere within a few hundred feet of 4,000 feet in altitude, is dissected most prominently by the deep canyon of Pine Valley Creek. In general the surface appears to slope southwest.

A third group of surfaces at still lower altitudes is the most extensive in the area. However, its component parts are separated from one another by several miles and their altitudes range through several hundred feet. One of these surfaces is in the northwest part of the area in the region around Tule Springs where the rather flat country over several square miles is close to 2,500 feet in altitude. To the south for several miles the area is cut deeply by the canyons of Conejas and King Creeks. South of this lowland area, however, the flat surface of the relatively high Viejas Valley, at slightly under 2,500 feet in altitude, may be correlated with the Tule Springs flat. To the south of Viejas Valley, the surface rises gently to the place where it is cut off by the deep canyon of the Sweetwater River. South of the river a small remnant of what seems to be the same surface forms the broad spur west of Bell Bluff at 2,100 to 2,200 feet in altitude; another extension south of the river forms a flat spur about a mile north of Bell Bluff. The area around Hidden Glen, at about the same altitude in the southwestern part of the quadrangle, is believed to represent the same surface. As in the second group of related surfaces, the general slope of this composite erosion surface is west and southwest.

Other erosion surfaces of very low relief have been formed at other localities such as Japatul Valley, but they appear to have only local significance and cannot be definitely correlated with generalized surfaces. Commonly their evolution seems to have been controlled by differences in resistance of underlying rocks to erosion.

Meadows. One of the most striking and widespread physiographic features of the Cuyamaca Peak quadrangle is the typical meadow. In the Peninsular Ranges the term "meadow" has a special connotation; it refers to the comparatively small level pockets of grassland that commonly occur in the midst of otherwise rugged topography. These puzzling features apparently do not have any one simple explanation, but may result from a variety of causes. Any geologic circumstance that creates level or near-level areas apparently encourages the formation of soil rather than the usual disintegrated rock or gruss, and where soil is created, the meadows tend to form. Many of the meadowlands in the quadrangle are found on all or part of the erosion surface remnants described in the foregoing paragraphs. Examples include East Mesa and Las Bancas. A second type is formed where bedrock of low erosional resistance is surrounded or nearly surrounded by rocks of much greater resistance, and a small topographic pocket or valley has resulted. The best examples of this kind of meadow are Hidden Glen in the southwestern part of the quadrangle and Japatul Valley about 2½ miles to the northeast. In both places, small lowland tracts underlain by Green Valley tonalite are almost encircled by rugged ridges of Woodson Mountain granodiorite. A third type of meadow is formed where the gradients of the stream flatten and the valleys widen. The marked changes in the maturity of the streams along their courses, however, cause such meadows to be scattered and discontinuous. Descanso Valley and Pine Valley are the best examples of this kind of meadowland in the quadrangle.

Streams and Valleys.—The stream pattern in the Cuyamaca Peak quadrangle is, in a general way, subdendritic, but locally other drainage patterns are developed. On most of the mountain peaks underlain by gabbroic rocks the drainage pattern is radial, and in much of the central

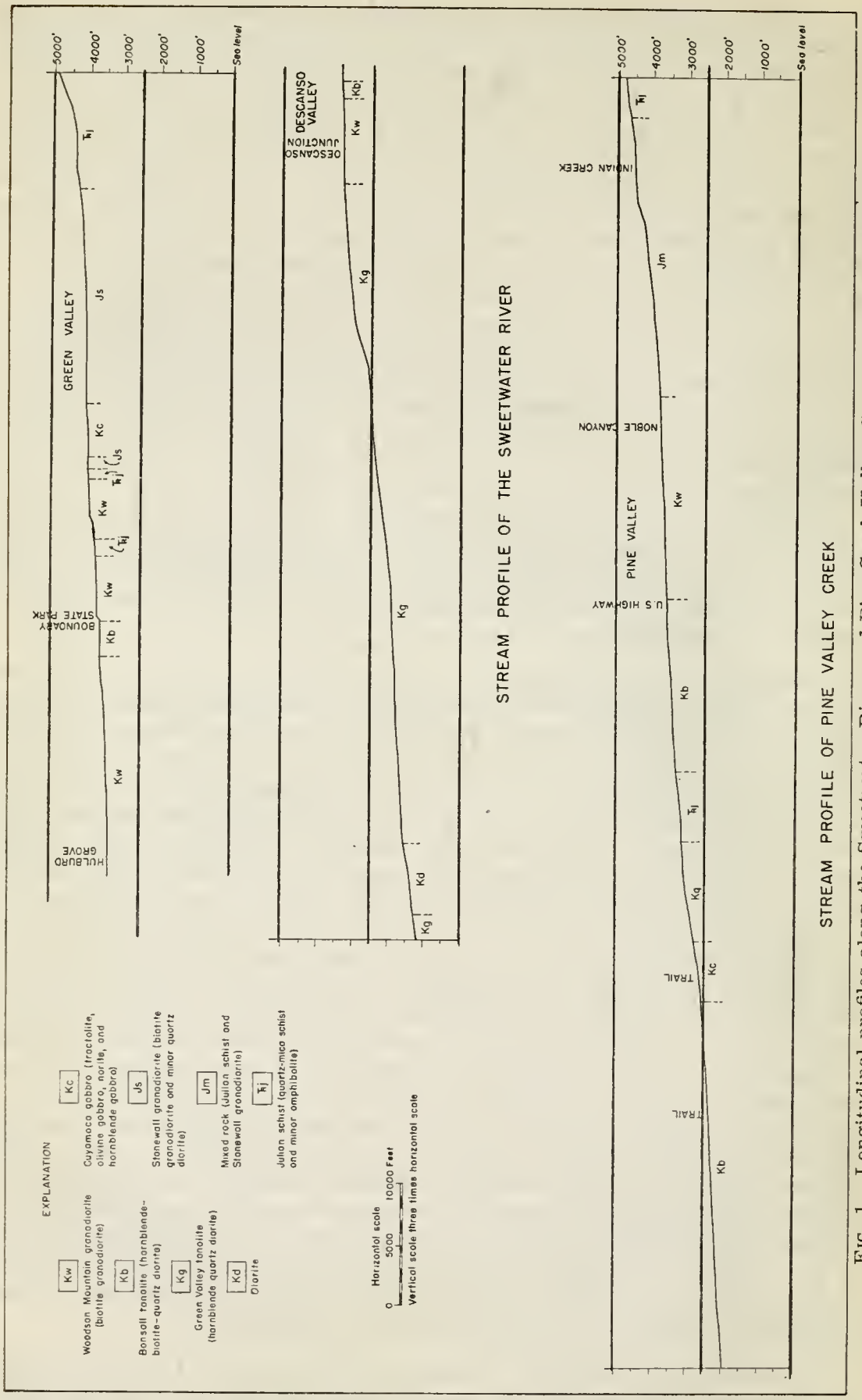

FIG. 1. Longitudinal profiles along the Sweetwater River and Pine Creek Valley, Cuyamaca Peak quadrangle.

and southern part of the area the pattern is subparallel. The direction of flow of the major drainage in the western half of the quadrangle is to the west, and throughout most of the remainder of the area it is to the southwest. North-flowing Oriflamme Creek and its tributaries in the northeast corner are exceptions.

The stream valleys in the quadrangle are of two distinctly different stages. One consists of youthful steep-sided V-shaped canyons where rapidly flowing streams are cutting far below the surrounding areas. Examples of these include the valleys along the lower courses of Boulder Creek, Pine Valley Creek, and the Sweetwater River. The other kind of valley is mature and has gentle slopes and comparatively low stream gradients; an example is the valley along the upper part of the Sweetwater River.

The streams of the V-shaped canyons are encroaching headward upon the wider valleys, particularly in the south-central part of the quadrangle. An example of such encroachment may be seen at the lower end of Pine Valley. Where the vigorous streams cut back and intersect the headwaters of another stream, they capture the waters from the more sluggish stream. The best example of such piracy is seen near Descanso Junction where the lower course of the Sweetwater River apparently has captured the upper drainage area of Horsethief Canyon Creek.

GEOLOGIC HISTORY

Observations of the geology and physiography of the Cuyamaca Peak quadrangle and a review of the geologic literature on related areas serve as a basis for the following general concept of the successive geologic events that formed the present rock bodies, structures, ore deposits, and land forms.

Beginning probably late in the Paleozoic era and extending into Triassic time, a succession of beds of sandstone and minor shale was laid down, along with a few scattered small basaltic and andesitic flows and beds of tuff. After the period of deposition, possibly near the end of Triassic time, compressive forces from the northeast and southwest tilted these rocks to a near-vertical position and induced mesozone metamorphism. The quartzites, schists, and scattered amphibolites thus formed are now known as the Julian schist.

Possibly during Jurassic time, a granodiorite to quartz dioritic magma intruded, injected, and to some extent replaced and granitized a part of the schist. The introduction of the magma was facilitated by the pre-existent schistosity and by assimilation. Consequently, where only intimate injection and intermixing occurred, the resultant mixed rock contains structures that parallel the old schistosity, and where the assimilation is more complete, as in the area now occupied by Stonewall Peak, the massive igneous rock contains structure that also parallels the older schistosity. The hybrid rock formed by the injection and partial replacement of the Julian schist has been mapped as Stonewall and Julian mixed rock, whereas the massive igneous rock is mapped as the Stonewall granodiorite.

During Upper Cretaceous time, the first of a sequence of batholithic rocks, which range from mafic to felsic, were emplaced. The mafic, but variable, rocks comprise the Cuyamaca gabbro, and the mechanism by which they formed has been especially studied and discussed by F. S.

Miller,[91] who concluded that they were derived from a single parent magma by a process of differentiation. The intrusion of the gabbro appears to have been relatively quiet inasmuch as there is no evidence of marked forcing aside of the Julian schist or Stonewall granodiorite. On the other hand, both stoping and at least moderate assimilation are suggested by the field observations. Stoping is indicated by the fact that the gabbro mass at Cuyamaca Peak includes in the middle of the body a relatively large block of the Stonewall formation, and assimilation is indicated by the local quartz- and biotite-bearing gabbros along contacts with the older rocks.

In two places in the quadrangle a magma that crystallized as diorite was intruded at approximately the same time as the gabbroic magmas, but it apparently was not a widespread or characteristic phase of the batholithic intrusion.

The next extensive intrusion of magma crystallized as the Green Valley tonalite, and its emplacement probably closely followed that of the gabbroic rocks. Again, assimilation and stoping appear to have been the dominant factors in the intrusion. Possibly most of the elliptical inclusions of the Green Valley tonalite represent pieces of gabbroic rocks that were torn loose from the walls and somewhat reworked chemically. However, it is also possible that at least some of these dark ellipsoidal bodies may be segregations from the magma and not inclusions of gabbro at all. There seems to be no way to prove either origin.

The emplacement of the Bonsall tonalite closely followed the intrusions of Green Valley tonalite. At the time of the Bonsall intrusion the Green Valley tonalite was probably not completely solidified, and indeed, according to Hurlbut,[92] the gabbro was still only semi-solidified when intruded by the magma that formed the Bonsall tonalite. Again, the widespread presence of inclusions, some of which appear to have once been Julian schist, is strongly suggestive of wholesale or partial assimilation by the Bonsall magma.

The Woodson Mountain granodiorite is believed to have been intruded after a much longer interval than that which separated any of the previous intrusions of the batholithic rocks, for its contacts indicate that all the older magmas were completely solidified before its intrusion. Furthermore its intrusion involved more forceful injection than did any of the former, as is best indicated by the injection gneiss zones along many of its contacts and the dikelike protuberances sent out from the main masses. The younger granitic rocks, which occupy only relatively small areas, are believed to be closely related genetically to the Woodson Mountain granodiorite.

After the solidification of at least the upper parts of all the intrusive bodies, aqueous and gaseous materials from the magma rose along fractures and formed granitic pegmatite dikes, aplite dikes, and quartz veins. Many of these fill near-vertical, northeast-trending, tension fractures formed by the same regional forces that cause strike-slip movement along the major faults of the California continental margin. The latest solutions rising along these fractures deposited a sufficient amount of metals, when they encountered the lower temperatures and pressures near the surface, to form the gold-bearing veins of the Cuyamaca Peak quadrangle.

[91] Miller, F. S., op. cit., 1937, pp. 1425-1426; op. cit., 1938, pp. 1229-1230.
[92] Hurlbut, C. S., op. cit., pp. 609-630.

According to Larsen,[93] the conduction of heat both through a thin cover and into the walls rapidly cooled the batholith and effected the crystallization of the rocks in a relatively short time—probably less than a million years. Subsequently, but while it was yet late Cretaceous time, sediments were deposited on the eroded batholithic rocks of Lower California; but if any were deposited in the Cuyamaca Peak area, they have been completely removed by erosion.

General uplift of the region including the Cuyamaca Peak quadrangle followed the deposition of the Cretaceous sediments. The nature of the uplift has been indicated by Ellis,[94] who pointed out that the Peninsular Ranges may be regarded in a broad sense as a tilted block with steep front to the northeast and gentler back slope to the southwest. The erosion history of this back slope, as deduced from the land forms in the Cuyamaca Peak quadrangle, includes several stages of erosion followed by uplift. The earliest stage now discernible was the development of the mature erosion surface represented by the area around Cuyamaca Reservoir and the East and West Mesas. Later rejuvenation of the streams developed a group of lower mature valleys represented by Green Valley, Descanso Valley, Pine Valley, and others. Possibly during the same cycle, the mature surface extending from Las Bancas southeastward to Corte Madera, Long Valley, and Bear Valleys was formed. Still another separate period of erosion may be needed to account for the erosion surfaces of Tule Springs Flat, Viejas Valley, and the broad spurs below Bell Bluff, but they may have developed during one of the early cycles. Alluvium was deposited in some of the mature valleys thus formed where the gradient was low enough to cause aggradation. The most recent event in the late erosional history has been rejuvenation of the streams to cut youthful V-shaped canyons in the western part of the quadrangle. These streams have sapped headward to capture some of the streams of the older mature drainage in the eastern part of the quadrangle. Other older streams are in imminent danger of similar piracies as the youthful streams continue their headward growth.

ECONOMIC GEOLOGY

Developed mineral resources in the Cuyamaca Peak quadrangle include more than a score of small gold deposits, one feldspar mine, and two quartz deposits that have been mined for silica. These have been observed in the present study, but they were not mapped in detail nor were their ores studied extensively. A short distance north of the quadrangle deposits of nickel-bearing sulfides have been found in the rocks of the Cuyamaca gabbro, but within the area covered by this report none have as yet been discovered. In several places in the area large volumes of fresh, massive igneous rock are suitable for building or ornamental stone, but in most places they are seemingly too inaccessible to be quarried economically. Unconsolidated sand beds made up of disintegrated and transported material from the bedrock of the area occur in some of the stream valleys, but they have not been used commercially. There are no gravel deposits of appreciable size in the area.

[93] Larsen, E. S., Jr., Time required for the crystallization of the great batholith of southern and Lower California: Am. Jour. Sci., vol. 243A (Daly volume), pp. 399-416, 1945.

[94] Ellis, A. J., and Lee, C. H., op. cit., Water-Supply Paper 446.

Gold Mines and Prospects

The mining of gold in the Cuyamaca Peak quadrangle began in 1870 [95] with the location of the Stonewall Jackson (later Stonewall) mine near what is now the south shore of the Cuyamaca Reservoir. Other mines were developed shortly thereafter, and the industry flourished until the end of the century. During the first quarter of the twentieth century some mining was carried on, but since that time activity has been sporadic. In the summer of 1946 no metal was being recovered even though a few prospectors were doing small-scale development work in scattered localities. Consequently, almost all the mine workings that had had significant production were inaccessible during the field work for this report, and therefore the study of the deposits has been largely confined to vein outcrops on the surface and in partly caved adits, and to specimens found on the dumps.

The gold deposits in the Cuyamaca Peak quadrangle are in the quartz veins; free gold and associated sulfides occur as open-space fillings and replacements in small, rather erratic veins with white, milky, or clear quartz as gangue. The veins themselves appear to be controlled by fractures in both the igneous and metamorphic rocks and were emplaced late in the geologic history of the region.

Gold is very rare, as is indicated by the value of the ore reported from most of the individual mines. It occurs in its free state in minute particles up to the size of a pinhead, both as open-space fillings and as replacements of older sulfides. Calaverite and other tellurides of gold have been reported, but were not observed or recognized by the writer. The sulfides accompanying the gold in order of abundance are pyrrhotite, pyrite, arsenopyrite, and rare galena. Pyrrhotite is rather common in the developed gold-quartz deposits and occurs as irregular replacement masses in and around the vein. Crystalline or granular pyrite occurs in much the same way, and small euhedral grains of arsenopyrite are scattered through the quartz in a number of the veins. A few grains of galena, occurring in much the same way as the arsenopyrite, have been identified.

Quartz, the principal gangue mineral, locally exhibits a variety of textural forms. Most of it is massive bull quartz, but in places it is banded, and in others, a late type forms drusy vugs in the central parts of the veins. Much of the quartz in the veins appears to be essentially contemporaneous with the gold and sulfides because in many places it entirely surrounds those minerals and neither consistently coats nor is coated by them. In other places, particularly at the Penny mine, the gold clearly replaces quartz and the sulfides. Biotite is associated with the quartz in some veins and is especially well developed along the vein margins. It commonly is extensively altered to iron oxide and in places also has a bleached appearance. Nearly all the mineralized quartz veins are stained dark brown by the alteration of the iron sulfides to hydrous iron oxides.

In general distribution, the gold-bearing quartz veins are concentrated in a zone near the contacts of the batholithic rocks with older rocks and are most abundant in the Julian schist and the mixed rock of the Julian schist and Stonewall granodiorite. Most of the gold mines and

[95] Wade, Kathleen Camilla, Cuyamaca Rancho State Park, State Park No. 69, part of the history of California state parks: California Dept. Nat. Resources, Berkeley, p. 34, 1937.

prospects of the area, therefore, lie along the east side and across the northern part of the quadrangle to the northwestern corner. Notable exceptions are the Descanso mine in the central part of the quadrangle and the nonproductive Wettleson prospect in the southwest corner. It should also be noted that the Eagle Nest and Tres Amigos mines and the Mahood prospect in the southeast part of the quadrangle are well within the area of batholithic rocks.

Most of the veins dip steeply and range in strike from northeast to northwest. They tend either to parallel the structure of the country rock, particularly in the schist and the mixed rock, or to follow north- or northeast-trending joints that cut across the structures of the older rocks.

It is believed by the writer that vein filling and marginal replacement by quartz and metalliferous compounds were accomplished by hydrothermal solutions in the last phases of the emplacement of the batholith and thus were most active and concentrated near the border of the batholithic rocks and the older country rock. In developing these vein deposits of metalliferous ore and in searching for similar deposits, it would therefore seem advisable to pay particular attention to the batholith border zone. Places of particular promise are where the border zone is cut by prominent fractures along which the metal-bearing solutions could have risen through the rocks. Because no large faults are believed to exist in the Cuyamaca Peak quadrangle and fracturing is confined to jointing, this area would not be expected to be as well metallized as the Julian mining district to the north. In the latter area, a similar batholithic border zone adjacent to Julian schist is cut by the Elsinore fault zone along antecedents of which hydrothermal mineralization was extensive.

Two recognized mining districts are within the Cuyamaca Peak quadrangle, and in addition there are several outlying individual mines. The Boulder Creek district is in the north-central part of the area and the Deer Park district is in the extreme east-central part. The gold mines and prospects of the quadrangle are alphabetically listed below by districts. All workings accessible in 1941 or 1946 have been examined by the writer, and general information concerning the deposits resulting from these examinations is presented. All supplementary information (in finer type) is taken from a report by Tucker.[96]

Boulder Creek District

Boulder Creek Mine (Mineral Hill Mine). The Boulder Creek mine is located in parts of secs. 9 and 10, T. 14 S., R. 3 E.[97] The underground workings, which were largely accesible but not being worked in 1946, consist of about 2,000 feet of drifts and crosscuts on three levels, 50 and 60 feet apart vertically. The drifts follow a quartz vein that strikes about N. 30° W. and dips on an average 80° SW. The maximum width of the vein is about 3 feet and the exposed length is about 300 feet. The vein cuts country rock that is a schistose phase of the Stonewall granodiorite and Julian schist mixed rock. The ore mineral is free gold in pyrite and arsenopyrite.

The mine encompasses ten claims. Ore shoots average 20-30 feet in length. Average value of the ore was $6-$12 per ton.

[96] Tucker, W. B., Los Angeles division, report on mining in California: California Div. Mines, Rept. 21, pp. 334-349, July 1925.

[97] Locations are based on the San Bernardino base line and meridian.

Elk and Landslide Prospects. The writer was not able to locate these prospects, and assumes that they have been idle and inaccessible for so long that the heavy brush of the area has obliterated all trace of the workings. The following information is given concerning them:

> The prospects are located in sec. 3, T. 14 S., R. 3 E., on Kelly Creek. The Elk vein is 6 feet in maximum width and strikes N. 20° W. The ore minerals are free gold, pyrite, and arsenopyrite. The Landslide vein strikes east. Both veins cut granodiorite country rock.

This area is underlain by mixed rock of the Stonewall granodiorite and Julian schist.

Gold Crown Group. The Gold Crown group of five claims lies in parts of secs. 1 and 12, T. 14 S., R. 3 E., and underlies a ridge north of Boulder Creek. The access adit was caved at the portal at the time of the field work for this report, but the following brief information is given by Tucker:

> A crosscut adit runs 70 feet eastward through granodiorite to cut a quartz dike that strikes north and attains a maximum thickness of 12 feet. The vein carries pyrite, arsenopyrite, and gold, and is valued at $2 per ton.

Last Chance Mine. The Last Chance mine consists of five claims in sec. 4, T. 14 S., R. 3 E. The country rock is gneissic mixed rock of the Stonewall granodiorite and Julian schist, which on the mine property is cut by a quartz vein that strikes N. 20° W., and has a vertical dip. The vein ranges from 1 foot to 4 feet in width. A two-compartment shaft has been sunk 115 feet but in 1946 was caved about 25 feet from the surface. Development work and mining are said to have been discontinued in 1941, but there is still a ball mill and assorted mine machinery in fair condition on the property.

> Tucker's description of the Last Chance mine includes the information that a 100-foot drift ran from the shaft at the 80-foot level and that the ore from the mine was valued at $18 to $35 per ton; it contained gold and a little silver. The ore minerals are listed as free gold, pyrite, and marcasite.

No identifiable marcasite was found by the writer on the dumps of the mine.

Lucky Strike, Damfino, Pocket, and Long-Time-No-See Prospects. This group of prospects is located in sec. 14, T. 14 S., R. 3 E., in an area underlain by mixed rock of the Julian schist and Stonewall granodiorite. Small quartz veins, which strike east and dip vertically, cut the country rock. These veins are said by the owner of the prospects to contain small quantities of free gold, a little alloyed silver, and gold and silver tellurides. Pyrrhotite also can be observed. The prospects were being developed in 1946 by small trenches and open pits by Mr. A. E. Goeppinger of Oceanside, California.

Nona and Coarse Gold Prospects. The Nona and Coarse Gold prospects, in sec. 5, T. 14 S., R. 3 E., contain small erratic quartz veins that strike northwest and dip northeast, essentially parallel to the primary structural features of the mixed rock of Stonewall granodiorite and Julian schist country rock. These veins, according to the owner, contain very small quantities of free gold and some silver sulfides. They were being developed through two shallow shafts in 1946 by Mr. Ben Santesson of Julian, California.

Penny Mine. The Penny mine, in sec. 11, T. 14 S., R. 3 E., exhibits rare free gold and prominent pyrrhotite in quartz veins following the northwest-trending, nearly vertical gneissic foliation of the country rock. The workings consist of one short adit that was caved in 1941 and 1946.

Prosperity Prospect. The Prosperity prospect, in sec. 3, T. 14 S., R. 3 E., has yielded a very small tonnage of high-grade gold ore. Free gold occurs in small vertical north-trending quartz veins that cut the structure of the country rock. Developed by one short adit, the vein zone was being worked in 1946 by Mr. Richard A. McCubbin of Julian, California.

Deer Park District

Free Coinage Mine. The Free Coinage mine, consisting of claims Nos. 1 and 2, lies in sec. 12, T. 15 S., R. 4 E., near the headwaters of Indian Creek. All surface evidence of the workings had virtually disappeared by 1946, but the mineralized vein was seen to strike N. 30° W. and dip steeply northeast, cutting the granodiorite country rock. Tucker's report supplies the following additional information:

> A few hundred tons of ore with values of about $18 per ton, was produced from a vein mined to a width of 12 to 18 inches. The vein was mined from a vertical shaft 96 feet in depth with a crosscut to the east to intersect the vein, and an open-cut.

Gold Standard and North Star Mines. The Gold Standard and North Star mines in sec. 12, T. 15 S., R. 4 E., had long been idle and inaccessible when visited in 1946. The following information is supplied by Tucker:

> The Gold Standard mine explores two parallel quartz veins striking north and dipping 45° W. The East vein is the wider of the two with an average of 4 feet. The North Star vein has a similar strike and dips 35° W. It ranges from 4 to 8 inches in width. Free gold, pyrite, and arsenopyrite are contained in the veins. Two drifts have been driven along the vein in the Gold Standard mine—150 feet and 190 feet in length with a 50-foot interval in elevation. In the North Star mine, the workings consist of a 50-foot inclined shaft and crosscut tunnel 190 feet in length.

Good Luck Mine. The Good Luck mine, inaccessible and idle in 1941 and 1946, consists of one claim in sec. 31, T. 14 S., R. 5 E., on the ridge east of Deer Park. Concerning this mine, Tucker gives the following information:

> A quartz vein with a maximum width of 4 feet strikes N. 30° E. and dips 50° SE. An inclined shaft follows the vein down for 50 feet.

Oak Canyon Mine (formerly Cascade). The Oak Canyon mine is situated in sec. 31, T. 14 S., R. 5 E. On this property a series of small erratic quartz veins trends northwest, and cuts the diorite country rock. The veins are developed by six short adits; the last development work was done in 1945 by Mr. A. T. Knight.

Two more groups of claims in this district are listed by Tucker:

> *Schley Group.* The Schley group of five claims in secs. 1 and 12, T. 15 S., R. 4 E., lies on the ridge east of Indian Creek. A quartz vein 4 feet wide strikes N. 30° W. and dips 80° E., cutting granodiorite. The limonite-stained quartz carries clots of pyrite and arsenopyrite. The property includes several short tunnels and shallow shafts.
>
> *Telluride Group.* The Telluride group includes the Blue Jay and Telluride claims in sec. 31, T. 14 S., R. 5 E., adjoining the Gold Standard claims on the north. Several parallel narrow quartz veins in a belt of mica

schist strike generally northwest, dip 70° SW., and are as much as a foot in width. The bluish-white ribbon quartz is mineralized with galena and pyrite.

Other Mines and Prospects

Decker Prospect. The Decker prospect is located in sec. 26, T. 15 S., R. 4 E., where a group of quartz stringers trends parallel to the primary structural features of the Bonsall tonalite, which it cuts. The group strikes about N. 20° W. and dips 68° NE. and is developed by one prospect tunnel 180 feet in length and an 80-foot shaft with a short drift off the bottom. The shaft has been sunk on low-grade ore that consists of highly fractured and iron-stained quartz containing flour gold, pyrite, and minute amounts of other sulfides. Two hundred pounds of ore had been extracted and were ready for experimental milling in 1946. At that time the shaft was full of water, and no development work had been done on the property recently.

Descanso Mine. The Descanso mine, in sec. 24, T. 15 S., R. 3 E., consists of 17 claims. According to Tucker:

> A series of steeply dipping parallel quartz veins generally trending east cuts Bonsall tonalite. Most development has been on the so-called Magdalena vein by means of a 230-foot inclined shaft. There were three levels with about 80 feet of workings in each. The vein was 1 foot to 3 feet wide and is said to have carried free gold, pyrite, marcasite, galena, and pyrrhotite, assaying $10-$50 per ton in gold.

The shaft was caved near the surface, and the mine was idle and inaccessible in 1946.

Eagle Nest (Fargo) Mine. The Eagle Nest or Fargo mine is in sec. 25, T. 16 S., R. 4 E. It explores a quartz vein that strikes N. 78° W., dips 72° SW., and cuts Bonsall tonalite. It is developed by one inclined shaft at least 200 feet in depth, with several short adjoining drifts, and three surface glory holes. The vein consists of quartz gangue and minor quantities of free gold, pyrite, arsenopyrite, pyrrhotite, and allanite (?). The mine was a sporadic producer until the spring of 1946, but later in the year the shaft was filled with water to within 15 feet of the surface and the mine was idle.

Mahood Prospect. At the Mahood prospect in sec. 7, T. 16 S., R. 4 E., a quartz veinlet striking N. 22° W. and dipping steeply southwest has been developed by an open trench about 8 feet deep, from which a short adit extends. The ore, which carries free gold and the usual sulfides of these veins, is said to assay $20 to $25 per ton, but the reserve tonnage appears to be very small. A small amount of development work was being carried on in the summer of 1946.

Oriflamme Mine. The long-abandoned and inaccessible Oriflamme mine is in sec. 1, T. 14 S., R. 4 E. and sec. 6, T. 14 S., R. 5 E. According to Tucker:

> Two quartz veins cut mica schist, the structural features of which strike northwest and dip 75° NE. The vein quartz carries pyrite and was reported to carry gold telluride and has been developed through approximately 1,000 feet of underground workings.

Stonewall (Stonewall Jackson) Mine. The Stonewall mine is located near the south shore of Cuyamaca Reservoir in the Cuyamaca Rancho

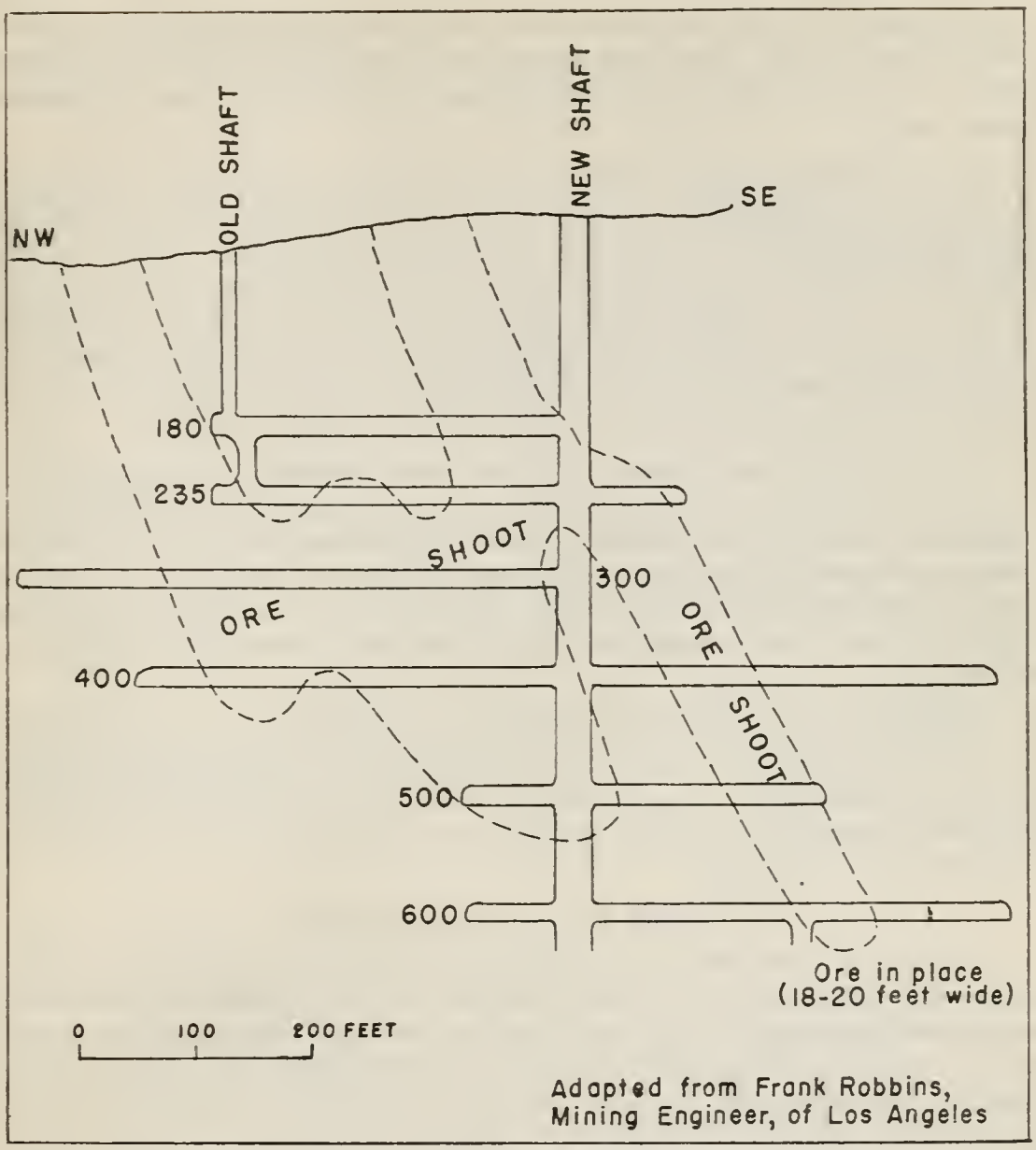

FIG. 2. Section of ore body and workings of Stonewall mine.

State Park. Gold was discovered here in March 1870 by Charles Hensley.[98] By 1872, it was a large mine, employing from 100 to 200 men. The period of greatest prosperity lasted until 1892 and the peak production came in the period 1888-91 when the mine produced $909,442 in gold. The property has not been mined since 1895, but the total value of output to that time has been variously estimated at $2,000,000 to $3,600,000.

Little is known of the nature of the rich ore that made the Stonewall mine such an outstanding producer, but the quartz vein that carried the ore strikes N. 35° W. and dips 65° SW., nearly parallel to the bedding and schistosity of the surrounding mica schist and gneissic Stonewall granodiorite. The rake of the large composite ore shoot was to the southeast. The deposit was developed by a three-compartment shaft, sunk to a depth of about 640 feet, from which nearly 2,700 feet of drifts were run on six different levels (fig. 2). Continuous narrow stopes followed the ore shoot.

[98] Wade, Kathleen Camilla, op. cit., pp. 34-35.

The shaft is now caved near the surface and the famous old mine is totally inaccessible. The area around the head of the shaft has been fenced off as an outdoor museum for visitors to the Cuyamaca Rancho State Park.

Tres Amigos Mine. The Tres Amigos mine is in sec. 7, T. 16 S., R. 4 E. Ore occurs in several quartz veinlets that strike about N. 25° W. and dip steeply NE. The strike is essentially parallel to that of the structural grain of the surrounding Bonsall tonalite, but the dip is in the opposite direction. Small amounts of extracted ore are said to have run $8 to $10 per ton in gold. The deposit has been developed by a shallow inclined shaft and two connected adits about 35 feet in length. Development work was carried on by one man in the summer of 1946.

Viejas Mountain Prospect. The Viejas Mountain prospect is in sec. 19, T. 15 S., R. 3 E. It consists of a single tunnel driven 128 feet in weathered norite by the Indians of the Viejas Reservation in 1940 under the auspices of the Civilian Conservation Corps. No sign of a vein or mineralized rock was noted in the tunnel, but one of the miners has reported that "very small amounts" of gold were taken from the workings.

Wettleson Prospect. The Wettleson prospect in is sec. 14, T. 16 S., R. 2 E. An old tunnel about 200 feet in length is driven in Green Valley tonalite to undercut a quartz ledge at the border of a body of Woodson Mountain granodiorite. Supposedly it is a gold deposit, but no production has been recorded.

Spanish Bayonet Feldspar Mine

The general nature of the pagmatite deposits has been described in a foregoing section. One of these deposits in the Cuyamaca Peak quadrangle has been mined on a small scale for potash feldspar and for quartz as a by-product, but was idle in the summer of 1946. The mine is on the Spanish Bayonet claim, located in February 1945 by P. H. Weber, J. F. Daugherty, and Cecil Lewinson of Alpine, California. It is in sec. 35, T. 14 S., R. 3 E. on an elongated, somewhat bulbous-shaped pegmatite body. The pegmatite is extremely coarse-grained, with nearly pure orthoclase and slightly rose-colored to white quartz in masses up to 12 inches in maximum dimension.

The development consists of an open pit about 100 feet in length, 25 feet in width, and 15 to 25 feet in depth elongated parallel to the strike of the pegmatite body—about N. 45° E. At the southwest end of the pit are two short outlet tunnels extending from the bottom to the side of a small adjacent canyon. One tunnel has been used for dumping waste material into the canyon, and the other leads to the end of an access road and presumably has been used as a passageway for loading the ore into trucks. The pegmatite dike is exposed in the ore tunnel, where it is 6 to 7 feet wide and dips steeply southeast, clearly crosscutting the structure of the Bonsall tonalite country rock.

Quartz Vein Deposits

At two localities in the south-central part of the quadrangle, quartz has been mined for silica from lodes of pure white bull or milky quartz.

Both deposits are at the summits of small peaks a little more than a mile from each other. One is in the southern part of sec. 2, T. 16 S., R. 3 E., and the other is in the southern part of sec. 34, T. 15 S., R. 3 E.

The first deposit has been named the Ajax lode in a claim located in July 1941 by Henry L. Walters. The lode forms an elliptical outcrop, being about 700 feet long by 150 feet wide. It strikes N. 33° W. and dips about 85° NE. The deposit is developed on the southwest side by a short trench, which exposes the sharp contact with the Woodson Mountain granodiorite country rock and explores the massive, shattered white quartz. Only a few tons of quartz apparently were mined.

The second deposit, apparently unnamed, is much larger than the first, underlying an area of about 125,000 square feet. It has an irregular shape, with no prominent elongation in any direction, but it appears to be more or less localized along a contact between Woodson Mountain granodiorite and a small body of norite. The contacts, where exposed, are steep, and dip outward. The pure, white, glassy quartz is closely jointed, cracked, and shattered in many directions. The deposit is developed by five prospect trenches and four open pits, the largest of which covers several hundred square feet in area and is as much as 10 feet deep.

Many sorting piles are found throughout the area, suggesting that the quartz was hand-picked. However, according to a neighboring rancher, even the best quartz taken from the deposit did not prove to be of commercial value.

GROUNDWATER IN THE BEDROCK IN WESTERN SAN DIEGO COUNTY, CALIFORNIA

By Richard Merriam *

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Figure 1. Isohyetal map of western San Diego County, showing average annual rainfall in inches. Modified from Ellis and Lee 119

Plate 7. Geologic map of western San Diego County, California ..... In pocket

ABSTRACT

Wells penetrating batholithic (mostly granitic) and metamorphic rocks are an important source of water in San Diego County. The yield of such wells is largely a function of the structure of the bedrock, type of bedrock, character of weathering, and topography. The selection of a well site is best done with a knowledge of the local geology and a consideration of the above factors.

INTRODUCTION

Water supply in the arid and semiarid climate of San Diego County has long been a major problem. It became more important with the introduction of irrigated crops and in the last few years has been one of the limiting factors in the utilization of land for agricultural and residential purposes. The situation has become critical due to an increase in population, subnormal precipitation, and increased acreage of irrigated crops.

The population of San Diego County has increased more than 120 percent in the last 10 years being 289,348 in 1940 and mounting to 665,000

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in 1950. A large part of this increase has occurred in the rural areas where water supply is chiefly from wells. The increase in irrigated acreage has also occurred in rural sections. These changes have been mainly in the poorer lands, such as hillsides underlain by bedrock where, unlike the already occupied bottom lands, water cannot be derived from wells in stream gravels or alluvial fill. The newly occupied land usually does not lie in an irrigation district. Hence, wells in the bedrock constitute the only source of water for hundreds of homes and small ranches as well as some large tracts.

The precipitation since 1940, given in table 1, is seen to be considerably below the normal amount. Even in years for which normal amounts are indicated the rains came in such a way that absorption underground was below normal. Even the normal precipitation of 10 to 20 inches is too little for most crops. Dry years have required more irrigation, hence more pumping. The water table is thus lowered by low precipitation and excessive pumping. Lowering of the water table by 10 to 20 feet since 1940 is not uncommon.

Table 1. Annual precipitation 1943-50.

	Escondido[1]	San Diego[2]
1943-44	16.48	17.74
1944-45	15.18	13.06
1945-46	14.03	9.23
1946-47	12.02	8.74
1947-48	9.03	6.28
1948-49	13.90	6.63
1949-50[3]	9.02	8.87[3]

[1] Average annual precipitation 16 inches.
[2] Average annual precipitation 10 inches.
[3] To March 15, 1950.

To relieve the water shortage in the city of San Diego, the San Jacinto-San Diego aqueduct was built in 1946, but even this is insufficient and an additional parallel line is planned.

The principal drainages of the back country have been dammed so that most of the runoff is efficiently utilized. The only remaining source is the groundwater. This is being so actively exploited that government control has been suggested. Thousands of wells have been dug for domestic and irrigation water; many areas contain 40 to 50 per square mile. Many are in bedrock rather than alluvium because the latter is absent or is unfavorable for drilling laterals.[1]

Some well sites are located on the basis of topography, others merely for convenience or accessibility, but the majority are located by "witching," a method which is still widely used in the region. Practically no wells are located by geological or geophysical means. Whatever the method, the finding of water in bedrock is largely a matter of chance, yet the chances of success can frequently be increased by selecting a well site with reference to certain geologic features.

Recognition of geologic conditions is also essential in estimating groundwater reserves. Wells in bedrock are often misleading in that

[1] Some of the most successful wells are those in which a series of near-horizontal radially arranged drill holes have been run from the bottom a large diameter well.

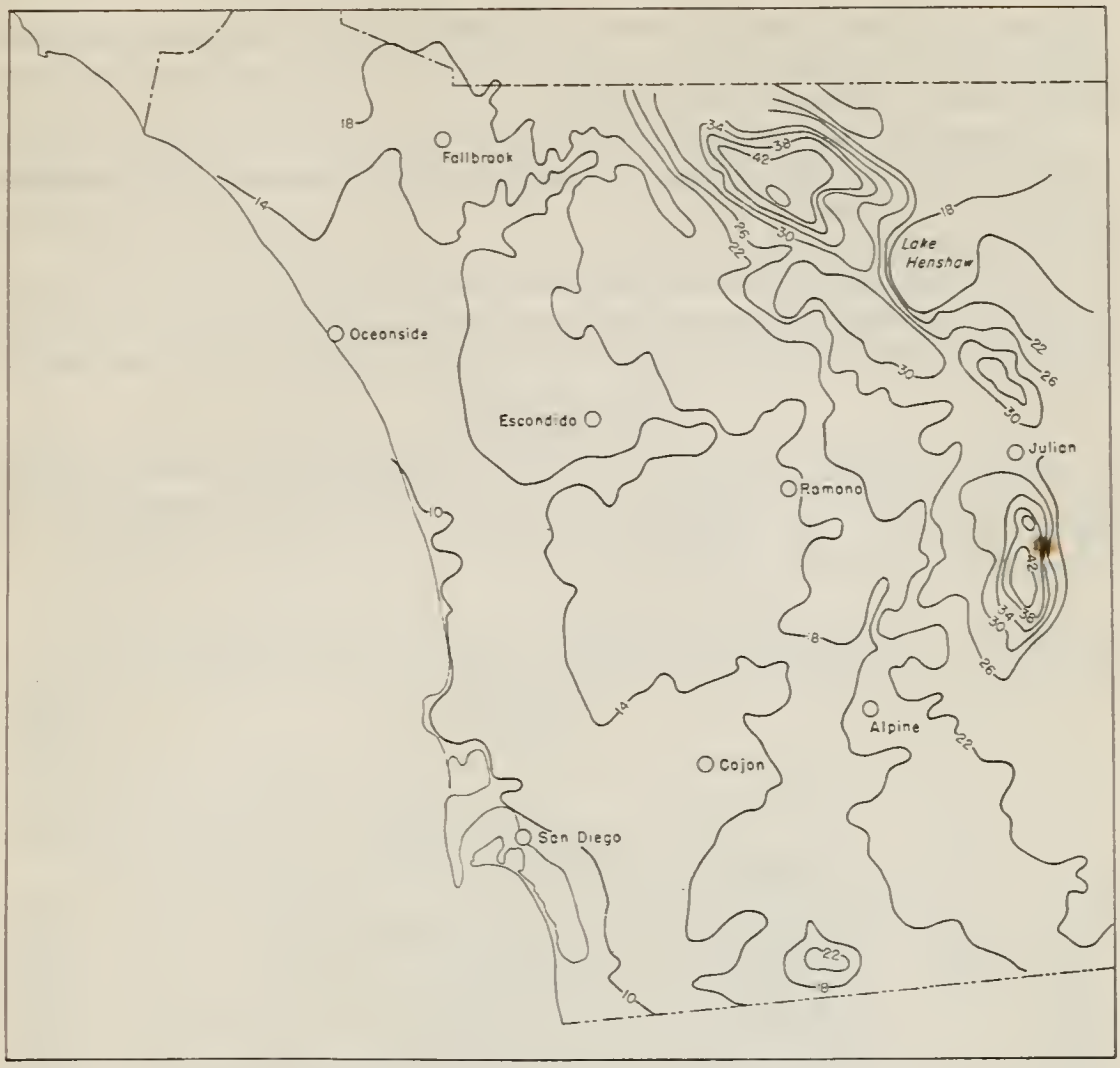

FIG. 1. Isohyetal map of western San Diego County, showing average annual rainfall in inches, modified from Ellis and Lee.

the initial production may greatly exceed the safe yield when pumped for a number of years. The installation of pumping equipment and pipelines on the assumption that the initial yield is to be permanent has led in some cases to serious financial losses.

REGIONAL GEOLOGY

Previous Literature

Groundwater conditions of the western part of San Diego County were studied and described by Ellis and Lee [2] in 1919. This work remains the best source of information on the general principles of groundwater of the region. However, much geologic work has since been done, many wells dug, and information of various sorts is now available which was not in 1919.

The most complete study of bedrock in a portion of the county is that of Larsen.[3] This publication describes in detail the igneous and metamorphic rocks of the northwestern part of the county. Larsen's

[2] Ellis, A. J., and Lee, C. H., Geology and groundwaters of the western part of San Diego County, California: U. S. Geol. Survey Water-Supply Paper 446, 1919.

[3] Larsen, Esper S., Jr., Batholith and associated rocks of Corona, Elsinore and San Luis Rey quadrangles, southern California: Geol. Soc. America Mem. 29, 1948.

geologic map is reproduced in this bulletin (pl. 1); his description of weathering of bedrock types, and a chapter on structural geology have greatly aided groundwater studies.

A paper on the geology of the southern part of the Ramona quadrangle [4] gives the distribution of rock types. The area east of this which includes Julian and Cuyamaca has been studied by Hudson,[5] who also includes a geologic map.

All of the coastal section has been described but bedrock is too deep in most places to be penetrated by water wells. Hanna,[6] who described La Jolla quadrangle, mapped bedrock in the eastern part of the quadrangle.

Geologic History

Table 2 lists the formations of the area and gives the approximate maximum thicknesses and general lithology. With the exception of a coastal strip 5 to 10 miles wide, nearly all the area is underlain by batholithic and metamorphic rocks.

Table 2. Summary of rock formations exposed in western San Diego County.

	AGE	FORMATION	THICKNESS
QUAT.	Recent	Recent alluvium	0–300′
	Pleistocene	Marine terrace deposits (Bay formation)—equivalent to Palos Verdes?	30′
TERTIARY	Pliocene	Sweitzer formation—conglomerate terrace deposits San Diego formation—marine sands	30′ 1250′
	Eocene	Poway conglomerate—massive conglomerate Rose Canyon shale—marine shales Torrey shale—brown, marine sand and shale Del Mar sand—massive, white, marine sandstone	875′ 300′ 200′ 200′
MESOZOIC	Upper Cretaceous	Chico formation—sandstone and shales	500′+
	Middle Cretaceous	Various granodiorites Various tonalites San Marcos gabbro (Cuyamaca basic intrusive)	
	Jurassic?	Santiago Peak volcanics (Black Mountain volcanics) (metavolcanics and associated intrusive rocks)	
	?	Stonewall granodiorite and quartz diorite	
	Triassic?	Julian series and Bedford Canyon formation (slates and schists)	

The oldest rocks are slates, schists, quartzites, and metavolcanic rocks with associated intrusives which occur throughout the area. These rocks were originally normal sediments and volcanics which once covered most of the region. Following deposition they were folded, depressed, and

[4] Merriam, Richard, Igneous and metamorphic rocks of the southwestern part of the Ramona quadrangle, San Diego County, California: Geol. Soc. America Bull., vol. 57, pp. 223-260, 1946.

[5] Hudson, F. S., Geology of the Cuyamaca region of California with special reference to the origin of nickeliferous pyrrhotite: Univ. California, Dept. Geol. Sci. Bull., vol. 13, pp. 175-252, 1922.

See also Creasey, S. C., Geology and nickel mineralization of the Julian-Cuyamaca area, San Diego County, California: California Div. Mines Rept. 42, pp. 15-29, 1946.

[6] Hanna, M. A., Geology of the La Jolla quadrangle, California: Univ. California, Dept. Geol. Sci. Bull., vol. 16, pp. 187-246, 1926.

subjected to mild or moderate regional metamorphism. During the middle of the Cretaceous invasion by a composite batholith took place. The batholith was emplaced by a series of closely spaced intrusions which largely displaced the metamorphics so that the latter are now represented by scattered, disconnected bodies which make up only a small percentage of the bedrock complex.

Following emplacement of the batholith the region was uplifted and eroded. In late Cretaceous and Tertiary time the western margin was periodically depressed and covered by marine sediments. Gravels of Eocene age, probably derived from eastern or southeastern highlands, once covered a large part of the area. The remnants of this formation, termed Poway conglomerate and Ballena gravels, are present as a few small patches near the center of the area and as large areas in the west and southwest.

A few very minor volcanic plugs intruded the sediments in late Tertiary time and gave rise to limited lava flows.

Faulting has no doubt occurred in the whole region although its effects are obscured in the main bedrock area where the younger sediments, which act as markers, are absent. Straight contacts, straight or aligned topographic features, aligned springs, and crushed zones are features that suggest faulting. Tunnels driven during construction of the San Jacinto-San Diego aqueduct encountered numerous crushed zones which probably represent faults.

Late Tertiary or Quaternary movement along normal faults trending roughly northwest is probably responsible for much of the present physiography, which roughly consists of three belts of different elevations—a low coastal belt covered largely by sedimentary rocks; an intermediate belt vaguely resembling a dissected plateau; and the highlands, an area which in spite of its usual rugged relief, is topped by surfaces of low relief. Bedrock groundwater is most important in the intermediate and highland belts. The physiography is of interest in the present study because the plateau-like surfaces appear to have been exposed to deeper weathering and thus have developed better aquifers and are more easily drilled.

TYPES OF WELLS

Wells in the bedrock are either drilled or dug. Drilled wells range from 20 to 200 feet or more in depth. All the deeper and many of the shallow wells are drilled with conventional churn drill rigs. Casing is often unnecessary while drilling but may be put in after completion before a pump is installed. Nearly all such wells are 12 inches in diameter. Wells up to 100 feet in depth can be drilled with rotary rigs such as "cesspool diggers." Rotary drilled wells are mainly shallow and are 24 to 36 inches in diameter.

If laterals are to be drilled a hole of at least 30 inches must be made. Wherever possible this is made by a rotary rig. Hard rock frequently prevents such procedures, in which case ordinary mining methods are used. Concrete or steel casing is placed in portions where the shaft will not stand unsupported. Ordinarily the lower 8 or 10 feet is enlarged or "belled out" to permit drilling of laterals. Laterals are drilled with rotary compressed air drills using a 2-inch steel bit, the design of which varies widely. Diamond bits are used only rarely owing to the high cost which is often increased because of inexperienced drillers. The

laterals are drilled approximately horizontal and arranged radially. Their length varies according to the formation and may reach 300 feet or more. A single well may have several hundred feet of laterals. Only rarely are these holes cased.

The yield of wells without laterals is seldom more than 50 gallons per minute and may be too little for even a domestic supply. Lateral drilled wells are better producers and are known to pump up to 400 gallons per minute.

FACTORS DETERMINING GROUNDWATER YIELD IN BEDROCK

The general principles of the subject have been covered by Meinzer [7] and Tolman.[8] Ellis and Lee [9] also briefly covered the subject. The following discussion refers only to the particular factors effective in the bedrock of western San Diego County.

The amount of water that can be taken from a formation depends upon its permeability and the amount of water in the formation or available to it.

Structures

In the bedrock of San Diego County the permeability is governed in part by structures such as joints and faults, and in the metamorphics, schistosity, and cleavage.

Joints in most of the batholithic rocks occur in three sets approximately at right angles to one another. One may be roughly horizontal and two, vertical. One of the vertical sets commonly follows a regional northwest strike or is parallel or subparallel to a contact.

Weathering, facilitated by movement of solutions along joints, usually produces boulders of disintegration at the surface. Although the exact joint planes cannot be seen, in most places they can be approximated by a study of the alignment and shapes of the boulders.

The joints are thought to have been formed by cooling and contraction of the intrusives. Larsen [10] found them to be more closely spaced in fine-grained rocks. Near contacts, prominent, nearly vertical joints may break the rocks into slab-like pieces.

The effect of faulting in bedrock is to increase permeability by creating openings by fracturing—quite unlike the effect in most sedimentary rocks where a fault may produce an impervious barrier. Weathering or some similar mineralogical alterations take place to a greater depth in faulted zones. Wells can be sunk to a greater depth and in some places the drilling of laterals is facilitated. However, the latter process may be difficult if brecciation occurred without softening by alteration.

Structures peculiar to the metamorphic rocks are locally important influences on permeability. In addition to having much more closely spaced joints the schists and slates are characterized by openings and passageways along the schistosity and laminations. If such rocks can be successfully drilled laterally, they yield water readily. Occasional hard quartzite bands, however, are a hazard to lateral drilling and must be drilled with a diamond bit.

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[7] Meinzer, O. E., The occurrence of groundwater in the United States: U. S. Geol. Survey Water-Supply Paper 489, 1923.

[8] Tolman, C. F., Groundwater, New York, McGraw-Hill Book Co., 1937.

[9] Ellis, A. J., and Lee, C. H., op. cit.

[10] Larsen, Esper S., Jr., op. cit., p. 116.

Weathering

Permeability, in addition to being influenced by structures, is largely a function of weathering. The processes of weathering which include hydration, carbonation, and possibly other mineralogical changes, are accompanied by small volume changes which may cause slight rearrangement, and which may result in separation of the constituents so that spaces are created where water can be absorbed and along which it can move. Although clay minerals and zeolites are often found they apparently do not prevent the rock from being fairly permeable.

Weathering in San Diego County appears to take place rapidly, as indicated by the finding of moderately weathered Indian artifacts. Weathering is more intense in the highland area where very little fresh rock can be found. Even boulders of disintegration are moderately weathered. This may be due to a higher annual rainfall and to the resulting more dense vegetation which holds water longer. Furthermore, the highlands appear to be recently uplifted old surfaces of low relief which have suffered considerable weathering before uplift.

The plagioclase generally weathers more rapidly than the potash feldspars. Thus, generally, the less silicic the rock the greater the weathering.

Topography

The yield of any particular well depends not only upon the rock it penetrates and that rock's physical characteristics but also upon the amount of water available to the rock. This is determined in large part by the topographic location of the well. In most cases, the water table in this area follows the conventional relations to topography, i.e., the water table is a subdued version of the configuration of the surface; it resembles the surface but has fewer irregularities and less relief. The depth from surface to the water table is thus less in valleys and greater on hills. Furthermore, inasmuch as groundwater is largely influenced by gravity its movement is predominantly similar to surface drainage. Consequently, more water will be available to a well in a valley than to one on a ridge. This is frequently contrary to the predictions of water witches.

The porosity, and consequently the storage capacity, of most bedrock aquifers is lower than that of most alluvium. In addition, wells drilled in bedrock are most commonly farther up the drainage, or near the ridges, than wells in alluvium. Therefore, most bedrock wells are inherently lower in reserves than other types unless the drainage includes alluvium. A blanket of sediments over the bedrock greatly increases the supply provided, of course, the water table lies well within the sediment. Where possible it is a common practice to sink a well through the alluvium into the bedrock. Laterals are drilled in bedrock which will stand uncased whereas the alluvium will not. Thus advantage is taken of the storage capacity of the alluvium and of the drilling properties of the bedrock.

CHARACTERISTICS OF SPECIFIC BEDROCK TYPES

The various properties of bedrock mentioned are different in intrusives and metamorphics. Differences occur even within one particular formation; however, it is possible to make some generalizations which are consistent throughout the area.

At least 20 distinct formations have been recognized and mapped in the bedrock, but the groundwater characteristics of many are similar so

that for the present purpose they can be divided into the following four groups: gabbros, tonalites, grandiorites, and metamorphic rocks. The approximate distribution of these groups is shown in plate 1.

Metamorphic Rocks

In the east the metamorphic rocks (the Julian schist) are chiefly Mesozoic quartz-mica schists, and a little amphibolite. Quartzite, largely in massive beds, is more common in the central and western areas. This and slaty or phyllitic metasediments (Larsen's Bedford Canyon formation) occur as strips or screens between igneous bodies usually striking with the regional northwest structure. The metavolcanic rocks consist of low grade metamorphic forms of intermediate to basic pyroclastics and flows. They were named the Black Mountain volcanics by Hanna.[11] Larsen [12] called the metavolcanic rocks and related extrusives Santiago Peak volcanics. The formation is limited to the most western part of the county.

Physical properties of the metamorphic rocks are variable but many are schistose or slaty and have closely spaced joints. Both factors aid permeability and increase storage capacity. With the exception of quartzite, the rocks weather deeply and consequently often form valleys. Metaandesite tuff and slates or phyllites are the most favorable aquifers and most easily drilled. Yield of water is most erratic in the metamorphics and the success of a well depends largely upon local conditions and upon characteristics of the particular phase of metamorphic rock rather than upon any general property of the group. A typical well in slates and thin-bedded quartzite is reported to yield about 9 gallons per minute per 100 feet of lateral. The rock is so hard that laterals are made with a diamond bit.

Gabbro

Gabbro occurs throughout the area. In the east it was named "Cuyamaca basic intrusive" by Hudson,[13] but in the central and western portions the term San Marcos gabbro has been used. Most geologists believe all the gabbros to be closely related. Several petrographic types occur such as norite, quartz gabbro, troctolite, and hornblende gabbro. All varieties show prominent joints breaking outcrops into rectangles varying from a foot to several feet on a side. Fresh rock is dark gray to black, fine- to medium-grained, and equigranular. Plagioclase always comprises 60-70 percent while olivine, hornblende, augite, and hypersthene are present in variable amounts. Weathering produces red clay-rich soil. All varieties do not weather in the same way but most gabbros weather deeply with the plagioclase altering to clay minerals and zeolites. Wells more than 200-feet deep have been drilled in weathered gabbro. Laterals are usually easily drilled in such rock.

With few exceptions the gabbro is a favorable formation from which to obtain water. Wells can be dug or drilled quite readily and laterals can be drilled satisfactorily. Weathered forms of the rock are quite permeable, hence are fine aquifers. In some places weathering along exceptionally widely spaced joints has produced boulder-like bodies which hinder well work, but elsewhere, especially in moderately crushed zones, conditions are favorable.

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[11] Hanna, M. A., op. cit., pp. 199-204 .
[12] Larsen, Esper S., Jr., op. cit.
[13] Hudson, F. S., op. cit., p. 193.

Larsen's Green Valley tonalite locally resembles the San Marcos gabbro and in places they appear to be gradational. For the present purposes such phases of the Green Valley tonalite should be classed with the gabbro.

Tonalite

Tonalites are the most common rocks and underlie more than half of the area. Although several types have been distinguished and mapped accurately, they are all very similar with the exceptions of the Green Valley tonalite mentioned above. The most widespread type, the Bonsall tonalite, has been described in detail by Hurlbut.[14]

Excepting a few fine-grained, leucocratic phases the tonalites are medium, even-grained light gray rocks with clean-cut textures made up of white feldspars and quartz, and euhedral to subhedral hornblende and biotite. Outcrops are usually in the form of boulders of disintegration averaging several feet in diameter. Jointing is regular and widely spaced and excepting locally does not form important openings for groundwater storage or movement.

Weathering is moderate to deep and results in friable sand-like soil and scattered boulders. Disintegration occurs with apparently only a slight breakdown of the minerals. The plagioclase alters more easily than other minerals and undergoes hydration or kaolization which renders the rock unsound or even friable. Intergranular openings resulting from weathering are the chief groundwater spaces. Tonalite underlies some relatively flat deeply weathered surfaces such as the Fallbrook and Valley Center districts. In the latter region, many wells are in the formation.

With the exception of bouldery areas the tonalite is a moderately good source of water. Drilling can be done with churn or rotary drills. The latter is widely used for digging a shaft to be laterally drilled. This drilling is done with the minimum of difficulty as the weathered rock is uniform and soft, yet not soft enough to flow. Small quartz stringers and aplite or pegmatite dikes are local hazards to drilling. Production from this formation is probably more consistent than from any other. Although some wells in gabbro may yield more, there are also more failures in it.

Granodiorite

Several varieties of granodiorite have been recognized and mapped in this region. In general they are massive, medium even-grained, light gray granitic rocks. They are the rocks that the drillers call granite, although few true granites are found. Mineralogically, the average granodiorite consists of quartz, 30 percent; plagioclase, 40 percent; potash feldspar, 25 percent; biotite, 3 percent; and magnetite, 1 percent. Hornblende may also be present. Some varieties are nearly devoid of dark minerals and may be termed leucogranodiorite.

Jointing commonly occurs in three directions roughly at right angles to each other, thus breaking the rock into blocks. The joints are quite prominent and systematic and continuous over large areas but are much more widely spaced than in any other rocks of the region. There are exceptions to this rule where faulting has occurred. The joints are clean-cut open fractures which yield water readily. In fine-grained varieties jointing is more closely spaced.

[14] Hurlbut, C. S., Jr., Dark inclusions in a tonalite of southern California: Am. Mineralogist, vol. 20, p. 609-630, 1935.

It is not uncommon for boulders of disintegration to be 10 to 20 or more feet in length. Exfoliation of fairly fresh concentric shells is a common type of disintegration of these rocks. In some areas, especially at higher elevations, the entire rock may weather more or less uniformly, largely through the decomposition of plagioclase feldspar. This weathering is less marked than in the other more basic batholithic rocks since the latter contains more plagioclase. Weathering results in a tightly cemented gruss so that the process of decomposition cannot be said to improve the water-bearing properties of the granodiorite.

The digging of wells in this formation is usually hindered by the presence of hard unweathered masses of granodiorite or of aplite dikes. When fresh rock is encountered in digging it is necessary to resort to blasting. Drilling with a churn drill is extremely slow. Lateral drilling can be easily accomplished except where unweathered rock occurs; there it must be done with a diamond drill.

In general, the granodiorite is the poorest source of bedrock water, although in some areas such as the Rainbow district many domestic wells get water from it. They rarely produce more than a few gallons per minute. A few small springs are found in granodiorite, most of them being along brecciated zones.

RECOMMENDATIONS FOR LOCATION OF WELLS IN BEDROCK

A consideration of the factors and rock features already discussed enables one to make several generalizations regarding the occurrence of groundwater in bedrock. Such generalizations should not be used implicitly because exceptions are common. Many situations are unique and require special consideration and interpretation.

Rock Types

As far as possible, and with due consideration to other factors, wells should be located to the best rock type. In order of decreasing desirability they are generally slate or phyllite, tonalite, gabbro, granodiorite, and massive quartzite.

Considering only the rock type, the most favorable well sites are in the slaty or phyllitic metamorphic rocks. Their cleavage and tendency to break with innumerable closely spaced joints as well as the absence of clayey alteration products, common in the igneous rocks, makes these rocks fairly good aquifers. An objectionable feature is the difficulty encountered in drilling laterals. Hard slaty bands and quartzite interbeds may prevent lateral drilling except with diamond drills.

The tonalites are generally moderately good aquifers due to openings produced by volume changes accompanying weathering. The formation is easily drilled and laterals are easily driven except in bouldery areas. Such areas can be recognized by abundant boulders of disintegration at the surface. It is probably the most consistent and uniform producer of water.

The gabbro is similar to the tonalites in most respects except that the former is less uniform and may contain unpredictable hard zones.

One of the least favorable formations is granodiorite. Its widely spaced joints and clayey weathering products make it a poor aquifer and frequent unweathered zones make drilling difficult.

Small areas of quartzite are massive and have widely spaced joints. Such rocks are quite expensive to drill and yield little water.

Rock Structures

Wells can be located so as to take advantage of structures such as joints, slaty cleavages, schistosity, faults, and contacts. Even though they may not be exposed in the immediate area, a study of the vicinity usually reveals a system or pattern which may be projected to the proposed well site. Aerial photographs are often a valuable aid in such a study. Zones with the most closely spaced joints or best developed schistosity are preferable. The relation of these openings to the drainage and topography should be noted for they may act as channels which collect water and conduct it to the well.

Contacts are sometimes discontinuities which are more previous and carry more water. Jointing is often more prominent at or near contacts. Most contacts can be located by a study of surface exposures and errors derived from extrapolations are not great.

Faults are most invariably zones which carry more groundwater; however, considerable geologic field work is usually necessary to determine their location.

Topography

Other things being equal, the best well site is one having the best surface drainage because the groundwater drainage is usually similar in plan. Thus the lowest point and that having the largest drainage area above it is best. Of two sites, each having the same area of drainage, the better is that having the better storage basin. The storage is apt to be greatest if the rock is jointed or decomposed bedrock or alluvium. The denser the vegetation and the deeper the soil or overburden the better. North sloping drainage generally is best in this respect.

ESTIMATING GROUNDWATER RESERVES

It is quite difficult, if not impossible, to make an accurate estimate of groundwater reserves even with much more data than is available in any part of San Diego County. However, a rough estimate of reserves can usually be made.

A study of the methods of making a groundwater inventory in a wide variety of geological environments has been made by Meinzer.[15] The particular factors of importance in making an inventory of groundwater which occurs as described in the present report are average rainfall; area of watershed topographically above well; loss of water by evaporation and transpiration; runoff, both surface and subsurface; and amount of pumping.

The average annual precipitation may be obtained from figure 2. Exceptionally wet or dry years cause variations in the water table. Locally the natural rainfall may be augmented by irrigation, possibly by water from outside the watershed. Only exceptionally is this sufficient to materially influence the water table.

The area of the watershed can be determined from a U. S. Geological Survey topographic map. The product of this area and the precipitation (plus irrigation water) is the volume of water entering the area. Obviously no well can perennially produce more than this amount.

Loss of water by transpiration from vegetation varies widely with differences in plant type and irrigation practices. Loss by evaporation

[15] Meinzer, O. E., Outline of methods for estimating groundwater supplies: U. S. Geol. Survey Water-Supply Paper 638-C, 1932.

is likewise variable and difficult to evaluate. Both processes are limited to water which lies within approximately 10 feet of the surface. Inasmuch as the water table of most of the area described here is well below that, such losses are of rain water or irrigation water before it penetrates 10 feet or more.

Surface runoff is important in areas of moderate or high relief such as most of the bedrock region. Depending upon the cover of vegetation and the rate of rainfall the runoff may range from none to 20 percent on the annual precipitation, the exact amount being quite difficult to measure.

Loss of water by subsurface runoff is quite slow. The direction of movement is roughly like the surface drainage. No quantitative data is available for such groundwater movement in bedrock in this area. However, measurements of underflow in the sediments of the San Luis Rey Valley at Bonsall indicate a rate of 340 acre-feet per year.[16]

Data on removal of water from the groundwater reservoir by pumping can be obtained from records kept by water users or from power bills if electric pumps are used.

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[16] Ellis and Lee, op. cit., p. 48.

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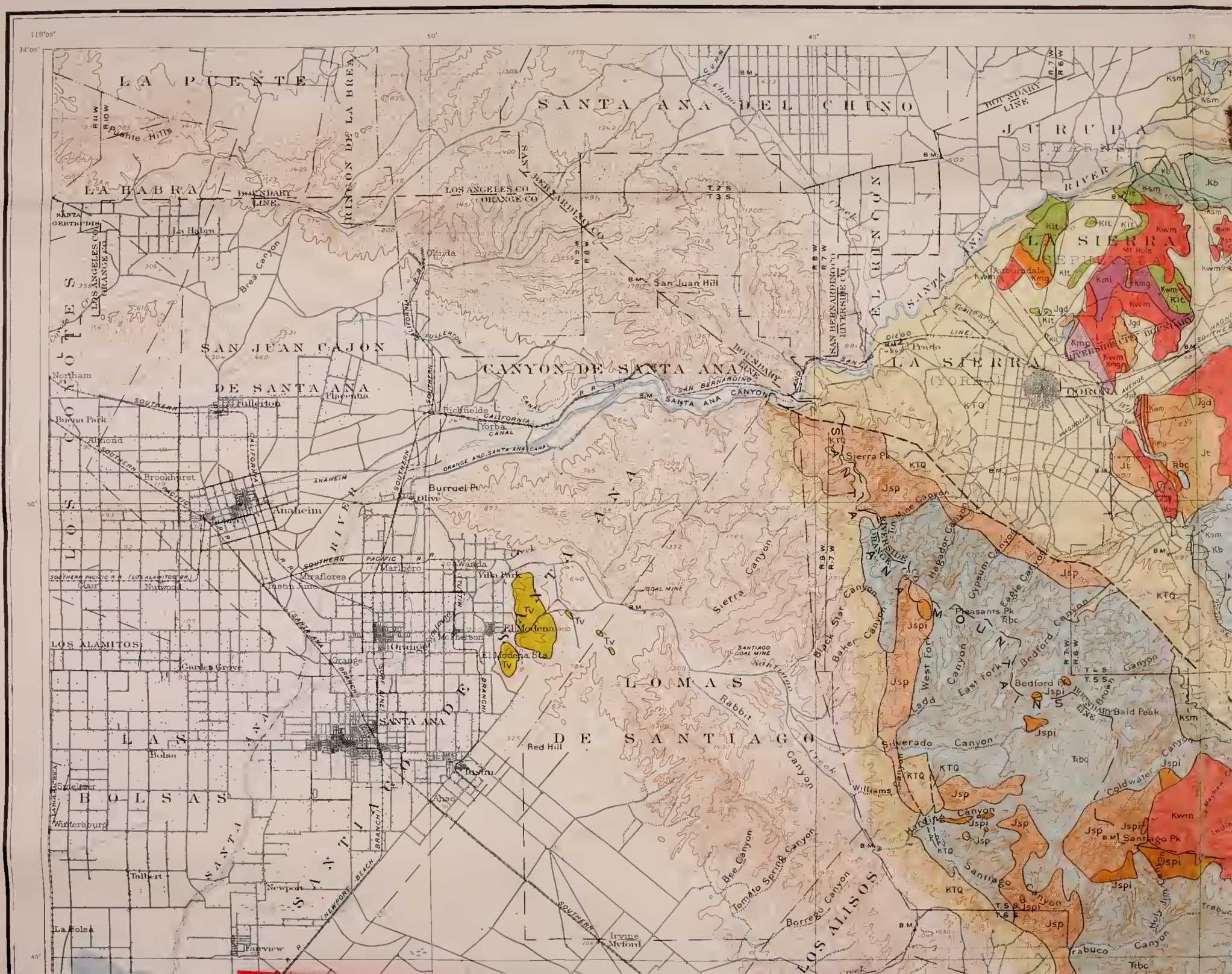

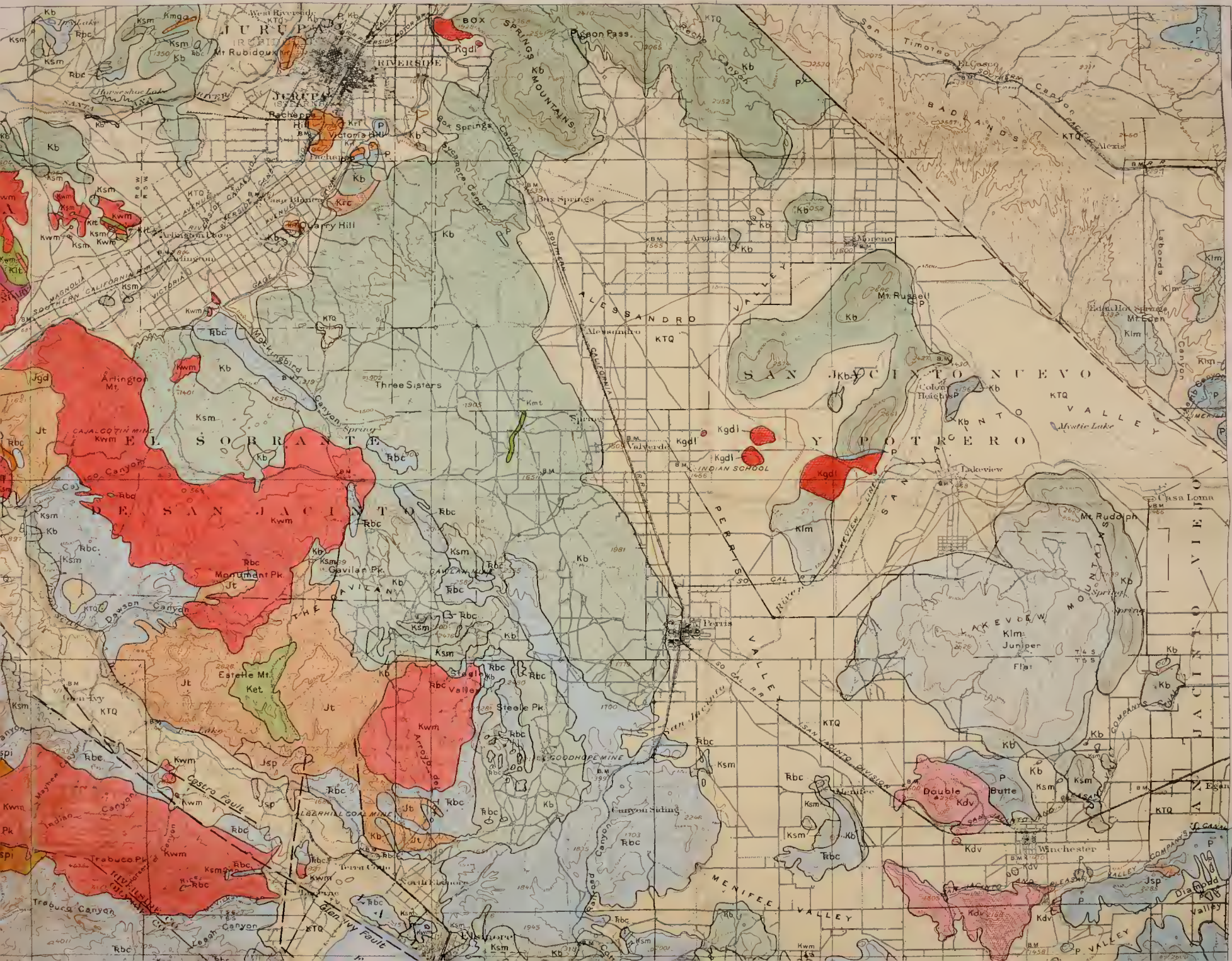
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Canyon Siding
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Canyon
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Elsinore
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Perris Valley
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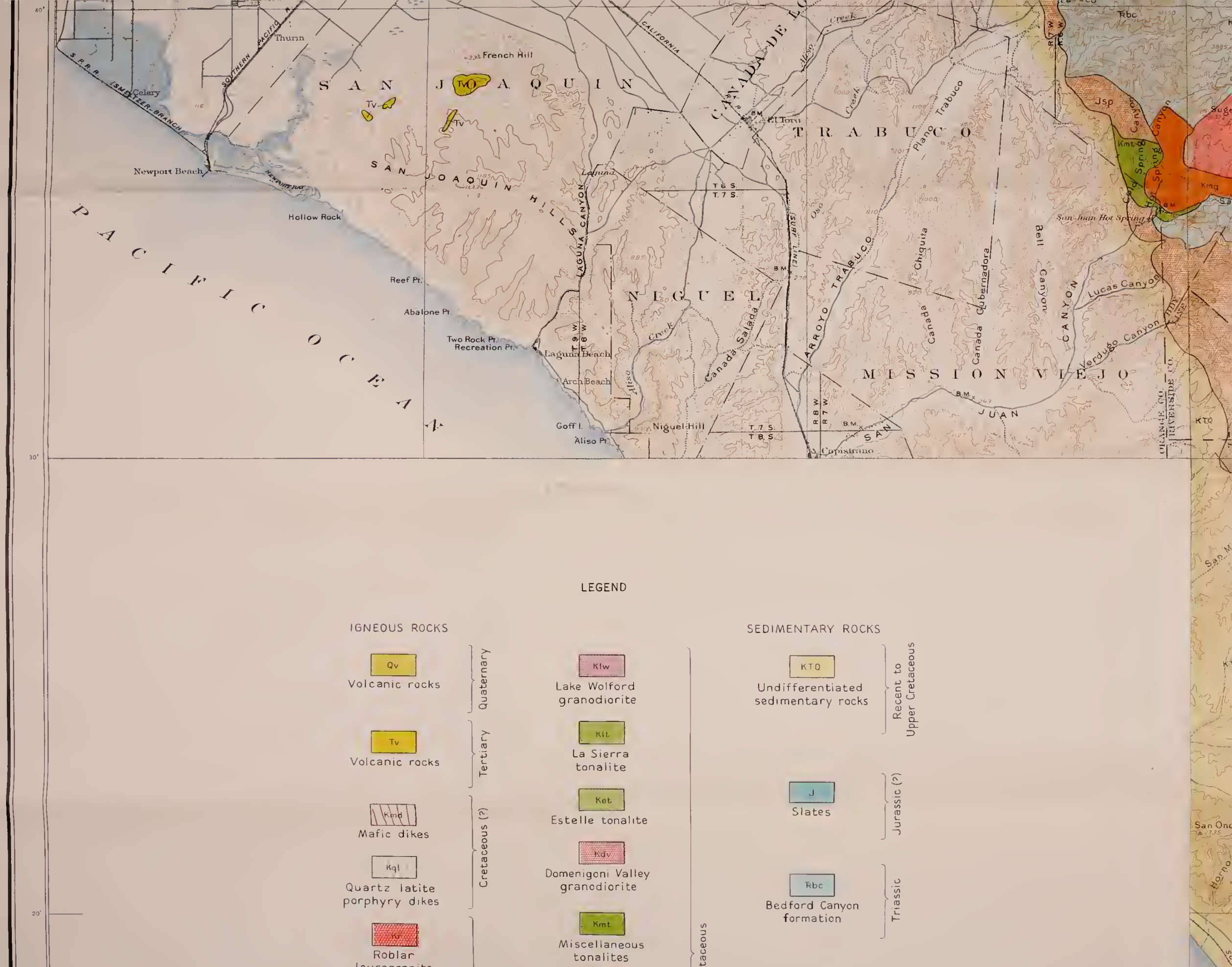


LEGEND

IGNEOUS ROCKS

Quaternary

- Qv — Volcanic rocks

Tertiary

- Tv — Volcanic rocks

Cretaceous (?)

- Kmd — Mafic dikes
- Kql — Quartz latite porphyry dikes

Cretaceous

- Kr — Roblar leucogranite
- Kmp — Micropegmatite-granite northeast of Corona
- Klw — Lake Wolford granodiorite
- Klt — La Sierra tonalite
- Ket — Estelle tonalite
- Kdv — Domenigoni Valley granodiorite
- Kmt — Miscellaneous tonalites
- Kgal — Granodiorite west of Lakeview
- Kb

SEDIMENTARY ROCKS

Recent to Upper Cretaceous

- KTQ — Undifferentiated sedimentary rocks

Jurassic (?)

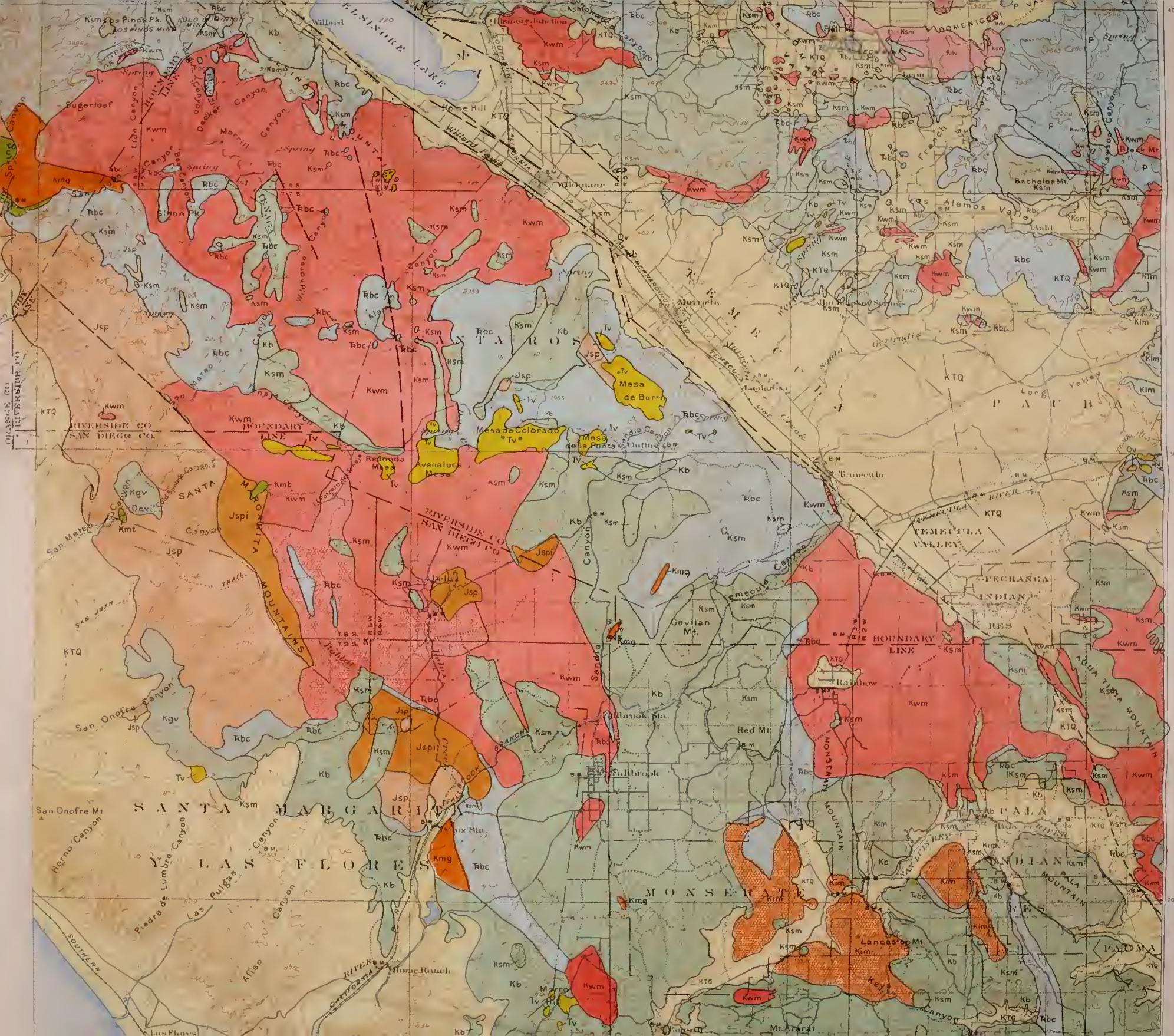
- J — Slates

Triassic

- Rbc — Bedford Canyon formation

Paleozoic

- P — Quartzite and schist


ELSINORE LAKE
Willard
Rose Hill
Willard Fault
Wildomar
Murrieta
Temecula
Lindenau
Mesa de Burro
Mesa de Colorado
Mesa de la Punta
Redonda Mesa
Avenaloca Mesa
RIVERSIDE CO
SAN DIEGO CO
BOUNDARY LINE
SANTA MARGARITA MOUNTAINS
Gavilan Mt.
Red Mt.
Fallbrook
Rainbow
Black Mt.
Bachelor Mt.
Los Alamos Valley
TEMECULA VALLEY
PECHANGA INDIAN RES
AGUA TIBIA MOUNTAIN
MONSERATE MOUNTAIN
PALA INDIAN RES
PALA MOUNTAIN
PADMA
Lancaster Mt.
Keys
Mt. Ararat
Home Ranch
Morro
Las Flores
SANTA MARGARITA
LAS FLORES
MONSERATE
SANTA ROSA
PALA
San Onofre Mt.
Sugarloaf
Silton Pk.
Los Pinos Pk.
Sandia Canyon
Wildhorse Canyon
Morrill Canyon
Deer Canyon
Devil Canyon
San Mateo Canyon
San Onofre Canyon
Horno Canyon
Piedra de Lumbre Canyon
Las Pulgas Canyon
Alisso Canyon
Temecula Canyon
Long Valley
Spring
Trail
SOUTHERN CALIFORNIA
RIVER
ORANGE CO
RIVERSIDE CO

leucogranite

Kmp
Micropegmatite-granite northeast of Corona

Krc
Coarse leucogranite of Rubidoux Mountain

Krf
Fine leucogranite of Rubidoux Mountain

Kmg
Miscellaneous granodiorites

Kml
Mt. Hole granodiorite

Ke
Escondido Creek leucogranodiorite

Kim
Indian Mountain leucogranodiorite

Kwm
Woodson Mountain granodiorite

Cretaceous

Kgdl
Granodiorite west of Lakeview

Kb
Bonsall tonalite

Klm
Lakeview Mountain tonalite

Kgv
Green Valley tonalite

Ksm
San Marcos gabbro

Cre

Jgd
Dark granodiorite porphyry east of Corona

Jt
Temescal Wash quartz latite porphyry

Jsp
Santiago Peak volcanics

Jspi
Intrusive rocks related to Santiago Peak volcanics

Jurassic (?)

P
Quartzite and schist

Paleozoic

Cor	El
	SLR

Base map of the Corona, Elsinore, and San Luis Rey quadrangles by the United States Geological Survey

Geology by Esper S Larsen, Jr

10'

33°00'

118°00'

50'

40'

30'

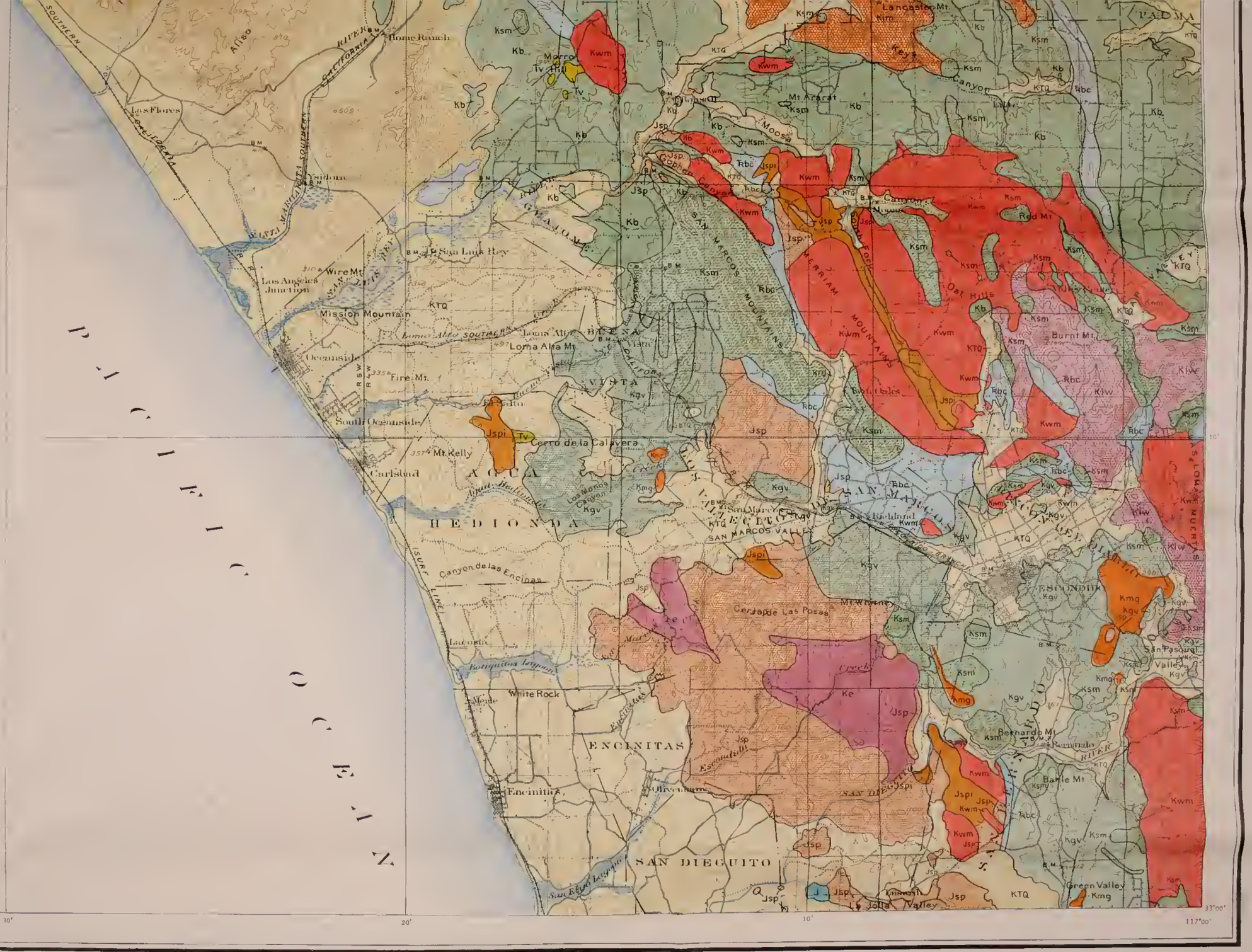
GEOLOGIC MAP OF THE CORONA, ELSINORE, AND S

Scale 1:25,000

Contour interval 100 Fe

Datum is mean sea level

1948



AND SAN LUIS REY QUADRANGLES, CALIFORNIA

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Miles

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LEGEND

QUATERNARY

Qal — Alluvium (gravels, sands and silt)

Cretaceous

Kq — Vein quartz

Ka — Aplite dikes

Kp — Granite pegmatite

Kr — Rattlesnake granite (biotite granite with muscovite)

Kl — Leucogranodiorite (light-colored, fine-grained granodiorite)

Kw — Woodson Mountain granodiorite, Kw (biotite granodiorite) (coarse grained phase with hypersthene, Kwh)

Kb — Bonsall tonalite (hornblende-biotite quartz diorite)

Kg — Green Valley tonalite (hornblende-quartz diorite)

Kd — Diorite

Cuyamaca gabbro (troctolite, olivine gabbro, norite and hornblende gabbro)

Jurassic (?)

Js — Stonewall granodiorite (biotite granodiorite and minor quartz diorite)

Mixed rock (Julian schist and Stonewall granodiorite)

Triassic (?)

ŦRj — Julian schist (quartz-mica schist, quartz, and minor amphibolite)

60 — Contact showing dip (dashed if gradational or approximately located)

55 — Strike and dip of beds. Schistosity is parallel to stratification

90 — Strike of vertical beds

70 — Strike and dip of primary foliation

Strike of vertical primary foliation

Corps of Engineers U. S. Army
Surveyed in 1940 1942

GEOLOGIC MAP OF THE CUYAMACA PEAK QUADRANGLE, CALIFORNIA

By Donald L. Everhart

Geology by Donald L. Everhart
1941 and 1946

Scale 1/62500

Contour interval 50 feet
Datum is mean sea level

ECONOMIC MAP OF THE CUYAMACA PEAK QUADRANGLE, CALIFORNIA

By Donald L. Everhart

Scale 1/62500

Contour interval 50 feet
Datum is mean sea level

LEGEND

QUATERNARY

- Qal — Alluvium (gravels, sands and silt)
- Kq — Vein quartz
- Ka — Aplite dikes
- Kp — Granite pegmatite
- Kr — Rattlesnake granite (biotite granite with muscovite)
- Kl — Leucogranodiorite (light colored fine-grained granodiorite)

Cretaceous

- Kw, Kwh — Woodson Mountain granodiorite, Kw (biotite granodiorite) (coarse grained phase with hypersthene, Kwh)
- Kb — Bonsall tonalite (hornblende-biotite quartz diorite)
- Kg — Green Valley tonalite (hornblende quartz diorite)
- Kd — Diorite
- Kc — Cuyamaca gabbro (troctolite, olivine gabbro, norite and hornblende gabbro)

Jurassic (?)

- Js — Stonewall granodiorite (biotite granodiorite and minor quartz diorite)
- Jm — Mixed rock (Julian schist and Stonewall granodiorite)

Triassic (?)

- Trj — Julian schist (quartz-mica schist, quartzite and minor amphibolite)

Contact showing dip (dashed if gradational or approximately located)

Strike and dip of beds. Schistosity is parallel to stratification

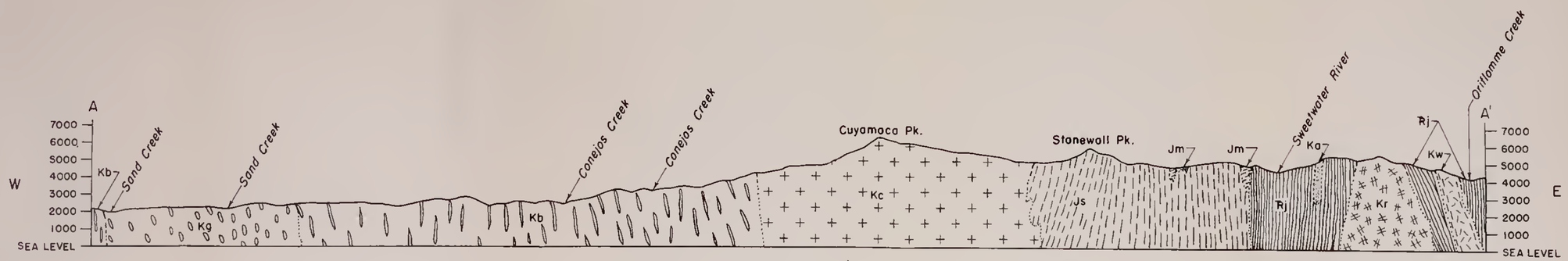
Strike of vertical beds

Strike and dip of primary foliation

Strike of vertical primary foliation

Mine

Prospect



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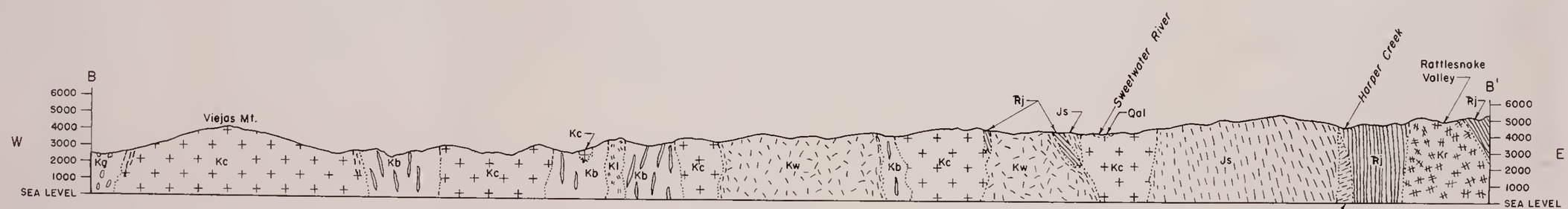

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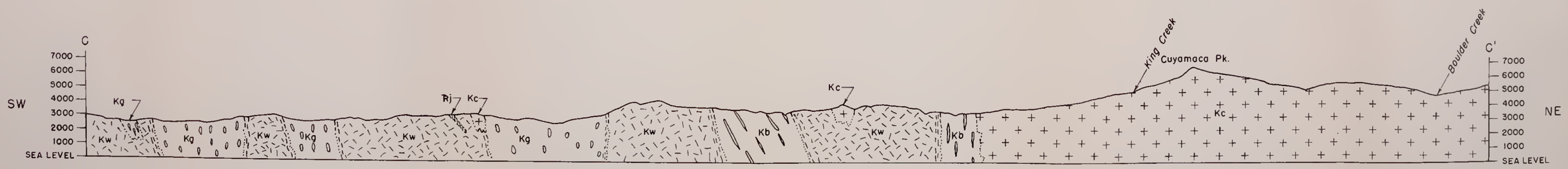


SECTION C-C'

LEGEND

QUATERNARY

- Qal — Alluvium

Cretaceous

- Ka — Aplite dikes
- Kr — Rattlesnake granite
- Kl — Leucogranodiorite
- Kw — Woodson Mountain granodiorite
- Kb — Bonsall tonalite
- Kg — Green Valley tonalite
- Kc — Cuyamaca gabbro

Jurassic (?)

- Js — Stonewall granodiorite
- Jm — Mixed rock

Triassic (?)

- Rj — Julian schist

HORIZONTAL AND VERTICAL SCALE
1 0 1 2 MI.

Geology by Donald L. Everhart

GEOLOGIC CROSS SECTIONS THROUGH THE CUYAMACA PEAK QUADRANGLE, SAN DIEGO COUNTY, CALIF.

LEGEND

QUATERNARY

- Qal — Alluvium

Cretaceous

- Kq — Vein quartz
- Ka — Aplite dikes
- Kp — Granite pegmatite
- Kr — Rattlesnake granite
- Kl — Leucogranodiorite
- Kw, Kwh — Woodson Mountain granodiorite
- Kb — Bansall tonalite
- Kg — Green Valley tonalite
- Kd — Diorite
- Kc — Cuyamaca gabbro

Jurassic (?)

- Js — Stonewall granodiorite
- Jm — Mixed rock

Triassic (?)

- Rj — Julian schist

Contact showing dip (dashed if gradational or approximately located)

Strike and dip of beds
Schistosity is parallel to stratification

Strike of vertical beds

Strike and dip of primary foliation

Strike of vertical primary foliation

Trace of flow lines, showing overall structural grain of rock units; structural features are locally erratic

Massive
Rocks showing no preferred structural orientation

Primary joints of Woodson Mountain granodiorite

Strike and dip of joints (G, gentle dip, less than 45°) (S, steep dip, 45°–90°)

Strike of vertical joints

Trace of joints

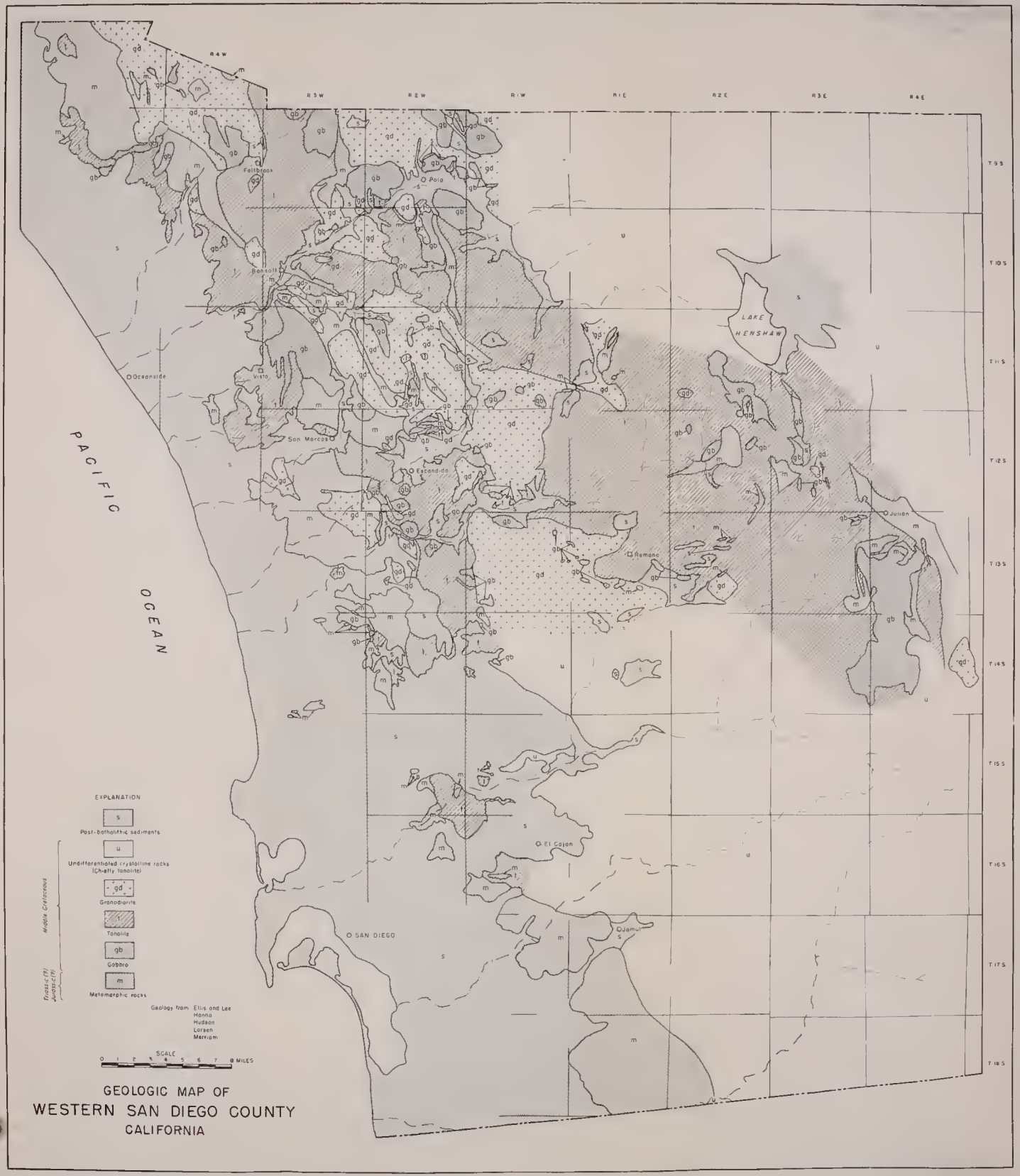
GEOLOGIC STRUCTURE MAP OF THE CUYAMACA PEAK QUADRANGLE

By Donald L. Everhart

1 0 1 2 3 MILES

NORTH

Vertical aerial photographs showing primary joint pattern in a Woodson Mountain granodiorite massif in the southwestern corner of Cuyamaca Peak quadrangle.



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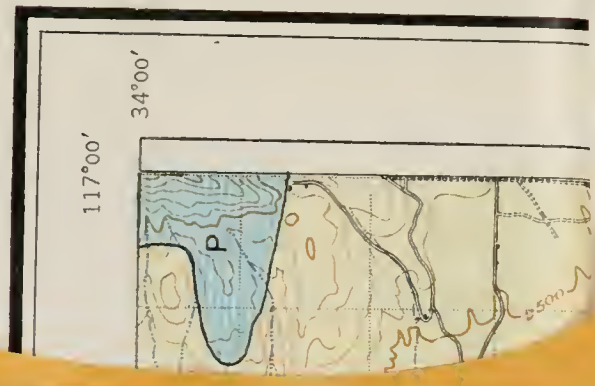

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