DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

GEORGE OTIS SMITH, DIRECTOR

GEOLOGIC ATLAS

OF THE

UNITED STATES

SAN FRANCISCO FOLIO

TAMALPAIS, SAN FRANCISCO, CONCORD, SAN MATEO, AND HAYWARDS QUADRANGLES

CALIFORNIA

BY

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GEOLOGIC ATLAS OF THE UNITED STATES.

[illegible]ogical Survey is making a geologic atlas of the [illegible] States, which is being issued in parts, called folios. Each folio includes topographic and geologic maps of a certain area, together with descriptive text.

THE TOPOGRAPHIC MAP.

The features represented on the topographic map are of three distinct kinds—(1) inequalities of surface, called *relief*, as plains, plateaus, valleys, hills, and mountains; (2) distribution of water, called *drainage*, as streams, lakes, and swamps; (3) the works of man, called *culture*, as roads, railroads, boundaries, villages, and cities.

Relief.—All elevations are measured from mean sea level. The heights of many points are accurately determined, and those of the most important ones are given on the map in figures. It is desirable, however, to give the elevation of all parts of the area mapped, to delineate the outline or form of all slopes, and to indicate their grade or steepness. This is done by lines each of which is drawn through points of equal elevation above mean sea level, the vertical interval represented by each space between lines being the same throughout each map. These lines are called *contour lines* or, more briefly, *contours*, and the uniform vertical distance between each two contours is called the *contour interval*. Contour lines and elevations are printed in brown. The manner in which contour lines express altitude, form, and grade is shown in figure 1.

FIGURE 1.—Ideal view and corresponding contour map.

The sketch represents a river valley between two hills. In the foreground is the sea, with a bay that is partly closed by a hooked sand bar. On each side of the valley is a terrace. The terrace on the right merges into a gentle hill slope; that on the left is backed by a steep ascent to a cliff, or scarp, which contrasts with the gradual slope away from its crest. In the map each of these features is indicated, directly beneath its position in the sketch, by contour lines. The map does not include the distant portion of the view. The following notes may help to explain the use of contour lines:

1. A contour line represents a certain height above sea level. In this illustration the contour interval is 50 feet; therefore the contour lines are drawn at 50, 100, 150, and 200 feet, and so on, above mean sea level. Along the contour at 250 feet lie all points of the surface that are 250 feet above the sea—that is, this contour would be the shore line if the sea were to rise 250 feet; along the contour at 200 feet are all points that are 200 feet above the sea; and so on. In the space between any two contours are all points whose elevations are above the lower and below the higher contour. Thus the contour at 150 feet falls just below the edge of the terrace, and that at 200 feet lies above the terrace; therefore all points on the terrace are shown to be more than 150 but less than 200 feet above the sea. The summit of the higher hill is marked 670 (feet above sea level); accordingly the contour at 650 feet surrounds it. In this illustration all the contour lines are numbered, and those for 250 and 500 feet are accentuated by being made heavier. Usually it is not desirable to number all the contour lines. The accentuating and numbering of certain of them—say every fifth one—suffices and the heights of the others may be ascertained by counting up or down from these.

2. Contour lines show or express the forms of slopes. As contours are continuous horizontal lines, they wind smoothly about smooth surfaces, recede into all reentrant angles of ravines, and project in passing around spurs or prominences. These relations of contour curves and angles to forms of the landscape can be seen from the map and sketch.

3. Contour lines show the approximate grade of any slope. The vertical interval between two contours is the same, whether they lie along a cliff or on a gentle slope; but to attain a given height on a gentle slope one must go farther than on a steep slope, and therefore contours are far apart on gentle slopes and near together on steep ones.

A small contour interval is necessary to express the relief of a flat or gently undulating country; a steep or mountainous country can, as a rule, be adequately represented on the same scale by the use of a larger interval. The smallest interval used on the atlas sheets of the Geological Survey is 5 feet. This is in regions like the Mississippi Delta and the Dismal Swamp. For great mountain masses, like those in Colorado, the interval may be 250 feet and for less rugged country contour intervals of 10, 20, 25, 50, and 100 feet are used.

Drainage.—Watercourses are indicated by blue lines. For a perennial stream the line is unbroken, but for an intermittent stream it is broken or dotted. Where a stream sinks and reappears the probable underground course is shown by a broken blue line. Lakes, marshes, and other bodies of water are represented by appropriate conventional signs in blue.

Culture.—The symbols for the works of man and all lettering are printed in black.

Scales.—The area of the United States (exclusive of Alaska and island possessions) is about 3,027,000 square miles. A map of this area, drawn to the scale of 1 mile to the inch would cover 3,027,000 square inches of paper and measure about 240 by 180 feet. Each square mile of ground surface would be represented by a square inch of map surface, and a linear mile on the ground by a linear inch on the map. The scale may be expressed also by a fraction, of which the numerator is a length on the map and the denominator the corresponding length in nature expressed in the same unit. Thus, as there are 63,360 inches in a mile, the scale "1 mile to the inch" is expressed by the fraction $\frac{1}{63,360}$.

Three scales are used on the atlas sheets of the Geological Survey; they are $\frac{1}{250,000}$, $\frac{1}{125,000}$, and $\frac{1}{62,500}$, corresponding approximately to 4 miles, 2 miles, and 1 mile on the ground to an inch on the map. On the scale of $\frac{1}{62,500}$ a square inch of map surface represents about 1 square mile of earth surface; on the scale of $\frac{1}{125,000}$, about 4 square miles; and on the scale of $\frac{1}{250,000}$, about 16 square miles. At the bottom of each atlas sheet the scale is expressed in three ways—by a graduated line representing miles and parts of miles, by a similar line indicating distance in the metric system, and by a fraction.

Atlas sheets and quadrangles.—The map of the United States is being published in atlas sheets of convenient size, which represent areas bounded by parallels and meridians. These areas are called *quadrangles*. Each sheet on the scale of $\frac{1}{250,000}$ represents one square degree—that is, a degree of latitude by a degree of longitude; each sheet on the scale of $\frac{1}{125,000}$ represents one-fourth of a square degree, and each sheet on the scale of $\frac{1}{62,500}$ one-sixteenth of a square degree. The areas of the corresponding quadrangles are about 4000, 1000, and 250 square miles, though they vary with the latitude.

The atlas sheets, being only parts of one map of the United States, are not limited by political boundary lines, such as those of States, counties, and townships. Many of the maps represent areas lying in two or even three States. To each sheet, and to the quadrangle it represents, is given the name of some well-known town or natural feature within its limits, and at the sides and corners of each sheet are printed the names of adjacent quadrangles, if the maps are published.

THE GEOLOGIC MAPS.

The maps representing the geology show, by colors and conventional signs printed on the topographic base map, the distribution of rock masses on the surface of the land and, by means of structure sections, their underground relations, so far as known and in such detail as the scale permits.

KINDS OF ROCKS.

Rocks are of many kinds. On the geologic map they are distinguished as igneous, sedimentary, and metamorphic.

Igneous rocks.—Rocks that have cooled and consolidated from a state of fusion are known as *igneous*. Molten material has from time to time been forced upward in fissures or channels of various shapes and sizes through rocks of all ages to or nearly to the surface. Rocks formed by the consolidation of molten material, or magma, within these channels—that is, below the surface—are called *intrusive*. Where the intrusive rock occupies a fissure with approximately parallel walls it is called a *dike*; where it fills a large and irregular conduit the mass is termed a *stock*. Where molten magma traverses stratified rocks it may be intruded along bedding planes; such masses are called *sills* or *sheets* if comparatively thin, and *laccoliths* if they occupy larger chambers produced by the pressure of the magma. Where inclosed by rock molten material cools slowly, with the result that intrusive rocks are generally of crystalline texture. Where the channels reach the surface the molten material poured out through them is called *lava*, and lavas often build up volcanic mountains. Igneous rocks that have solidified at the surface are called *extrusive* or *effusive*. Lavas generally cool more rapidly than intrusive rocks and as a rule contain, especially in their superficial parts, more or less volcanic glass, produced by rapid chilling. The outer parts of lava flows also are usually porous, owing to the expansion of the gases originally present in the magma. Explosive action, due to these gases, often accompanies volcanic eruptions, causing ejections of dust, ash, lapilli, and larger fragments. These materials, when consolidated, constitute breccias, agglomerates, and tuffs.

Sedimentary rocks.—Rocks composed of the transported fragments or particles of older rocks that have undergone disintegration, of volcanic ejecta deposited in lakes and seas, or of materials deposited in such water bodies by chemical precipitation are termed *sedimentary*.

The chief agent in the transportation of rock débris is water in motion, including rain, streams, and the water of lakes and of the sea. The materials are in large part carried as solid particles, and the deposits are then said to be mechanical. Such are gravel, sand, and clay, which are later consolidated into conglomerate, sandstone, and shale. Some of the materials are carried in solution, and deposits of these are called organic if formed with the aid of life, or chemical if formed without the aid of life. The more important rocks of chemical and organic origin are limestone, chert, gypsum, salt, iron ore, peat, lignite, and coal. Any one of the kinds of deposit named may be separately formed, or the different materials may be intermingled in many ways, producing a great variety of rocks.

Another transporting agent is air in motion, or wind, and a third is ice in motion, or glaciers. The most characteristic of the wind-borne or eolian deposits is loess, a fine-grained earth; the most characteristic of glacial deposits is till, a heterogeneous mixture of bowlders and pebbles with clay or sand.

Sedimentary rocks are usually made up of layers or beds which can be easily separated. These layers are called *strata*, and rocks deposited in such layers are said to be stratified.

The surface of the earth is not immovable; over wide regions it very slowly rises or sinks, with reference to the sea, and shore lines are thereby changed. As a result of upward movement marine sedimentary rocks may become part of the land, and most of our land areas are in fact occupied by rocks originally deposited as sediments in the sea.

Rocks exposed at the surface of the land are acted on by air, water, ice, animals, and plants, especially the low organisms known as bacteria. They gradually disintegrate and the more soluble parts are leached out, the less soluble material being left as a *residual* layer. Water washes this material down the slopes, and it is eventually carried by rivers to the ocean or other bodies of water. Usually its journey is not continuous, but it is temporarily built into river bars and flood plains, where it forms *alluvium*. Alluvial deposits, glacial deposits (collectively known as *drift*), and eolian deposits belong to the *surficial* class, and the residual layer is commonly included with them. Their upper parts, occupied by the roots of plants, constitute soils and subsoils, the soils being usually distinguished by a notable admixture of organic matter.

Metamorphic rocks.—In the course of time, and by various processes, rocks may become greatly changed in composition and in texture. If the new characteristics are more pronounced than the old such rocks are called *metamorphic*. In the process of metamorphism the constituents of a chemical rock may enter into new combinations and certain substances may be lost or new ones added. A complete gradation from the primary to the metamorphic form may exist within a single rock mass. Such changes transform sandstone into quartzite and limestone into marble and modify other rocks in various ways.

From time to time during geologic ages rocks that have been deeply buried and have been subjected to enormous pressures, to slow movement, and to igneous intrusion have been afterward raised and later exposed by erosion. In such rocks the original structures may have been lost entirely and new ones substituted. A system of planes of division, along which the rock splits most readily, may have been developed. This structure is called *cleavage* and may cross the original bedding planes at any angle. The rocks characterized by it are *slates*. Crystals of mica or other minerals may have grown in the rock in such a way as to produce a laminated or foliated structure known as *schistosity*. The rocks characterized by this structure are *schists*.

As a rule, the oldest rocks are most altered and the younger formations have escaped metamorphism, but to this rule there are many important exceptions, especially in regions of igneous activity and complex structure.

FORMATIONS.

For purposes of geologic mapping rocks of all the kinds above described are divided into *formations*. A sedimentary formation contains between its upper and lower limits either rocks of uniform character or rocks more or less uniformly varied in character, as, for example, an alternation of shale and limestone. Where the passage from one kind of rocks to another is gradual it may be necessary to separate two contiguous formations by an arbitrary line, and in some cases the distinction depends almost entirely on the contained fossils. An igneous formation contains one or more bodies of one kind, of similar occurrence, or of like origin. A metamorphic formation may consist of rock of uniform character or of several rocks having common characteristics or origin.

When for scientific or economic reasons it is desirable to recognize and map one or more specially developed parts of a varied formation, such parts are called *members*, or by some other appropriate term, as *lentils*.

AGES OF ROCKS.

Geologic time.—The time during which rocks were made is divided into *periods*. Smaller time divisions are called *epochs*,

DESCRIPTION OF THE SAN FRANCISCO DISTRICT.

By Andrew C. Lawson.

GEOGRAPHY.

SITUATION AND GENERAL DIVISIONS OF THE AREA.

The five sheets of the San Francisco folio—the Tamalpais, San Francisco, Concord, San Mateo, and Haywards sheets—map a territory lying between latitude 37° 30′ and 38° and longitude 122° and 122° 45′. Large parts of four of these sheets cover the waters of the Bay of San Francisco or of the adjacent Pacific Ocean. (See fig. 1.) Within the area mapped

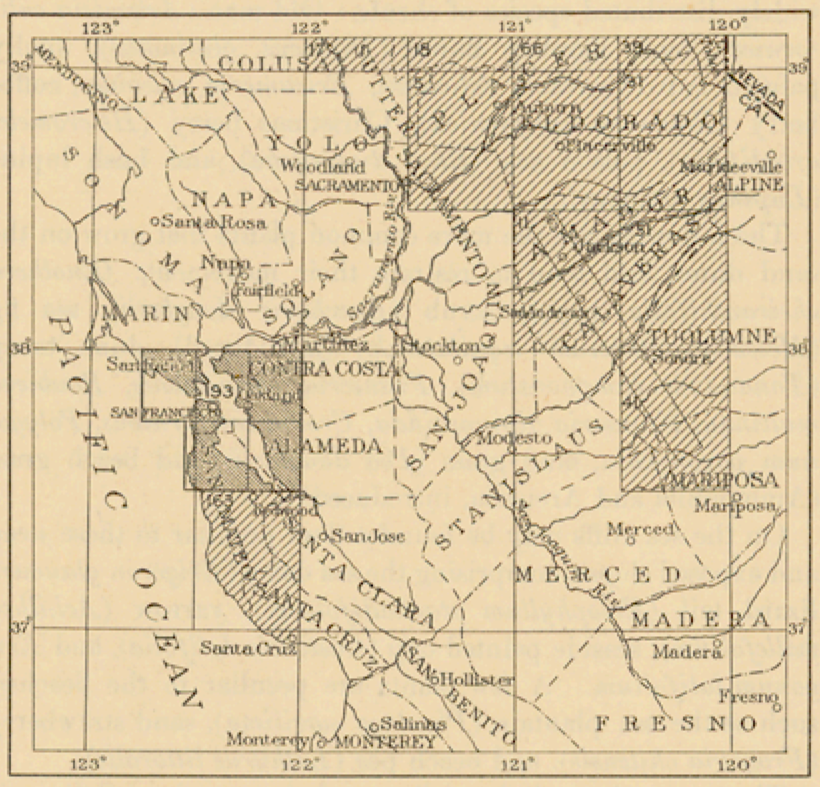

FIGURE 1.—Index map of central California.

The location of the five quadrangles described in the San Francisco folio is shown by the darker ruling (No. 193). Published folios describing other quadrangles are indicated by lighter ruling and the proper serial numbers and are included in the numerical list on the back cover of this folio.

are the cities of San Francisco, Oakland, Berkeley, Alameda, San Rafael, and San Mateo, and many smaller towns and villages. These cities, which have a population aggregating about 750,000, together form the largest and most important center of commercial and industrial activity on the west coast of the United States. The natural advantages afforded by a great harbor, where the railways from the east meet the ships from all ports of the world, have determined the site of a flourishing cosmopolitan, commercial city on the shores of San Francisco Bay. The bay is encircled by hilly and mountainous country diversified by fertile valley lands and divides the territory mapped into two rather contrasted parts, the western part being again divided by the Golden Gate. It will therefore be convenient to sketch the geographic features under four headings—(1) the area east of San Francisco Bay; (2) the San Francisco Peninsula; (3) the Marin Peninsula; (4) San Francisco Bay. (See fig. 2.)

AREA EAST OF SAN FRANCISCO BAY.

Relief.—The area east of San Francisco Bay embraces a belt of hilly country lying between the bay and the western flank of Mount Diablo. The ridges trend generally northwest and southeast. Portions of two wide valleys lie within this area. One of these is the valley of San Francisco Bay, on whose shores stand the cities of Berkeley, Oakland, and Alameda; the other is Ygnacio Valley, which occupies the northeast corner of the Concord quadrangle and extends with a very flat slope northward beyond the limits of the quadrangle to the shores of Suisun Bay. The southern extension of this valley, up the drainage line of Walnut Creek, is the well-defined flat-bottomed San Ramon Valley, which sharply separates the belt of hills above mentioned from Mount Diablo, the greater mass of which lies farther east, in the adjacent quadrangle. The dominant range of hills is that which forms the southwestern limit of the belt and which immediately overlooks the Bay of San Francisco. The culminating point on this range is Bald Peak, east of Berkeley, which stands at an altitude of 1930 feet above sea level. Other peaks whose altitudes afford an idea of the general height of the range are Grizzly Peak, 1759 feet; Round Top, 1750 feet; and Redwood Peak, 1608 feet. This range is commonly referred to as the Berkeley Hills, although the area to which that term is applicable appears to be rather vaguely defined. It is also often referred to as the Contra Costa Hills, but this term apparently applies more properly to the broad group of hills between the Bay of San Francisco and Mount Diablo. A rather well defined line of valleys, including San Pablo and Moraga valleys, separates this dominant range from the more eastern portion of the hilly belt. The hills thus lying between the dominant ridge and Ygnacio and Ramon valleys show a less pronounced linear trend, are much more mature in their geographic expression, and in general are much lower. The culminating points in this part of the belt are Rocky Ridge (2000 feet) on the south, and the Briones Hills (1432 feet) on the north.

In the Haywards quadrangle there is a notable sag in the longitudinal profile of the range, and at Haywards there is a gap at the level of the alluvial plain, which here stands about 100 feet above sea level. This gap is the outlet of a remarkably open low valley known as Castro Valley.

Drainage.—The drainage of the area includes several features worthy of special mention:

1. The dominant ridge of the hill belt does not form the divide that separates the waters flowing directly to the Bay of San Francisco from those flowing to Suisun Bay by way of Walnut Creek, in San Ramon and Ygnacio valleys. The divide runs through the center of the belt of hills, so that a very considerable portion of the lower ground northeast of the dominant ridge is drained either through or around the end of the ridge. The southern half of the range drains through gaps in the ridge, which form outlets to the bay for San Leandro and San Lorenzo creeks. The northern half is drained by San Pablo Creek, which flows around the end of the main ridge, and by Pinole Creek, which flows to San Pablo Bay.

2. A second feature of the drainage of especial interest is that, though the streams on the northeast side of the dominant ridge are manifestly subsequent, those draining the southwestern slope of the same ridge directly to the bay are manifestly consequent, presenting a condition which suggests that the slope to San Francisco Bay is of more recent origin than the maturely dissected hill country farther northeast—a suggestion which is more fully discussed in this text, under the heading "Structure."

3. A third feature is the prevailing alluviation of the valley bottoms and the steep-sided stream trenches cut in the alluvium, which do not as a rule reach the bedrock, clearly indicating that the former conditions in this area favored more vigorous downward corrasion by the streams, at a time when the canyons and valleys were deeper, and that with the passing of these conditions others ensued which reduced the transporting power of the streams and caused them to drop their load of detritus in the bottoms of the canyons and valleys, making these flat and broad, as well as helping to give the country its geomorphically mature aspect and adding to its agricultural value. Since these flat-bottomed valleys were thus formed there seems to have been a slight but distinct tendency toward a recurrence of the older conditions, indicated by the trenching of the valley floors, but this trenching may be due, in part at least, to the disturbance of natural conditions caused by culture.

Attention may be called also to the rather noteworthy convergence of drainage in Castro Valley near Haywards. Most of this drainage is carried by San Lorenzo Creek through a pronounced break in the Berkeley Hills.

The only other notable feature of the drainage is the fact that the stream flowing in San Ramon Valley, the largest, most mature, and broadest valley in the Concord quadrangle, has cut through the alluvium on the valley floor at several places, particularly from Alamo to the village of Walnut Creek, where it runs on bedrock.

FIGURE 2.—Map of vicinity of San Francisco Bay, showing topographic features and the geomorphic divisions resulting from the adjustment by tilting of great fault blocks.

The eastern boundary of the Berkeley Hills block is not sharply defined: it may be drawn along a general zone of overthrust folding and faulting just east of the Berkeley Hills, on which the Mount Diablo thrust block has ridden westward. This thrust movement antedated the tilting of blocks to the west. The submerged bar outside the Golden Gate originated as a delta deposit of the stream that flowed in the old valley of San Francisco Bay before the land was submerged.

The five quadrangles described in this folio are shown by heavier lines than the boundaries of other quadrangles.

Soil.—The soils of the country may be divided into two classes. The soil on the hillsides and ridge tops above the level of the valley floors is sedentary—that is to say, it has been formed in place by the chemical and mechanical disintegration of the underlying rocks. This soil has been modified chiefly by the abstraction of certain constituents which nourished the generations of plants that have grown upon the surface and by the addition of organic matter formed by the decay of the same vegetation. On these hill slopes earthworms are uncommon, probably because the soil is very dry and parched during the summer, so they have not aided in turning over and mixing the soil and in thus making it more useful for agriculture. This work, however, has been performed, probably with equal efficiency, by several kinds of burrowing mammals, such as the gopher (Thomomys) and the ground squirrel (Spermophilus). These animals formerly infested the region in great numbers and have persisted there until very recently, in spite of the efforts of the farmers to destroy them, but during the last few years, by more systematic efforts, the health authorities have almost completely exterminated them, because they are regarded as a menace to the public health as propagators of the bubonic plague through the fleas which infest them.

These sedentary soils, having been formed from the immediately underlying rocks, vary in character from place to place, and here and there the slopes are so steep that little or no soil can accumulate. The soils derived from the Cretaceous and Eocene formations are perhaps those best adapted to agriculture, but they lie chiefly on high ground that is cut by rather steep canyons, so that they are not so generally cultivated as the soils of the lower ground. The sandstones of the Monterey group, which are very quartzose, yield nearly everywhere a light sandy soil, whereas the shale and chert formations of the same group yield scant and poor soils. Considerable areas that are underlain by the shale and chert carry no soil whatever, the bare mechanically disintegrated rock forming the surface of the ground. The fresh-water deposits of the Orinda formation have generally yielded deep and excellent soils, which, however, are in many places heavy and clayey.

The soil in the bottoms of the valleys is not sedentary but has been derived from various sources in the course of the degradation of the surrounding hills and is excellent. It varies from a sandy to a clayey loam and in certain localities is even gravelly, but in practically all places it is well adapted to successful tillage.

Vegetation.—The region is almost devoid of forest. Hilltops and slopes are bare of trees (see Pl. II) and the prevailing mantle of vegetation in uncultivated tracts is composed of the wild oat (*Avena fatua*) and other wild grasses (*Danthonia californica, Festuca myuros, Lolium temulentum*, and species of Hardeum); but on the south sides of steep canyons the slopes may be covered with a more or less dense growth of brush. The only native timber to which the term forest might be applied is the grove of redwoods (*Sequoia sempervirens*) on the west side of Redwood Canyon, extending from the creek to the summit of Redwood Peak. The only other conifers in the district are the digger pine (*Pinus sabiniana*), which is a feature of the lower slopes of Mount Diablo on the east side of San Ramon Valley, and the knobcone pine (*Pinus alternata*), which grows locally on the summit of the first ridge east of Redwood Canyon.

The most abundant tree is the live oak (*Quercus agrifolia*), common in canyons and on north and east slopes and also notable for filling shallow gulches or south and west slopes of otherwise treeless hills. The valley oak (*Quercus lobata*) is characteristic of the open valleys, growing only sparingly or not at all on the hills. It is most common in San Ramon and Ygnacio valleys. The blue oak (*Quercus douglasii*) is scattered over dry hills in the eastern part of the area. The buckeye (*Æsculus californica*) grows along the bases of low hills. The laurel (*Umbellularia californica*) is the commonest tree in canyon bottoms. It also clusters about rocky knolls on ridges and slopes. Along the stream courses are found the red alder (*Alnus oregona*) and the white alder (*Alnus rhombifolia*), the latter, however, only east of the crest of the Berkeley Hills. There are three willows, the most abundant and widely distributed being the white willow or arroyo willow (*Salix lasiolepis*), which thrives in dry gulches in the hills as well as along living streams. The yellow willow (*Salix lasiandra*) and the red willow (*Salix lævigata*) are mostly confined to living streams. The madrone (*Arbutus menziesii*) is rare and is found chiefly with the redwoods but extends northward to Strawberry Canyon. The big-leaf maple (*Acer macrophyllum*), the box elder (*Negundo californicum*), and the sycamore (*Platanus racemosa*) are rare. The California walnut (*Juglans californica*) grows along streams at Walnut Creek and Lafayette. Taking the territory as a whole, the brush-covered areas are more striking than the wooded areas. The brush of the Berkeley Hills is composed chiefly of nine-bark (*Neillia capitata*), coffee berry (*Rhamnus californica*), hill scrub (*Baccharis pilularis*), poison oak (*Rhus diversiloba*), and mountain lilac (*Ceanothus thyrsiflorus* and *C. sorediatus*). Typical chaparral is not common, although colonies of manzanita (*Arctostaphylos manzanita*) and similar shrubs are found, particularly east of the crest of the Berkeley Hills. Chamiso grows more or less extensively on Las Trampas Ridge, on the hill east of Redwood Peak, and at the base of Mount Diablo.[a]

Climate.—The crest of the Berkeley Hills is a dividing line for the climate of this region. The climate of the area east of the crest is somewhat like that of the interior valleys; that of the west slope of the Berkeley Hills is like that of the coast. In the area east of the crest the summers are hotter and the winters are colder than in the area farther west. The sea breezes and fogs that temper the summer heat on the west slope have a greatly diminished influence on the east side of the Berkeley Hills. The annual rainfall at Berkeley is about 27.48 inches, and it falls almost wholly in winter, the summer being rainless. Snow rarely falls, even on the highest ground, and no snowfall lasts more than a day.

SAN FRANCISCO PENINSULA.

The territory west of the Bay of San Francisco is naturally divided into a northern and a southern part by the Golden Gate. South of the Golden Gate lies the San Francisco Peninsula, with the city of San Francisco at its northern extremity; north of it lies the Marin Peninsula, whose most notable feature is Mount Tamalpais.

Relief and drainage.—The San Francisco Peninsula is divided into two parts by Merced Valley. Each of these parts has the general profile of a much dissected orographic block having a gentle slope to the northeast and a crest line on its southwest margin. The culminating crest of the northern block is San Bruno Mountain (elevation 1315 feet), and the corresponding crest of the southern block is Montara Mountain (elevation 1952 feet). The structural line separating the surface areas of the blocks is the trace of the San Bruno fault, which lies at the base of the steep southwest front of San Bruno Mountain. In character of relief these two blocks present an interesting contrast. The surface of the northern block is irregularly hilly and, except in San Bruno Mountain, shows but little linearity in the disposition of its crests and valleys. Its geomorphy is fairly mature, although a characteristic feature of that maturity is a certain ruggedness of profile due to the presence of formations composed of radiolarian chert. The exceptional resistance which these offer to erosion causes the areas they occupy to present a marked contrast with adjoining areas composed of sandstone. San Bruno Mountain, however, is a simple linear ridge with an immature frontal slope overlooking Merced Valley.

The southern block is marked by notable linearity in its crests and valleys, and its geomorphy is in general much less mature than that of the northern block. The most remarkably linear feature is the valley in which lie San Andreas and Crystal Springs lakes (see Pl. IX), a short segment of the San Andreas rift valley, a feature due to repeated faulting in recent geologic time. The trace of the fault of 1906 follows this rift for about 300 miles. The valley is due in part directly to earth movement but in large measure also to the mashing of the rock in the fault zone and its consequent easy erosion. Northeast of the San Andreas rift lies the equally linear Buriburi Ridge, which slopes down to Merced Valley and to the Bay of San Francisco. San Mateo Creek cuts across this ridge transversely at nearly its widest part, draining the valley of the San Andreas rift, both the part which lies northwest and that which lies southeast of the point where the creek leaves the rift to flow through a sharply incised gorge toward the Bay of San Francisco. The position of this trunk drainageway of the rift valley indicates that it is a superimposed stream, the course of which was established when the slope was mantled by softer formations, now removed. The slope of the Montara orographic block in the area southwest of the rift valley is dissected by a series of subparallel steep-sided canyons and intervening ridges, which are in large part remnants of the original tilted surface. Viewed in a large way, however, this tilted slope, taken as a whole, from the crest of Montara Mountain to the Bay of San Francisco, presents a broadly terraced aspect. It comprises two terrace levels or steps, one the flat-topped ridge that is elsewhere called the Buriburi Plateau, the general elevation of which is about 700 feet, and the other the Sawyer Plateau, comprising a number of flat-topped ridges that stand at elevations of 1100 to 1200 feet.

The crest of the tilted block known as Montara Mountain is composed of quartz diorite and is somewhat serrate in its longitudinal profile, its serration being due to its incision by the headwater erosion of the high-grade streams on its southwest front. On the precipitous shoulders and ridges of the southwest face of the mountain there are obscure traces of terraces at elevations of 400 to 500 feet. At the base of the mountain front, but separated from it by an alluviated valley, is a low ridge, known as Miramontes, terminating in Pillar Point. This ridge is composed of folded late Pliocene strata, which rest upon the quartz diorite. A little north of this, at Montara Point, is a fine example of a superimposed stream cutting through a foothill ridge, with lower ground between it and the base of Montara Mountain.

The sand dunes of the city of San Francisco are notable features of the north end of the peninsula. The sand is blown in from the beach south of the Golden Gate by the westerly winds and drifts eastward over the western part of the city as a wide expanse of ripple-marked dunes. The encroachment of the sand is now, however, in large measure checked by the extension of city improvements toward the beach and by the planting of suitable vegetation in the sand to restrain its movement.

Shore lines.—The shore lines of the two sides of the peninsula present a marked contrast. On the bay side the shore contour is immaturely serrate, with tidal marshes and other evidences of silting in the bays between the points, cliff cutting is relatively feeble, and there are no clean sandy or pebbly beaches. On the ocean side the attack of the waves has developed extended lines of sea cliffs with sandy beaches at their bases, and the embayments between the cliffs are filled out. This process has proceeded so far as to give the shore a simple and mature contour, only a few short points—as, for example, San Pedro Point—projecting seaward. The shore features, particularly those on the bay side of the peninsula, indicate the recent subsidence of an erosionally dissected land mass, and a like subsidence on the seaward side is indicated by Merced Lake, which before it was modified for use as a reservoir was a flooded stream valley shut off by drifting sands.

Soil.—The soil of the peninsula is largely sedentary on the gentler slopes of the surface that are underlain by the sandstones of the Franciscan group and the comparatively soft strata of the Merced (Pliocene) and Quaternary formations. But little soil accumulates upon areas occupied by the radiolarian cherts of the Franciscan group, by the serpentine associated with the Franciscan, or by the quartz diorite ("Montara granite"). At the base of the hills and in some of the valleys there are belts of rich soil formed by the accumulation of alluvium washed from higher levels. In the vicinity of San Francisco the loose sandy soil is intensively cultivated, with the liberal use of fertilizers, for growing vegetables for the local market. A part of the hill land is adapted to cattle grazing and dairying, but the large reserves maintained by the Spring Valley Water Co. to keep the city water supply free from pollution have restricted the areas available for these industries.

Vegetation.—Climatic conditions are adverse to forest growth on the San Francisco Peninsula. Most of the high ground is bare of trees. In the gullies and canyons, however, there is a more or less luxuriant growth of shrubs and low trees, comprising California laurel (*Umbellularia californica*), coffee berry (*Rhamnus californica*), creek dogwood (*Cornus pubescens*), arroyo willow (*Salix lasiolepis* var. *bigelovii*), wax myrtle (*Myrica californica*), coast live oak (*Quercus agrifolia*), and blue blossom (*Ceanothus thyrsiflorus*).

On the open hills may be found the following common and widely distributed species of shrubs: Old man (*Artemisia californica*), bush monkey flower (*Diplacus glutinosus*), woolly painted cup (*Castilleia foliolosa*), *Ericameria ericoides*, coffee berry (*Rhamnus californica*), Christmas berry (*Heteromeles arbutifolia*), poison oak (*Rhus diversiloba*), and bush lupine (*Lupinus arboreus*).

The following are the more common plants that grow on the sand dunes and tend to restrain their movement: *Œnothera cheiranthifolia*, coyote scrub (*Baccharis douglasii*), sea fig (*Mesembryanthemum æquilaterale*) (introduced), dune tansy (*Tanacetum camphoratum*), *Franseria chamissonis, Roubieva multifida, Franseria bipinnatifida, Croton californicus, Polygonum paronychia*, sand grass (*Poa douglasii*), and beach grass (Ammophila and Arenaria, introduced).

On the sea cliffs may be found a flora peculiar to these steep and exposed slopes, comprising the sea daisy (*Erigeron glaucus*), lizard tail (*Eriophyllum stæchadifolium*), yarrow (*Achillæa millefolium*), seaside painted cup (*Castilleia latifolia*), and *Eriogonum latifolium*. A few plants are peculiar to the beaches, such as the sea plantain (*Plantago maritima*), sand strawberry (*Fragaria chilensis*), and beach pea (*Lathyrus littoralis*).

The vegetation of the salt marshes comprises *Salicornia ambigua, Triglochin maritima, Frankenia grandifolia, Atriplex patula, Atriplex hastata, Tissa macrotheca*, and *Cotula coronopifolia*. Near the tidal channels and in the parts of the marshes that have been longest reclaimed to vegetation there may be found a variety of sedges and tules, such as *Scirpus lacustris* var. *occidentalis, Scirpus olneyi, Scirpus robustus, Cyperus brongniartii, Juncus patens, Juncus xiphioides*, and *Typha latifolia*.

Climate.—At San Francisco the only marked seasonal change is due to difference in precipitation. The mean annual temperature is 56° F. The coldest month is January, which has a mean temperature of 50°, and the warmest is the period from the middle of September to the middle of October, during which the mean temperature is 60°. On summer afternoons a layer of fog 1700 feet deep spreads over the city. The mean annual rainfall is 22.83 inches, which falls in winter, the summer being rainless. The prevailing winds are westerly, and their average velocity is 9.7 miles an hour. The mean relative humidity is 88 per cent in the morning and 73 per cent in the evening. At Pilarcitos Lake, about 15 miles south of the center of San Francisco, the annual rainfall is about double that at the city; but the rainfall decreases southeastward, along the valley of the bay, from 22.83 inches at San Francisco to 15 inches at San Jose. Places on the bay side of the peninsula are colder in winter and warmer in summer than the city of San Francisco. In winter the valley bottoms on the bay side are subject to frequent morning frosts, but on the slopes of the surrounding hills frosts are less frequent and less severe. In summer the valleys may be bathed in bright sunshine while San Francisco and the Golden Gate are mantled in dense fog. The climate of the peninsula thus presents marked local variations, and these variations are doubtless related to the relief.

MARIN PENINSULA.

Relief.—The Marin Peninsula presents the features of a dissected mountain mass which has been depressed sufficiently to permit the waters of the ocean to enter the stream valleys and so convert them into bays or inlets. Its highest point is Mount Tamalpais, which has an elevation of 2604 feet. From this peak a ridge with a fairly even crest extends westward and then northwestward beyond the Tamalpais quadrangle. From the peak and crest the surface falls away in steep slopes on all sides, in an alternation of canyons and steep-crested ridges. The canyons are all of steep grade and have steep sides, but where they reach the sea level they widen very notably and their bottoms become flaring, flat valley floors, which are occupied for the most part by salt marshes. This description applies particularly to the bay side of the peninsula, where Tiburon Peninsula and San Quentin Point separate three embayments that reach far inland to the base of the mountain and that are very evidently drowned valleys. On its west side

[a] For much of the information contained in this and other paragraphs dealing with the vegetation the writer is indebted to Prof. W. L. Jepson.

the main mass of the Marin Peninsula has a very even steep slope, which in part descends to the sea and in part to the bottom of the straight, narrow valley that separates the Point Reyes Peninsula from the mainland. This declivity ranges in width from 1½ to 2 miles and except at its southern end is not deeply trenched by the streams that cross it. This western shore of the Marin Peninsula, which is without notable embayments and promontories, presents a marked contrast to the extremely indentate and irregular eastern shore on the bay side, and the geomorphic asymmetry of the peninsula suggests that it is a tilted orographic block, elevated on its western and depressed on its eastern margin. This interpretation of the origin of its geomorphic features agrees with that given for the north end of the San Francisco Peninsula, for, as the west or southwest boundary of the Marin block is similar to the southwest boundary of the San Francisco block, as exemplified in the front of San Bruno Mountain, and as the two lie in the same general straight line, the mainland of the Marin Peninsula and the north end of the San Francisco Peninsula are evidently parts of the same tilted crustal block and have had a common geomorphic history. This block is transected by the Golden Gate, which separates it superficially into two parts. The Golden Gate is without doubt the gorge of a trunk stream which maintained itself across the block during the slow progress of its tilting and which subsequently, after the depression of the region, became a marine strait through which the sea flooded the valley on the lower side of the block.

Besides the Golden Gate, another valley completely transects the tilted block. This is Elk Valley, which extends across the Marin Peninsula from the head of Richardson Bay to Tennessee Cove. It is a narrow valley of low gradient, which has steep mountain slopes on both sides and which lies at right angles to the axis of the block. The bottom of this valley, though narrow, is alluviated throughout by the wash from the adjacent slopes. The highest point of the valley bottom is about midway between the bay and the ocean and lies between the 175-foot and 200-foot contours. This point is evidently the headwater portion of a stream that crossed a part of the block prior to the tilting. Rodeo Lagoon, just north of the Golden Gate, occupies the only drowned valley on the west side of the mainland of the Marin Peninsula.

San Andreas rift valley.—The Point Reyes Peninsula is geographically distinct from the mainland of the Marin Peninsula and is separated from it by a long, narrow, straight valley, the north end of which is occupied by Tomales Bay and the south end by Bolinas Lagoon, a lake cut off from the ocean by a sandspit. This forms a notable segment of the San Andreas rift valley, and the trace of the fault of April 18, 1906, runs completely through it. Its straight, linear course was undoubtedly determined by the existence of the zone of recurrent faulting which, partly by displacement and partly by excessive erosion induced by rock mashing, finds topographic expression in the rift valley.

Point Reyes Peninsula.—The dominant feature of the relief of the Point Reyes Peninsula is a comparatively straight ridge on its eastern margin, parallel to and close to the rift valley. From this ridge the ground slopes, with many minor irregularities, westward to the seashore. The streams that drain this slope have in their lower stretches been drowned by subsidence, and both Tomales Bay and Bolinas Lagoon were also formed by subsidence.

At the south end of the Point Reyes Peninsula is one of the most clearly evident wave-cut terraces on the coast of California. It has the form of a very even topped, gently sloping plateau, the rear of which, where it abuts against ancient and now much degraded sea cliffs, stands about 250 feet above the sea. This wave-cut terrace has a maximum width of over a mile and a half and terminates on its seaward side at the brink of the modern sea cliffs. It is now dissected by numerous small streams, which run seaward across it from the high ground on the north.

We thus have side by side—in the drowned streams and the elevated sea cliffs—abundant evidence of the opposite movements of elevation and subsidence of this part of the coast, subsidence having been probably the later movement. It is remarkable that although there is so fine an elevated wave-cut terrace on the Point Reyes Peninsula there is no well-defined trace of elevated strands on the western shore of the mainland of the Marin Peninsula.

Soil.—The soil of the Marin Peninsula is chiefly sedentary, so that its character in most places depends on that of the underlying formations. The principal formation, the sandstone of the Franciscan group, yields a sandy loam soil, which, however, is scant on the prevailingly steep slopes. There is but little soil upon the radiolarian chert formations of the Franciscan group and the associated serpentine. The spheroidal basalt yields a red soil, which is deep enough to be tillable on gentle slopes. In the valley bottoms above the limit of the salt marsh the soil is a fertile alluvium composed of the wash of the valley slopes. Cattle raising and dairying are the chief agricultural industries on the peninsula.

Vegetation.—The woody vegetation of the Marin Peninsula is either chaparral or tree growth of various sorts. Chaparral is the dominant type. It covers the main slopes of Mount Tamalpais up to its summit and considerable areas farther north, along Bolinas Ridge and toward San Rafael, becoming less abundant toward the north. It includes mainly the following species: *Arctostaphylos tomentosa*, *A. manzanita*, *A. nummularia*, *Ceanothus thyrsiflorus*, *C. foliosus*, *C. rigidus*, *C. prostratus* var. *divergens*, *C. cuneatus*, *C. sorediatus*, *Garrya elliptica*, *Rhamnus californica*, *Quercus dumosa*, *Q. wislizenii* var. *frutescens*, and *Adenostoma fasciculatum*, or chamiso.

The tree growth is confined mostly to canyons or occurs as a scattered stand on northern slopes. In the canyons it consists mainly of *Sequoia sempervirens*, *Pseudotsuga taxifolia*, and *Umbellularia californica*. On the lower northern slopes of Mount Tamalpais is an open stand comprising *Quercus californica* (the most abundant species), *Q. garryana*, and *Arbutus menziesii*.

Along the streams may be found *Fraxinus oregana*, *Alnus rubra*, and *Acer macrophyllum*. Associated with the scattered oaks there is considerable *Rhus diversiloba*, and the redwoods of the canyons are accompanied by the plants that commonly form the undergrowth of the main redwood belt, comprising *Vaccinium ovatum*, *Gaultheria shallon*, *Oxalis oregana*, *Scoliopus bigelovii*, *Trillium ovatum*, and *Clintonia andrewsiana*.

On the western slope of Mount Tamalpais are a few patches of the rare *Cupressus sargentii*, and in the valleys near San Rafael is a form of valley oak that shuns the coast.

The vegetation on the west side of the San Andreas rift valley is radically different from that on the east side. From Bolinas Lagoon northward the eastern slope of the main ridge of the Point Reyes Peninsula is covered with a forest which, though not continuous, is fairly dense in the areas where it is best developed. This forest is composed almost exclusively of *Pinus muricata*, which is accompanied by a little *Pasania densiflora* and *Quercus agrifolia* and by considerable *Umbellularia californica* on very steep slopes. The densest part of the forest is, however, pure *Pinus muricata*. The shrubs of the Point Reyes Peninsula are northern types, which have here their southernmost or nearly their southernmost representation. These shrubs include *Rubus spectabilis* var. *menziesii*, *Ledum glandulosum*, and *Rhododendron californicum*.

The vegetation of the marsh lands is practically the same as that which characterizes the marshes of the San Francisco Peninsula, already listed.

Climate.—The climate of the Marin Peninsula, unlike that of the city of San Francisco, is characterized by fairly well marked seasonal changes in temperature. The mean annual temperature is 55° F., nearly the same as that of San Francisco, but the mean January temperature is 40° and the mean July temperature is 70°. The mean annual rainfall at Kentfield (elevation 65 feet) is 51.34 inches, which is over double that of San Francisco; but at Point Reyes Light it is only 30.80 inches. The prevailing winds are northwest, and their average velocity on Mount Tamalpais is 17.8 miles an hour. The maximum velocities occur at Point Reyes Light. The summer afternoon fogs generally do not extend to the top of Mount Tamalpais, and the upper surface of the fog seen in the bright sunlight from the summit is a most remarkable and beautiful sight. The coast north of the Golden Gate, particularly in summer, is covered by a sea fog 100 to 1700 feet thick, which lies along the coast with its bottom frequently a hundred feet or less above sea level.

BAY OF SAN FRANCISCO.

The Bay of San Francisco is a submerged valley and is a most notable example of a great harbor formed by the influx of the sea into the low parts of a subsiding coast. (See Pl. IV.) If the region were uplifted so that the water were drained out of the bay, the depression would not differ in its essential features from the Santa Clara, Santa Rosa, or Napa valleys. If, on the other hand, the coast were still farther depressed, so that these valleys also were flooded, they would have features entirely analogous to those of the Bay of San Francisco. The isolated hills and some of the foothill ridges would become islands similar to Angel Island and Goat Island, the tributary valleys would become embayments or inlets similar to Richardson Bay and San Rafael Bay, and the intervening ridges would become peninsulas or promontories like Tiburon Peninsula, Hunter Point, and San Pablo Point.

Before the valley of the Bay of San Francisco was submerged there flowed through it a river that drained the great interior valley of California. This river probably ran between the Tiburon Peninsula and Angel Island, where, in Raccoon Strait, there is a deep channel with a sounding of 39 fathoms. Thence it flowed through the gorge of the Golden Gate, where the present maximum depth of water is 69 fathoms, between Fort Point and Lime Point. The position of this ancient river in Raccoon Strait suggests that it was a superimposed stream whose course had been determined when the region was covered with soft Pliocene formations, which have since been carried away by erosion.

The waters of the bay that lie away from the main channel are comparatively shallow. From Raccoon Strait to San Pedro Point the main channel has a maximum depth of 16 fathoms in the narrowest place, but the depth of the water in general in this part of the bay ranges from 4 to 8 fathoms. The channel through San Pablo Bay at most places beyond San Pedro Point does not exceed 4 fathoms in depth, but it deepens notably at Carquinez Strait, where it is constricted. The water in San Pablo Bay is shallow, its depth averaging perhaps 7 feet at low tide. In the area between San Francisco and Goat Island the maximum depth is 20 fathoms, and south of this area the deeper water channel has in general a depth diminishing from 10 fathoms to 6 fathoms, with rather shallow water on both sides. The fact that the deepest channel lies in the most constricted parts indicates that these depths are maintained by tidal scour and that the present deep-water channel can not be assumed to represent throughout its course the trench of the ancient river.

Before the submergence of the valley now occupied by the bay the streams draining the surrounding hills flowed down over more or less gravelly or sandy bottoms to the trunk drainageway and spread gravel and sand over the valley bottom. As subsidence proceeded these gravels and sands became buried by finer silts. This process continued by stages, so that beneath the floor of the valley and beneath the bay there is an alternation of sands or gravels with finer silts or clays, and some of these deposits contain marine fossils, which have been discovered by boring. This recurrent burial of fluviatile gravels and sands by fine silt or clay involved many changes in the courses of the stream channels as they ran out from the canyons over the floor of the valley, but each of these gravelly channels, whatever its course at any stage of the infilling of the valley, remained connected as a strip of sand and gravel with the portion of the stream that lay above the zone of aggradation. Thus were established the conditions of an artesian basin, the features of which will be further described under the heading "Economic geology."

The Bay of San Francisco is evidently a submerged land valley, and the geomorphic features of its periphery and the valley itself were manifestly shaped by the ordinary agencies of erosion, but as the valley lies on the relatively depressed sides of the San Francisco-Marin and Montara crustal blocks it was probably in large part outlined by the movement that tilted these blocks, and to that extent it is of diastrophic origin. A second movement of depression appears to have affected the region as a whole and allowed the sea to enter the gorge at the Golden Gate, which had been cut by stream erosion across the crest of the rising side of the northern block. That the earth movements in this region were not simple is shown by the fact that on the southeast side of San Pablo Bay and about the west end of Carquinez Strait there are wave-cut terraces and elevated deposits of marine shells of species that are still living; whereas in the area south of San Pablo Bay there are no such terraces or elevated late Quaternary marine deposits. The evidences of uplift on San Pablo Bay appear on a third and quite distinct crustal block, represented by the Berkeley Hills, and the only place where this block touches the Bay of San Francisco is at San Pablo Bay. The Haywards fault, which skirts the western flank of the Berkeley Hills, is in the zone of dislocation between this block and the block on whose depressed side lies the greater part of the bay.

Outside of the Golden Gate, extending out to the Farallon Islands, there is a broad submerged embankment, which lies beneath an area of very shallow water. (See fig. 2.) This embankment probably in part represents the delta of the ancient river that once flowed through the Golden Gate before the depression, but it has been also in part built up by deposits of fine silt, which in the flood season are carried through the Bay of San Francisco and dropped outside the Gate.

GEOLOGY.[a]

STRATIGRAPHY AND AREAL GEOLOGY.

GEOLOGIC FORMATIONS OF THE MIDDLE COAST RANGES.

The middle Coast Ranges of California, within which lie the quadrangles described in this folio, are composed of many different kinds of rock, both igneous and sedimentary. The geologic history of the region is varied, including records of deposition, erosion, diastrophism, and volcanic eruptions, and the geologic structure is correspondingly complex and interesting.

[a] The geologic mapping of the area covered by this folio has afforded an opportunity for training in field geology many students in the University of California, who have contributed observations that are recorded in the text. The list of these contributors is long, however, and the same ground has been worked over by different students, so that it is impracticable to make individual acknowledgments for the aid rendered. The nominal author of the folio is familiar with all parts of the field and assumes responsibility for the correctness of the observations made and conclusions reached in the work done under his direction, but he gratefully acknowledges his obligations to all who have aided in this work.

In the study of the fossiliferous formations the author has had the active cooperation of Prof. J. C. Merriam, whose contributions, with those of his students, have been indispensable in unraveling the intricate geology of the Concord quadrangle. All the fossils named in the lists here published have been identified by Prof. Merriam.

The formations comprising the sedimentary rocks are graphically represented in the section on the columnar-section sheet.

The oldest known rocks are certain quartzites, limestones, and crystalline schists, which are best exposed in the Santa Cruz, Santa Lucia, and Gabilan ranges. The age of these rocks is not yet known, but some of them are probably early Mesozoic and some are possibly Paleozoic.

These older rocks are intruded by the granitic and dioritic rocks of the ranges just mentioned and their extensions northward through Montara Mountain, the Farallon Islands, and the Point Reyes Peninsula as far as Bodega Head.

Upon the eroded surface of the complex of plutonic and metamorphic rocks rests the Franciscan group, composed chiefly of sandstones, radiolarian chert, foraminiferal limestone, and lavas, associated with which are intrusive masses of spheroidal basalt and serpentinized peridotite. These rocks are widely distributed in the middle Coast Ranges, occurring notably in the Mount Hamilton and Mount Diablo ranges, about the Bay of San Francisco, and in areas north of the bay.

Upon the Franciscan group the Shasta series (Lower Cretaceous) rests in unconformable relation, and upon this group lies the Chico formation (Upper Cretaceous). These Cretaceous formations were once coextensive with the territory now occupied by the present Coast Ranges, and although removed by erosion over large areas where the Franciscan and older rocks now appear at the surface, they still constitute one of the largest elements in the stratigraphy of the region. They are composed chiefly of shales and sandstones and in the ranges north of the bay have a measured thickness of between 5 and 6 miles. The Eocene rocks, which succeed the Chico, are much less widely distributed. They comprise two assemblages of sandstones and shales known as the Martinez and the Tejon formations, which near the Bay of San Francisco aggregate between 4000 and 5000 feet in thickness and in the area farther south are probably much thicker. Evidences of unconformity between the Eocene and Cretaceous rocks have been observed in some places, but the discordance is not very pronounced. The fossil faunas of the two series are, however, very different.

Some strata referable to the Oligocene series have been observed and recorded, but the next great group of rocks is of Miocene age and is known as the Monterey group. The formations of this group have a wider distribution south of the Bay of San Francisco than those of Eocene age, and in some places they rest directly upon Cretaceous or older rocks, neither the Martinez nor the Tejon intervening. The most characteristic feature of the group is its content of bituminous shale, with which nearly all the oil of California is directly or indirectly associated. These shales alternate with sandstones, and the basal formation of the group is at many places conglomeratic. The group attains a thickness of several thousand feet, and in areas where it rests upon the Eocene the superposition is unconformable. The rocks of this group were doubtless originally deposited over the greater part of the area of the Coast Ranges from the Bay of San Francisco southward, but since their deformation and uplift they have been extensively eroded. Their remnants, however, form a considerable element of the stratigraphy of the region.

The next overlying formation, the San Pablo, is unconformable with the Monterey group and is much less widely distributed. In its southern areas the discordance is strongly marked, but in some of the northern areas it is scarcely discernible. The rocks, which are chiefly marine sandstones that are locally intermixed with tuffs, are found on both flanks of the Coast Ranges. Their thickness in the best-known sections ranges from 1500 to 2000 feet.

Above the San Pablo unconformably, but in few places resting directly upon it, lies the Merced formation, a thick accumulation of marine sandstones, clays, and conglomerates, which were laid down in Pliocene time in deep local troughs that sank as fast as the sediments were deposited. These basins of Pliocene marine deposits were apparently confined to the coastal side of the Coast Range region. On the inland side of that region similar geosynclinal troughs were developed to corresponding depths, in which accumulated fluviatile and lacustral sediments, constituting the Orinda[a] formation. The Orinda and Merced formations are each more than a mile thick. Interstratified with the beds of both formations are layers of volcanic ash.

Upon the Orinda and Merced lie various lavas and volcanic tuffs alternating with lacustral clays, limestones, and sandstones. Of these lacustral formations, the Siesta[a] (Pliocene) and the Campus[a] (Pleistocene) are the most extensive.

The later Quaternary formations comprise marine shell beds, sands, and clays overlain by a thick deposit of alluvium that is rich in the bones of extinct Mammalia.

PRE-FRANCISCAN ROCKS.

CHARACTER AND DISTRIBUTION.

The oldest rocks of that part of the Coast Ranges which is here especially considered comprise the quartz diorite ("Montara granite") and some fragments of the formations into which that rock was intruded as a batholithic mass. In the southern Coast Ranges these pre-granitic formations constitute a large volume of strata, of unknown age, made up chiefly of crystalline limestones, quartzites, and schists. They are exposed on the flanks of the Montara batholith in Santa Cruz County (see Santa Cruz folio, No. 163) and on the Point Reyes Peninsula in Marin County, according to F. M. Anderson.[a]

[a]In this folio the names Orindan, Siestan, and Campan have been changed to Orinda, Siesta, and Campus. The names originally employed have been in use for more than 12 years and the author prefers them.

GAVILAN LIMESTONE.

Only one of the pregranitic formations, the Gavilan limestone,[b] which takes its name from the Gabilan[c] Range, between San Benito and Salinas valleys, is represented in the area here described. It occurs only in isolated masses included in the quartz diorite of Montara Mountain, in the southern part of the San Mateo quadrangle. This limestone is a coarsely crystalline marble in which the calcite crystals show striations due to multiple twinning. Besides the carbonate of lime of which it is chiefly composed it generally contains a considerable proportion of magnesia, some silica, and some carbon in the form of lustrous flakes of graphite. The silica may occur in the form of silicates, such as wollastonite, which is abundant in the same rock on the Point Reyes Peninsula.

QUARTZ DIORITE ("MONTARA GRANITE").

The so-called "Montara granite" is a coarse-grained gray rock made up of quartz in abundance, plagioclase, orthoclase, and biotite or hornblende. One common facies of the mass contains both biotite and hornblende. In an earlier paper the writer stated that the rock is a hornblende-biotite granite, but subsequent examinations have shown that a facies of the mass which contains no hornblende but includes biotite is perhaps more widespread than that in which hornblende occurs either in association with biotite or alone. It was found also that by an increase in the proportion of plagioclase the rock at many places passes into quartz diorite, so that this designation is petrographically more correct for the mass as a whole, and the term granite is justified only by popular usage. Titanite and apatite are common accessories and titanite is locally abundant. The rock is more or less deeply weathered so that it is disintegrated in almost all its exposures except those on the shore and in the deeper canyons, where corrasion is rapid. The mass is at some places characterized by blotchlike inclusions of a dark, more basic rock and contains small dikes of aplite and pegmatite, two rocks that are in places intimately associated and locally include small crystals of garnet and magnetite. The rock shows occasionally a foliated or gneissic structure, which is clearly due to deformation, and evidences of deformation appear in the microscopic structure of the rock even where no foliation is apparent.

The quartz diorite makes up the bulk of Montara Mountain, a bold ridge nearly 2000 feet high, which extends from northwest to southeast across the southwest corner of the San Mateo quadrangle. The ridge affords two complete and easily accessible transverse sections, one on the coast between San Pedro Point and Halfmoon Bay, the other on the road from Crystal Springs to Spanish Town, along Pilarcitos Canyon, just beyond the southern border of the quadrangle; and the rock is well exposed over the greater part of the surface of the ridge, some of the slopes being mantled with a coarse arkose sand resulting from its disintegration.

Along the northeastern slope of Montara Mountain the quartz diorite is flanked by sandstones, grits, shales, and conglomerates of probably Eocene age. These lie directly on the worn surface of the quartz diorite and dip away from it to the northeast. At the northwest extremity of the mountain the sandstones and basal conglomerate mantle over the axis of the ridge and rest at low angles upon the quartz diorite, as may be easily seen on the coast road near the Devil's Slide. At Pilarcitos Lake the plane of contact of the sandstones and quartz diorite has a lower angle than the slope of the mountain, so that an isolated outcrop of the underlying rock appears as an inlier in the sandstone at the south end of the lake. At places farther north these Eocene rocks appear to be faulted down against the rocks of the Franciscan group and in the earlier reports they were assigned to that group, although their difference from the normal type of Franciscan rocks was pointed out and the desirability of segregating them was suggested.

In the area southeast of Pilarcitos Lake the quartz diorite is bounded by a fault that brings the Franciscan against it. The southern limits of the quartz diorite lie beyond the San Mateo quadrangle and are mapped in the Santa Cruz folio.

On the strip of land between the mountain slopes and Halfmoon Bay and in an area lying farther north, between that bay and Seal Cove, the quartz diorite is covered by alluvium composed of its own débris, which has been spread out by alluvial fans formed by streams that run down the mountain slopes. Near Seal Cove the quartz diorite, as may be seen in the sea cliffs, forms the basement on which rests the littoral Merced formation. Here a Pliocene terrace cut in the quartz diorite and encumbered by beach material stands only a few feet above the present sea level. From Seal Cove to the Devil's Slide the quartz diorite forms the shore of the Pacific.

[a]California Univ. Dept. Geology Bull., vol. 2, No. 5.

[b]Becker, G. F., U. S. Geol. Survey Mon. 13, p. 181, 1888.

[c]This name, Spanish for sparrow hawk, is spelled Gavilan in modern orthography and in the geologic literature of California. The United States Geographic Board, however, has decided in favor of the older form Gabilan (pronounced Gah-vee-lahn') for the mountain range.

The quartz diorite area of Montara Mountain thus outlined is only a part of a much more extensive mass. It is in reality but an inlier of a granitic terrane which certainly extends from Santa Cruz to Bodega Head and which emerges from beneath the overlying mantle of Mesozoic and Tertiary sediments in the Santa Cruz Mountains, Montara Mountain, the Farallones Islands, the Point Reyes Peninsula, and Bodega Head. This great batholith has an extent from northwest to southeast of not less than 120 miles and may even be regarded as the continuation of the similar rocks of the Gabilan Range. The mountain mass of which this was the core was truncated by erosion, the overlying stratified rocks of the crust into which it was intruded were removed except some remnants on its flanks, and a large part of the quartz diorite itself was worn away prior to the submergence which permitted the deposition of the sediments of the Franciscan group.

JURASSIC (?) ROCKS.

FRANCISCAN GROUP AND ASSOCIATED IGNEOUS ROCKS.

CHARACTER.

The Franciscan group was named from San Francisco, where it occurs in extensive exposures, from which it was first described. It comprises (1) a voluminous accumulation of sedimentary formations, some of them clearly marine, others doubtfully so; (2) some intercalated lavas of contemporary age; and (3) certain crystalline schists produced by the metamorphism of both the sedimentary and the igneous rocks.

The formations of the Franciscan group are pierced at many points by igneous intrusives, which are so intimately associated with the sedimentary rocks, both as to age and as to distribution, that they constitute one of the most characteristic features of the group and they will therefore be briefly described in connection with the Franciscan rocks. This treatment is also desirable because these intrusives produced the metamorphism that formed the crystalline schists and so gave to the Franciscan group one of its most interesting features.

The sedimentary rocks of the group comprise (1) sandstones, conglomerates, and shales; (2) limestone; and (3) radiolarian cherts. The igneous rocks are (1) basalt or diabase, in many places having a strongly pronounced spheroidal or ellipsoidal structure, (2) peridotites, which have in general become thoroughly serpentinized. The dominant rock in the crystalline schists is glaucophane schist, which is so abundant in them that the schists as a whole are commonly referred to as "the glaucophane schists," although other varieties of crystalline schist are associated with them.

STRATIGRAPHY.

Owing to the general absence of fossils from the sandstones of the Franciscan group and to the similarity of these rocks at several horizons, as well as to the general obscurity of their planes of stratification, only the broader features of the stratigraphy of the group can be determined; but although these sandstones are not susceptible of subdivision and correlation by means of their petrographic character or their faunal content, two radiolarian chert formations that occur in them constitute well-defined and easily recognizable stratigraphic horizons that traverse the group. As neither of these cherts forms the base or the summit of the group they serve to divide the Franciscan sandstones into three distinct formations, which, with the cherts themselves, constitute the five formations of the group. Very few sections of the Franciscan rocks, however, include all five of these formations. Some sections comprise only the lower part of the group, others only the upper part, but as the sequence is constant these partial sections may be combined to construct a complete stratigraphic column.

The formations which by this mode of division constitute the Franciscan group are as follows, the series beginning at the top:

Bonita sandstone.
Ingleside chert (radiolarian chert).
Marin sandstone.
Sausalito chert (radiolarian chert).
Cahil sandstone (including Calera limestone member and some volcanic rocks).

CAHIL, MARIN, AND BONITA SANDSTONES.

Character.—The Cahil sandstone is named from Cahil Ridge, in the San Mateo quadrangle; the Marin from Marin Peninsula, in Marin County; and the Bonita from Bonita Point, on the north side of the Golden Gate. These three formations are petrographically very much alike and may therefore be described together. The prevailing rock in all three formations is a massive, obscurely bedded sandstone of dark greenish-gray color and medium texture. Where it is fresh, or unweathered, it is so strongly cemented that when it is broken the fracture traverses its constituent grains. The cementation has involved a considerable amount of recrystallization of the finer interstitial material of the rock, but the larger sand grains appear to have been little affected by this secondary crystallization of the matrix in which they are embedded. The sand of which it is composed was not well washed and sorted at the time of its deposition and comprises several other minerals besides quartz, which is, of course, its principal constituent. When examined under the microscope it is seen to contain more abundant fragments of plagioclase, orthoclase, biotite, hornblende, and zircon than are usually found in rocks of this class. Besides these minerals, it contains pieces of chert, volcanic rock, and schist. This heterogeneity of composition and the prevailing angularity of the grains suggest that the rock may be an arkose rather than a beach-washed sand. It includes flakes of black carbonaceous matter, which in some places are so abundant as to give the rock a rude cleavage. This carbonaceous material indicates that the sands were deposited in places to which were carried also the remains of vegetation. In certain localities, too, the sandstone includes thin seams of coal, and the carbonaceous fragments are exceptionally abundant near these seams. The coal is of no commercial value.

The sandstones of these formations include lenses of pebbly conglomerate and beds of dark shale, but most of these are difficult to trace for more than short distances and they form beds that are thin in comparison with the general mass of the sandstones.

Where erosion is not exceptionally active the sandstones of these formations, by their secular decay and disintegration, yield an abundant soil. Wherever it may be examined in cliff sections or in cuttings the sandstone beneath the soil presents a more or less shattered appearance, being traversed in all directions by intersecting parting planes. Some of these partings are joints or planes of differential movement, but most of them show no indications whatever of movement or of shattering action. Nearly all of these partings have been formed by weathering, and their development seems to be due to the slow secular disintegration of the sandstone. They are more numerous near the surface, and they have divided the sandstone immediately beneath the soil into small angular pieces, which, after they are loosened by surface agencies, become incorporated into the soil itself. The sharply marked alternation of wet and dry seasons and the general absence of trees in this region are peculiarly favorable to this disintegration.

In steep canyons and on the crests of ridges these massive sandstones are usually well exposed, but on the intervening slopes they appear only in isolated knobs that protrude above the generally smooth surface, so that the distribution of the formations must be to a large extent determined by examining the rock fragments in the soil. The weathered rock is commonly of a tawny-yellow color, due to surface oxidation, and this discoloration ordinarily extends below the zone of mechanical disintegration mentioned above.

Although these sandstones are prevailingly massive, significant glimpses of their bedding obtained at many places show that they are normally stratified. The bedding in these places is usually made apparent by intercalated beds of shale rather than by any notable differences from horizon to horizon in the character of the sandstones themselves. The sandstones at certain horizons might even be described as thin bedded, but where this thin bedding occurs the mantle of soil is heavy and the exposures of the rock are few and small. No positive indication of dynamic metamorphism has been observed in these formations, but where they lie near certain intrusive rocks they have been affected by a peculiar kind of contact metamorphism, which has produced the rocks that are described farther along in this text under the heading "Metamorphic schists."

In the Cahil formation there is a conspicuous foraminiferal limestone, an oceanic deposit, laid down far from the shore, which separates the sandstones below and above it into distinct divisions. The attempt to indicate this separation in the mapping was, however, not entirely successful, and on the geologic maps the limestone is therefore treated as a member of the Cahil sandstone, under the name Calera limestone member. On the summit of Fifield Ridge, in the San Mateo quadrangle, a thin stratum of obscurely fossiliferous impure limestone appears as a lens in the Cahil sandstone at a horizon several hundred feet above the Calera limestone. It has been observed at only a few points and is apparently not persistent. This bed probably nowhere exceeds 10 feet in thickness. It does not resemble the Calera limestone and could not easily be confounded with it.

Owing to the obscurity of the stratification the thickness of the Cahil, Marin, and Bonita sandstones can not be determined with precision. The Cahil, which is approximately 2560 feet thick, is made up of about 60 feet of limestone (Calera limestone member) with 500 feet of sandstone below and 2000 feet of sandstone above. The Marin sandstone in its best exposure on the Marin Peninsula is about 1000 feet thick and the Bonita is about 1400 feet thick, though this estimate is less certain, as the exposures are obscure.

These three formations occur principally on the San Francisco and Marin peninsulas, but it is only where they are immediately associated with the Sausalito and Ingleside cherts that they can be distinguished from one another and so be assigned to their proper stratigraphic positions in the geologic sequence. All three formations are remarkably deficient in fossils, yielding only a few isolated forms or fragments of forms, which are of no value in determining the age of the rocks.

Calera limestone member of Cahil sandstone.—The Calera limestone is so named from Calera Valley, in the San Mateo quadrangle, where it is well exposed on the sea cliffs at the lower end of the valley. It is a gray compact rock of aphanitic texture, resembling lithographic limestone. Its weathered surface is much lighter in color than its freshly broken faces. Smooth surfaces or thin sections of the rock show a great many clear, hyaline spots, the largest measuring half a millimeter across. These spots are the remains of foraminiferal shells. Under the microscope the limestone appears to be uniformly dense and structureless and is composed of a cryptocrystalline aggregate of calcite. The individuals of the aggregate are so small that one can not be discriminated from another. The character of the limestone and the distribution of the foraminiferal shells through it indicate that it is essentially a chemical precipitate in which the Foraminifera were sporadically entombed. Minute veinlets of calcite traverse the rock in all directions.

The limestone is more or less distinctly stratified and contains lenses of chert, which generally lie parallel to the planes of stratification. (See Pl. III.) These lenses are rather irregular in form and the longer axes of some of them are oblique to the bedding. The chert consists of nearly pure silica and may be either dark or light colored. The lenses range in thickness from about an inch to about a foot and have ordinarily rather abrupt or obtusely rounded terminations. Some of them appear to have very much the same relation to the limestone that the flint nodules and lenses in the chalk of the south of England have to the chalk.

The limestone itself contains very little silica, even in the immediate vicinity of the chert lenses, and although it is traversed by numerous small veins these are composed of calcite. The chert lenses are easily separable from the limestone, which is a very pure carbonate of lime with but little admixture of magnesium carbonate, as may be seen from the following analyses, made by Wm. L. Lawson, of samples of the limestone from Permanente Canyon, San Mateo County, where it is quarried for use in the manufacture of beet sugar.

	1	2
CaO	54.44	54.84
MgO	.20	.14
CO_2	42.92	43.23
$Al_2O_3 + Fe_2O_3$	.56	.47
Soluble SiO_2	.10	------
Insoluble	1.98	1.52
H_2O	.05	.15
SO_3	Trace.	Trace.
P_2O_5	Trace.	Trace.
	100.25	100.35

The Calera limestone lies in a belt of discontinuous outcrops that extend from northwest to southeast across the southern part of the San Mateo quadrangle. The thickness of the limestone in these outcrops varies greatly but averages about 60 feet.

SAUSALITO AND INGLESIDE CHERTS.

General character.—These formations consist of radiolarian chert and are so much alike that one description will serve for both. The Sausalito chert, the lower of the two formations, is named from the town of Sausalito, in the Marin Peninsula, near which it is extensively exposed; the Ingleside chert takes its name from Ingleside, in the San Francisco Peninsula. The rocks of which these two formations are composed are the most remarkable of the Franciscan group. They are neither so thick nor so persistent as the sandstones, but their great hardness and their resistance to weathering make them the best-exposed formations of the group, and they constitute the most rugged features of the relief. The interest which these rocks excite by their bold outcrops is intensified by the most cursory inspection of their structural and petrographic features. In color they are prevailingly dull brownish red, especially in their thicker and more evenly bedded portions, but they include some rock that is yellow and green. White, colorless, blue, purplish, gray, brown, and black cherts are also seen, but these colors are usually local and are not characteristic of extensive masses of the rock. Where the cherts have been subjected to heat, as at their contact with irruptive rocks, they are a brilliant vermilion-red.

One of the most remarkable features of the cherts is their bedding, which is well displayed in numerous excellent sections, not only in natural outcrops but even better in many rock cuttings that have been made in the hills of San Francisco for extending and grading streets and for procuring road metal. All these exposures show a strikingly constant form of bedding the essential feature of which is the alternation of thin sheets of chert with partings of shale. (See Pl. VIII.) The shale and the chert are usually of about the same color. The thickness of the sheets of chert in the typical sections generally ranges from about 1 to 3 or 4 inches, averaging perhaps 2 or 3 inches. Some beds are much thicker, but the sections of the chert nevertheless in general show thin and even bedding. The shaly partings between these sheets usually range from about one-eighth to one-half inch in thickness, but many of them are mere films. As the formations are in some places exposed in sections that are several hundred feet thick they present the remarkable phenomenon of an alternation of thousands of layers of chert with as many layers of shale. In the common red phase of the formations the regularity of this thin-sheeted stratification is amazing. In other phases, in which red iron oxide is not so abundant, the regularity is much less marked and the sheets assume lenticular forms. In these less ferruginous phases the chert beds reach their maximum thickness and the shaly partings their minimum. In these phases the chert beds may not be separated by shale and may be several feet thick, so that the formations may locally present a massive aspect having litttle resemblance to the prevailing thin-bedded facies. There are also gradations from the massive to the thin-bedded variety.

Petrographic features.—The radiolarian cherts are not petrographically uniform. In many places they are true jaspers and have been so designated in some of the earlier descriptions of them. In other places the silica of which they are composed is chiefly amorphous and the rocks resemble flint or hornstone. In still other places the proportion of iron oxide and other pigment they contain is so large that they are not cherty but are so soft that they can be easily scratched with a knife. In a few phases, notably those that contain no coloring matter, they become a quartz rock that is not flinty or jaspery and that does not differ essentially from vein quartz. This phase, however, is exceptional and is probably due to local causes.

If a selected series of thin sections of these cherts is viewed under the microscope they present a gradation from those that are composed almost wholly of amorphous or isotropic silica to those that are a holocrystalline aggregate of quartz granules. The most isotropic sections, however, exhibit numerous minute scattered points that polarize light and that can not be sharply separated, even by the highest powers, from the isotropic base. These points are not inclusions; they are centers of incipient crystallization in the amorphous rock, corresponding to the products of devitrification in glass. In other sections these centers of crystallization are much more thickly crowded and well-defined areas composed of interlocking granules of quartz appear, interlocking also with the isotropic base. The actual boundaries of these areas can be made out only with difficulty and uncertainty, owing to the fact that the quartz grains are under molecular strain, which produces undulatory extinction as the stage is revolved between crossed nicols. In still other sections these areas coalesce and the proportion of amorphous base to the whole rock is very small. Finally, some sections show a holocrystalline aggregate of interlocking quartz grains. Most of the grains are under molecular strain, as is shown by undulatory extinction, and somewhat resemble chalcedony. The discrimination between the amorphous and the crystalline silica is easy in those varieties of the rock that contain little iron-ore pigment but becomes more difficult as the abundance of the obscuring pigment increases. The gradation thus observed in a series of thin sections prepared from specimens taken at random seems clearly to be a gradation in time and not merely a gradation in space. It indicates different stages of a process of crystallization in a solid amorphous mass. If this be granted, there seems to be no good ground for doubting that in general the holocrystalline cherts, or jaspers, were originally amorphous silica, and that they have reached their present form by a process of crystallization quite analogous to that of devitrification in volcanic rocks.

In addition to these general petrographic features the radiolarian cherts present a few features that are of subordinate or local interest. The oxide of manganese seems by paragenesis to be connected with the cherts. This oxide is not usually found in masses but appears only as films and stains in the crevices of the chert and along its bedding planes. In some places the stain is so abundant that the body of the rock is locally blackened. In the chert at Red Rock, in the Bay of San Francisco, a thick deposit of oxide in the form of psilomelane lies in the bedding planes, which are here nearly vertical. Other similar deposits occur in these cherts in the Coast Ranges. So far as the writer is aware the manganese ore is confined to these cherts. Another interesting feature of these rocks is their passage locally into an iron ore. Still another characteristic feature, which, however, varies in the degree of its development, is the system of minute fissures that traverse the hard beds transverse to the bedding planes. Many of these fissures are fault planes along which have occurred tiny dislocations that are apparent in the steps which mark the otherwise even surfaces that form the upper and lower limits of the chert beds. Some of these fissures are lines of very evident veining, and doubtless all of them would prove to be veins if examined in thin section. The vein matter is quartz, which is usually white or hyaline, whereas the chert is colored. None of these fissures, faults, or veins pass through the shaly partings, the plasticity of which has prevented their development, so that each thin sheet of chert has its own system of fissures.

Fossils.—On a smooth surface of almost any specimen of these cherts a lens will reveal minute round or oval dark, hyaline, or whitish dots. These dots, which are scattered through the rock, prove on microscopic examination to be the remains of Radiolaria, the characteristic fossils of these formations. The Radiolaria are minute animals that thrive in sea water and secrete siliceous skeletons of very complex structure. These skeletons evidently accumulated in great numbers on the floor of the sea while the radiolarian cherts were being deposited and thus contributed to their formation. As a rule they are sporadically embedded in the siliceous matrix above described, but in some places they are so closely crowded as to constitute the greater part of the chert. Where the Radiolaria are scantily distributed through the chert it is uncertain whether or not the matrix also is derived from these organisms, and the alternative hypothesis that it was formed by the purely chemical precipitation of silica, supplied possibly by submarine springs, is worthy of consideration. If the silica is wholly of organic origin it must have been dissolved and reprecipitated in its present form as an ooze on the sea bottom.

Under the microscope the radiolarian remains appear in ordinary light as circular or oval spaces or as clear rings free from pigment. Between crossed nicols these clear spaces are seen to be occupied by chalcedony. The clear areas are more sharply defined in the amorphous varieties of chert and they are somewhat indefinite in outline, yet distinct as areas, in the holocrystalline varieties. In thin section they are most readily observed in the red cherts, by reason of the contrast which they make with the pigmented matrix.

In the better preserved remains of these organisms the spines, lattice work, and other structural features may be observed and the genera to which they belong thus determined. Specimens of radiolarian cherts from the Franciscan group and their fossils were described many years ago by Dr. George J. Hinde.[a]

Distribution and thickness.—The Sausalito and Ingleside cherts are most extensively displayed in the hills in the northern part of the San Francisco Peninsula and in the southern part of the Marin Peninsula, but smaller areas of these cherts and of other cherts of undefined horizons are common throughout the Franciscan terrane. The maximum thickness of the Sausalito chert is about 900 feet and that of the Ingleside chert about 530 feet. The absence or paucity of land-derived sediment in both formations indicates that they were deposited far from the shore, in deep water.

CONDITIONS OF SEDIMENTATION.

The basal part of the Cahil sandstone was deposited upon the sinking bottom of a transgressing sea. When the subsidence had proceeded so far that the land-derived sediments failed to reach the deeper water, detrital accumulation gave way to the formation of foraminiferal ooze on the bottom of a clear-water sea, the shore having migrated far to the east. The product of this period of deposition is the Calera limestone member. An upward movement of the sea bottom caused the shore line to move westward again, the water became too shallow for foraminiferal life, and the layer of ooze on the sea bottom was buried under the detrital sediments which form the upper part of the Cahil sandstone. As these sediments are very thick the sea bottom must have continued to subside during the period of their deposition. As subsidence proceeded the detrital material washed from the receding shore again failed to reach the region, and organic agencies once more resumed sway. This time, however, calcareous organisms were replaced by those which secrete silica from the sea water, so that the sea bottom was covered with radiolarian ooze, which eventually consolidated as the Sausalito chert. The rhythmical oscillation of conditions which produced the remarkable alternation of layers of chert and shale in this formation has not yet been explained but was probably due to alternating conditions in the sea water which affected or interrupted the swarming of radiolarian life. The accumulation of this radiolarian ooze was stopped by a recurrence of the shallowing of the sea and the return of the shore to a line sufficiently near to insure the deposition of sands upon the siliceous deposits. These sands now form the Marin sandstone. After this sandstone had accumulated to a thickness of about 1000 feet the subsidence of the sea bottom, which had been in progress during the period of its deposition, caused the shore again to retreat so far that the conditions became once more favorable to marine life, and another deposit of radiolarian ooze was laid down. This ooze formed the Ingleside chert. Again uplift set in, shallow water prevailed, the shore was close at hand, and the sands of the Bonita sandstone were deposited. As these sediments attain a thickness of 1400 feet we must assume that the uplift that started their deposition was followed by gradual depression, which continued during their accumulation.

Thus the mere consideration of the character of the formations listed in the fivefold subdivision of the Franciscan group, taken with their sequence in the geologic column, leads to the recognition of a remarkable series of vertical oscillations of the sea bottom and of a consequent series of horizontal migrations of the sea shore during the time occupied by the deposition of the sediments of the group.

It may be well to note, however, that in the above outline of the conditions of sedimentation that existed during the deposition of the Franciscan formations it is assumed that the Cahil, Marin, and Bonita sandstones are wholly marine. The character of these formations suggests, as has been indicated in the description of them, that they may be in part at least nonmarine or continental deposits. If this should prove to be the fact the record of oscillation and the consequent migration of the continental margin to and fro must have been even more complicated than if they were marine.

At many places and at several geologic horizons in the sandstones of the Franciscan group there are small isolated areas of radiolarian chert that can not be referred to either the Sausalito or the Ingleside formation. Such areas are particularly noteworthy on Buriburi Ridge, in the San Mateo quadrangle. Most of these isolated patches of radiolarian chert are residuals of somewhat larger masses, but many of them appear to have been originally discrete lenses, which indicates that during the deposition of the sandstones of the Franciscan group the conditions were from time to time locally favorable to the accumulation of radiolarian ooze.

CONTEMPORANEOUS VOLCANIC ROCKS.

The volcanic lavas which are interstratified with the sedimentary deposits of the Franciscan group are basaltic rocks, which are generally vesicular or amygdaloidal and which in most of their outcrops are greatly decomposed. Where thus decomposed they are as a rule not essentially different from other basaltic rocks that are clearly intrusive in the Franciscan. The masses of intrusive rock, however, cut boldly and irregularly across the stratification of the sedimentary beds, whereas the volcanic rocks occur in sheets of moderate thickness that conform to the planes of stratification and are in some places associated with pyroclastic rocks. These distinctly interbedded lavas are much more common in the lower sandstone formations than in higher portions of the group. The most noteworthy sheets of volcanic rock are on the flanks of Cahil and Sawyer ridges, in the San Mateo quadrangle. They are mapped with the intrusive basalt and diabase.

INTRUSIVE ROCKS ASSOCIATED WITH THE FRANCISCAN GROUP.

The greater part of the igneous rocks associated with the Franciscan group are not of contemporaneous origin with it but have been intruded into it and are therefore not properly a part of the group. There are several distinct types of these intrusives, two of which are dominant. These are (1) genetically allied peridotites, pyroxenites, and gabbros, the first named preponderating and being generally very thoroughly serpentinized; and (2) spheroidal and variolitic basalts and diabases.

Peridotite and serpentine.—The intrusive rocks of the first class may be referred to generally as peridotite and serpentine, for although they are associated with pyroxenites and gabbros these are very subordinate in amount and are regarded as differentiation products of the same magma. These rocks form dikes and laccolithic sills as well as irregular masses, most of which appear to be the eroded remnants of intrusive lenses. Some writers on Coast Range geology have erroneously supposed that these bodies of serpentine are products of the metamorphism of the sandstone, an idea that still finds occasional expression, although it has been entirely disproved. The serpentine in its several variations has the usual character of that rock. Much of it is massive and unsheared, but in places it shows abundant evidence of pronounced internal movement, being composed of slickensided, sheared, and schistified serpentine in which lie rounded masses of unsheared rock. The massive varieties contain crystals of enstatite that show lustrous cleavage faces, and this fact and the results of microscopic study indicate that the serpentine was derived from a peridotite having the mineralogic character of saxonite or lherzolite. These massive varieties of the serpentine are also usually traversed by numerous small veins of chrysotile, but none of these veins are large enough to constitute marketable asbestos. Small seams of magnesite also appear here and there in the serpentine. Bodies of glaucophane and other crystalline schists lie near some of the masses of serpentine but are too small for representation on the geologic maps.

Perhaps the largest areas of serpentinized peridotite lie in the belt that extends across the city of San Francisco from Hunter Point to Fort Point. This belt apparently includes two distinct sheets of serpentine, which are intrusive in the Franciscan group and are separated by a moderate thickness of Franciscan rocks, the twofold character of the intrusion being very evident in the excellent exposures at Hunter Point, the Potrero, and Fort Point. These sheets lie nearly flat but are in places so warped that they are more or less discordant with the stratification planes of the Franciscan rocks. The intruded rocks at Fort Point are seamed with veins containing magnesite, datolite, pectolite, and other minerals but apparently have not been altered by contact metamorphism except for a very few inches from the contact surface. Near the serpentine, however, both at Fort Point and at Hunter Point, small loose fragments of glaucophane schist have been found. In this belt of serpentine, particularly at Hunter Point, there are stringers and nests of chromite, irregular masses of chlorite several feet across, and small veins of talc. The serpentine is nearly everywhere thoroughly sheared by movements that have been set up within its mass, probably in connection with the gradual and irregular increase of volume attendant upon serpentinization. This sheared mass, which is traversed in all directions by slickensided surfaces, contains numerous subangular and rounded bowlders as well as much larger masses of unsheared serpentine, most of which are traversed superficially by a roughly rectangular network of minute veins of chrysotile. The sheared serpentine of the Potrero and of Hunter Point incloses many rather short, thick lenses of fresh fine-grained diabase, which are evidently dislocated fragments of dikes that were intruded into the peridotite before its serpentinization and which by this process became sheared apart into discrete lenses. The intrusive character of these diabase lenses is shown by the fact that their edges that lie against the serpentine have been chilled and are fine grained and grade into a coarser-textured rock toward the centers of the lenses.

Another belt of intrusive peridotite lies along Buriburi and Pulgas ridges, on the northeast side of Crystal Springs Lake, in the San Mateo quadrangle, where it is also thorougly serpentinized. It occurs to a minor extent in the form of dikes but chiefly in the form of lenticular flat-lying laccolithic sheets, from which the overlying formations have been to a large extent removed by erosion. On the southwest side of Fifield Ridge there is a zone of outcrops of sheets and dikes of serpentine which is smaller than that on Buriburi Ridge but lies parallel to it.

On the Marin Peninsula there are two well-defined belts of serpentinized peridotite. One of these extends northwestward from a point near the west peak of Mount Tamalpais beyond the northern limit of the Tamalpais quadrangle. The serpentine here occurs in the form of a rather thin warped sheet, which has been partly exposed by the removal of the overlying formations, into which it is intrusive, and has been so dissected that it is represented by several separate areas. The second belt traverses the Tiburon Peninsula longitudinally and is also in the form of intrusive sheets and dikes, with glaucophane schists at the contact zones, one of the most notable of which is that on Angel Island, described by F. L. Ransome.[a]

Still another belt of serpentine lies on the east side of the Bay of San Francisco, near the edge of the Franciscan group, where it passes beneath the overlying Knoxville formation. This belt extends through the San Francisco, Concord, and Haywards quadrangles. Glaucophane schists are intimately associated with these masses of serpentine, particularly at the north end of the belt, and the relations of the two rocks indicate that the schists are due to metamorphism at the contact with the peridotites. Gabbros and pyroxenites occur as local facies of the serpentinized peridotites. Although the peridotites from which the serpentines are derived are clearly intrusive in the Franciscan group they appear to be confined to that group; they do not traverse the overlying Cretaceous formation. They were, however, well exposed by denudation before the overlying Knoxville formation was deposited, for they formed part of the floor on which that formation was laid down. In this way they occur in some places at the contact of the Franciscan with the overlying shales, and as both shales and serpentine have been deformed the relations of the rocks are in places extremely involved, suggesting contacts which really do not exist.

Silica-carbonate rock.—Considerable parts of the serpentine have been altered to an aggregate of carbonate and silica, which weathers in very rugged masses that are strongly stained with limonite. This rock has been referred to in an earlier paper as silica-carbonate sinter, but more recent studies[b] have shown that the rock is in many places closely associated with serpentine and in some places grades into it, so that there is little doubt that the so-called silica-carbonate sinter is a product of the alteration of the serpentine, the bases having been carbonatized and the silica set free to be redeposited in the form of chalcedony, opal, and quartz. These forms of silica occur as a plexus of small veins traversing an aggregate of carbonates of

[a] Hinde, G. J., Note on the radiolarian chert from Angel Island and from Buriburi Ridge: California Univ. Dept. Geology Bull., vol. 1, No. 7, pp. 235-240, 1894. (Appendix to paper by F. L. Ransome on the geology of Angel Island.)

[a] Ransome F. L., The geology of Angel Island: California Univ. Dept. Geology Bull., vol. 1, No. 7, pp. 193-233, 1904.

[b] Knopf, Adolph, An alteration of Coast Range serpentine: California Univ. Dept. Geology Bull., vol. 4, No. 18, 1906.

iron, magnesia, and lime. Under the weather the carbonates are dissolved out at the surface, leaving the silica prominent, as well as rusty with iron oxide. The more notable masses of this rock are found north of Berkeley, in the valley of Temescal Creek, and at San Bruno Point, but many other smaller bodies may be seen elsewhere.

Spheroidal basalt and diabase.—The second class of intrusives invading the Franciscan rocks are the variolitic and spheroidal basalts and diabases. These are confined to the Franciscan group; they are not found in later formations. They antedate the peridotites, which at many places appear to cut across them. These masses of basalt and diabase occur at numerous points in the Franciscan group in all the quadrangles and though most of them are small, several are rather large. They are of irregular shape, they include no clean-cut dikes or intrusive sills, and their exposed contacts with the rocks they intrude are generally irregular and jagged. (See Pl. VI.) Fragments of the incasing rocks, especially of the radiolarian cherts, are abundant at the contacts, where the chert is usually baked to a bright vermilion-red and its structure is in some places also greatly changed. Some inclusions show evidence of partial resorption. The spheroidal structure of these intrusive rocks is clearly revealed only on sea cliffs, as at Hunter Point and Point Bonita (see Pl. VII), but may also be detected in numerous road cuttings and on natural exposures on hillsides. On sea-cliff exposures the rock presents the appearance of an irregular pile of filled sacks, each sack having its rotundity deformed by contact with its neighbor. The average dimensions of these sacklike or ellipsoidal masses are about 3 feet in the longest and about 1 foot in the shortest diameter. The rock between the ellipsoids is usually more decomposed than that elsewhere and so weathers out easily under the action of the waves, leaving the more resistant ellipsoids prominent. Some of the ellipsoids are vesicular, others are variolitic, and still others are both. The cause of this peculiar structure and the mode of its development are not yet understood. At some places, as on the cliffs at Hunter Point, these spheroidal basalts present also a remarkable brecciated appearance, as if made up of innumerable small, angular fragments cemented together. At both Point Bonita[a] and Hunter Point the margins of such spheroidal masses show a pronounced variolitic structure. At Hunter Point the rock is in places filled with closely packed spherical varioles ranging in size from one-sixteenth to one-half inch. These varioles weather out of the rock easily, being much harder than the matrix in which they are embedded.

The intrusive rocks of Angel Island described by Ransome[b] under the name fourchite are probably a facies of the rocks here grouped under the general designation "Spheroidal basalt and diabase."

These spheroidal basalts occur wherever the rocks of the Franciscan group are exposed in this area, but most abundantly on the Marin Peninsula, the largest masses being in the canyon of Lagunitas Creek northwest of Mount Tamalpais.

METAMORPHIC ROCKS.

One of the most interesting features of the Franciscan group consists of crystalline schists formed by the local metamorphism of its sedimentary and igneous rocks. These schists vary considerably in petrographic character from place to place and are of widespread though sporadic occurrence. Most of the areas they occupy are small, many of them comprising only an acre or two, but some of them include hundreds of acres. These schists are more or less intimately associated with the serpentinized peridotites or at some localities with the spheroidal basalts and diabases. They are usually exposed in discrete areas on the periphery of the intrusive masses but occasionally appear to be inclusions. In several places where these metamorphic rocks are dissociated from intrusive bodies the dissociation is probably due to erosion. The serpentinized peridotites were in many places originally intruded as laccolithic lenses, which have been removed by denudation, and the more resistant crystalline schist which lay on their peripheries or beneath them form knobs that project from the general surface. Exceptionally the metamorphic rock forms a continuous belt along the margin of an intrusive mass. The process of alteration seems to have been erratic or selective in its operation, so that the metamorphic rocks occur in patches, various in form and size, which are disposed in a general way about the margins of the intrusive masses. In this respect these metamorphic rocks are quite different from those which form a contact zone due to pure thermal metamorphism on the periphery of a granitic intrusion, a zone that is commonly persistent and uniform. The metamorphism in the Franciscan group apparently occurred only at certain localities on the peripheries of the intruding bodies, either where the emanations from the intrusive mass found freer escape, or where the incasing rocks, by reason of their composition, were more susceptible to alteration, or where there was a combination of these two favorable conditions. The composition of a part of the metamorphic rocks suggests that this part was derived from basic igneous rocks preexistent in the Franciscan, but other parts are evidently altered sedimentary rocks.[a]

Considered petrographically these metamorphic rocks may be grouped in several classes, among which are (1) amphibolitic schists, (2) mica schists, (3) quartz schists, and (4) albite schists.

The amphibolitic varieties include—

1. Black or dark-green schists, composed chiefly of hornblende, which is usually accompanied by some albite or quartz.
2. Hornblende-garnet schists.
3. Actinolite schists, with or without chlorite and talc. One facies of these actinolite schists occurs in the form of nodules in serpentine, the prisms of actinolite being long and thick.
4. Glaucophane schists, composed almost wholly of glaucophane.
5. Glaucophane-quartz schists.
6. Glaucophane-albite schists.
7. Glaucophane-epidote schists.
8. Glaucophane-lawsonite schists.
9. Crocidolite-quartz schists.
10. Massive aggregates of green or blue amphibole, omphacite, and the garnet known as eclogite.

The micaceous varieties comprise (1) biotite-quartz schists, (2) muscovite-glaucophane schists, and (3) schists in which muscovite, glaucophane, garnet, and quartz are about equally developed.

The quartz schists comprise varieties in which the dominant constituent is quartz, with which are associated subordinate amounts of glaucophane or mica or crocidolite. In the albite schists the dominant constituent is feldspar, which is accompanied by subordinate amounts of glaucophane or crossite. All these schists of course contain numerous accessory minerals, and some of them include large amounts of titanite.

The mere mineralogic description and nomenclature of these interesting rocks, however, form only the first step toward solving the intricate problem of their genesis. The fact that they are derived from various kinds of rocks, both sedimentary and igneous, and yet have common features, such as their content of blue amphibole, suggests that some regional condition influenced their development. The fact that some of the most characteristic minerals of the body of the schists—for example, lawsonite—also occur in veins that traverse the same schists indicates that the agencies of metamorphism must have been somewhat like those that fill veins, and that the metamorphism is therefore not purely thermal. The further fact that a characteristic mineral of these schists, blue amphibole, is developed in different kinds of rocks without deformation indicates that the agencies that formed the schists were not the forces of dynamic metamorphism. If purely thermal contact metamorphism and dynamic metamorphism be thus both set aside as possible agencies in producing the schists the only remaining explanation of their origin is that they are due to metamorphism by chemical reactions, which, however, have not greatly modified the original chemical composition of the rocks affected. The nature of these reactions is at present obscure, but they are doubtless various and complicated, and their localization is no doubt intimately connected with emanations from intrusions of basic magma.

These metamorphic rocks occur most extensively in the San Francisco quadrangle, at places north of Berkeley, and on the Tiburon Peninsula.

AGE OF THE FRANCISCAN GROUP.

The age of the Franciscan group has not been positively determined either in the quadrangles here mapped or elsewhere in the Coast Ranges. Neither the Foraminifera of the Calera limestone nor the Radiolaria of the Sausalito and Ingleside cherts appear to be sufficiently distinctive to determine the age of the rocks in which they are found. Certain plant remains that were discovered by Fairbanks in the Franciscan rocks at Slate Springs, Monterey County, are regarded by some paleobotanists as forms that represent an age transitional from Jurassic to Cretaceous time—Cretaceous rather than earlier. F. H. Knowlton, however, expresses the opinion that these fossil plants may be either Cretaceous or Jurassic. Two marine Mollusca, one a single specimen of an Inoceramus, found many years ago on Alcatraz Island, in San Francisco Bay, the other a fragment of either an Inoceramus or an Aucella, found $2\frac{3}{4}$ miles south of San Mateo, afford the only other paleontologic evidence available. These forms indicate a Jurassic or Cretaceous age but are otherwise indecisive.

Although the paleontologic evidence as to the age of the Franciscan group is thus extremely meager and inconclusive the stratigraphic evidence is curiously self-contradictory and leads to a conclusion that few geologists may be willing to accept. The rocks of the Franciscan group are overlain unconformably by the Knoxville formation, which is generally regarded by paleontologists as Lower Cretaceous. Exposures of the Knoxville resting upon the eroded surface of the deformed and locally metamorphosed rocks of the Franciscan group occur on the southwest flank of the Berkeley Hills, particularly north of Berkeley, and similar exposures occur in the San Luis quadrangle and have been described by Fairbanks. The relations exhibited in these exposures would indicate that the Franciscan is pre-Cretaceous in age. Unfortunately for the stability of this conclusion, however, other available evidence leads to another decision. In several folios of the United States Geological Survey the granite of the Sierra Nevada is mapped and described as of post-Jurassic age. This granitic rock extends continuously from the southern Sierra Nevada, in the Mount Whitney region, around the southern end of the Great Valley of California, into the Coast Ranges, where it forms a part of the complex upon which the Franciscan rocks rest unconformably, as has been indicated in the San Luis and Santa Cruz folios. In the area here mapped the Franciscan rocks are nowhere superposed upon the granitic rock, which is confined to Montara Mountain and has the facies of a quartz diorite. In an earlier paper the writer described the Franciscan as resting upon this quartz diorite ("Montara granite"), but later field work has shown this to be an error, the supposed Franciscan being in reality a block of Eocene strata faulted against the Franciscan. Where the Franciscan lies in contact with the quartz diorite in the San Mateo quadrangle the juxtaposition is due to faulting. Nearly all writers on Coast Range geology are, however, agreed that the Franciscan is later than the granitic rocks. The considerations that support this view may be summarily stated as follows:

1. The sandstones of the Franciscan group are composed very largely of granitic débris, as was first pointed out by Becker, who regarded these rocks as Lower Cretaceous.
2. At no place has the granite been observed to be intrusive in the Franciscan.
3. The intrusive relation of the granite to the older rocks is clearly shown at many localities.
4. Included fragments of these older rocks are very common in the granite, but no fragments of Franciscan strata have been found in the granite, although the radiolarian cherts are well adapted to preservation as inclusions, as is shown by the fact that they are common in the rocks that intrude the Franciscan strata.
5. The pre-granitic rocks are generally metamorphosed and consist chiefly of coarsely crystalline marbles (which are locally graphitic), quartzites, and various crystalline schists, none of which resemble the Franciscan strata.
6. The local metamorphism of the Franciscan is not due to granitic intrusion but is intimately associated with basic irruptives.
7. The Franciscan rocks have not been subjected to the same dynamic metamorphism that has generally affected the rocks into which the granite is intruded.
8. In general, there are in the Coast Ranges two different assemblages of very diverse sedimentary rocks, into one of which the granite is clearly intrusive, whereas the other contains no such intrusions; therefore it is highly probable that the latter assemblage is post-granitic.

Considering, then, the fact that the Franciscan is post-granitic, and accepting the view that the granitic rocks of the Coast Ranges are continuous with and of the same age as the granite of the Sierra Nevada, we must conclude that the Franciscan group is post-Jurassic. This conclusion is clearly in conflict with that drawn from the fact that the Franciscan lies unconformably below the Knoxville (Lower Cretaceous). At present there appears to be no way of harmonizing the conflict without (1) either extending the geologic time at the interval between the recognized Cretaceous and the Jurassic, an extension that should not be made without the justification of more thorough investigation, or (2) assuming a period of batholithic development in the Coast Ranges that was distinct from and older than that in the Sierra Nevada, an assumption that should also not be made without further and fuller investigation.

It is hoped that this statement of the difficulty of determining the age of the Franciscan group may stimulate California geologists to make further field studies directed to the solution of the problem.

CRETACEOUS SYSTEM.

DISTRIBUTION.

The Cretaceous formations constitute an important feature of the geology of the region mapped but are confined to the east side of the Bay of San Francisco. Their chief outcrops lie in a belt that extends through the San Francisco, Concord, and Haywards quadrangles, widening toward the southeast. An area of the upper part of the system occurs also in the northern part of the Concord quadrangle.

The Cretaceous rocks lie unconformably upon those of the Franciscan group along the southwest front of the Berkeley

[a] Ransome, F. L., The eruptive rocks of Point Bonita: California Univ. Dept. Geology Bull., vol. 1, No. 3, 1893.

[b] Ransome, F. L., The geology of Angel Island: California Univ. Dept. Geology Bull., vol. 1, No. 7, 1894.

[a] These metamorphic rocks are described more fully in several papers, particularly in The geology of Angel Island, by F. L. Ransome (California Univ. Dept. Geology Bull., vol. 1, No. 7, 1894), and in The paragenesis of the minerals in the glaucophane-bearing rocks of California, by J. P. Smith (Am. Philos. Soc. Proc., vol. 45, 1907). Other papers, dealing chiefly with the mineralogy of the rocks, are mentioned in the bibliographic list at the end of this folio.

Hills and are the dominant rocks of that range. They strike northwest and dip generally to the northeast at rather high angles, although in places the dip is reversed by irregular plication of the strata. On the northeast side of the range the upper formation of the Cretaceous rocks is unconformably overlain by Tertiary strata that occupy a great trough in the central part of the Concord quadrangle. The outcrop of the Cretaceous rocks along the Berkeley Hills is thus the southwest limb of a great synclinorium, the northeast limb of which appears in the northern part of the Concord quadrangle, south of the town of Martinez, and also, more extensively, in the Mount Diablo quadrangle, which adjoins the Concord quadrangle on the east. Of these two areas of Cretaceous rocks, that of the Berkeley Hills is stratigraphically the more important, for it affords complete sections of the system from the Franciscan to the Tertiary, and it will therefore be described in greater detail.

The system as represented in these quadrangles comprises two distinct formations, which, named in ascending sequence, are designated the Knoxville formation and the Chico formation.

LOWER CRETACEOUS (SHASTA) SERIES.

KNOXVILLE FORMATION.

The Knoxville formation, named for Knoxville, in Napa County, is exposed in a practically continuous belt along the southwest slope of the Berkeley Hills, being confined to the lower part of the slope in the northwestern part of the range but reaching the summit in the southeastern part and descending to the foot of the slope beyond Haywards. The belt widens notably from northwest to southeast, across the Concord quadrangle, its width at Berkeley being only a few hundred feet, whereas at the southern border of the quadrangle it is over three-quarters of a mile. Farther southeast, in the Haywards quadrangle, the belt of Knoxville rocks may be still wider, but the rocks are in part mantled over by later rhyolite or by the alluvium of the valley floor, and their extent beneath these deposits can not be positively stated. The widening of the belt of outcrop toward the southeast signifies a thickening of the formation, although it is in part due to plication of the strata, to which the increased volume of overlying soft rocks is conducive. The maximum thickness of the formation in the Concord quadrangle is not less than 1000 feet and may be as much as 1500 feet. The formation thins out rapidly northwest of Berkeley and at its northwestern extremity is represented by outlying patches that rest upon the worn surface of Franciscan rocks. This thinning, however, is probably due in large part to erosion in Tertiary time, for these remnants are unconformably overlain by Pliocene and Quaternary formations.

The Knoxville, being the basal formation of a series that rests unconformably upon the Franciscan rocks, might reasonably be expected to consist of the coarse detritus that is characteristic of transgressive beds—that is, it should be in large measure conglomeratic. This, however, it is not, and the prevailing absence of conglomerate in a formation so situated is interesting and significant. The formation is composed almost wholly of dark, more or less carbonaceous, argillaceous, or finely arenaceous shale but includes occasional small lenses of compact gray limestone. In some sections it consists of alternate beds of shale and thin beds of rather fine sandstone; in others, particularly in the San Francisco quadrangle, it contains beds of fine pebbly conglomerate, the pebbles being on the average not much larger than peas. Freshly exposed sections show that this shale is evenly and thinly laminated, but owing to the readiness with which it slacks under the atmosphere and breaks down into soil fresh exposures are uncommon, and the dip of the strata can not be easily observed even in road cuttings only a few years old. The stratification in the more recent exposures, however, indicates that the formation as a whole dips to the northeast, beneath the next higher formation. Locally the dip is reversed, as, for example, north of Laundry Farm, in the southwestern part of the Concord quadrangle, where the shale wraps around an area of underlying serpentine in anticlinal fashion, and also near the southern border of the same quadrangle, where a synclinal fold occurs.

The shaly character of the Knoxville formation is not merely a local anomaly but is a general feature, which prevails over a large part of the Coast Ranges of California. This fact would seem to preclude the idea of a slow transgression of the Knoxville sea over an uneven surface in the region of the present Coast Ranges; it suggests rather the sudden submergence of a land surface of low relief, or, to put it in another way, a sudden transition from a condition of very advanced aerial erosion to a condition of marine deposition in extensive shallow lagoons and swamps.

At several places along the belt of outcrop of the Knoxville formation the characteristic Knoxville fossil *Aucella piochii* has been found, and an ammonite obtained in it at the mouth of Strawberry Canyon, at Berkeley, was identified by T. W. Stanton as probably a species of Hoplites. At the same locality a small Pecten was also found, perhaps a new species. Fragments of Belemnites are common in the formation, particularly north of Berkeley, where they occur in a calcareous sandstone and in the fine pebbly conglomerate already mentioned. Near the northwestern limit of the formation as mapped, north of Berkeley, it includes a few patches of impure limestone and some rusty-weathering pebbly grits. This limestone has yielded a number of fossils, which have been studied by F. M. Anderson, who identifies them as forms characteristic of the upper Knoxville. These fossils are *Modiola major*, *Lucina colusaensis*, *Pecten complexicosta*, Cardinia?, Myoconcha?, Turbo, *Atresius liratus*, and *Phylloceras onoense*. The lower Knoxville is here wanting, the limestone resting directly upon the Franciscan rocks. Besides these fossils obscure remains of plants are fairly abundant in the shales.

In the southern part of the San Mateo quadrangle two small areas of conglomerate are represented on the geologic map as probably of Knoxville age. This reference is based on the fact that in the territory just south of the quadrangle a similarly isolated patch of conglomerate contained remains of Aucella. A like area of conglomerate of probable Knoxville age is mapped at the head of Bolinas Lagoon in the Tamalpais quadrangle.

UPPER CRETACEOUS SERIES.

CHICO FORMATION.

Oakland conglomerate member.—In the Berkeley Hills the basal portion of the Chico formation consists of a conglomerate to which the name Oakland conglomerate member is applied, from its typical exposure at the city of Oakland. This conglomerate outcrops along a belt paralleling that of the Knoxville formation, upon which it lies conformably. Like the Knoxville it increases in volume from the northwest toward the southeast, but the increase is not uniform. At the mouth of Strawberry Canyon the conglomerate has not been discovered. In the valley southeast of Claremont Creek it is exposed in rather small outcrops, which are not mapped, and at Temescal Lake it is exposed to a thickness of perhaps 100 feet. From this point it may be traced southeastward almost continuously to Redwood Peak, where it bulges out to a thickness of about 1000 feet. Beyond Redwood Peak it diminishes in volume for about a mile to 200 or 300 feet and then expands again, reaching a width of about 1000 feet northeast of Laundry Farm. From this point southeastward its thickness ranges from 500 to 700 feet, and still farther southeast, in the Haywards quadrangle, it again expands. The average thickness of the conglomerate in the Concord quadrangle may be about 500 feet. In the Haywards quadrangle its average thickness may be nearer 1000 feet.

The conglomerate at many places shows distinct stratification and the strata dip uniformly to the northeast, beneath the overlying sandstones and shales of the Chico formation, at angles ranging from 45° to 65°. The conglomerate exhibits none of the subordinate plication observed in the underlying shale of the Knoxville formation, a fact due to the more massive character of its strata and their competence to propagate the stresses to which the region was subjected. Here and there beds of coarse sandstone are intercalated with the conglomerate, but the member as a whole is distinctly conglomeratic. Its constituent pebbles are very much waterworn and rounded and range in size from the dimensions of a marble to those of a man's head. This conglomerate rests conformably upon the soft shales of the Knoxville formation and its stratigraphic position is significant of an important event in the geologic history of the region, for it indicates an abrupt change in the conditions not only of deposition but of erosion. When it is recalled that the Knoxville is the basal formation of the Cretaceous system over a very wide extent of the Coast Ranges the inference is that the region surrounding the basin of deposition must have been one of low relief, with low-grade streams carrying fine silt rather than coarse sand. The sudden appearance of the conglomerate above the shales, not only in this quadrangle but at several other localities in the Coast Ranges, indicates the encroachment of the deltas of high-grade streams upon the basin. It would seem clear from this that the period of accumulation of the Knoxville deposits was brought to a close by the orogenic deformation of the continental margin of the basin in which they were deposited, though such deformation did not cause the floor of the basin to emerge from the water.

Upper part of Chico formation.—In the Berkeley Hills the principal part of the Chico formation—the part that conformably overlies the Oakland conglomerate—comprises a thick accumulation of sandstones and shales, the sandstones preponderating. The upper beds of the Oakland conglomerate grade rather abruptly into the overlying sandstones of the Chico formation, by transitional beds of pebbly sandstone. The outcrop of the sandstones and shales occupies a broad belt along the summit of the Berkeley Hills, parallel to the belts occupied by the Knoxville formation and the Oakland conglomerate. This belt widens gradually but steadily toward the southeast, its increase in width being due to an increasing volume of strata in this direction. Although the Chico sandstones and shales form the prominent ridges of the Berkeley Hills these rocks disintegrate readily under the weather and yield a heavy mantle of sedentary soil, so that, as a rule, their stratification can be seen only in steep-walled canyons, where observations show that though the strike of the strata remains fairly constant, the dip is at some places reversed, indicating sharp folding. The strata and the formation as a whole dip in general to the northeast at angles ranging from 30° to 80°. The thickness of the strata is difficult to measure on account of the obscurity of the exposures and the uncertainty as to repetition by folding, nearly all parts of the formation being very much alike. It is estimated, however, that the part of the formation above the Oakland conglomerate member has a thickness of about 2000 feet at the northwest end of the belt and of about 5000 feet at the southeast end, within the Concord quadrangle. The belt of outcrop of the sandstones and shales of the Chico formation widens steadily from a feather edge at a point north of Berkeley to over 4 miles in the vicinity of Haywards.

The only fossils discovered in the Chico of this belt are fragments of a large Inoceramus and a small Pecten, found in Strawberry Canyon, and a number of echinoderms and other more obscure fossils, found at the sandstone quarry in Shepard Canyon.

On the northern border of the Concord quadrangle, south of Martinez, an area of sandstones and shales of the Chico formation lies in the heart of an anticlinal fold, which is flanked on both sides by synclines of Tertiary strata. The general trend of the axis of this fold is northwest and southeast and the pitch of that part of it which lies within the Concord quadrangle is to the southeast. The belt has a maximum width of 2¼ miles and the dips are prevailingly steep, so that the belt seems to include a great thickness of strata, but this apparent thickness probably much exceeds the real thickness, the volume of strata being multiplied by folding. The anticline has not been eroded deeply enough to reveal the base of the Chico and the underlying rocks, but the partial section exposed has a thickness of not less than 3000 feet. This body of strata is composed almost wholly of massively bedded sandstone but includes subordinate beds of shale and one lens of conglomerate. The sandstone is of medium fine texture, is well cemented, and has a bluish-gray color. Under weathering, however, it becomes rather incoherent and crumbling, takes on a tawny color, and affords an abundant soil, so that fresh faces of the rock are rarely seen.

Fossils.—Numerous characteristic Chico fossils have been found in these beds. The locality within the area here described that has yielded them most abundantly is in the upper part of the section exposed on the east side of the Arroyo del Hambre, about three-quarters of a mile south of the northern border of the Concord quadrangle. The more important fossils found here, as determined by Prof. J. C. Merriam, are as follows:

Fossils of the Chico formation.

Corbula cultiformis Gabb.	Venus varians Gabb.
Meekia sella Gabb.	Cinulia obliqua Gabb.
Meekia navis Gabb.	Cylindrites ? brevis Gabb.
Meretrix arata or fragilis Gabb.	Dentalium cooperi Gabb.
Mytilus quadratus Gabb.	Gyrodes expansa Gabb.
Mytilus pauperculus Gabb.	Perissolax brevirostris Gabb n. var.
Nucula truncata Gabb.	Pugnellus hamulus Gabb.
Pecten martinezensis Gabb.	Solarium inornatum Gabb.
Pectunculus veatchi Gabb.	Helicoceras vermicularis Gabb.
Tellina hoffmanniana Gabb.	Sharks' teeth.
Tellina ? æqualis Gabb.	Teleost fish scale.

TERTIARY SYSTEM.

EOCENE SERIES.

SUBDIVISIONS.

As Prof. J. C. Merriam has clearly shown, the Eocene rocks of the California Coast Ranges may be divided into two paleontologically well-defined formations — the Martinez and the Tejon. The line of stratigraphic separation between these two formations is not well marked, and, as the sandstones of both yield an abundant soil, which is generally cultivated, the mapping of the dividing line is not easy. Certain differences in the character of the rocks, however, taken in connection with the fairly frequent occurrence of fossils in the beds, facilitates an approximately correct separation, which has been indicated on the map. These formations are found only in the northern and eastern parts of the Concord quadrangle and the southern part of the San Mateo quadrangle.

Along the northeast flank of the Berkeley Hills strata of Miocene age rest directly upon the Chico. This absence of Eocene rocks in this part of the field is significant in the geologic history of the region. It signifies either that no Eocene rocks were deposited over this part of the region, it being a land area bordering the Eocene basin, or that, if they were deposited, they had been lifted above sea level by orogenic movements and completely removed before the subsidence which permitted the deposition of the next series of rocks. The relative probability of these two interpretations is considered under the heading "Geologic history."

Although the Eocene series is not found on the northeast flank of the Berkeley Hills, where it should have been deposited if the sequence were conformable, it is abundantly represented on the flanks of the anticline south of Martinez, named the Franklin anticline, from Franklin Creek, which runs almost across it. Here both the Martinez and Tejon formations are important elements of the stratigraphy. The Tejon appears also in the core of a large anticline northeast of Sobrante Ridge, which has not been dissected deeply enough to reveal the underlying formations. It also occurs on Shell Ridge and Lime Ridge, two northwestern spurs of Mount Diablo, although the paleontologic indications at these places are not so satisfactory, as well as northwest of Pacheco, where the underlying Martinez outcrops at the north border of the quadrangle.

MARTINEZ FORMATION.

Character and distribution.—The Martinez formation, named from the town of Martinez, in Contra Costa County, is, in its typical form, composed of heavily bedded sandstones in which much glauconite occurs, giving the rocks a greenish-gray color. The formation includes also some reddish sandstones and intercalated shales. Both sandstones and shales break down readily under the weather. A thick lens of rather coarse, well-cemented conglomerate also occurs in the southeasternmost extension of the terrane, south of Grayson Creek. These strata dip away from the Chico in apparently conformable sequence on both flanks of the Franklin anticline at angles ranging from 30° to 80°, the steeper dips being on the northeast flank. The anticline is, however, complicated by a subordinate fold and perhaps by an axial fault, which brings a tongue of the Martinez rocks into the center of the Chico area and causes the beds to dip apparently under the Chico. The sections that best reveal the strata show that the Martinez formation is probably not less than 2000 feet thick. Northeast of the Franklin anticline is a broad syncline of Martinez strata, in the trough of which lie folded strata of the Tejon formation, and above these, in the axis of the trough, is a belt of Monterey rocks. The Martinez rocks in the northeast limb of this syncline are exposed in low hills about a mile north of Pacheco. Southwest of the Franklin anticline the outcrop of the Martinez strata on this limb of the fold is cut off a mile or more south of the Santa Fe tunnel by a thrust fault which causes the Chico to override the Monterey.

Fossils. — Fossils occur at many places in the Martinez formation, most abundantly on the southwest limb of the Franklin anticline. These fossils have been studied by Stanton, Merriam, Weaver, and Dickerson, in whose papers, as well as in earlier papers by Gabb, the paleontology of the formation is fully discussed. The work of these paleontologists shows that the Martinez formation contains a fauna which is quite distinct from that of the underlying Chico and from that of the overlying Tejon. So far as is now known only four of the species of this fauna range downward into the Chico and only twenty-five upward into the Tejon. Ninety-seven species are confined to the Martinez. It has been even possible to separate the fauna into two parts, corresponding to an upper and lower division of the Martinez formation. This distinctively Martinez fauna comprises the following species, the list of which has been revised by Dr. Dickerson.[a]

Characteristic fossils of the lower part of the Martinez formation.

Flabellum remondianum Gabb.	Actæon lawsoni Weaver.
Trochocyathus zitteli Merriam.	Cylichna costata Gabb.
Schizaster lecontei Merriam.	Dentalium cooperi Gabb.
Cardium cooperi Gabb.	Discohelix californicus Weaver.
Cucullæa mathewsoni Gabb.	Fusus æquilateralis Weaver.
Leda gabbi Conrad.	Neptunea mucronata Gabb.
Lima multiradiata Gabb.	Perissolax tricarinatus Weaver.
Meretrix sp.	Siphonalia lineata Stanton.
Modiolus merriami Weaver.	Urosyca caudata Gabb.
Nucula cf. truncata Gabb.	Urosyca robusta Weaver.
Pholadomya nasuta Gabb.	Xenophora zitteli Weaver.
Tapes (aff.) quadrata Gabb.	Teredo sp.
Tellina martinezensis Weaver.	Turbinella crassatesta Gabb.

Characteristic fossils of the upper part of the Martinez formation.

Schizaster lecontei Merriam.	Solen stantoni Weaver.
Cancer sp.	Tellina martinezensis Weaver.
Cardium cooperi Gabb.	Tellina hornii Gabb.
Cucullæa mathewsoni Gabb.	Tellina undulifera Gabb.
Leda gabbi Conrad.	Ampullina cf. striata Gabb.
Modiolus merriami Weaver.	Brachysphingus liratus Gabb.
Modiolus ornatus Gabb.	Bullinula subglobosa Weaver.
Dentalium cooperi Gabb.	Siphonalia lineata Stanton.
Dentalium stramineum Gabb.	Architectonica tuberculata Weaver.
Heteroterma gabbi Stanton.	Strepsidura pachecoensis Stanton.
Heteroterma trochoidea Gabb.	Tritonium pulchrum Weaver.
Heteroterma sp. indet.	Turritella infragranulata Gabb.
Natica sp.	Turritella pachecoensis Stanton.
Perissolax tricarinatus Weaver.	Turritella conica Weaver.
Perissolax blakei Gabb.	Turris sp. indet.
Nucula truncata Gabb.	Urosyca caudata Gabb.
Pholadomya nasuta Gabb.	

Rocks of San Pedro Point.—In the San Mateo quadrangle a belt of early Tertiary sedimentary beds lies on the north flank of Montara Mountain and extends from Pilarcitos Lake to the coast at San Pedro Point, where the beds are well exposed in cliff sections. (See Pl. I.) These beds were at one time assigned to the Franciscan group, although they were recognized as a peculiar facies of that group which might possibly be segregated from it. The recent discovery in these rocks of a stratum containing poorly preserved remains of early Tertiary fossils has led to their separation from the Franciscan group and to their tentative assignment to the Martinez formation. The beds consist of conglomerates, coarse arkose sandstones or grits, finer laminated micaceous sandstones, dark shales, and thin strata of limestone. The conglomerates rest directly on the quartz diorite ("Montara granite"), and are followed, in ascending sequence, by sandstones and shales, the whole having an aggregate thickness of several hundred feet. The beds in the coast section are folded in at least two irregular and rather twisted synclines and an intervening anticline, and the folds are traversed by a number of faults. These beds were probably deposited across the contact of the Franciscan and the quartz diorite and after being folded were faulted against the Franciscan on their north side.

The fossils found in these beds indicate that they are of early Eocene age, and they are referred to the Martinez formation by R. E. Dickerson, who has kindly supplied the following list of forms identified by him:

Fossils found in the beds at San Pedro Point.

Flabellum sp.	Amauropsis (?) sp.
Paracyathus (?) sp.	Alaria sp.
Cidaris sp.	Chlorostoma (?) sp.
Terebratulina cf. tejonensis Stanton.	Cylichna costata Gabb.
Cardium cf. cooperi Gabb.	Dentalium sp. striated.
Cucullæa cf. mathewsoni Gabb.	Dentalium cooperi Gabb.
Dosinia cf. lawsoni n. sp.	Discohelix sp.
Glycimeris sp.	Fissurella sp.
Glycimeris cf. veatchii var. major Stanton.	Galerus excentricus Gabb.
Macrocallista (?) packi n. sp.	Hipponyx sp.
Meretrix stantoni n. sp.	Natica sp. a.
Modiolus cf. bakeri n. sp.	Natica (?) sp. b, spiral lined.
Ostrea buwaldana n. sp.	Patella sp.
Phacoides diaboli n. sp.	Ringinella cf. pinguis Gabb.
Phacoides quadrata n. sp.	Spiroglyphus (?) sp.
Semele (?) sp.	Tritonium martinezensis n. sp.
Tapes (?) quadrata Gabb.	Tritonium sp. a.
Teredo sp.	Turritella sp.
Venus (?) sp.	Turritella cf. pachecoensis Stanton.
Venericardia sp.	Urosyca cf. caudata Gabb.
	Crustacean fragments.

TEJON FORMATION.

Distribution and character.—The beds of the Tejon formation are best exposed for study in the area northeast of the Franklin anticline, where they lie in a steeply dipping syncline and where their thickness is not less than 2000 feet. The rocks are generally free from glauconite and are composed of more cleanly washed sand than that which formed the sandstones of the Martinez formation. They are either of a very light color or are stained red with oxide of iron. They are also much more strongly cemented and more resistant to degradation than the Martinez rocks. The belt of Tejon represented by the two limbs of this syncline is continued on the southeast side of Ygnacio Valley in the two spurs of Mount Diablo that embrace the lower part of Pine Canyon. On the southern of these spurs the Tejon rocks rest upon and dip away from younger (Monterey) rocks on the limb of an overturned syncline. On the northernmost spur the strata dip at varying angles to the northeast. The rocks are sandstones that are generally as hard and resistant as those of the Pacheco syncline, except some of the heavy-bedded sandstones southeast of Concord, which are highly calcareous and softer. The only other locality at which the Tejon appears is in the heart of the Sobrante anticline, where it is flanked on both sides by strata of Monterey age. The formation is named from Fort Tejon, in Kern County, where it is typically developed.

Fossils.—In the Tejon formation of the Concord quadrangle about 43 species of fossils have been found. Dr. Roy E. Dickerson has kindly supplied the following list as a result of his recent studies of this fossil fauna:

Fossils of the Tejon formation.

Nummuloid (?) sp.	Solen stantoni Weaver.
Orbitoides sp.	Venericardia planicosta var. hornii Gabb.
Trochocyathus striatus Gabb.	Dentalium stramineum Gabb.
Turbinolia n. sp.	Amauropsis alveata (Conrad).
Cardium cooperi Gabb.	Architectonica sp.
Cardium breweri Gabb.	Ancilla (Oliverato) californica Cooper.
Glycimeris sagittata Gabb.	Bela cf. clathrata Gabb.
Glycimeris cor Gabb.	Cylichna costata Gabb.
Leda gabbi Conrad.	Conus remondii Gabb.
Modiolus ornatus (Gabb).	Ficopsis renondii Gabb.
Modiolus merriami (Weaver).	Megistostoma striata Gabb.
Meretrix hornii Gabb.	Morio tuberculatus Gabb.
Meretrix uvasana Conrad.	Perissolax blakei (Conrad).
Meretrix ovalis Gabb.	Perissolax n. sp.
Nucula (Acila) n. sp.	Rinella canalifera Gabb.
Spisula n. sp.	Spiroglyphus (?) tejonensis Arnold.
Tellina hornii Gabb.	Turris monolifera Cooper.
Tellina cf. remondii Gabb.	Turritella uvasana Conrad.
Tellina longa Gabb.	Turritella conica Weaver.
Tellina martinezensis Weaver.	Tritonium cocenicum Weaver.
Thracia karquinezensis Weaver.	Tritonium impressum Weaver.
Solen parallelus Gabb.	

Only two of these species extend down into the Chico and eight into the Martinez, and four of these eight are rare or noncharacteristic. The fauna as a whole is therefore quite distinctive for the Tejon, and, as Merriam has shown, the sharp difference between this fauna and that of the Martinez formation is significant of an important event in the geologic history of the region in Eocene time and thus warrants the separation of the two formations on the geologic map.

MIOCENE SERIES.

MONTEREY GROUP.

PETROGRAPHIC CHARACTER.

The Monterey group, named for the town of Monterey, consists of a thick mass of sediments of Miocene age, which forms a prominent feature of the stratigraphy and structure of the Coast Ranges, particularly the part south of the Bay of San Francisco. On the California coast north of the bay the strata of this group have been found only in the vicinity of Point Reyes and Point Arena. In the area here considered the group is represented in the Concord, Haywards, San Francisco, and Mount Tamalpais quadrangles, and although it does not occur in the San Mateo quadrangle it forms a well-exposed terrane just south of it. The best sections are those in the Concord quadrangle, where the group is composed of two kinds of rock. One of these is ordinary sandstone, generally of light color and not strongly cemented except where it contains many fossils, which give it a firm bond of carbonate of lime. The other kind of rock of the Monterey group embraces a number of varieties, all of which have been grouped together in the older writings on California geology as "bituminous slates." In this text "slates" will be replaced by "shales," a word that expresses more correctly the character of their lamination, the term "bituminous shale" being a convenient and fairly expressive designation for these peculiar and interesting rocks.

The bituminous shale is in part of organic origin. Some of its beds resemble diatomaceous earth; they are white, soft, chalky, and more or less pulverulent. The microscope shows that they contain abundant organic remains, and chemical examination shows that they are composed chiefly of silica. Other varieties of these white, chalky beds are somewhat harder and are harsher to the touch; they consist in part of fine volcanic ash and may even grade into varieties in which this constituent seems to predominate. Though still remaining soft and chalky, this white bituminous shale grades into creamy or purplish or brownish varieties. The color appears to be due wholly to organic matter, for it can be burnt out, the rock becoming white or assuming a slightly reddish tint, due to the presence of a small quantity of ferric oxide. When heated on platinum foil both the white and the colored varieties emit a very distinct bituminous odor. These rocks generally contain a large proportion of soluble silica, which may be removed by digestion with caustic potash. The proportion of soluble silica in many of the chalky facies, presumably those that are richer in organic remains, averages probably 50 per cent. The residue after digestion is an isotropic cloudy substance containing a variable admixture of angular chips of doubly refracting minerals, chiefly quartz and some angular fragments of glass. This isotropic residue is probably only in small part detrital material and is doubtless chiefly a palagonitic decomposition product of very fine volcanic glass dust.

This chalky facies of the bituminous shale may occur either in thinly and evenly laminated beds or in rather massive thick beds that are traversed by numerous irregular shrinkage joints. Locally the chalky facies may pass into an opaline rock, which is dense and compact but may be easily scratched with a steel point.

These nondetrital rocks, which were undoubtedly deposited far from the continental margin, grade into clayey and finely arenaceous varieties, which indicate that at certain stages of their accumulation, or over certain areas of Monterey sea bottom, there were distinct influxes of detrital material.

A quite different facies of the bituminous shale is prevailingly cherty or flinty and is usually characterized by very even lamination. This laminated rock may consist wholly of chert or, as is more common, it may be composed of an alternation of thin partings of soft shale with beds of chert that generally range in thickness from 1 to 3 inches. This facies is well displayed in the band of bituminous shale which forms in part the crest of the Berkeley Hills (see Pl. V) and which presents a very striking resemblance to the typical beds of radiolarian chert of the Franciscan group in the Coast Ranges. Many of the chert beds that lie between the shale partings are laminated, though they show not the slightest tendency to cleave along the laminæ. In these beds and those in which the shale partings are absent the lamination is made apparent by differences in the color of the layers of chert. The colors commonly observed are dull yellow, gray, purplish, and black. These cherts, like the chalky facies, contain some silica that is soluble in caustic potash, but very much less—not more than 3 or 4 per cent. Traces of microscopic organisms may be discerned in some thin sections of the cherts, but these traces do not resemble the diatomaceous remains found in the chalky shale, and their character is indeterminate. Nearly all these cherts, of whatever color, weather light yellowish or whitish and break down under the atmosphere into small, sharply angular or subcubical fragments. The bituminous matter of the rocks is found chiefly in the soft shale partings but may also be detected in the cherts themselves.

These two chief kinds of bituminous shale, the chalky and the cherty, usually occur at fairly distinct and separate hori-

[a] Dickerson, Roy E., Fauna of the Martinez Eocene of California: California Univ. Dept. Geol. Bull., vol. 8, No. 6, Berkeley, 1914.

zons in the Monterey group, but in some places one grades into the other. A bituminous shale at one horizon may be persistently cherty over a wide area, whereas a shale at another horizon in the same deposit may be as persistently chalky. In the Concord quadrangle, where the bituminous shale is separated into distinct formations by intervening formations of sandstone, one of the shale formations may consist typically of chert beds interlaminated with thin partings of shale, while another may be uniformly chalky.

Any account of the petrography of the bituminous shales, even such a general account as is here attempted, would be incomplete without a reference to certain rock formations that are rather constantly associated with them, although in very subordinate volume. One of these formations is a light-colored or whitish quartzose rock, which resembles in texture and appearance an indurated sandstone; the other is a gray compact limestone, which generally weathers ocherous yellow and in places contains considerable cherty silica. Both these rocks occur rather commonly at several horizons in the bituminous shale and by their hardness, texture, mode of weathering, and other physical properties may be readily discriminated from both the cherty and the chalky types of the shale. They generally occur in distinct beds not more than 2 or 3 feet thick. The quartzose beds as seen in hand specimens appear to be aggregates of vitreous particles through which considerable earthy white material and some dark grains are interstitially distributed. The microscope shows that the body of the rock is composed of fragments of quartz, orthoclase, and acidic plagioclase and siliceous rocks, the quartz greatly preponderating. All these are remarkably angular and are embedded in an amorphous cloudy matrix which resembles the insoluble residue of the chalky shales. The sharply angular fragments of quartz and feldspar are very uniform in size, ranging in diameter from about 0.12 millimeter to 5 millimeters. The dark particles are not uniform in composition, but many of them are volcanic glass. This remarkable rock, though here called a sandstone, has rather the character of a quartzose tuff than of a detrital rock, and its intercalation in the cherts and shales, which generally include little detrital material, supports this suggestion. The question of its origin is, however, left open for the present. No fossils have been found in these rocks.

The limestone is generally magnesian and is usually devoid of fossils. Specimens of rock taken from certain of its beds, however, contain a small percentage of phosphoric acid, and molluscan remains, as well as bones of large cetaceans, have been found in it at some places, as at Miner's ranch, on the east side of San Pablo Valley, in the Concord quadrangle, where the shells and the bones occur in the same matrix.

RELATIONS TO OLDER FORMATIONS.

The Monterey is exposed in superposition upon older rocks at five localities. At three of these it rests upon the Tejon, at one upon rocks that are probably of Martinez age, and at one upon the Chico. The simplest relations are those exposed in the Pacheco syncline, where a fairly symmetric synclinal trough of Monterey strata with low southeastern pitch is flanked on either side by Tejon strata. The basal portion of the Monterey is characterized by thick lenses of conglomerate, and the sandstones associated with these lenses contain fossils which, in the opinion of Prof. J. C. Merriam, are characteristic of the lower Monterey. There is no apparent structural discordance, but the basal conglomerates are significant of an unconformable relation. On the northeast side of Shell Ridge the Monterey is similarly in contact with the Tejon, but with reversed dips, owing to the overturning of the syncline in which the strata are folded. In the Shell Ridge section there is no structural discordance, but farther along the contact, in Pine Canyon, in the Mount Diablo quadrangle, there are abundant conglomerates at the base of the Monterey, which again indicate an unconformity. In the Bear Creek anticline, in the northwestern part of the Concord quadrangle, the lower Monterey strata rest upon the Tejon, but here the structure of the Tejon is so obscure that it is not possible to discover whether or not there is structural discordance, and no conglomerate has been observed at the base of the Monterey. The consideration of these three sections thus affords evidence of no very profound degradation of the Tejon in the pre-Monterey interval of uplift.

In the section exposed in the Berkeley Hills, however, about 5 miles southwest of the Bear Creek anticline, the Monterey rocks rests directly upon the Chico. Both Tejon and Martinez are absent. The Claremont shale, the second formation of the Monterey group, lies almost in direct contact with the Chico, the Sobrante or basal sandstone of the Monterey group being represented by only a thin layer of yellow incoherent sandstone, mapped with the Claremont. There are no conglomerate beds at the base of the Monterey in this section, for here the Eocene rocks, which are more than 4000 feet thick 9 or 10 miles farther northeast, either were not deposited or, as seems more probable, had been completely removed in pre-Monterey time. One justification for the view that the Eocene rocks once extended over the region of the Berkeley Hills and were removed in the Eocene-Miocene interval is that this part of the Coast Ranges contains no representative of the San Lorenzo formation (Oligocene), which occurs to the thickness of 2500 feet in the Santa Cruz quadrangle. In San Lorenzo time the Berkeley Hills region was probably a zone of erosion.

The fifth section in which the Monterey is exposed in superposition upon older rocks is at Selby, on San Pablo Bay, in the Napa quadrangle, a few miles north of the San Francisco quadrangle, where a well-defined unconformity is revealed in a cliff. The surface upon which the Monterey rocks rest is a marine wave-cut terrace, perforated by many holes made by boring mollusks. The strata in which this terrace is cut are soft black shales, which are probably Martinez in age, for Martinez fossils have been found in the sandstones that adjoin them on the north. These shales have a southerly dip of about 70°, and the surface of the perforated terrace and the superimposed sandstones of the Monterey dip in the same direction at about 60°. It is evident that the shales were elevated above sea level and inclined at about 10° to the horizon when they were truncated to form the terrace. The sandstone of the Monterey contains a fossil fauna which, in the opinion of Prof. J. C. Merriam, is that of the middle Monterey. The Tejon is apparently absent here, although it is abundantly represented only a few miles to the southeast, along the strike of the rocks. The Monterey sea evidently did not extend over this part of the region until middle Monterey time, and therefore part of the erosion is referable to early Monterey time. In general, however, the historical facts that are so clearly manifest at Selby are consistent with and support the interpretation of the section in the Berkeley Hills, where the Monterey rests directly upon the Chico.

SUBDIVISIONS.

In the Concord and San Francisco quadrangles the Monterey group is made up of sandstones and bituminous shales, indicating an alternation of deposition along a shore with deposition in the deeper water in which the nondetrital shale was laid down. In its most complete section the bituminous shale occurs in four distinct divisions with intervening divisions of sandstone. Sandstones occupy the top and bottom of the section, so that the Monterey here consists of nine stratigraphic divisions. This ninefold subdivision, however, is local and seems to represent a vertical oscillation of the coast in Monterey time, whereby a region of shoal water, in which detrital material was accumulating so abundantly as to mask any volcanic or organic admixture, was four times depressed, permitting the accumulation of the deep-water sediments that were deposited off the coast at this time—sediments in which organic and volcanic material were greatly in excess of terrigenous detritus. These oscillations in Monterey time doubtless also affected the deeper off-shore region but probably did not change the character or interrupt the continuity of sedimentation, so that the sequence of nine subdivisions in the region east of the Bay of San Francisco may well be the chronologic equivalent of a solid, undivided columnar section of shale in Monterey County. In neighboring territory, however, the uppermost shale thins out toward the south and finally disappears, so that the seventh and ninth subdivisions, which consist of sandstone, come together, and as they are very much alike it is practically impossible to map the boundary between them. It thus becomes convenient on the map to treat the uppermost shale as a member and to represent the two sandstones as one formation. A little farther east, in the Concord quadrangle and in parts of the Mount Diablo quadrangle, the absence of certain of the shales shows that the deeper water did not extend so far inland, except at times of maximum depression, the Monterey being there represented largely by sandy littoral deposits, and the record of oscillation is not sufficiently impressed upon the sediments to be clearly legible.

Similar evidence of the oscillation of the sea bottom in Monterey time may be found in other portions of the Coast Ranges. In Santa Barbara County, for example, according to Fairbanks, the lower part of the Monterey group consists chiefly of gypsiferous clays. These clays and gypsum beds doubtless represent shallow-water deposits in parts of the Pacific Ocean that became landlocked by uplift and were subsequently depressed, so that they received the accumulation of bituminous shale that rests upon the clays. In the bituminous shales of Santa Cruz County and Mendocino County the continuity of the shale is interrupted by strata of ordinary sandstone and even pebbly beds, indicating unmistakably the presence of shallow water. One such pebbly bed occurs in a shale formation in the San Francisco quadrangle.

The subdivisions of the strata of the Monterey group in the San Francisco and Concord quadrangles represent events in the geologic history of the region that are sufficiently important to entitle each of them to receive a distinctive name. These names will facilitate the discussion of the local geology and the correlation of the geologic record in this region with similar records of oscillation in other parts of the Coast Ranges; but while the Monterey group may be thus divided, according to its purely physical features, into several parts, and each may receive a formation name, the group if considered paleontologically can be divided into only three parts. The formations of the Monterey group, particularly the sandstones, are at many localities richly fossiliferous, and a study of the stratigraphic distribution of these fossils by Prof. J. C. Merriam shows that the group contains three fairly characteristic though not wholly distinct faunas. The names of the stratigraphic subdivisions, their relations to the paleontologic divisions, and the approximate thickness of each as observed in a section across the Bear Creek anticline, in the Concord and San Francisco quadrangles, are given in the following table:

Subdivisons of Monterey group.

Paleontologic subdivisions.	Stratigraphic subdivisions.	Petrographic character.	Thickness.
			Feet.
Upper faunal zone.	Briones sandstone	Sandstone	800
	Hercules shale member	Bituminous shale	500
	Briones sandstone	Sandstone	1000
Middle faunal zone.	Rodeo shale	Bituminous shale	670
	Hambre sandstone	Sandstone	1200
	Tice shale	Bituminous shale	460
	Oursan sandstone	Sandstone	600
	Claremont shale	Bituminous shale and chert	250
Lower faunal zone.	Sobrante sandstone	Sandstone	400

Total thickness, 5880 feet.

SOBRANTE SANDSTONE.

The largest exposure of the Monterey group in the area here considered is in the broad belt that traverses the Concord quadrangle diagonally from northwest to southeast. The strata in this belt have been folded into a series of synclines and anticlines, locally complicated by faulting, the dissection of which has revealed in their normal sequence all the formations of the group. This belt also cuts across the northeast corner of the San Francisco quadrangle. In the axis of the Sobrante anticline the basal formation of the group, the Sobrante sandstone, named from Sobrante Ridge, rests on the Tejon formation, and it is exposed in another anticline in the valley of Pinole Creek, where, however, the underlying Tejon is not revealed. The Sobrante sandstone is somewhat variable in character but is prevailingly fine grained and light colored, though it shows local ferruginous staining. Some of the beds, however, are gritty and some are flaggy. In this sandstone, near its base, is a bed of white rock that ranges in thickness from a few inches to 20 feet or more. On microscopic examination this rock proves to be a volcanic ash, made up chiefly of pumiceous glass and angular fragments of well-cemented quartz.

FOSSILS OF LOWER FAUNAL ZONE.

Some of the beds of the Sobrante sandstone are richly fossiliferous, and by means of these fossils the Sobrante can be separated from the rest of the Monterey group to form the lowest of its three paleontologic divisions. A list of the most characteristic fossils of the formation is given below; the species were identified by Prof. J. C. Merriam and Dr. Bruce Clark. These fossils are typical of the lower part of the Monterey of the Coast Ranges generally.

Common fossils of the Sobrante sandstone.

Pelecypoda:
- Arca devincta Conrad.
- Chione mathewsoni Gabb.
- Chione n. sp.
- Dosinia whitneyi Gabb.
- Glycimeris sp.
- Leda taphria Dall.
- Mytilus mathewsoni Gabb.
- Nucula (Acila) n. sp. (?)
- Ostrea titan Conrad.
- Pecten n. sp.
- Panopea generosa Gould.
- Phacoides acutilineatus Conrad.
- Psammobia n. sp.
- Solen curtis Gould.
- Spisula occidentalis Gabb.
- Tellina cf. congesta Conrad.
- Tivela n. sp.
- Tellina n. sp.
- Yoldia impressa Conrad.
- Thracia cf. trapezoides Conrad.

Gastropoda:
- Agasoma gravida Gabb.
- Ancillaria fishii Gabb.
- Bathyloma keepi Arnold.
- Crepidula sp. cf. prærupta Conrad.
- Calyptræa cf. costellata Conrad.

Gastropoda—Continued.
- Calliostoma n. sp.
- Cancellaria n. sp. cf. hemphilli.
- Cancellaria condoni Anderson.
- Fusus stanfordensis Arnold.
- Gyrinium mathewsoni Gabb.
- Molophorus biplicata Gabb.
- Neptunæa recurva Gabb.
- Ocinebra n. sp.
- Opalia n. sp.
- Polynices (Neverita) callosa Gabb.
- Polynices n. sp.
- Scalaria n. sp.
- Terebra cooperi Anderson.
- Turritella aff. ocoyana Conrad.
- Turritella variata? Conrad.
- Thais (Micella) præcursor Dall.

Scaphopoda:
- Dentalium n. sp.

Cirripedia:
- Balanus sp.

Cephalopoda:
- Aturia n. sp.

Anthozoa:
- Reef coral sp.

Vertebrata:
- Fish scales and bones.

This fauna is so different from that of the underlying Tejon that the two formations are probably unconformable. The failure to recognize a structural discordance at the base of the Sobrante sandstone does not preclude the existence of such a discordance, for the exposures of the underlying Tejon do not fully reveal the structural relations of these rocks.

CLAREMONT SHALE.

The Claremont shale, which is named from Claremont Creek, in the Concord quadrangle, represents the earliest appearance of the bituminous shale in the Monterey group. It occurs not only in the Sobrante and Pinole Valley anticlines but appears in bold and persistent outcrops along the crest and northeastern edge of the Berkeley Hills. In the Sobrante anticline it is in part soft and distinctly shaly or chalky and in places contains a large admixture of fine detrital material, but in the Berkeley Hills it is notably cherty, consisting of beds of hard, flinty chert alternating at regular intervals with partings of shale. (See Pl. V.) This belt in the Berkeley Hills extends in unbroken continuity across the southwestern part of the Concord quadrangle and across the northeast corner of the Haywards quadrangle. The bituminous Claremont shale in the Berkeley Hills rests upon the Chico formation, no Eocene strata intervening, and it has a thickness of about 1000 feet. The Sobrante sandstone, if present, is represented only by a thin bed of yellowish friable sandstone, difficult to observe in the field and too slight a feature of the stratigraphy to be represented on the map. The stratigraphic relations indicate a well-marked unconformity between the Monterey in general and the older rocks.

OURSAN SANDSTONE.

The Oursan sandstone, named from Oursan Ridge, in the Concord quadrangle, is a rather fine grained rock. It outcrops parallel to the Claremont shale in the Sobrante and Pinole Valley anticlines and flanks the Claremont belt in the southern part of the Berkeley Hills, having been removed by erosion from the northern part prior to the deposition of the next higher series of rocks. It persists southeastward as a belt traceable with some uncertainty across the northeast corner of the Haywards quadrangle. In its northwestern exposures it flanks the anticline that extends from the Concord into the San Francisco quadrangle on the north side of Pinole Valley.

TICE SHALE.

The bituminous shale to which the name Tice shale is here applied parallels the Oursan sandstone in both the Sobrante and the Pinole Valley anticlines along the northeast flank of the Berkeley Hills, in the southern part of the Concord quadrangle and the northwestern part of the Haywards quadrangle, and in the vicinity of the town of Walnut Creek. It is a persistent formation of bituminous shale, prevailingly chalky, in some places whitish, in others pinkish or yellowish, and has been named the Tice shale from its exposures along Tice Creek, in the Concord quadrangle.

HAMBRE SANDSTONE.

The Hambre sandstone, named from the Arroyo del Hambre, in the Concord quadrangle, has a wider distribution. Besides flanking the Sobrante and Pinole Valley anticlines in parallel outcrop to the lower formations, it has an extensive outcrop along the southwest flank of the Franklin anticline, where it is the lowest formation of the Monterey group and lies next to the Martinez and Tejon formations. The Hambre sandstone appears also in the heart of the sharply appressed anticline of Las Trampas Ridge and in the axis of an anticline that lies north of Lafayette Ridge. It occurs also in the Walnut Creek syncline. The formation everywhere consists of medium-textured, slightly ferruginous sandstones with some sandy shales.

RODEO SHALE.

The bituminous shale to which the name Rodeo shale is here applied occurs at a strongly marked stratigraphic horizon in the northwest quarter of the Concord quadrangle and is also exposed in the adjoining part of the San Francisco quadrangle. The formation is named from Rodeo Creek, in the Concord quadrangle. The shale is mostly chalky and more or less stained with oxide of iron but is locally cherty. Its chief exposures are on the flanks of the Sobrante and Pinole Valley anticlines and on the southwest limb of the Franklin anticline. It occurs also in a narrow belt, difficult to trace continuously, which incloses the Hambre sandstone in the Las Trampas anticline and appears also on the northeast flank of the Berkeley Hills in their extension across the Haywards quadrangle.

FOSSILS OF MIDDLE FAUNAL ZONE.

The three formations of bituminous shale, the Claremont, the Tice, and the Rodeo, the stratigraphic position and distribution of which have been briefly indicated, together with the two separating sandstone formations, the Oursan and the Hambre, have sufficient paleontologic community to warrant their segregation as a faunal zone distinct from the Monterey formations above and below. The fossils which thus distinguish these formations in the middle zone of the Monterey group are chiefly the following, the determinations having been made by Prof. J. C. Merriam:

Fossils of the middle faunal zone.

Pelecypoda:
- Arca devincta Conrad.
- Chione mathewsoni Gabb.
- Chione aff. securus Shumard.
- Chione n. sp
- Corbicula cf. dumblei Anderson.
- Leda cœlata Hinds.
- Hemimactra lenticularis Gabb.
- Mactra n. sp.
- Macoma nasuta Conrad.
- Marcia n. sp.
- Modiolus rectus Conrad.
- Panopea generosa Gould.
- Pandora scapha Gabb.
- Pecten peckhami Gabb.
- Pecten andersoni Arnold.
- Pecten n. sp.

Pelecypoda—Continued.
- Phacoides acutilineatus Conrad.
- Psammobia n. sp.
- Ostrea titan Conrad.
- Tellina oregonensis Conrad.
- Tellina n. sp.
- Thracia cf. trapezoidea Conrad.
- Solen curtis Conrad.
- Tirela n. sp.
- Yoldia submontereyana Arnold.

Gastropoda:
- Agasoma gravida (?) Gabb.
- Agasoma sanctacruzana Arnold n. var.
- Cancellaria condoni Anderson.
- Crepidula sp. indet.
- Lunatia n. sp.

BRIONES SANDSTONE.

Character and distribution.—The Briones sandstone, so named from the Briones Hills, in the Concord quadrangle, is the most widely distributed formation of the Monterey group. It is prevailingly a light-colored to whitish well-washed sandstone, in some places pebbly or conglomeratic and in general of coarser texture than the lower sandstones. Many of its strata are abundantly fossiliferous and some of them are veritable shell beds. As it is a cleanly washed quartzose sandstone it yields only a light and generally a thin soil. It is one of the chief geologic features of the Concord quadrangle, forming a belt that extends diagonally across it from northwest to southeast. It flanks the combined Bear Creek and Pinole Valley anticlines and is the most conspicuous formation of Las Trampas Ridge, several of its beds being hard and resistant and standing out as prominent ridges or as ribs on the walls of the transverse canyons. This sandstone forms the crest and upper slopes of Rocky Ridge, one of the boldest features of relief in the Concord quadrangle.

Hercules shale member.—The continuity of the deposition of the Briones sands was interrupted in the northern part of the quadrangle by the deposition of sediments such as make up the bituminous shale. As this particular deposit of shale is nonpersistent it is mapped not as a distinct formation but as a shale member of the Briones sandstone and is named the Hercules shale, from Hercules station, on San Pablo Bay.

FOSSILS OF UPPER FAUNAL ZONE.

The fossils listed below, which were identified by Prof. J. C. Merriam and Dr. Bruce Clark, are common in the Briones sandstone or the upper faunal zone of the Monterey group:

Fossils of the upper faunal zone.

Echinodermata:
- Scutella breweriana Rémond.

Pelecypoda:
- Arca trilineata Conrad.
- Cardium quadrigenarium Conrad.
- Cardium corbis Martin.
- Chione securus Shumard n. var.
- Cryptomya ovalis Conrad.
- Diplodonta harfordi Anderson.
- Dosinia n. sp.?
- Dosinia cf. whitneyi Gabb.
- Marcia oregonensis Conrad.
- Metis alta Conrad n. var.
- Macoma secta Conrad.
- Macoma n. sp.
- Modiolus directus Dall (?)
- Modiolus rectus Conrad.
- Modiolus n. sp.
- Mulinia cf. densata Conrad.
- Nucula sp.
- Pandora scapho Gabb.
- Panopea generosa Gould.
- Pecten crassicardo Conrad.
- Pecten acutilineatus Conrad.

Pelecypoda—Continued.
- Ostrea bourgeoisii Rémond.
- Saxidomus nuttalli Conrad.
- Schizothærus nuttalli Conrad.
- Solen sicarius Gould.
- Solen curtis Conrad.
- Siliqua lucida Conrad.
- Spisula albaria Conrad.
- Spisula catilliformis Conrad.
- Tivela n sp.
- Tellina 3 sp.
- Tellina oregonensis Conrad.
- Yoldia cooperi Gabb.

Gastropoda:
- Calyptræa filosa Gabb.
- Cancellaria vestusta Gabb.
- Cancellaria 2 sp.
- Chrysodomus 3 sp.
- Crepidula princeps Conrad.
- Nassa n. sp.
- Neverita recluziana Petit n. var.
- Polynices n. sp.
- Trophon ponderosum Gabb.
- Trophon n. sp.

PARTLY DIFFERENTIATED MONTEREY STRATA IN THE CONCORD QUADRANGLE.

In the northeastern part of the Concord quadrangle there are two other belts of strata which belong to the Monterey group and which appear to represent more nearly persistent shallow-water deposition. The bituminous shale in these belts is meager in amount and prevailingly sandy, so that in this area the group can not be subdivided into formations by its petrography as easily as in the more central portion of the quadrangle.

One of these belts, which is flanked on both sides by the Tejon formation, lies in a synclinal trough between Martinez Ridge and Pacheco. The fossils collected in this belt indicate that it includes both upper and lower Monterey. The lower and upper faunal zones are well represented, but the middle zone is represented only by a comparatively thin sandy bituminous shale, which may be the equivalent of the entire fivefold alternation of sandstone and bituminous shale found a few miles farther west or any part of it but which is mapped as the Tice shale.

The second belt forms the crest of Shell Ridge, a northwestern spur of Mount Diablo, constituting the northeastern limb of an overturned syncline. This, like the belt near Pacheco, also apparently represents all the deposits of Monterey time but is deficient in bituminous shale, including only one shale formation. The character of the rocks in this belt indicates that this part of the basin of deposition was only once removed by subsidence far enough from the shore to permit the deeper-water sedimentation represented by the bituminous shale. This body of bituminous shale has been mapped as the Tice formation.

UNDIFFERENTIATED MONTEREY STRATA IN THE TAMALPAIS QUADRANGLE.

The only other Monterey strata that remain to be noted form the thick body of bituminous shale that occupies the peninsular ridge west of Bolinas Lagoon and Olema Creek, in the Tamalpais quadrangle. Neither the bottom nor the top of the Monterey group is here exposed, the bottom being deeply buried and outcropping only in the quadrangle to the north, on the Point Reyes Peninsula, and the top having been completely removed by erosion. Moreover, so far as has been observed, the shale here includes no intercalated sandstones. The rocks consist of fine-grained soft or chalky shales, which are locally strongly bituminous, the bituminous matter being at some places so abundant that it colors the rocks deep brown or even black. In other places the shales are prevailingly of a faded purplish or creamy color. The lower part of the section contains evenly laminated cherty varieties of shale, and the section includes also small concretionary masses of impure limestone, the largest 2 feet in diameter. The strike of the beds is prevailingly that of the ridge but is locally complicated by folding, which makes it difficult to estimate the thickness of the rocks in sections normal to the general strike. The southern end of the ridge is in general anticlinal, the beds on the northeast side of the ridge dipping toward Bolinas Bay and those on the southwest side dipping toward the Pacific. The total revealed thickness is probably not less than 2000 feet.

If this body of bituminous shale represents all the shale formations of the middle part of the Monterey group in the Concord quadrangle, as it probably does, the conditions that prevailed in this part of the basin of deposition were the complement of those that prevailed in the belts near Pacheco and at Shell Ridge, in the Concord quadrangle, for the sea floor here in the middle of Monterey time was apparently never brought close enough to the shore by uplift to permit an influx of littoral sands. The continuity of bituminous-shale deposition in this region was thus unbroken and produced a single formation, which corresponds probably to five or more formations in the Concord quadrangle.

BASALT.

Within the Santa Cruz quadrangle there are several masses of basalt and diabase, which have been closely studied by Haehl and Arnold,[a] who have determined that these rocks were the products of a volcanic eruption that occurred in Miocene time. Small masses of similar basalts occur also at and near the southern boundary of the San Mateo quadrangle. These may be erosional residuals of flows that rest upon the worn surface of the Franciscan rocks, but the relations shown in structure sections F–F and G–G suggest that they may be intrusive. They are of post-Franciscan age and are doubtless the products of volcanic activity of the period to which were assigned the rocks in the Santa Cruz quadrangle, so that they are probably of Miocene age. These basalts and diabases are fully described by Haehl and Arnold, who present minute details as to their petrographic character and geologic relations in the Santa Cruz quadrangle.

SAN PABLO FORMATION.

General features.—In the area mapped in this folio the San Pablo formation occurs only in the Concord and Haywards quadrangles. The rocks composing the formation are of marine origin and consist chiefly of medium-grained sandstones which, where unoxidized are of a pronounced blue color. This blue sandstone occurs generally in massive beds that show only obscure traces of bedding and weathers typically in very rugged outcrops that have a more or less cavernous appearance. In some parts of the formation the sandstone is admixed with volcanic tuff, and at a few localities thin beds of tuff are intercalated with the sandstones. Certain beds of the blue sandstone are richly fossiliferous and yield a fauna that is different from that of the Monterey, on which the formation rests, and from that of the distinctly Pliocene formations of the region. The same assemblage of fossils occurs in other beds of sandstone that is regularly stratified, that is not blue, and that can not easily be distinguished from the sandstones of the Monterey group.

Distribution.—The San Pablo formation is rather widely distributed in the Concord quadrangle, lying in several belts. One of these belts is in a synclinal trough east and southeast of Walnut Creek, a second is in a syncline that extends northwestward from Walnut Creek to the northern limits of the quadrangle and thence to San Pablo Bay, and a third runs diagonally across the central part of the quadrangle, on the northeast side of the large synclinal trough that contains the Orinda formation. This third belt splits into three parts toward the southeast, owing to overthrust faulting, one part

[a] Haehl, H. L., and Arnold, Ralph, The Miocene diabase of the Santa Cruz Mountains in San Mateo County, Cal.: Am. Philos. Soc. Proc., vol. 43, No. 175, p. 16, 1904.

following the southeast flank of Las Trampas Ridge, the second lying along the southwest flank of Rocky Ridge, and the third passing northeast of Las Trampas Ridge.

In the vicinity of Walnut Creek the syncline in which the San Pablo formation lies is sharply appressed and overturned, so that the San Pablo strata on the northeastern limb of the fold dip under the older Monterey beds at angles ranging generally from 40° to 60° but in some places as low as 30°. The average dip is about 45°. The thickness of the formation on this limb of the syncline averages about 1400 feet. The outcrop along this limb forms the southwestern crest of Shell Ridge, a spur of Mount Diablo, and is the northern limit of a large outcrop that encircles Mount Diablo on the south. The western limb of the syncline outcrops in a belt about half a mile wide along Walnut Creek, extending from the lower end of San Ramon Valley to Ygnacio Valley. Here beds of the San Pablo dip away from the beds of the Monterey group at lower angles than those displayed by the Monterey beds. In the town of Walnut Creek a bed of fine-textured white volcanic ash, from 1 to 2 feet thick, occurs in the lower part of the San Pablo formation.

In the northwestern part of the quadrangle the San Pablo formation occurs as a series of outlying synclinal patches, of low dip, which possibly lie unconformably upon the Briones sandstone. These are outliers of a well-defined synclinal trough of the San Pablo which is well exposed on the shores of San Pablo Bay, in the Napa quadrangle.

The largest exposure of the San Pablo formation forms a belt that lies between the Monterey and the Orinda, on the northeast side of the dominant syncline of the quadrangle. Southeast of Lafayette this belt broadens and is synclinally folded. Its distribution is determined by a series of faults, which are shown on the map.

Thickness.—The thickness of the San Pablo formation, which may be best determined in the sections exposed on the shores of San Pablo Bay, in the Napa quadrangle, is about 1700 feet. On the west flank of Las Trampas Ridge it seems to have about the same thickness. In the Walnut Creek syncline about 1400 feet of strata are exposed. At the north end of Las Trampas Ridge and in the northwest corner of the Concord quadrangle only remnants of synclinal troughs are preserved.

Age.—The age of the San Pablo formation is determined partly by its superposition upon the Monterey in relations that indicate unconformity and partly by the fossils it contains. Although the structural discordance indicated is apparent at only a few places in the area here discussed, it is clearly evident in other parts of the Coast Ranges, where the Monterey formations were disturbed and eroded and the configuration of the basins of deposition was radically changed before the sediments that formed the San Pablo were laid down. The San Pablo fauna has been considered Miocene by nearly all paleontologists who have studied it, but C. E. Weaver, who several years ago studied the fauna in the middle Coast Ranges, referred it to the Pliocene because he identified with living forms 41 species, or 56 per cent, of the 73 species in the fauna examined by him. It is interesting to note that he found twice as many San Pablo forms that persist to the present day as have been discovered in the Merced, or later Pliocene—a fact that throws light on the vicissitudes of the region in Tertiary time. Bruce Clark's more recent and still unpublished investigations of the paleontology of the San Pablo formation have, however, greatly reduced the percentage of living forms and indicate a Miocene rather than Pliocene age for its fauna.

The Santa Margarita formation in the Santa Cruz quadrangle and the more southern part of the Coast Ranges is probably the equivalent of the San Pablo, for it contains practically the same fauna and its stratigraphic relations are the same.

Fossils.—The following list of fossils has been revised by Dr. Bruce Clark, who refers the fauna to the Miocene and considers it more closely related to the Monterey than to the Merced fauna:

Fossils of the San Pablo formation.

Echinodermata:
- Astrodapsis tumidus Rémond.
- Astrodapsis whitneyi Rémond.
- Scutella gabbi Rémond.
- Astrodapsis 4 n. sp.
- Asteris remondi Gabb.

Pelecypoda:
- Amiantis 2 n. sp.
- Cardium quadrigenarium Conrad.
- Cardium corbis Martyn.
- Chama pellucida Conrad.
- Chione 2 n. sp.
- Dosinia 3 n. sp.
- Diplodonta orbella Gould.
- Macoma 4 n. sp.
- Macrocallista newcombiana Carpenter.
- Mactra n. sp.
- Modiolus n. sp.
- Mulinia densata Conrad.
- Mulinia n. sp.
- Mytilus 3 n. sp.
- Paphia staminea Conrad.
- Pecten pabloensis Conrad.
- Pecten crassicardo Conrad.

Pelecypoda—Continued.
- Pecten estrellanus Conrad n. var.
- Pecten 5 n. sp.
- Petricola n. sp.
- Phacoides richthoffeni Gabb.
- Phacoides tenuisculpta Carpenter.
- Pitaria 2 n. sp.
- Nucula conradi Dall.
- Platyodon cancellatus Conrad.
- Sanguinolaria alata Gabb.
- Sanguinolaria nuttalli Gabb.
- Solen curtis Conrad.
- Solen sicarius Gould.
- Spisula catilliformis Conrad.
- Spisula abscissa Gabb.
- Spisula cf. falcata Gould.
- Siliqua lucida Conrad.
- Yoldia n. sp.
- Zirpheadentata Gabb.

Gastropoda:
- Calliostoma 2 n. sp.
- Calyptræa filosa Gabb.
- Calyptræa inornata Gabb.
- Calyptræa 2 n. sp.
- Crepidula onyx Sowerby.

Gastropoda—Continued.
- Crepidula n. sp.
- Polynices (Euspira) 2 n. sp.
- Polynices (Neverita) recluziana Petit n. var.
- Bittium 3 sp.
- Chrysodomus 4 n. sp.
- Hemifusus n. sp.
- Leptothyra n. sp.

Gastropoda—Continued.
- Littorina remondi Gabb.
- Littorina n. sp.
- Ocinebra 2 n. sp.
- Priene n. sp.
- Ranella n. sp.
- Tegula 3 n. sp.
- Trophon carisaensis Anderson.
- Trophon ponderosum Gabb.

PLIOCENE SERIES.

LEONA RHYOLITE.

Distribution and character.—The formation for which the name Leona rhyolite is here used is a lava that forms a discontinuous belt along the west front of the Berkeley Hills, in the Concord and Haywards quadrangles, from Hamilton Gulch, in Berkeley, nearly to Decoto, a distance of 21 miles. It reaches its maximum width a little south of Leona Heights, in the Concord quadrangle, where it is about a mile and a half wide. The formation is named from Leona Heights. The rock varies in appearance from place to place but is in general an acidic or rhyolitic lava, though it includes local masses of darker, more basic rock, which in the field can not easily be segregated from the general mass. When fresh or unweathered the rhyolite is a light bluish-green compact rock, feebly porphyritic and studded with minute crystals of pyrite, and contains apparently no ferromagnesian silicates. It appears very massive and generally shows no flow structure, but in its larger exposures it is traversed by rather irregular joints and cracks. In certain local facies it is amygdaloidal and some of the vesicles are drawn out. In other local facies it is of coarser texture and has a granular structure. Under erosion this rock forms steep slopes that are resistant to degradation, so that its profiles present a contrast to those of the formations with which it is associated. Under the weather the rock disintegrates both mechanically and chemically. The mechanical alteration yields a soil charged with small, sharply angular fragments; the chemical alteration is due to the oxidation of the pyrite to limonite and hematite and to the decomposition of the silicates of the rock by the sulphuric acid formed by this oxidation. The general result is that the outcrop and soil are reddish or yellowish brown, but in many prominent outcrops where the iron oxides have been leached out the rock is yellowish white. A microscopic examination of typical specimens of the least decomposed facies of the rock shows that it consists of a microcrystalline aggregate of quartz and feldspar in which are embedded a few small phenocrysts of orthoclase, oligoclase and andesine and, more rarely, corroded phenocrysts of quartz. It includes also some polysomatic quartz that grades into and interlocks with the groundmass, but this may be secondary. It contains a few slender prisms of apatite and crystals of zircon and, in addition to the pyrite, some small crystals of magnetite.

The decomposition of the rock forms much white isotropic, nearly opaque earthy material in the groundmass, through which chlorite is usually disseminated. This material is probably residual amorphous silica. The chlorite is not derived in place from preexisting ferromagnesian silicates but has migrated through the rock. Secondary quartz, calcite, and chlorite fill minute cracks. The abundant chlorite makes the rock dark. The feldspars are cloudy and in part silicified. Many of the crystals of pyrite, both the cubes and the pentagonal dodecahedra, are surrounded by the white earthy material above mentioned. Some of the pyrite occurs partly in the feldspars, which bear allotriomorphic relations to them, indicating that the pyrite may perhaps be an original constituent of the rock. Other occurrences of pyrite are, however, probably of secondary origin.

Chemical composition.—The chemical composition of the rock is shown in the following analyses of samples selected from collections made near Laundry Farm:

Analyses of Leona rhyolite.

	1	2	3
SiO_2	71.00	72.12	71.60
TiO_2		.17	.12
Al_2O_3	12.70	11.49	11.93
Fe_2O_3	.66	2.77	3.00
FeO	2.44	2.30	3.40
MnO		.10	.09
CaO	.90	.94	.52
BaO		Trace.	
MgO	1.39	.85	1.33
Na_2O	6.45	5.28	4.62
K_2O	2.99	.86	1.90
P_2O_5		.88	.62
SO_3			.08
CO_2		1.15	.38
FeS_2		.03	
Cl		Trace.	
H_2O (at 110° C.)	.28	.06	.07
Ignition	1.56	.96	.55
	100.37	99.96	100.21

1. Analyzed by C. P. Richmond in the laboratory of the University of California.
2 and 3. Analyzed by G. E. Colby in the laboratory of the University of California.

The high content of silica, the low content of lime, and the proportion of soda to potash indicate clearly that the rock is a soda rhyolite; but the fact that all the material is more or less altered precludes the possibility that these analyses may represent the true composition of the original rock. Some of the ferric oxide in samples 2 and 3 is doubtless contained in hematite produced by the oxidation of pyrite. Sample 1 was practically free from pyrite. Chemically it closely resembles the Northbrae rhyolite, to be described under the next heading, but reasons are there given why it is regarded as a separate lava flow.

Field relations.—This rhyolite is a lava which lies indifferently on the several formations of the Franciscan group, on the rocks intruded into it, and on the Knoxville formation. The rhyolite belt follows in a general way the line of the Knoxville-Franciscan contact. It is evident that before the extrusion of the lava the Cretaceous rocks had been deeply eroded and in part completely stripped from the underlying Franciscan. The linear disposition of the rock is probably due to the fact that the lava flowed along a valley that followed the contact. At some places the rhyolite lies on a pebbly conglomerate that probably represents the river gravels of the valley into which the lava flowed.

The belt of rhyolite is in general coincident with the fault zone of the Haywards rift, and in this zone there are many minor or auxiliary faults, some of which traverse the rhyolite, so that in some places the boundaries of the formation are fault contacts. Several faults cut entirely across the rhyolite, particularly at Hamilton Gulch, in Berkeley, and near Temescal Lake, in the Concord quadrangle, and at San Leandro Canyon, in the Haywards quadrangle.

Age.—The age of the rhyolite can not be determined precisely. Its superposition in certain places upon the Knoxville formation clearly indicates that it was laid down after a post-Cretaceous erosion and is therefore Tertiary or Quaternary. The western flanks of the rhyolite belt are covered by rather early Quaternary alluvium, so that the rhyolite is doubtless Tertiary in age, but to what division of the Tertiary it belongs is largely a matter of conjecture. Analogy with other localities would suggest that it is of late Tertiary age, probably Pliocene. Since it is of about the same age and of the same chemical composition as the Northbrae rhyolite, it might be regarded as part of the same lava flow if it were not for certain physical differences, to be described later.

NORTHBRAE RHYOLITE.

Distribution.—On the western slope of the Berkeley Hills north of Berkeley there are numerous isolated patches of a white rhyolite lava, apparently the remnants of a flow, the greater part of which has been removed by erosion. The area covered by these patches is about 5 miles long and about 1 mile wide, and the thickness of the rock probably nowhere exceeds 100 feet. This rock is named the Northbrae rhyolite from the district of that name near Berkeley, in the San Francisco quadrangle, where it is most abundant, and should be distinguished from the Leona rhyolite, found southeast of Berkeley. It lies indifferently upon the worn surface of the Franciscan and of the Cretaceous formations. Dikes of similar rock that cut the Franciscan formations may have been composed of the same molten rock that formed this lava. The rhyolite is overlain by conglomerate, which is referred to the Campus formation, and its relation to the Orinda formation at the northern end of the area indicates that the Orinda also overlies it. It may safely be regarded as of pre-Orinda or early Orinda age.

Correlation.—Its position suggested that the rhyolite might be the massive correlative of the pumiceous Pinole tuff, which farther north occurs at the base of the Orinda formation and in Sonoma County at the base of the Merced formation. An analysis by George E. Colby of a sample of the Pinole tuff obtained near Cordelia is given in the table below with analyses of the Northbrae rhyolite made by Charles Palache.

Comparison of analyses of Pinole tuff and Northbrae rhyolite.

	1	2	3
SiO_2	65.40	75.46	69.85
TiO_2	.55		
Al_2O_3	15.35	13.18	13.34
Fe_2O_3	2.10	.91	.73
FeO	1.22		
MnO	.05		
CaO	1.12	.95	.87
MgO	.60	.10	Trace.
Na_2O	2.07	6.88	5.58
K_2O	3.21	1.09	2.68
Cl	.01		
H_2O (at 110° C.)	1.18	.93	6.15 (H₂O and Ignition together)
Ignition	7.00		
	100.04	99.50	99.20

1. Pinole tuff near Cordelia.
2. Northbrae rhyolite, spherulitic facies.
3. Northbrae rhyolite, glassy facies.

The comparison does not support the suggestion afforded by stratigraphic considerations.

Petrographic features.—The Northbrae rhyolite has been studied and described in detail by Palache.[a] In some places it shows pronounced flow structure, locally marked by vesiculation and layers of small spherulites. In other places it contains hollow spherulites, the largest several inches in diameter, which make up a considerable part of the otherwise glassy rock. One facies of the rhyolite is holocrystalline and porphyritic. The groundmass is a fine aggregate of quartz and feldspar and the phenocrysts are corroded quartz, orthoclase, and acidic plagioclase. The rock contains no ferromagnesian silicates but in places includes a little magnetite.

The Northbrae rhyolite is chemically similar to the Leona rhyolite and is probably of about the same age. It differs physically, however, in showing flow structure, with spherulites, in being glassy in certain facies, and in containing no pyrite, the presence of which is a striking feature of the Leona rock. This physical contrast indicates that the two rocks are not different parts of the same lava flow.

PINOLE TUFF.

General features.—The Pinole tuff occurs only in small exposures in the Concord and San Francisco quadrangles but is more extensively exposed in the Coast Ranges farther north. The formation is named from the town of Pinole, on San Pablo Bay, near which it is well exposed. Stratigraphically it lies chiefly between the San Pablo formation and the Orinda formation, but it is in part interbedded with the basal sediments of the Orinda and therefore appears to have been associated in its deposition with the Orinda rather than with the San Pablo. The San Pablo is a marine formation, whereas the Pinole tuff on the shores of San Pablo Bay, immediately north of the San Francisco quadrangle, contains fresh-water fossils and the bones of terrestrial mammals, thus allying it with the Orinda and indicating that it represents the first deposits laid down in the basin that contained the Orinda lake. The same kind of tuff, moreover, occurs in the fresh-water Orinda formation in Sobrante Ridge, in the northern part of the San Francisco quadrangle and in the Mount Diablo quadrangle, indicating that the volcanic activity which gave rise to the materials of the tuff persisted into the early part of the Orinda epoch. The Pinole tuff, though occupying a well-defined stratigraphic position between the San Pablo and the Orinda in several sections, is not so persistent as either of these formations. On San Pablo Bay it has a thickness of about 1000 feet, but southeast of this bay, in the San Francisco and Concord quadrangles, its volume abruptly diminishes and it thins out and disappears in the eastern part of the Concord quadrangle. It was evidently laid down in a fresh-water basin which displaced, probably after an interval of erosion, the marine basin of San Pablo time, so that there is warrant for assuming disturbances at the close of the San Pablo epoch sufficient to cause an unconformity between the San Pablo and the Pinole formations, although no angular discordance between the two formations has been detected.

Petrographic character.—In most of its deposits the Pinole tuff is distinctly stratified and appears to have been assorted by currents of water. It consists almost wholly of whitish or light-yellowish pumice, partly in fragments ranging in size from 1 to 50 millimeters and partly in fine dust, the pumiceous character of which can be observed only by means of the microscope. The general absence of quartz from the tuff and the fact that at some places it contains fragments of andesite indicate that the formation as a whole represents the froth of an andesitic magma which was scattered over a wide expanse of country by violent explosions from volcanoes whose site is not yet known but which probably lay north of the Bay of San Francisco.

Distribution.—The most extensive exposures of the Pinole tuff in the Concord quadrangle are on the flanks of the overturned syncline that lies east of Walnut Creek. Here the outcrop of the underlying San Pablo on the west side of the syncline is paralleled by a belt of the tuff for 5 miles, and that on the east side is paralleled by a similar belt for about 3½ miles. The tuff on the west limb of the syncline dips away from the San Pablo in the vicinity of Walnut Creek at an angle of about 45°, and that on the east limb of the syncline dips under the San Pablo formation at an angle of 45°. The tuff on the west limb has a maximum thickness of probably 100 feet. At the north end of this exposure it is cut off by the alluvium of Ygnacio Valley, and at the south end it abuts abruptly against an east-west fault. Its maximum thickness on the east limb of the syncline is perhaps 150 feet, but it thins out and disappears before it reaches the eastern boundary of the quadrangle.

Another deposit of the Pinole tuff lies at the northwest end of Las Trampas Ridge, where it forms a simple open synclinal trough, having the San Pablo beneath it and the Orinda above it. Around the edge of the syncline the rocks dip from 20° to 45° toward the axis of the fold, which strikes northwest.

[a]Palache, Charles, California Univ. Dept. Geology Bull., vol. 1, No. 2, pp. 61–72, 1893.

The thickness of the tuff here does not exceed 50 feet. Between Grizzly Creek and Las Trampas Creek, on the west side of Las Trampas Ridge, the Pinole tuff crops out with a northerly strike and westerly dip and evidently represents the anticlinal correlative of the syncline just described, which, however, has been broken by an axial fault.

In the northeast corner of the San Francisco quadrangle there are two areas of the Pinole tuff, one on each side of Sobrante Ridge. One of these is on the east side of Pinole Valley, where it presents a bold outcrop along a low ridge about a mile long. The strike of the tuff strata here is a little west of north and is transverse to the strike of the Monterey formations, which abut upon it. The tuff here has evidently been brought against the Monterey by a fault that coincides in trend with Pinole Valley, so that the mass is an outlying remnant that has been preserved from erosion. The outcrop on the southwest side of Sobrante Ridge is about 2 miles long, the strata having a northwesterly strike and a low dip to the southwest and being interstratified with the basal beds of the Orinda formation. The thickness of the tuff here probably does not exceed 50 feet. It is remarkable that in neither of these localities is there any trace of the San Pablo formation between the Pinole tuff and the rocks of the Monterey group, although the San Pablo is represented by about 1500 feet of strata a few miles farther north, on the shores of San Pablo Bay, and is equally well represented farther southeast, in the Concord quadrangle. This absence of the San Pablo from its normal stratigraphic horizon indicates either that the unconformity between the Pinole tuff and the San Pablo formation represents a longer time than might be inferred from their relations in other localities in these quadrangles, the whole of the San Pablo having been removed by erosion before the tuff was deposited, or that the San Pablo was not deposited in the region of Sobrante Ridge because that region was a land area in San Pablo time.

ORINDA FORMATION.

General features.—The Orinda formation, which is confined to the Concord and San Francisco quadrangles, is named from Orinda, in the Concord quadrangle. It forms a broad belt that traverses the middle of the Concord quadrangle from southeast to northwest and extends across the northeast corner of the San Francisco quadrangle. Another belt, broadening toward the southeast, where it passes into the Mount Diablo quadrangle, lies in the overturned syncline east and southeast of Walnut Creek. The formation consists of a thick accumulation of fresh-water beds comprising (1) conglomerates that include waterworn polygenous pebbles, few larger than a man's fist, and in places strongly cemented; (2) light-colored sandstone; (3) blue, gray, and brown clay shales; (4) limestones; (5) some thin seams of lignite; and (6), at a few horizons, thin layers of brown decomposed volcanic tuff. Farther east, in the Mount Diablo quadrangle, the formation includes a few beds of pumiceous tuff similar to the Pinole tuff, in its lower part. Fresh-water ostracodes are found at certain horizons in the clay shale and the sandstone. The limestone is of two kinds. Certain beds are made up wholly of remains of ostracodes; in others the rock is dense or compact, is light gray or bluish in color, and, instead of ostracodes, contains fresh-water mollusks, such as Limnæa, Physa, and Planorbis. This variety is generally cherty, and the chert may be irregularly distributed through the limestone or may be interlaminated with it. Here and there the remains of mollusks are found in the chert. The limestone beds are thin and in the aggregate constitute probably less than 1 per cent of the formation. In San Pablo Ridge, in the San Francisco quadrangle, toward the northwest end of the main belt, the formation is from 2000 to 2500 feet thick, but farther southeast, near the southern boundary of the Concord quadrangle, its thickness increases to about 6000 feet.

Stratigraphic relations.—The Orinda formation lies conformably upon the Pinole tuff, but southeast of Walnut Creek, where the tuff thins out and disappears, and elsewhere along the eastern border of the area of its exposure, it rests directly upon the San Pablo formation. In a large part of its outcrop in these quadrangles, however, it is underlain by neither the Pinole tuff nor the San Pablo formation, for it rests with marked angular discordance upon the worn edges of either Monterey or Franciscan strata. The general structure of the main belt of the Orinda is that of a great synclinal trough with subordinate folds. One of these folds forms a syncline along San Pablo Ridge east of Berkeley, in the trough of which lies a later series of volcanic rocks. Between this syncline and the main trough of the Orinda there is a low anticline on the northeast flanks of San Pablo Ridge. Another subordinate syncline, on the other side of the main trough, determines the course of Pleasant Valley, northwest of Lafayette, and outlying remnants of this syncline of Orinda rest upon the Pinole tuff in small canoe-shaped troughs at the northwest end of Las Trampas Ridge.

The Pleasant Valley syncline is separated from the main trough by a broad anticline that pitches southeastward and can not be followed far. In the southern part of the Concord quadrangle, near the head of Las Trampas Creek, the main belt of the Orinda bifurcates at the end of an upthrust fault block of Monterey and San Pablo strata which constitutes the high and bold Rocky Ridge, one portion following the course of Bolinger Canyon to the eastern limit of the quadrangle and the other flanking Rocky Ridge on the southwest and extending southeastward across the northeast corner of the Haywards quadrangle.

The synclinal trough of the Orinda southeast of Walnut Creek is a simple fold, which, with the underlying strata already described, has been overturned by overthrust pressure from the northeast, so that the Orinda beds on the northeast flank of the syncline dip under the Pinole tuff at an angle of about 45°. The strata in certain low gravel-strewn hills in the northeast corner of the Concord quadrangle are also referred to the Orinda as a result of studies made by C. E. Weaver in the adjoining Napa quadrangle, where their character is better displayed.

Fossils.—Besides the ostracodes of the Orinda formation, the following fresh-water mollusks have been recorded by J. G. Cooper[a] from the west side of San Pablo Creek, along the road from Berkeley to Lafayette:

Anodonta nuttalliana Lea var. lignitica Cooper.	Limnæa contracosta Cooper.
	Planorbis pabloanus Cooper.

These fossils were found in association with a thin seam of lignite. The first is a living species; the two others are extinct. The following fossils, described by Cooper, were collected north of Livermore, from beds that are probably the extension of the Orinda formation across the Mount Diablo quadrangle into the Pleasanton quadrangle.

Bythinella binneyi Tryon.	Limnophysa palustris Linné.
Carinifex newberryi Lea.	Limnophysa desidiosa Say.
Cochliopa rowelli? Tryon.	Menetus opercularis Gould.
Gyraulus vermicularis Gould.	Physa diaphana Tryon.
Helix californiensis Lea.	Pisidium occidentale Newberry.
Limnophysa humilis Say.	Pompholopsis whitei Call.

The following vertebrate remains, identified by Prof. J. C. Merriam, have been found in the Orinda formation near the upper part of Las Trampas Creek and in Bolinger Canyon, in the Concord quadrangle:

Right superior molar of Hipparion speciosum.
Left superior molar of Hipparion speciosum.
Radius, ulna, carpus, and metacarpus of a camel.
Left superior molar of a camel.
Metapodial of undetermined form.
Pelvis of undetermined form.

Age.—The Orinda formation can with confidence be assigned to the Pliocene epoch, for it lies stratigraphically above the Pinole tuff, which is Pliocene. Its correlation with other Pliocene formations of the Coast Ranges is, however, somewhat more difficult. The mammalian fossils recorded above, fragmentary as they are, indicate older Pliocene having affinities with the Miocene, and their consideration has led to the opinion, expressed in earlier papers, that the Orinda antedates the Merced formation of the Pacific coast, which has usually been held to represent later Pliocene, but the work of Osmont[b] in the Coast Ranges north of the Bay of San Francisco has shown that the Sonoma tuff of that area is intercalated in the lower portion of the Merced. Work done by C. E. Weaver in the Napa quadrangle, the results of which are not yet published, and the writer's review of the whole field since Osmont's and Weaver's work was done show further that the Sonoma tuff is probably identical stratigraphically as well as petrographically with the Pinole tuff, which underlies the Orinda formation. If this is true the Orinda should obviously be correlated with the Merced on grounds which are independent of the evidence afforded by the fossils obtained from the two formations. According to this view the Orinda is the fresh-water equivalent of the Merced, laid down in an interior diastrophic trough and shut off from the sea by a ridge corresponding in position and trend with the present Berkeley Hills.

MERCED FORMATION.

General character and distribution.—The Merced formation, named for Lake Merced, comprises a thick accumulation of marine sediments, which occur chiefly on the San Francisco Peninsula, in the San Mateo quadrangle, but of which there is an outlying patch at and north of Bolinas, in the Tamalpais quadrangle, and a similarly isolated deposit at Miramontes, northwest of Halfmoon Bay, in the San Mateo quadrangle. The Merced is well exposed in the section along the sea cliffs between San Francisco and Mussel Rock, where the maximum height of the cliffs is about 700 feet. The section here shows about 5800 feet of marine clays, sandy shales, sandstone, fine pebbly conglomerates, and shell beds, all of which dip prevailingly northeastward at angles ranging from 15° to 75°, though a small part dip more nearly eastward at lower angles, some as low as 5°.

[a]Cooper, J. G., On some Pliocene fresh-water fossils of California: California Acad. Sci. Proc., 2d ser., vol. 4, p. 169, 1894.

[b]Osmont, V. C., A geological section of the Coast Ranges north of the Bay of San Francisco: California Univ. Dept. Geology Bull., vol. 4, No. 3, pp. 39–87, 1904.

Stratigraphic relations.—The basement upon which the Merced formation rests in the vicinity of Mussel Rock is the worn surface of volcanic rocks of the Franciscan group. Between the basement volcanic rock and the basal beds of the Merced is a wedge of post-Franciscan and pre-Merced alluvium, now firmly cemented, composed almost wholly of fragments derived from the underlying volcanic rock. Upon this ancient alluvium lies a layer of forest material, less than a foot thick, comprising carbonized wood, bark, matted leaves, and pine cones of the species *Pinus insignis*, and above this are the marine beds. Cones of the same species have been found in the marine beds a few hundred feet higher in the section, just north of the landslide near Mussel Rock. Still higher are cones of *Pseudotsuga douglasi*. In one of the canyons east of Mussel Rock, where a small stream has cut down into the formation, several trunks of coniferous trees are exposed, the wood and bark being excellently preserved. These trunks lie in the Merced formation, and a sandstone bed a little above them contains numerous remains of marine mollusks. Thin lignitic seams also occur here and there in this section. Toward the upper part of the section there is a bed of white volcanic ash, which consists chiefly of minute fragments of pumiceous glass. The ash contains no quartz and is probably andesitic. It ranges in thickness from a few inches to perhaps 2 feet. On the cliffs north of Mussel Rock the actual exposure of the inclined beds measures about $3\frac{3}{4}$ miles along the shore, or obliquely across the strike. From the cliffs the beds strike southeastward along the southwest side of Merced Valley and have been traced nearly as far as San Mateo. The breadth of the outcrop along this belt decreases steadily to the southeast by the disappearance of the upper beds. Everywhere, however, the base of the Merced rests upon the Franciscan. As a large part of the formation is composed of soft beds it is exposed at but few places along the northeastern side of the belt, and it can with difficulty be discriminated from the soft alluvial Quaternary formations and the sand dunes that occupy the adjoining territory. The belt of Merced is limited on the northeast by a fault that drops the formation not less than 7000 feet against the Franciscan rocks of San Bruno Mountain. The actual trace of this fault is, however, obscured by an overlying mantle of Quaternary sands. Toward the northwest it passes beneath the waters of the Pacific, and toward the southeast it passes beneath the Bay of San Francisco.

On the low coastal ridge known as Miramontes, northwest of Pillar Point, in the southwest corner of the San Mateo quadrangle, a remnant of the Merced forms a belt about 2 miles long and a quarter of a mile wide, striking northwest. The rocks of this belt are chiefly sandstones, sandy shales, and shell beds, in part gently folded in open anticlines and synclines, as may be seen clearly on the wave-cut terrace at low tide, and in part so closely appressed that they stand nearly vertical. At the north end of the belt, near Seal Cove, the basal beds of the Merced formation rest directly upon the granitic rocks that form the shore farther north. Here all the phenomena of a bowldery beach may be seen at the base of the section.

North of the Golden Gate, at Bolinas, in the Tamalpais quadrangle, another mass of the same formation, containing typical Merced fossils, rests unconformably upon much-disturbed beds of the Monterey group and dips eastward beneath Bolinas Bay so as to abut upon the Franciscan, against which the Merced beds have been faulted by a northwestward extension of the San Bruno fault.

Fossils.—The beds of the Merced formation are at several horizons abundantly fossiliferous and have yielded the forms named in the following list. The species were determined by B. M. Martin, who has recently made an exhaustive study of the fauna and who finds that 63 per cent of the forms in the lower part of the formation, constituting its greater part, are those of living species.

Fossils of the Merced formation.

Echinodermata:
- Scutella interlineata Stimpson.

Pelecypoda:
- Arca trilineata Conrad.
- Cardium meekianum Gabb.
- Cardium quadriginorum Conrad.
- Cardium corbis Martyn.
- Chione succincta Valenciennes.
- Cryptomya californica Conrad.
- Macoma inquinata Deshayes.
- Macoma nasuta Conrad.
- Marcia oregonensis Conrad.
- Modiola recta Conrad.
- Mya japonica Jay.
- Mytilus edulis Linné.
- Nucula superstriata Carpenter.
- Ostrea lurida Carpenter.
- Pandora grandis Dall.
- Paphia staleyi Conrad.
- Paphia staminea Conrad.
- Paphia staminea var. diversa Sowerby.
- Paphia tenerrima Carpenter.
- Pecten sp.
- Phacoides annulatus Reeve.
- Cardium centifilosum Carpenter.

Pelecypoda—Continued.
- Saxidomus giganteus Deshayes.
- Saxidomus nuttalli Conrad.
- Siliqua patula var. nuttalli Conrad.
- Solen sicarius Gould.
- Spisula albaria Conrad.
- Spisula catilliformis Conrad.
- Schizothærus nuttalli Conrad.
- Schizothærus pajaroanus Conrad.
- Tellina bodegensis Hinds.
- Transennella tantilla Carpenter.
- Zirphæa gabbii Tryon.

Gastropoda:
- Amphissa corrugata Reeve.
- Astyris californica Gaskoin.
- Astyris gausapata var. carinada Reeve.
- Astyris richthofeni Gabb.
- Bittium asperum Gabb.
- Cerithidea californica Hinds.
- Chrysodomus portolaensis? Arnold.
- Chrysodomus stantoni Arnold.
- Chrysodomus tabulatus Baird.
- Crepidula grandis Midd.

Gastropoda—Continued.
- Crepidula onyx Sowerby.
- Crepidula princeps Conrad.
- Drillia inermis Hinds.
- Drillia mercedensis n. sp.
- Lacuna compacta Conrad.
- Margarita pupilla Gould.
- Monoceros engonatum Conrad.
- Nassa fossata Conrad.
- Nassa mendica Gould.
- Nassa mendica var. cooperi Forbes.
- Natica clausa Broderip and Sowerby.
- Olivella biplicata Sowerby.

Gastropoda—Continued.
- Olivella pedroana Conrad.
- Pachypoma sp.
- Pisania fortis Carpenter.
- Pisania fortis var. angulata Arnold.
- Thais canaliculata Ducl.
- Thais crispata Martyn.
- Thais crispata var. septentrionalis Reeve.
- Tritonium sp.
- Trochita radians Lamarck.
- Trochita filosa Gabb.
- Balanus sp.

These fossils establish the age of the formation as late Pliocene. Considered paleontologically, the upper part of the formation might be regarded as Quaternary, as it is, indeed, by some writers. This upper part, in which the living species of mollusks predominate, shows perfect stratigraphic continuity with the lower part, which is clearly Pliocene, and the formation as a whole antedates the diastrophic movements which deformed the region and ushered in the Quaternary throughout the greater part of California. It therefore seems best to use this diastrophic event as a line of demarcation between the Tertiary and the Quaternary and to class the formation as a whole as Pliocene.

BERKELEY GROUP.

GENERAL DESCRIPTION.

A group of volcanic lavas and intercalated fluviatile and lacustral deposits lies on the southwest side of the main belt of the Orinda formation in the Concord and San Francisco quadrangles. This group, which was originally named the Berkeleyan, from the city of Berkeley, near which the formations composing it are well exposed, originally included the Orinda (then Orindan) formation, which has now been separated from it, chiefly to simplify the statement of geologic relations, the Berkeley group being largely volcanic and lying unconformably on the Orinda formation, which consists chiefly of fresh-water sediments. The Berkeley group as here defined comprises three formations, which, named in ascending order, are (1) the Moraga formation, consisting chiefly of lavas with subordinate sedimentary beds; (2) the Siesta formation, composed of lacustral deposits; and (3) the Bald Peak basalt, which includes very subordinate sedimentary intercalations.

MORAGA FORMATION.

The Moraga formation, so named from Moraga Valley, in the Concord quadrangle, consists chiefly of flows of andesite and basalt, with which are associated some basic tuffs and beds of well-cemented rhyolite tuff. Between these volcanic rocks lie lenticular beds of conglomerate, clay, and limestone. One of these limestone beds, which contains fresh-water fossils, is 30 feet thick and has lavas above and below it. This bed is well exposed on the northeast side of Siesta Valley, the outcrop extending to Eureka Peak. One of the lenses of conglomerate attains in places a maximum thickness of about 200 feet. The earliest flow of the formation is a rather basic amygdaloidal andesite, which shows great constancy in character and strong persistence in occurrence and which has a uniform thickness of about 50 to 60 feet. The lavas that lie above this flow are less persistent in occurrence and thickness and are therefore more lenticular in form. Rather long intervals evidently elapsed between the successive flows of these lavas, as may be judged by the presence of brick-red laterite at the top of several of the lavas, indicating considerable exposure to the atmosphere before they were buried by later flows. One of these intervals was unusually long, and during its continuation the region was subject to notable degradation, so that when later lavas were poured out upon the surface thus modified they filled the ravines and are therefore discordant with the rocks below them. The first of the flows after this interval was the andesite of Grizzly and Ruin peaks. Its discordant relation to the lavas and conglomerate of the lower part of the formation is well exposed below Ruin Peak, on the southwest side of San Pablo Ridge. The total thickness of the Moraga formation differs from section to section, but its maximum is about 1200 feet.

SIESTA FORMATION.

The lavas of the Moraga formation that have just been described appear to have so greatly interfered with the drainage ways that they formed an extensive lake basin, which lay partly on the surface of the lava and partly on older rocks. In this lake basin were deposited the beds of the Siesta formation, which in places has a thickness of 200 feet. The formation was originally named Siestan, from Siesta Valley, in the Berkeley Hills. It comprises fresh-water sandstones that grade into conglomerates, clay shales with seams of lignite, cherty limestones containing abundant fresh-water fossils, and layers of volcanic tuff. In the clays have been found the skull of a beaver (*Sigmogomphius lecontei*), the teeth of a species of Lepus, and the dentary bone of a species of Lacerta. The same beds contain remains of fresh-water shells belonging to the genera Limnæa, Helix, and Ancylus. In the limestone beds of the Siesta, which in places attain a thickness of 10 to 20 feet, species of Planorbis, Limnæa, and Pisidium are common. Some of these fossils are found in the chert as well as in the limestone.

BALD PEAK BASALT.

The Siesta lacustral epoch was brought to a close by the flooding of the lake basin with basaltic lavas in a succession of flows that are well exposed on Bald Peak, from which they have been named. These lavas have a maximum aggregate thickness of 300 to 350 feet and constitute the summit of the Berkeley group, but as they are an erosional residual it is impossible to say how much thicker they may have been. Between two of these flows of basalt at the head of Siesta Valley is a short lens of fresh-water limestone.

RELATIONS OF THE GROUP TO ADJACENT FORMATIONS.

After the volcanic and lacustral rocks of the Berkeley group had accumulated to a thickness somewhat exceeding their present known mass the region was disturbed by a sharp orogenic movement, which bent the Berkeley and underlying strata into a well-marked syncline and a subordinate anticline. Practically all the Berkeley group that is known to-day is the remnant of this synclinal trough, which is sunk into the Orinda and forms a belt extending from Moraga Valley to Wildcat Canyon, a distance of about 9 miles, nearly all of it in the Concord quadrangle. This belt, by reason of its hard volcanic rocks, which adjoin the softer Orinda formation, makes the boldest and highest ridges of the Berkeley Hills. The two limbs of the syncline form parallel ridges, composed of lavas of the Moraga formation, and between them lies a long subsequent valley, bottomed for the most part by the clays of the overlying Siesta formation. Some remnants of rocks of the Berkeley group are also found in the subordinate anticline on the northeastern flanks of San Pablo Ridge.

The position of the Berkeley trough on the southwest side of the Orinda belt and the fact that the Orinda is much thicker and more varied in its strata on the northeast side than on the southwest indicate that the Orinda was affected by crustal movements before the lavas of the Moraga formation were poured out and that the Orinda may therefore be separated from the Berkeley by an unconformity.

TERTIARY AND QUATERNARY DEPOSITS.

SANTA CLARA FORMATION.

On the southwest side of Crystal Springs Lake, in the San Mateo quadrangle, is an embankment of ancient alluvium, which is well exposed on the wagon road to Halfmoon Bay. The north end of this embankment lies a few hundred yards northwest of the road along the side of the lake. This appears to be the northern part of a large area of alluvium that has been mapped in the Santa Cruz folio as the Santa Clara formation. The embankment at Crystal Springs Lake, which is probably 300 feet thick, is a rudely stratified deposit of angular fragments of rock and waterworn pebbles, few of them larger than a hen's egg.

The Santa Clara formation has been referred in part on very slender evidence to the late Pliocene and its beds in the Santa Cruz quadrangle are regarded as a terrestrial chronologic equivalent of the Merced. The correlation with the Merced of some of the deposits mapped in the Santa Cruz folio as the Santa Clara formation is questionable, however, for they consist of Quaternary alluvium and other distinctly fluviatile and lacustral beds of undetermined age. The deposit at Crystal Springs Lake closely resembles the San Antonio formation at East Oakland, and parts of the Santa Clara formation that lie farther south are still more like the San Antonio beds, but the data necessary for the geologic correlation of the Santa Clara with other deposits are lacking.

QUATERNARY SYSTEM.

PLEISTOCENE SERIES.

CAMPUS FORMATION.

The Campus formation occurs on the ridge of the Berkeley Hills which separates Strawberry Canyon and the head of Wildcat Canyon from the valley of the Bay of San Francisco near Berkeley, in the San Francisco and Concord quadrangles. The formation extends from Strawberry Canyon northwestward along this ridge into Wildcat Canyon for a distance of about 3 miles. It is a mile and a quarter wide just northeast of North Berkeley, and from this width it tapers to a point at each end.

The formation is made up of fresh-water deposits, fluviatile and lacustral, and various lavas, tuffs, and agglomerates. The basal part of the formation, which has the widest distribution, consists of conglomerates mixed with tuff and sandstones with intercalated beds of clay shale and lenses of limestone. This accumulation is interrupted here and there by sheets of andesite and small but relatively thick layers of tuff. Above these there is a series of beds consisting largely of tuff but containing conglomerate, lenses of limestone, and small patches of basalt. Above these beds is a thick series of basalt flows, and lastly, resting on the basalt, there are remnants of a once extensive deposit of rhyolitic tuffs and agglomerates, now well cemented.

The formation occupies a trough which trends about northwest and which lies athwart the northwest end of the older syncline of the Berkeley group—a trough that is formed in part by a synclinal fold and in part by a fault, the fault having dropped the northeast side of the trough against formations of the Berkeley and Monterey groups. This faulting appears, however, to have affected only the lower members of the Campus formation, since the volcanic rocks of the upper part of the formation are spread out over the trace of the fault in the upper part of Wildcat Canyon, in the Concord quadrangle, and the displacement must have occurred during the deposition of the formation. The fault in general, however, determines the northeastern boundary of the trough. On its southwestern boundary the basal beds of the Campus formation rest successively upon the Chico, the Knoxville, the Franciscan, and the Orinda. Although the lower part of the Campus formation is faulted down against the Berkeley group, it is apparent from the map that the Berkeley strata had been folded and in large measure degraded before the fresh-water basin in which the Campus formation accumulated had been formed and that an unconformity therefore exists between the Berkeley and the Campus. At the northwest end of the trough the conglomerates of the Campus rest on the Orinda, and as both formations are of much the same character and break down readily into soils it is difficult to discriminate the two, so that the mapping is somewhat doubtful. The Campus trough has been dislocated by a number of faults besides the one that forms its northeastern boundary.

The Campus formation is regarded as Pleistocene in age because it lies unconformably upon the Moraga and Siesta formations of the Berkeley group, which is later than the Orinda. The Orinda has been correlated in time with the Merced and is therefore regarded as Pliocene. The Campus formation was originally named Campan, from the campus of the University of California, within which portions of the formation occur.

ALAMEDA FORMATION.

Beneath the alluvial deposits of Oakland and Berkeley there is a formation of yellow sandy clay, of very uniform fine texture, which has been revealed in numerous excavations and well borings in these cities and is exposed in the trench of Diamond Creek. Without much change in character it passes into beds that carry marine shells, and intercalated with these marine deposits are nonpersistent beds of gravel of fluviatile origin, the conditions indicating delta formation alternating with marine or estuarine deposition. Three wells sunk at the corner of Twenty-eighth Street and Thirteenth Avenue, East Oakland, after passing through the yellow sandy clay with some layers of sand and gravel, struck blue clay at a depth of about 142 feet. This blue clay was 20 feet thick, and at its base were fragments of marine shells. Below this bed was a layer of blue sand, 10 feet thick, and below the sand was clay that extended to the bottom of the well, 190 feet. The same well borer found shells in the same formation at a depth of 110 feet on Eleventh Avenue and "clam" shells at a depth of 125 feet on Fifth Street near Clay Street. In the artesian wells at Roberts Landing, which pierce chiefly clays and sands and some layers of gravel, marine shells were found 133 feet, 148 feet, and 317 feet below the marsh, which stands very close to the level of high tide.

The same formation is exposed in the cliffs at the water front of West Berkeley, where it is a blue sandy clay, superficially and irregularly oxidized brown. This sandy clay extends nearly to the base of the Berkeley Hills and underlies the alluvium of the slope upon which Berkeley is situated. In a well sunk on the property of the late J. F. Sims, on Prospect Street, Berkeley, immediately at the base of the hills, this clay was 40 feet thick. A light-yellowish sand, doubtless a phase of the same formation, was exposed to a thickness of about 12 feet some years ago in excavations made when the Mechanics Building was erected on the University campus.

From the facts narrated it appears that practically everywhere beneath the alluvial slopes of Berkeley and Oakland there is a Quaternary formation, predominantly of marine origin, having a thickness of several hundred feet. This formation is here called the Alameda formation, from the city of Alameda, where it is well developed. The contrast between the Alameda formation and the overlying alluvium indicates an important event in the geologic history of the region. The fine sandy clay which everywhere forms the upper part of the Alameda formation extends close to the foot of the steep front of the Berkeley Hills. It is evident that this steep front and therefore the Berkeley Hills themselves were not in existence when the sandy clay was deposited, for such a slope would be subject to rapid degradation immediately after its uplift and no products of this degradation appear in the Alameda formation.

Between Lake Merced and the Pacific Ocean in the San Mateo quadrangle there is a deposit of light-yellow sands, about 200 feet thick, which probably lies unconformably upon the Merced and is therefore of Quaternary age and may be the correlative of the Alameda formation. These beds are but slightly disturbed but can not easily be distinguished from the Merced and therefore have not been separately mapped. They probably underlie a considerable part of the valley southwest of San Bruno Mountain.

SAN ANTONIO FORMATION.

At the foot of the steep face of the Berkeley Hills between East Oakland and Berkeley there is a great series of alluvial fans built up by streams that emerge from the hills. This alluvial deposit, which records a significant chapter in the Quaternary history of the region, is here called the San Antonio formation, from the township of that name.

The alluvium is divisible into two parts, an older and a younger part, which are mapped separately. The older gravel forms a belt that lies closer to the foot of the range and is the product of stream work done in the adjoining hills before the streams had cut back very far into the upland. It consists only of rock fragments derived from the front of the hills, for it contains no débris from the prominent band of chert, of Monterey age, which traverses the range a short distance back of its front slope. The later or upper part of the alluvium contains abundant fragments of the chert and so represents a later stage of the dissection of the range, at a period when the streams had cut into the belt of Monterey rocks. This younger deposit is referred to as the chert-gravel member of the formation.

Since its accumulation this deposit has been thoroughly dissected and terraced. One of its highest points is in the vicinity of Laundry Farm, where its surface stands 250 feet above sea level. Farther northwest a broad terrace is cut out of the alluvium at an altitude of about 175 feet above sea level, and below this is a flat-bottomed valley or stream terrace, the upper part of which stands at an altitude of 125 feet. This lower terrace, which is between 500 and 600 feet wide, is further dissected by the sharp, narrow trench of Diamond Creek, about 30 feet deep.

The San Antonio formation, particularly that part of it which lies north of the San Francisco quadrangle, contains the bones of extinct vertebrates, the following having been identified:

Morotherium gigas Marsh.	Equus sp.
Bison antiquus Leidy.	Camelid.
Elephas sp.	Large carnivore, genus indet.
Mastodon americanus Kerr.	Æchmothorus occidentalis.
Equus pacificus Leidy.	

A tidewater canal dug to a depth of 18 feet a few years ago at the east end of Alameda exposed 13 feet of sand resting on 5 feet or more of the San Antonio formation, in which were found the femur and pelvis of a ground sloth (*Morotherium gigas*).

MERRITT SAND.

The outer edge of the terraced alluvial embankment of the San Antonio formation in Oakland has a prevailingly steep front, which is evidently not its original front but is a cut cliff, probably a sea cliff formed when the east side of the valley of the Bay of San Francisco was 60 or 70 feet lower than it is now. The lower terrace of Diamond Creek was the graded flood plain of the stream when the base of this cliff was at sea level, the terrace at the mouth of the valley where it emerges from the low gravel hills having the same altitude as the base of the cliffs. Marine sediments deposited at the time of this depression now form the sand underlying Oakland and Alameda, here named the Merritt sand, from its occurrence on Lake Merritt, in the city of Oakland. In a well sunk on the property of Prof. W. J. Raymond, at the corner of Grove and Sixteenth streets, in Oakland, this sand has a maximum thickness of 44 feet and rests upon blue and yellow clay having a thickness of 45 feet. Below this clay lies gravel, which was pierced to a depth of 6 feet and yielded a flow of water. The Merritt sand is well exposed in Alameda, where it is probably 43 feet thick, an estimate made by assuming that the highest part of Alameda stands about 30 feet above high tide.

TERRACE GRAVEL.

A small area of gravel on the slope of Buriburi Ridge, in the San Mateo quadrangle, near the head of Crystal Springs Lake, is one of several such small remnants of stream gravels left on terraces of extinct streams. Its high elevation indicates that it is of Pleistocene rather than Recent age.

RECENT SERIES.

TEMESCAL FORMATION.

The Merritt sand would naturally grade into a beach deposit at the base of the cliffs cut into the San Antonio formation, but the base of the cliffs is now everywhere buried under secondary alluvium, which was derived from the alluvial embankment of the San Antonio formation in the course of its degradation and which consists of the same kind of material—fragments of the Mesozoic and Tertiary rocks of the Berkeley Hills. The superposition of this secondary alluvium upon the marine Merritt sand was well exposed a few years ago by a deep trench dug on Telegraph Avenue in Oakland. Just south of Hobart Street the trench was cut wholly in clean sand. Nearer Hobart Street the trench disclosed the feather edge of an alluvial deposit which thickened toward the north and between Hobart and Twenty-second streets rested directly on the sand. At Twenty-second Street it was 11 feet thick, and a little beyond it showed a thickness of 13 feet, the full depth of the trench. This alluvium extends up to the foot of the old sea cliffs and conceals the underlying beach deposit. It is called the Temescal formation, from the creek of that name in the San Francisco quadrangle, where it is well developed.

The alluvial deposits at the base of the steep slopes of the San Francisco, Haywards, and San Mateo quadrangles appear to be the chronologic equivalents of the Temescal formation and are so mapped.

OTHER RECENT DEPOSITS.

Terrace deposits.—A wave-cut terrace at Bolinas carries patches of marine sands, which still remain on divides between the ravines and gullies that have been cut into the terrace since its uplift but which are not mapped.

Travertine.—On the western slope of the Berkeley Hills north of Berkeley there are sheets of travertine, which were deposited by springs of calcareous water. Most of these deposits have been more or less affected by landslides, some having been carried far down the slope, and they are therefore not shown on the geologic map. Larger and thicker deposits of travertine, which are mapped, occur on Lime Ridge, a spur that projects into the Concord quadrangle from Mount Diablo near the town of Concord.

Dunes.—Wind-blown sands cover large areas in the city of San Francisco. These sands drift in from the ocean beach south of the entrance to the Golden Gate and naturally take the form of dunes. Similar dunes occur at intervals along the coast in the San Mateo quadrangle but are nowhere so extensive as in San Francisco. Most of these dunes are of very recent origin, but several other eolian deposits in the area are evidently much older and may be Quaternary—such deposits, for example, as those which form part of the cliffs on the south side of Hunter Point.

Salt-marsh deposits.—The only other deposits that remain to be mentioned are the clays and silts now accumulating in the salt marshes that fringe the Bay of San Francisco. The deposits are gradually encroaching upon the bay and tend to restrict its area.

STRUCTURE.

GENERAL FEATURES.

The dominant structure of the region about the Bay of San Fransisco is expressed in three long orographic blocks that extend from northwest to southeast, each tilted northeastward, with its crest on the southwest side, as shown in figures 2 and 3. These are (1) the Montara block, culminating in Montara

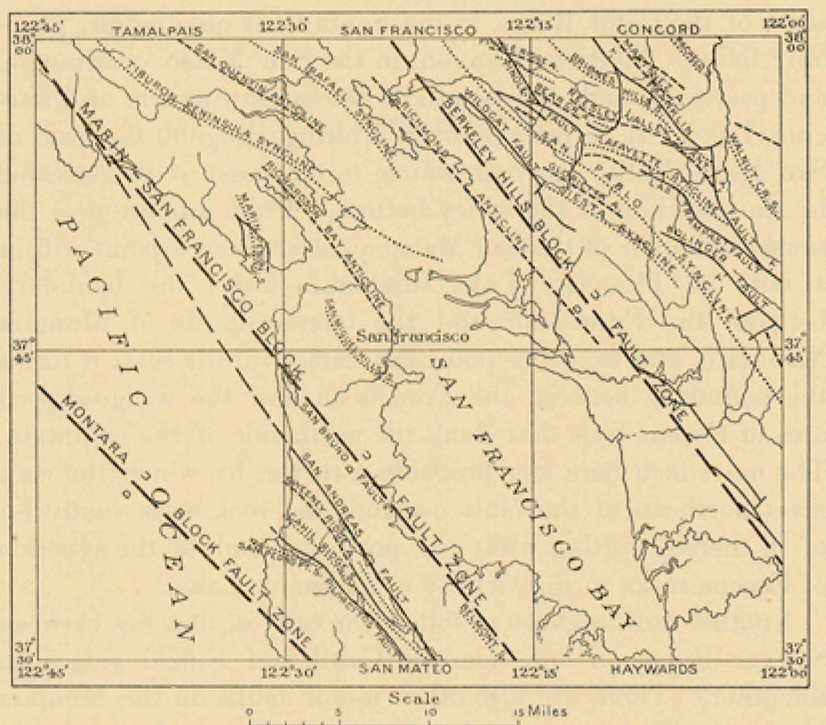

FIGURE 3.—Outline map of the Tamalpais, San Francisco, Concord, San Mateo, and Haywards quadrangles, showing the limits of the great fault blocks, the larger faults, and the axes of folds.

The folding and faulting occurred at intervals from the Cretaceous into the Quaternary period. The limits of the major fault blocks are shown by heavy dashed lines; faults by continuous lighter lines, except in the ocean, where they are broken; anticlinal axes by dashed lines; synclinal axes by dotted lines. T indicates the thrust side of an overthrust fault; U the upraised side of a fault block; D the downthrown side of a fault block.

Mountain and extending northward to the foot of San Bruno Mountain; (2) the San Francisco-Marin block, dissected superficially at the Golden Gate and culminating south of it in San Bruno Mountain and north of it in Mount Tamalpais; and (3) the Berkeley Hills block, overlooking the bay from the east. The outlines of the form and structure of these three earth blocks are shown in figure 3.

MONTARA BLOCK.

FAULTS.

The southwest and south sides of Montara Mountain form a bold, precipitous slope, which is incisively scarred by steep ravines. The main part of this slope is on the quartz diorite ("Montara granite"), but at the base of the slope south of the San Mateo quadrangle lie sedimentary beds that are tilted at high angles. These beds are coarse sandstones, which rest upon the quartz diorite and lie directly beneath a thick body of typical bituminous shales of the Monterey group. It was once suggested that these sandstones might be Tejon in age,[a] but it now seems more likely that they are the basal beds of the Monterey. The attitude of these beds, which are thus steeply inclined against the massive plutonic rock, suggests that a fault plane lies at the base of the mountain along which the strata on the north side have been raised and those on the south side have been dropped, and this is doubtless the movement that gave the northern mass its asymmetric profile—a profile characteristic of slightly degraded tilted blocks. The beds of the Monterey group that now lie on the lower southern flank of the mountain are remnants of deposits which at one time extended well over the area of the mountain but which have been eroded away on its uplifted side. A large part of this erosion, however, occurred before the movement that gave the block its present profile. From the crest of Montara Mountain northward the general profile of the tilted block descends rather gently and by steps to the Bay of San Francisco, or to the base of the southwest front of San Bruno Mountain, which is the degraded scarp of the San Bruno fault. The entire Merced formation, which occupies the northeastern part of the Montara block, abuts upon this fault plane, as shown in sections A–A and B–B, and the amount of differential displacement that has occurred on it is therefore estimated at not less than 7000 feet.

The San Bruno fault is paralleled by another, which lies closer to the face of the mountain and is regarded as auxiliary to the main fault, probably converging downward toward it and joining it far below the surface. The trace of this fault where it crosses the buttress-like shoulders of San Bruno Mountain is marked by fault breccia in the saddles.

The chief structural feature within the Montara block is the San Andreas fault, which finds expression at the surface in the well-defined San Andreas rift valley, shown in Plate IX. This is a long, straight, narrow valley, which trends about N. 34° W. In this rift valley lies the trace of the San Andreas fault, on which repeated movements have taken place, the last notable movement occurring on April 18, 1906, when there was a differential displacement of such a nature that the country northeast of the fault moved horizontally southeastward and the country southwest of the fault moved horizontally northwestward, the maximum displacement in this region having been 12 to 16 feet. In its prolongation northwestward beneath the sea, outside of the Golden Gate, this fault converges upon the San Bruno fault, and the two appear to be coincident in the rift valley between Bolinas Lagoon and Tomales Bay. The rift produced during the movement in 1906 along this fault is shown in Plate X.

The fault that parallels the San Andreas fault on the west slope of the Cahil Ridge, in the Santa Cruz quadrangle, probably follows Pilarcitos Canyon, in the San Mateo quadrangle, and passes through the length of the southwest arm of Pilarcitos Lake. It is traceable over Whiting Ridge to the head of San Pedro Valley, beyond which, to the coast, it is concealed by the alluvium of the valley bottom. From a point near the southern border of the San Mateo quadrangle to a point within a mile of Pilarcitos Lake this fault forms the boundary between the Franciscan and the quartz diorite of Montara Mountain, and from the point last named to the coast it forms the boundary between the Franciscan and the wedge-shaped area of Eocene beds that flank the north side of the mountain. The movement here was probably a thrust, by which the rock mass northeast of the fault overrode the rock mass southwest of it, thereby cutting away the northeast limb of the syncline of Eocene rocks in the vicinity of Pilarcitos Lake.

Another fault appears to follow the canyon that lies between Sawyer Ridge on one side and Cahil and Fifield ridges on the other. There are also other minor faults in the Montara block, but their structural relations have not been clearly deciphered.

Along some of the fault planes in the region about San Francisco Bay earth movements still occur and are accompanied by earthquakes. The importance of giving due consideration to these faults in connection with engineering projects is considered under the heading "Economic geology."

FOLDS.

In the Franciscan group of the Montara block the folding is obscure and difficult to decipher in detail, partly because the prevailing sandstone has but feebly marked stratification and is everywhere very much the same in appearance in its weathered outcrops and partly because the strata include irregular sheets of basic igneous rock, some contemporaneous and some intrusive, and are also much broken and dislocated in a minor way. In general, however, the folds of the Franciscan rocks are notably open, the strata dipping at low angles.

[a] Lawson, A. C., Sketch of the geology of the San Francisco Peninsula: U. S. Geol. Survey Fifteenth Ann. Rept., p. 458, 1895.

Sawyer Ridge appears to be a very flat syncline pitching southeastward. (See section E–E.) Cahil Ridge is a slightly more appressed syncline, with no perceptible pitch, but near its south end, almost at the southern border of the quadrangle, it has a rather complicated twist. This syncline, with its subordinate folds, probably extends through to the coast at Calera Valley. The sandstone of Sweeny Ridge is probably anticlinally related to the basalts that flank it on both sides.

In the area just northeast of the San Andreas rift valley, near Belmont, Sausalito chert lies on the Cahil sandstone in a flat but broken syncline, which, on Belmont Hill, locally takes the form of a sharply overturned fold. (See section G–G.)

The structure of the sedimentary rocks of Buriburi and Pulgas ridges is masked by abundant igneous rocks, but where the stratification is exposed the beds in general appear to stand much steeper than in the area southwest of the San Andreas rift. A marked structural feature of these two ridges is their slightly inclined, gently undulating surfaces, which were determined by a laccolithic sheet of peridotite, now serpentinized. Associated with this laccolithic sheet are dikes of the same material.

A notable fold of the Montara block is that in which lies the tapering belt of Eocene rocks between the Franciscan rocks and the quartz diorite of Montara Mountain, extending from San Pedro Point beyond Pilarcitos Lake. These beds were evidently laid down across the line of contact of the Franciscan and the quartz diorite and have since been buckled up in an irregular syncline by movements antedating the formation of the Pilarcitos fault, an overthrust which has cut off the northeast limb of the syncline at the southeast end of the belt, as shown in section D–D. The rocks in this general trough show a double syncline on the coast section and are traversed by a great many small faults. It is evident that these strata yielded much more readily under compressive stress than the stronger rocks on either side of the trough.

Another notable fold within the Montara block is a syncline on its northeast margin, which involves the Merced formation. The southwest limb of this syncline is well exposed in the sea cliffs between Merced Lake and Mussel Rock, where the Merced strata dip uniformly to the southeast at angles ranging from 15° to 75° but are broken by numerous small normal faults, which have throws ranging from a few inches to a few feet. The strata are over a mile thick in the measured section of the sea cliffs, and the dip of this great volume of sedimentary beds indicates that they abut upon the San Bruno fault beneath Merced Valley, as shown in sections A–A and B–B. If the Merced strata were folded before the San Bruno fault was formed, as seems probable, then the northeast limb of the fold has been carried up by the fault and removed by erosion.

The Merced strata are similarly preserved in the same syncline in the rift valley northwest of Bolinas Lagoon, in the Tamalpais quadrangle. (See section A–A.) The underlying bituminous shales of the Monterey group that occupy the south end of the Point Reyes Peninsula are much broken and confused in structure, but the outcrops of these shales on the shore between Bolinas and Duxbury Point display part of an anticline in which the strata dip prevailingly toward the northwest. The relation of these beds to the San Bruno and San Andreas faults is further described under the heading "San Francisco-Marin block."

Some interesting folding of Merced strata occurs at Miramontes Ridge and on the wave-cut terrace at its base, in the southwest corner of the San Mateo quadrangle. This area of Merced lies beyond the southwestern limit of the Montara block, but its structural features may conveniently be mentioned here. The Merced formation rests directly upon the surface of the quartz diorite, its basal deposits being those of a bowlder and pebble beach and containing abundant marine fossils of beach habitat. These beach deposits are firmly cemented, but the beds immediately above them show notable differences in resistance to marine corrasion, some being easily worn away and others remaining as salient reefs. The strata are folded into a series of small synclines and anticlines, and in the development of the wave-cut terrace the arches or domes of many of these small anticlines have been truncated. The hard beds of these truncated anticlines form circular or oval reefs that inclose depressions out of which the softer underlying beds have been washed by the waves. Between these circular reefs lie the sinuous depressions of the intervening synclines, from which soft beds that lay above the hard reefs have been similarly scoured away. At low tide there is thus presented to view over the broad terrace a remarkable model of the folded structure. The structure is, however, even more remarkable than it appears superficially, for the folded strata rest upon an early Merced, relatively smooth wave-cut surface of the quartz diorite, as shown in sections C–C and D–D, and it is difficult to picture in the mind the adjustments that have taken place within these Merced beds. It seems almost necessary to assume that they had been crowded horizontally over the flat quartz diorite surface upon which they rest, and that the forces that thus folded them had not greatly deformed the underlying massive rock.

SAN FRANCISCO-MARIN BLOCK.

FAULTS.

That part of the San Francisco-Marin block which lies in the peninsula south of the Golden Gate is bounded on the southwest by the San Bruno fault. The general features of the degraded San Bruno scarp are continued in the Marin Peninsula by the steep slope that overlooks the Pacific and the rift valley between Bolinas Lagoon and Tomales Bay. It is therefore probable that the San Bruno fault extends across the sea floor outside the Golden Gate and follows the rift valley from Bolinas Lagoon northwestward. (See fig. 3.) This interpretation is supported by the fact that at Bolinas the Merced strata dip northeastward and appear to abut upon the fault, as shown in section A–A, just as they do on the San Francisco Peninsula. But on entering the rift valley the San Bruno fault becomes coincident with the zone of the San Andreas fault, which is probably a later feature of the structure of the region and which locally followed the line of weakness and rupture already established by the San Bruno fault.

The history of displacement along the zone of faulting in the rift valley of Marin County is long and complicated. The rocks on the two sides of the fault zone are very different and owe their juxtaposition to the faulting. On the northeast side lies a great thickness of Franciscan strata, with which are associated igneous rocks. On the southwest side there are no Franciscan rocks, but in the area northwest of the Tamalpais quadrangle there is an extensive body of pre-Franciscan granitic rock, which is overlain by strata of the Monterey group,[a] and these are in turn unconformably overlain by Merced strata. It would therefore seem probable that the earlier movements on this fault zone were pre-Miocene and that they caused a relative upthrow on the southwest side of the fault, in consequence of which the Franciscan rocks were lifted into the zone of erosion and stripped off the underlying granitic rock. This erosion may have taken place in any part or during the whole of Cretaceous and Eocene time.

In the southern part of the Point Reyes Peninsula there is a great thickness of bituminous shale of the Monterey group. The shore line of the sea in which these bituminous shales were deposited must have lain far east of Bolinas Ridge, for we can not regard the beds at the western base of the ridge as in any sense littoral. It follows that the Monterey beds were laid down not only over the area of the Point Reyes Peninsula but also over a large part of the territory farther northeast, and that they were therefore spread over the trace of the old fault. In post-Miocene time there was probably a recurrence of movement on the fault plane at the time of the deformation of the Monterey strata and their uplift into the zone of erosion, but the effect of this movement can not be satisfactorily differentiated from that of a later post-Pliocene displacement. After the erosion of part of the folded and crushed Monterey strata the region was again depressed and received the Merced deposits, and at the close of the Pliocene epoch there was a great displacement on the San Bruno fault. It was this movement which raised the southwest margin of the San Francisco-Marin block and depressed the northeast margin of the Montara block. In consequence of this uplift the Merced strata on the northeast side of the fault zone were completely removed by later erosion, and whatever Monterey strata remained over that region after the post-Monterey period of erosion were also removed. The facts thus stated and particularly the similar relation of the Merced strata to the San Bruno fault on both sides of the Golden Gate show that the Point Reyes Peninsula is orogenically a part of the Montara block.

In later Quaternary time, subsequent to the large displacements that are represented by the San Bruno fault, there began the movements which find expression in the San Andreas fault—movements which are still in progress but are as yet relatively small and are characterized by a great excess of their horizontal over their vertical component. In the Tamalpais quadrangle the trace of the San Andreas fault is coincident with that of the San Bruno fault, but in the area south of the Golden Gate the line of the San Andreas fault is separate and divergent from the older line of dislocation.

Within the San Francisco-Marin block there are many minor faults, some of which are indicated on the geologic maps. One of these is well exposed on the sea cliffs about three-quarters of a mile south of Fort Point, San Francisco.

[a] Anderson, F. M., The geology of the Point Reyes Peninsula: California Univ. Dept. Geology Bull., vol. 2, No. 5, 1899.

By this fault a band of radiolarian chert of the Franciscan group (probably Ingleside) is brought against sandstone of the same group (probably Marin). The fault doubtless extends southeastward across the city of San Francisco, but back from the shore its trace is obscure. A number of faults in the southern part of the Marin Peninsula have been recognized by dislocations which they cause in the Franciscan strata. In the main portion of the Franciscan group, however, where the rocks are prevailingly sandstone, similar faults are difficult to detect, and even if a fault is observed at one place it is difficult to follow and map. The region therefore probably contains many more faults than are indicated on the geologic maps.

FOLDS.

In general, the folds of the Franciscan rocks in the San Francisco-Marin block show remarkably little appression, particularly in their larger features, but in parts of the Franciscan terrane where the rocks are thin bedded and therefore incompetent to transmit pressure they show the results of great crushing, the beds having been broken and crumbled. The strike of the folded beds is in general inconstant, even where the strata are highly inclined, and the axes of such folds as can be made out are also very diverse in direction. This irregularity of structure is doubtless due to the fact that the folding is the result of a succession of earth movements having different directions. The irregular folding in the Franciscan strata presents a striking contrast to the folding in the later sedimentary beds of the Coast Ranges, which is simpler and more like the Appalachian type.

The prevailing dip of the Franciscan rocks on the San Francisco Peninsula is to the northeast. The San Miguel Hills, on the southwest edge of the city, lie in an undulating syncline, the sandstone of the southwest flank of the hills passing under the cherts of the summits at a low angle. The sandstones at the northwest end of San Bruno Mountain, near Ocean View, dip to the southwest, their attitude indicating that they lie on the southwest limb of an anticline, but the strata here differ from the the usual sandstones of the Franciscan and may possibly belong to the Cretaceous system. The structure northeast of the San Miguel syncline is obscured by bodies of serpentine and by an extensive mantle of dune sand. The sandstones south of Fort Point are very evenly stratified and dip to the northeast, and as those on the south side of Hunter Point, although intensely contorted, appear to have the same general dip, their attitude suggests that they lie in the northern limb of an anticline. On Rincon Hill, above Rincon Point, the prevailing dip is similarly to the northeast. In the San Miguel Hills and in the neighboring hills the sequence of the Franciscan formations and the character of the folding can be made out fairly well, but the structure elsewhere in the city of San Francisco is obscure. In many exposures in street cuts and other excavations even the local dip can not be determined, owing to the mashing of the softer strata, the complications due to intrusive rocks, the depth of rock decomposition, and the surface creep. The general structure across the southeastern part of the city, however, is shown in section E–E.

On the Marin and Tiburon peninsulas certain broad features of the folding can be made out, but a detailed interpretation of the structure is possible only locally. On the northeast sides of Tiburon Peninsula and Angel Island the dips are southwest, but at Belvedere and on the southwest side of Angel Island the dips are northeast. The structure of Tiburon Peninsula and Angel Island is therefore synclinal, though complicated by numerous intrusions. (See sections B–B and C–C.) On the hills northwest of Sausalito the general dip is to the southwest or south, so that Richardson Bay and Strawberry Point lie in an anticline. At the south end of the Marin Peninsula, west of Sausalito, the strike swings from northwest to west and the dip from southwest to south. The general structure is that of an open syncline of low pitch to the southwest. It is noteworthy that much of the stratification at this end of the peninsula is transverse to the San Bruno fault and probably abuts against it farther west, under the ocean.

From Frank Valley northwestward to the northwest corner of the Tamalpais quadrangle the strike becomes parallel to the trend of Bolinas Ridge, and the prevailing dip from the base of the ridge to its summit is northeastward at moderate angles. This would indicate that Mount Tamalpais occupies the axis of a broad syncline (see section A–A), perhaps the same syncline that is recognized on the Tiburon Peninsula. The strata north and northeast of San Rafael dip northward and the ridge that terminates in Point San Quentin would therefore appear to be an anticline lying between the Tiburon Peninsula syncline and another synclinal fold on the northern border of the Tamalpais quadrangle. In figure 3 these are named the San Quentin anticline and San Rafael syncline. The prevailing dip on the Potrero San Pablo Peninsula is southwestward, though this dip is at several places locally reversed. The sandstones on Goat Island dip northeastward but show local small folds, some of which are broken and overthrust.

BERKELEY HILLS BLOCK.

FAULTS.

The Berkeley Hills orogenic block is bounded on its southwest or uplifted margin by a zone of acute deformation, which extends through the San Francisco, Concord, and Haywards quadrangles. At several places in this zone a fault, named the Haywards fault, is manifested by geomorphic features similar to those of the San Andreas rift, and in the same zone there are numerous subordinate faults, many of them more or less oblique to the general trend of the rift, and some of them even transverse to it.

Notable manifestations of rift geomorphy occur in all three quadrangles, but the faults that caused them are not mapped because it has not been possible to determine their locations exactly. Perhaps the most striking manifestation is that in the Concord quadrangle, between Claremont Creek and the Arroyo Viejo. Along the foothills between these points lies a long, narrow interrupted valley which is parallel to the trend of the range. The drainage lines of the west slope of the Berkeley Hills are consequent upon the surface resulting from the uplift of this margin of the block and run down the steep slope transverse to the trend of the range. This narrow longitudinal valley is therefore a strikingly exceptional feature of the slope. Most of the transverse consequent streams whose valleys intersect the longitudinal valley in passing down the slope are diverted for short distances along the longitudinal valley before they pass southwestward through breaches in its wall. (See fig. 4.) Kohler

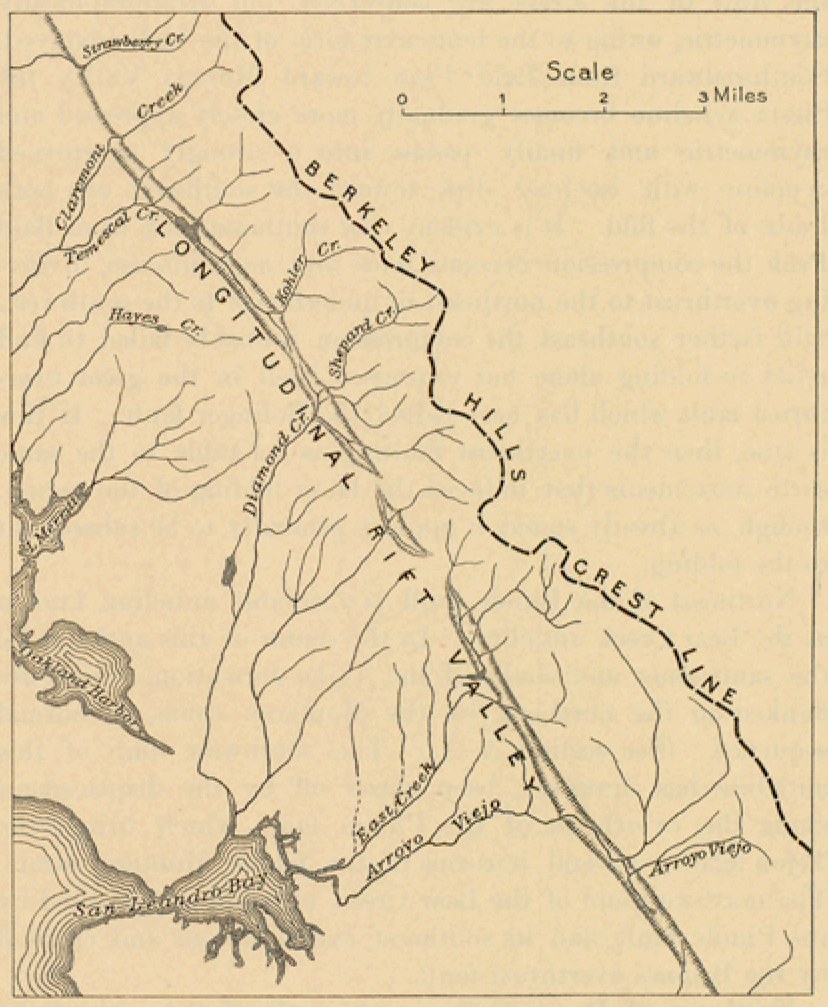

FIGURE 4.—Outline map of the western slope of the Berkeley Hills in the southwestern part of the Concord quadrangle and adjacent parts of the San Francisco and Haywards quadrangles, showing the deflection of streams by the longitudinal rift valley of the Haywards fault zone.
Several of the southwestward-flowing consequent streams follow the longitudinal valley for a short distance before continuing their southwestward courses.

Creek and Hayes Creek appear to represent an originally continuous consequent drainageway that has been divided into two parts by the longitudinal valley, along which the upper stretch of the stream has been diverted. The Arroyo Viejo, similarly, may once have flowed through a notch in the ridge which now bars its path to the southwest but was deflected to the north along the longitudinal valley. A typical transverse consequent stream, however, Shepard Creek and its continuation as Diamond Creek, shows very little deflection, and the gorge in which it flows is continuous on both sides of the longitudinal valley.

It would thus appear that the consequent drainage of the southwest slope of the Berkeley Hills, though still immature, nevertheless antedates the longitudinal valley, which is probably in part diastrophic in origin and was in part formed by the more rapid erosion of subsequent drainage along a line of exceptional weakness due to the faulting. Therefore, as the consequent drainage was begun by the uptilt of the Berkeley Hills block, it follows that the Haywards fault, which finds its chief expression in the longitudinal rift valley, occurred subsequent to the development of the main fault zone between the Berkeley Hills block and the San Francisco-Marin block. In this respect the relation of the Haywards fault to this fault zone is analogous to that of the San Andreas fault to the earlier San Bruno fault. The Haywards fault may therefore mark the advent of an earth movement that was unrelated to and different from that which displaced the large blocks, just as the San Andreas fault appears to have been unrelated to the movement that displaced the Montara and the San Francisco-Marin blocks, although it is in part of its course coincident with the San Bruno fault.

The rift valley which is so well developed in the Concord quadrangle extends only a short distance southward, into the Haywards quadrangle, as a continuation of the northwest-southeast depression in which a part of the Arroyo Viejo flows. Beyond this point toward Haywards, however, the trace of the Haywards fault may be followed southeastward through a line of sags and saddles in the hills west of Lake Chabot, until, at Haywards, it passes out to the base of the hills. The faults mapped between Haywards and the edge of the quadrangle, east of Decoto, and those shown in the vicinity of Lake Chabot are features of the general zone of deformation that bounds the Berkeley Hills on the southwest and probably represent the earlier movement, which defined the Berkeley Hills block, rather than that which produced the Haywards fault.

The zone of deformation on the southwest flank of the Berkeley Hills is marked in the San Francisco quadrangle by a series of step faults, the effects of which are still clearly defined in the profile of the slope between Strawberry Creek and Cordonices Creek. Beyond Cordonices Creek similar faults are indicated by stratigraphic displacements, although they are only feebly expressed in the geomorphic profile. In the district known as Cragmont, east of Northbrae, one of the faults is marked by abundant coarse fault breccia in a silicified facies of the soda rhyolite which outcrops as a bold knob on the slope. On the crest of the northwest end of the ridge that separates Wildcat Canyon from the valley of the Bay of San Francisco there is a saddle-like depression, which lies parallel to the crest, and in the line of this depression there are several sinks or undrained ponds, features that have their counterpart in certain places along the San Andreas rift and are believed to have had a similar seismic origin.

The more notable transverse faults that cross the zone of deformation are at Cordonices Creek, Strawberry Creek, Hamilton Gulch, Temescal Creek, and San Leandro Creek.

Of the numerous other faults in the Berkeley Hills block only the more important will be mentioned here. They are shown in figure 3. A large and well-defined displacement on a nearly vertical fault plane having a general northwest strike traverses Strawberry and Claremont canyons. The downthrow is on the southwest side and amounts to several hundred feet. This fault is traceable southeastward beyond the head of Temescal Canyon. In Strawberry Canyon it intersects two of the transverse faults, and in the triangle between them a block of soft Quaternary beds (Campus formation) has been dropped against the Cretaceous rocks. The fault is traceable northwestward beyond Strawberry Canyon for several miles along the northeast side of Wildcat Canyon and may therefore be called the Wildcat fault. In one part of the canyon, on its southwest side, the Orinda strata, dipping to the northeast, appear to abut upon the Franciscan rocks, exposed on the northeast side, but because of the smallness of the exposure of the Franciscan beds they are not so mapped.

A notable fault enters the San Francisco quadrangle from the north in the valley of Pinole Creek. The downthrow is on the west side, which brings the tuff of the basal part of the Orinda formation against several different divisions of the Monterey. This fault may be referred to as the Pinole fault. About a mile and a half south of the northern limit of the quadrangle the line of faulting leaves Pinole Creek and, passing through the hills on its south side, enters the Concord quadrangle near the summit of Sobrante Ridge, which it follows as far as Bear Creek. Here it turns southward and changes from a longitudinal or strike fault to a transverse fault, cutting across the trend of the folded strata. In the southern part of its course the fault may be followed down Bear Creek, across San Pablo Creek, and thence to the crest of San Pablo Ridge and into Siesta Valley, where it appears to die out. This fault traverses strata that had been previously folded, and the discordance due to displacement is very strikingly shown in many sections along its course, the downthrow being uniformly on the southwest or west side. It is apparently due to overthrust from the northeast (see section F–F on the San Francisco map), and at its maximum displacement it brings the Tejon formation against the upper part of the Monterey.

A less persistent fault enters the same group of hills from San Pablo Valley at a point about 3 miles east of the town of San Pablo and, with a southeast strike, converges toward the Pinole fault for a distance of about 3 miles. Its strike is parallel to that of the strata, but its structural effect is not altogether clear.

Another remarkably curved fault line appears at the southeast end of the Bear Creek anticline, in the northwestern part of the Concord quadrangle. This fold is broken and overthrust by a fault having a northwest-southeast strike. The fault follows Briones Valley for $2\frac{1}{4}$ miles from Bear Creek and then turns sharply to the north, across the Briones Hills, and crosses Vaca Canyon to a shoulder of Franklin Ridge, where it is cut off by another fault, which extends along the southwest side of Franklin Ridge and which will be referred to later. This curving fault, which may be called the Briones fault, also cuts strata that had been previously folded, and the apparent horizontal displacement of the faulted formations is very marked and easily mapped. The curvature of the fault trace and the character of the displacements of the surface outcrops suggest that the fault movement was an overthrust on a flat-lying plane, involving a slight rotation of the overthrust slab on a vertical axis.

A prominent fault, here named the Franklin fault, enters the Concord quadrangle near the west end of the Franklin Canyon tunnel, on the Santa Fe Railway. It is an overthrust fault by which the Cretaceous rocks on the northeast have been caused to override the Monterey rocks on the southwest. The thrust plane passes through the tunnel with a low dip to the northeast, and the shales of the Monterey group, which in the tunnel lie beneath the Cretaceous sandstones that outcrop at the surface, have been reduced by the movement to a clayey mass which when wet flows into the tunnel, so that the railway engineers have had great trouble in keeping it open. West of the trace of the fault there are isolated patches of Cretaceous strata, which lie upon the Monterey. Three of these patches are shown near the top of the map. These are residual parts of a former extension of the overthrust Cretaceous terrane. For nearly a mile and a half south of the northern limit of the Concord quadrangle the trace of this flat thrust is the boundary between the Cretaceous and the Monterey. Farther south it is the boundary between the Martinez and the Monterey for a little over 3½ miles, and beyond this, still farther south, it is the boundary between the Tejon and the Monterey for about 4 miles. At the end of this stretch the thrust is dislocated by a transverse fault and its trace is offset over an eighth of a mile, the horizontal displacement being to the east on the south side of the transverse fault. South of this point the fault plane is distinctly traceable for more than 5½ miles as the boundary between the Tejon and the upper beds of the Monterey group and the San Pablo formation. Its strike is the same as that of the strata of the overthrust block. For the next mile and a quarter it is not so clearly traceable, but it probably continues southward and joins obliquely another thrust fault on the northeast flank of Las Trampas Ridge, at a point about a mile west of Danville, at the eastern edge of the quadrangle.

The thrust fault last mentioned may be called the Las Trampas fault, since it crosses the ridge of that name obliquely. It extends from the vicinity of Lafayette to a point about a mile south of Danville, at the eastern edge of the Concord quadrangle, beyond which it is lost in the alluviated floor of San Ramon Valley. It brings several horizons of the Monterey against the San Pablo along the main portion of its course, and its strike is in general parallel to that of the strata of the overthrust block on the southwest. The movement on this fault was from the southwest, in a direction opposite to that of the Franklin fault, so that where the two faults meet, west of Danville, the fault planes intersect like the blades of a pair of shears, the plane of the Las Trampas fault being the upper blade and so cutting out the Franklin fault at the surface, as shown in section E–E.

On the southwest side of Bolinger Canyon, well up toward the crest of Rocky Ridge, there is another notable thrust fault, which may be called the Bolinger fault. For a considerable part of its course its trace is roughly parallel to that of the Las Trampas fault, and the displacement is in the same direction in the two thrusts—that is, the rocks southwest of the fault line have overridden those northeast of it. As a result of this thrust the Monterey rocks of the crest of Rocky Ridge overlie and dip away from the Orinda formation on the southwest side of Bolinger Canyon. The trace of this fault farther north, beyond the head of Bolinger Canyon, swings westward down Las Trampas Creek and can not be found in the alluviated valleys of the Orinda formation. It is probable, however, that the thrust movement was taken up by the overturned syncline that extends northwestward from Moraga Valley. This overturned syncline becomes more and more symmetrical in cross section toward the northwest and finally, east of Berkeley, becomes a simple open syncline.

A transverse fault whose downthrow is on the southeast side extends from the Las Trampas fault to the Bolinger fault, passing just north of Las Trampas Peak. This transverse fault appears to have antedated both the thrust faults between which it lies. Near the south end of Rocky Ridge two parallel transverse faults are cut at nearly right angles by the Bolinger fault. A narrow mass of rock between these two faults appears to have dropped in the manner of a graben. Farther south, at the end of the ridge, is another transverse fault, with larger throw, the trace of which lies in the line of Crow Creek. The displacement of the strata on this fault is to the southwest on the south side of the fault, indicating an upthrow on this side.

FOLDS.

The folding of the strata in the Berkeley Hills block is strongly marked and for the most part may be easily deciphered, owing to the contrast between the different formations and the abundant fossils that many of them contain. The general structure between the southwest front of the Berkeley Hills and Mount Diablo is that of a great synclinorium. The basal rocks having this general structure are Franciscan. They appear on the lower flanks of the southwest front of the Berkeley Hills and again in Mount Diablo, in the country adjoining the Concord quadrangle on the east. Within this general synclinorium are many folds, some simple and open, others appressed and overturned. The folds are complicated by numerous faults, already described, most of which appear to have been developed after the folding of the country. The axes of the folds and the faults are shown in figure 3. The most persistent of the folds is the synclinal trough in which lies a broad belt of the Orinda formation, extending from Sobrante, in the San Francisco quadrangle, to the southeast corner of the Concord quadrangle, and called the San Pablo syncline. (See section F–F, San Francisco map, and sections D–D and E–E, Concord map.)

Southwest of the San Pablo syncline, on the slopes of San Pablo Valley above the town of Orinda, is an anticline, which fades out rapidly toward the northwest but which persists for several miles toward the southeast. Southwest of this anticline is a well-marked syncline, the axis of which extends from the head of Wildcat Canyon through Siesta Valley to Moraga Valley and possibly beyond. It may be called the Siesta syncline. This fold affects not only the Orinda formation but also the volcanic and fresh-water formations of the Berkeley group, as shown in section B–B. In the hills back of Berkeley the fold becomes an open syncline, symmetric in so far as the dips of the strata are concerned, but stratigraphically asymmetric, owing to the lenticular form of the beds involved. Southeastward from Bald Peak toward Moraga Valley the Siesta syncline becomes gradually more closely appressed and asymmetric and finally passes into a strongly overturned syncline with isoclinal dips toward the southwest on both limbs of the fold. It is evident that southeastward from Bald Peak the compression becomes more and more intense, involving overthrust to the northeast or underthrust to the southwest. Still farther southeast the compression probably failed to find relief in folding alone but expressed itself in the great overthrust fault which has been called the Bolinger fault. If this is true, then the overthrust faulting is referable to the same earth movements that induced the latest folding of the region, though, as already stated, it appears generally to be subsequent to the folding.

Northeast of the Pinole fault is a notable anticline, known as the Bear Creek anticline. In the center of this anticline lie the sandstones and shales of the Tejon formation, which are flanked on the northeast by the Monterey strata, in normal sequence. (See section A–A.) The southwest limb of this anticline has, however, been sliced off by the displacement along the overthrust of the Pinole fault, which brings the Tejon against several horizons of the folded Monterey strata. The northwest end of the Bear Creek anticline is truncated by the Pinole fault, and its southeast end is broken and crushed by the Briones overthrust fault.

Northeast of Pinole Valley and north of the end of the Bear Creek anticline is the well-defined Pinole Ridge anticline, which is also truncated and offset by the Pinole fault. The axis of this fold is well marked for about 3 miles southeast of the Pinole fault, but beyond this stretch the fold dies out. The Pinole Ridge anticline extends west of the Pinole fault for another mile, to the place where it passes beneath the unconformably overlying Orinda formation. The axis of the fold is, however, distinctly offset by the fault. Between this anticline and the northern part of the Bear Creek anticline lies a synclinal fold, which is also transected by the Pinole fault.

Between the Bear Creek and Pinole Ridge anticlines on the southwest and the Franklin fault on the northeast there is a broad syncline of Monterey formations, in the center of which lie irregularly shaped remnants of the San Pablo formation. (See section A–A.) This syncline persists halfway across the Concord quadrangle, although it is traversed by the Briones fault, which offsets its constituent formations. It may be appropriately named the Briones Hills syncline. The fold terminates against the Franklin thrust fault near the town of Walnut Creek, after being offset again by a later transverse fault.

Northeast of the Franklin fault, in the northern part of the Concord quadrangle, is a massive anticline, known as the Martinez anticline, which exposes the Chico formation for a breadth across the strike of about 2 miles. The Chico rocks are flanked in normal sequence by the Martinez and Tejon strata, but on the southwest flank of the fold these are successively, from south to north, sliced away by the Franklin thrust, so that finally the Chico rocks near the Santa Fe tunnel rest directly upon the Monterey. The complementary syncline northeast of the Martinez anticline is known as the Pacheco syncline, a simple fold in the middle of which lie the upper beds of the Monterey group. Its axis has a straight northwest course extending from Ygnacio Valley beyond the northern limits of the quadrangle. (See sections A–A and B–B.)

At the south end of Ygnacio Valley, near the village of Walnut Creek, is another deep synclinal fold, known as the Walnut Creek syncline. This trough lies between the Franklin overthrust fault and the Arroyo de las Nueces y Bolbones. It is an overturned syncline, the outcrops on its limbs diverging southeastward in the direction of the pitch of the fold. In the middle of the trough lies the Orinda formation and outward from this on either flank lie the other formations in normal sequence down to and including the Tejon. The syncline is thus stratigraphically symmetric but structurally asymmetric, owing to overturning to the southwest. (See section D–D.) The axial plane of the fold dips northeastward and the axis pitches southeastward. On the southwest limb of the fold the formations are in their normal superposition, with northeasterly dip, but on the northeast limb, the San Pablo rests upon the Orinda, the Monterey upon the San Pablo, and the Tejon upon the Monterey, the reversed dip being commonly about 45° but in places as low as 30°. This overturned syncline extends far beyond the Concord quadrangle and is one of the dominant structural features of the southwest flank of Mount Diablo. Beneath this overturned fold lies the thrust plane of the Franklin fault. It is evident that the great pressure, which found partial relief first in the folding of the strata and next in the overturning of the fold, found further and more complete relief in the rupture and overthrusting manifested in the Franklin thrust fault.

Between the Franklin fault and Las Trampas fault is an extended syncline, which passes through Lafayette. This is truncated at its northwest end, on Bear Creek, by the Pinole fault and at its southeast end by the Franklin fault. It involves the Monterey, San Pablo, and Orinda strata, as shown in section D–D. This, the Lafayette syncline, is flanked on the north by a rather sharp anticline, which extends from the Franklin fault near Walnut Creek through Reesley Valley to the Briones fault and for some distance beyond. This, the Reesley Valley anticline, appears to have a low pitch to the southeast. On the south side of the Lafayette syncline is a more open anticline, which extends southeastward from the Pinole fault at Bear Creek and pitches rather steeply in that direction. Between the Reesley Valley anticline and the south end of the Bear Creek anticline is a short but well-defined syncline pitching southeastward toward and abutting upon the Briones fault at its sharp bend. There are also a minor syncline and anticline between the Bear Creek anticline and the San Pablo syncline on the southwest flank of Sobrante Ridge.

South of the Bolinger fault is a large anticline which has been overthrust northeastward upon a syncline of the Orinda formation that occupies Bolinger Canyon. The northwest limb of this syncline has been cut off by the fault, and the northeast limb of the anticline has been buried by the overriding mass.

In general, the folding and the faulting in the Berkeley Hills block are related in the sense that they are both manifestations of the same compressive forces, but most of the faulting was later than the folding and marked the culmination of the movement caused by the compressive forces. The most noteworthy general fact is that the overthrusting, whether manifested in overturned folds or in thrust faults, is not all in the same direction. The great thrust movement which appears in the Walnut Creek syncline and, in more intense form, in the Franklin thrust fault is clearly due to a force that acted from the northeast toward the southwest. Along this general line of deformation Mount Diablo has been shoved to the southwest, the older rocks having been pushed up over the younger. It is equally clear that the overturning of the Siesta syncline between Bald Peak and Moraga Valley and the overthrusting on the Bolinger and Las Trampas thrust faults are due to similar forces acting from the southwest.

The date of the folding and associated faulting may be determined approximately by the fact that not only the Orinda formation but also the overlying volcanic rocks and fresh-water beds of the Berkeley group have participated in these movements, even in their most acute manifestations. The correlation of the Orinda with the Merced epoch indicates clearly that the principal deformation of the region as expressed in folds and certain associated faults of the Tertiary formations was post-Pliocene in age and may therefore be referred with confidence to the general epoch of mountain making which ended the Tertiary and began the Quaternary throughout the California region. The faulting that titled and separated the great orogenic blocks, however, occurred later, in Quaternary time.

It should be noted that there is evidence of an earlier and milder deformation of the Berkeley Hills region in the unconformity between the Orinda and the San Pablo. In the normal sequence the Orinda rests upon the San Pablo, but over considerable areas the San Pablo had been removed by erosion before the deposition of the Orinda, which therefore rests upon the upturned edges of the several divisions of the Monterey. Inasmuch as the structural discordance between the San Pablo and the Monterey is not pronounced, it seems probable that the pre-Orinda folding was post-San Pablo. There is also clear evidence of uplift and erosion of the Eocene formations prior to the deposition of the Monterey, but the angular discordance is not great. Similarly, there was but slight deformation in the interval between Cretaceous and Eocene time. In the interval between Franciscan and Cretaceous time, however, there was notable and widespread disturbance, uplift, and erosion. It therefore appears that of the numerous and various earth movements that have affected the region since Franciscan time the movement at the close of the Tertiary period was the most intensely deformational in its effects.

GEOLOGIC HISTORY.

PRE-FRANCISCAN TIME.

The geologic history of the area described in this folio begins with the story told by the Gavilan limestone of Pilarcitos Canyon. This limestone is included in the quartz diorite and is but a fragment of a series of marbles, quartzites, and crystalline schists that occur more abundantly in other parts of the Coast Ranges, particularly farther south. These rocks are the highly metamorphosed representatives of sediments of unknown age, which were deposited in this region long before the advent of the quartz diorite batholith that now forms a large part of the southern Coast Ranges.

The intrusion of the quartz diorite into these ancient sedimentary rocks was doubtless the culminating event of a series of profound disturbances that formed a high mountain chain. Both the quartz diorite and the rocks of the sedimentary series into which it is intruded extend without material change of character or apparent structural break from the Coast Ranges to the Sierra Nevada. If followed northward into the Sierra Nevada they appear to be continuous with the granite and the metamorphic rocks, respectively, of the parts of that range which are described in several folios of the Geologic Atlas of the United States.[a] In these folios the granitic rocks have been shown to be post-Jurassic in age and the invaded rocks to be in part Upper Jurassic. It therefore appears that the bedrock complex of the Sierra Nevada extends into the Coast Ranges, and that if the granitic rocks of the Sierra Nevada are post-Jurassic the granitic rocks of the Coast Ranges are also presumably post-Jurassic.

FRANCISCAN EPOCH.

The high mountain chain that was formed in the region of the Coast Ranges by the disturbances that culminated in the intrusion of the granitic rocks was subjected to long-continued erosion and was greatly degraded before it was submerged to receive the Franciscan sediments. The character of the formations of the Franciscan group indicates a migration to and fro of the shore line of the Franciscan sea. The foraminiferal limestones and the radiolarian cherts were probably deposited on a sea floor at places so far from the shore as to preclude large admixtures of terrigenous sediments, whereas the sandstones of the same series are, if marine at all, clearly littoral deposits. The migration of the shore line thus indicated by the alternation of sandstone with either limestone or radiolarian chert is only an expression of a vertical oscillation of the land in respect to sea level if the sea level was practically stationary, and its deviation from a stationary position was probably not great enough to weaken the conclusion that in Franciscan time the region was subject to alternating uplift and depression. As the Franciscan group includes at least three nonterrigenous formations that are separated by detrital formations the stratigraphy indicates at least three notable depressions of the region in Franciscan time and three movements of uplift.

Certain sheets of amygdaloidal lava that are interstratified with the sandstones of the Franciscan group show that during part of Franciscan time volcanoes were active and that their lavas were poured out on the area of deposition on which the sandstones were accumulating.

The Franciscan epoch of sedimentation was brought to a close by the uplift and deformation of the region. A feature of the disturbance was the intrusion into the Franciscan strata at many places of irregular bodies of basalt and diabase which show ellipsoidal or spheroidal structure. This intrusion was followed by the intrusion of peridotites in the form of laccolithic lenses and dikes. These peridotites have since been altered to the serpentine which is so common in the Franciscan rocks of the Coast Ranges. Closely associated with these intrusive bodies of ellipsoidal basalt and serpentinized peridotite are belts and irregular areas of glaucophane schists and other metamorphic rocks. These schists are metamorphosed igneous and sedimentary rocks, and their mode of occurrence indicates that they are a product not of dynamic metamorphism but of contact action. This metamorphism took place in the Franciscan rocks before the deposition of the Knoxville formation and, indeed, before the erosion interval between Franciscan and Knoxville time. From this it appears that the intrusions of the peridotite and ellipsoidal basalt must have occurred so soon after the deposition of the Franciscan strata that they may with propriety, as well as convenience, be referred to Franciscan time.

[a] U. S. Geol. Survey Geol. Atlas, folios 3, 5, 11, 15, 17, 18, 29, 31, 37, 39, 41, 43, 51, 63, 66, and 138.

KNOXVILLE EPOCH.

The erosion which followed the uplift of the Franciscan rocks appears nowhere to have entirely removed them. The degradation and removal of the uplifted Franciscan was interrupted by the depression that ushered in the Cretaceous period of sedimentation. The basal formation of the Cretaceous is the Knoxville, which in this area is composed largely of shale. The occurrence of only small deposits of conglomerate or other coarse detrital beds at the base of the Knoxville and the entire absence of such beds in many sections show that peculiar conditions attended the beginning of the Cretaceous depression. The coarse sandstones and conglomerates which are usually spread over a sinking continental slope by a transgressing sea are here but very feebly if at all represented. The facts observed indicate that the profile of the coast of the Knoxville sea was very flat and that the streams which flowed into that sea were of low grade, carrying chiefly fine sediment. A slight subsidence of a coast so low would produce broad expanses of shallow lagoons and swamps devoid of powerful currents. In such shallow, relatively stagnant water the Knoxville appears to have been deposited.

But if the land surface that subsided and received the Knoxville deposits was low and flat, the low relief must have been due to peneplanation in post-Franciscan time, so that the interval between Franciscan and Knoxville time was long. Further, the post-Franciscan disturbance could not have involved any large vertical displacements, for if such displacements had occurred the peneplanation of the region would have completely removed the Franciscan from the uplifted blocks, so that the Knoxville would have been deposited upon pre-Franciscan rocks, but the Knoxville generally rests upon the Franciscan. The fact that the Knoxville beds attain a very considerable thickness in neighboring portions of the Coast Ranges indicates that the sea floor continued to subside steadily during Knoxville time while the adjoining land, from which the sediments were drawn, suffered no marked uplift or steepening of its gentle slopes.

CHICO EPOCH.

In most of the area mapped the Knoxville formation is succeeded by the Oakland conglomerate member of the Chico formation. This member reaches a maximum thickness of about 1000 feet and in places is rather coarse, containing waterworn bowlders 6 to 10 inches in diameter, although the dimensions of most of the pebbles are, of course, much less than these, the smaller ones being of the sizes of marbles and peas. This conglomerate is interesting and significant and would ordinarily be regarded as indicating an unconformity, but this member appears to rest concordantly upon the Knoxville formation, the relation showing that the sea floor upon which the Knoxville beds were accumulating was probably not uplifted at the beginning of the deposition of the conglomerate. The thickness of the conglomerate indicates that during its accumulation there was progressive subsidence to an amount measured by that thickness. But if the subsidence of the Knoxville sea floor continued into Oakland time without reversal the sudden change in the character of the sediments shows that the region from which these sediments were drawn was changed at the close of Knoxville time from a low-lying country, with low-grade streams, to an upland dissected by actively eroding torrents. The Knoxville subsidence was widespread and may be regarded as an epeirogenic movement, and the Oakland conglomerate may be regarded as the depositional record of an orogenic movement which deformed the coast of the Cretaceous sea but which only slightly affected the adjacent sea bottom.

The Oakland conglomerate member is succeeded by a great thickness of sandstones and shales, with scattered lenses of conglomerate, which comprise the rest of the Chico formation. The prevalence of fine-grained sandstones, the notable dearth of limestones, and the scarcity of conglomerates clearly indicate that the abrupt profiles which characterized the continental margin in Oakland time had been greatly subdued and that the later Chico sea remained shallow though steadily subsiding.

MARTINEZ EPOCH.

The advent of the Tertiary appears to have been marked by no violent orogenic movements, but there is evidence of general warping and uplift of the floor of the Chico sea and of an interval of erosion. In the quadrangles described in this folio no angular discordance between the early Eocene strata and the underlying Chico has been detected, but in the adjoining Mount Diablo quadrangle there is a well-defined unconformity between the Martinez and the Chico,[a] and this unconformity doubtless prevails over the Concord quadrangle, although conditions there are adverse to its discovery. The Martinez rocks of San Pedro Point, in the San Mateo quadrangle, rest directly upon a pre-Knoxville surface, yet on the coast a little farther south, in the Santa Cruz quadrangle, there are several thousand feet of Chico strata. It seems probable that the Chico beds once extended over the San Francisco Peninsula and were thus continuous on both sides of the Bay of San Francisco. If they were so deposited there must have been a long period of degradation in post-Chico time to permit the deposition of the Martinez beds of San Pedro Point upon a pre-Chico surface. This presumption of a considerable interval of erosion between the Cretaceous and the Tertiary is consistent with the abrupt change of the fossil fauna from one terrane to the other. The fact that the Martinez formation is not so widely distributed as the Chico indicates that the marine basin of sedimentation was smaller in early Tertiary time than it was before the uplift at the close of the Chico.

[a] Dickerson, R. E., California Univ. Dept. Geology Bull., vol. 6, No. 8, 1911.

TEJON EPOCH.

After more than 2000 feet of sandstones and shales had accumulated in Martinez time the region again suffered disturbance and uplift. The denudation begun by this movement appears to have been moderate, for although, as Dickerson[a] has shown, an unconformity exists between the Martinez and the overlying Tejon in the Mount Diablo quadrangle, no discordance at this contact has been detected in the Concord quadrangle except in so far as it may be inferred from the conglomerate at the base of the Tejon northwest of Walnut Creek. There is, however, a pronounced contrast in the fossil faunas of the two formations. The Tejon subsidence reestablished in a general way the conditions that had prevailed in Martinez time, but the Tejon area of sedimentation was probably larger than that of the Martinez. The sea was shallow and the subsidence permitted the deposition of about 2000 feet of sandstones and shales.

MONTEREY EPOCH.

The Tejon subsidence and sedimentation was brought to a close by earth movement and uplift, and, after erosion, a widespread submergence ushered in the period of deposition of the Monterey group. The interval between the Tejon and the Monterey was probably a notable period in the geologic history of the region. The facts presented under the heading "Monterey group" indicate that large areas of pre-Monterey rocks were raised above the sea and somewhat folded and faulted by the uplift and that these areas were extensively eroded before the Monterey submergence began, so that the Monterey rocks lie unconformably upon the Tejon and older formations, the discordance in dip being in places considerable.

The fact of chief historic interest connected with the Monterey is the record of crustal oscillation revealed by its constituent formations. Even in the Concord quadrangle the sequence of the Monterey formations is not uniform. The most complete section, containing not only the greatest thickness of strata but also the largest number of petrographically distinct formations, is found in the large syncline that lies between the Bear Creek anticline and the Franklin overthrust fault. Here five divisions of sandstone alternate with four divisions of bituminous shale, as described in detail under the heading "Monterey group." In their purer facies the shales are nonterrigenous deposits, though in places they include silt or even fine sand, and they were evidently deposited rather far from the shore, but the sandstones between the shales and those at the bottom and top of the Monterey group are littoral deposits.

The migration of the shore line to and fro implied by this alternation in conditions of sedimentation is interpreted to signify a vertical oscillation of the region. Apparently four movements of depression and four of uplift occurred during Monterey time, but the net result of these upward and downward movements was a depression, which corresponded approximately in amount to the entire thickness of the Monterey group in this region. Although this oscillation so greatly affected the depth of the water and the position of the shore that it radically changed the conditions of deposition in the region indicated, it may not have affected these conditions in the neighboring parts of the sea floor that lay farther from the continental margin, so that the deposition of bituminous shales there may have proceeded continuously. Thus a uniform body of bituminous shales would become the stratigraphic and chronologic equivalent of a series of alternating sandstones and shales nearer shore. Conversely, the margin of the basin might have remained a littoral region notwithstanding depressions that affected chiefly the rest of the basin, so that sandstones may have been continuously deposited along the shore as the stratigraphic equivalent of the alternating sandstones and shales laid down farther out.

Conditions favoring the continuous deposition of bituminous shale after the transgressional basal sandstone and conglomerate had been formed were probably realized in the Monterey of the Point Reyes Peninsula and probably also in the Monterey

[a] Idem

of Monterey County. The second condition—that of continuous littoral sedimentation—is in some measure realized in the Monterey of the Pacheco syncline and Shell Ridge. At both of these places we find the lower and upper portions of the Monterey, but the deep-water sediments of the middle Monterey are represented by a single comparatively thin and impure formation of bituminous shale.

SAN PABLO EPOCH.

Monterey time was brought to a close by uplift and disturbance of the Coast Range region. The disturbance was great in Santa Cruz County, where, as W. F. Jones[a] has shown, the San Pablo formation rests upon the worn edges of the nearly vertical Monterey strata and, moreover, has a basal conglomerate. The discordance, though not so pronounced, is still well marked in the Mount Diablo quadrangle.[b] There is also distinct indication of discordance between the San Pablo and Monterey in the distribution of the San Pablo along the middle of the large syncline in the northwestern part of the Concord quadrangle. Elsewhere in the Concord quadrangle, however, the San Pablo follows the Monterey without appreciable discordance. The subsidence that permitted the deposition of the San Pablo beds appears to have formed a much smaller basin than that which existed in Monterey time. The prevailingly thick bedding and rather coarse grain of the sandstones of the San Pablo and their general blue color tend to mark off this formation from the underlying commonly light-colored or rusty-yellow sandstones of the Monterey and indicate a change in the conditions of deposition. The absence of the bituminous shales that so strongly characterize the Monterey also points to such a change.

MERCED EPOCH.

The superposition of the Merced formation upon the San Pablo has nowhere been observed in the area here mapped, but such superposition, with evidence of unconformity, occurs near Chittenden, in Santa Cruz County, and has been described by W. F. Jones.[c] The absence of the San Pablo below the Merced in the San Mateo and Tamalpais quadrangles itself suggests an unconformity between the two, unless the San Pablo basin was so small that it did not cover this part of the field.

The depression which permitted the accumulation of Merced strata to the thickness of over a mile on the site of the present San Francisco Peninsula appears to have been local and to have formed a sinking trough in which there accumulated marine clays, sands, and conglomerates. The land surface that was thus gradually depressed more than a mile below sea level had supported a forest growth, represented by abundant pine cones, which occur in the basal bed of the series at Mussel Rock. The fresh-water Orinda formation, which is partly fluviatile and partly lacustrine, lies in a similar geosynclinal trough east of the Berkeley Hills—a trough that must have subsided as the formation was deposited. These two deposits were probably synchronous in origin, for the basal beds of the marine Merced formation in Sonoma County, described by Osmont,[d] contain abundant white tuff, which extends southward to the Bay of San Francisco and is probably identical with the Pinole tuff. This tuff occurs also in the basal beds of the Orinda formation in the northeastern part of the San Francisco quadrangle and is thus common to the marine Merced and the fresh-water Orinda. The barrier between the marine trough and the fresh-water trough thus formed appears to have been nearly coincident with the present line of the Berkeley Hills but may have lain a little west of it.

Volcanic ash occurs in beds high up in both the Merced and Orinda and was probably ejected from distant volcanoes that were intermittently active. The ash in the Merced appears to be a fresh white andesitic pumiceous glass, but that in the Orinda is thoroughly decomposed.

BERKELEY EPOCH.

At the close of Orinda time a slight depression probably occurred on the southwest side of the structural trough in which the fresh-water sediments of that epoch accumulated, and into this depression there was poured a succession of andesitic and basaltic lavas and occasional showers of ashes. Between these volcanic flows and showers there were times when fluviatile and lacustral conditions recurred and other times in which the lava was exposed to atmospheric oxidation or to erosion. The beds of tuff or ash that are intercalated with the lavas include rhyolitic tuff but no flows of massive rhyolite. This accumulation of volcanic and interstratified fresh-water beds forms the Berkeley group.

DEFORMATION AT CLOSE OF TERTIARY PERIOD.

At the close of Berkeley time, which marked also the end of the Tertiary period, the Merced, Orinda, and Berkeley strata became involved with all the older rocks in the great earth movements which deformed the region. The basement upon which the Merced had been deposited and which, as we have seen, had been depressed more than a mile below sea level, was lifted far above sea level, as may be plainly seen at the exposure near Mussel Rock, in the San Mateo quadrangle. The extent of this uplift shows the magnitude of the orogenic movements that closed the Tertiary period. The overturning of the syncline involving the Berkeley group near Moraga Valley and the overturning of the Orinda beds in the opposite direction in the Walnut Creek syncline indicate the intensity of the action. Most of the folding and faulting shown on the structure-section sheets of this folio occurred at this time.

[a] California Univ. Dept. Geology Bull., vol. 6, No. 3, 1911.

[b] Clark, B. L., The Neocene section at Kirker Pass, on the north side of Mount Diablo: Idem., vol. 7, No. 4, pp. 47-60, 1912.

[c] Idem.

[d] Idem., vol. 4, No. 3, 1904.

CAMPUS EPOCH.

After a partial degradation of the Siesta syncline another fresh-water basin was formed across the eroded edges of the upturned lavas of the Berkeley group, and in this apparently rather small basin accumulated the gravels, clays, tuffs, and lavas of the Campus formation.

ALAMEDA EPOCH.

After the Campus basin had been filled but before the Berkeley Hills had been uplifted the degradation of the uplands continued, and in the depressions there accumulated the Alameda formation, which is chiefly a sandy clay with intercalated delta gravels derived from Alameda Creek and a few beds of sand containing marine shells, all indicating that parts of the region which are now sharply accentuated were then of moderate relief.

POST-ALAMEDA DIASTROPHISM.

After the deposition of the Alameda formation a movement occurred that separated the San Francisco-Marin block from the Berkeley Hills block and probably also from the Montara block. This movement consisted chiefly of faulting and monoclinal tilting, one result of which was the outlining of the valley system of the Bay of San Francisco. A considerable interval had thus elapsed between the diastrophism which closed the Tertiary, exemplified in the folding and faulting of the Merced and Orinda, and this later movement, which brought the tilted blocks into their present positions and left the Campus rocks in the form of steps on the steep west front of the Berkeley Hills block. This final uplift left the fine Alameda sediments close to the base of the same steep front, a situation in which they evidently could not have been originally deposited.

SAN ANTONIO EPOCH.

In the fault valley of the Bay of San Francisco were deposited later Quaternary sediments. The earliest of these is the San Antonio formation, a series of fans of coarse alluvium spread out at the base of the Berkeley Hills and made up of detritus derived from the newly formed steep front of the Berkeley Hills block. That the San Antonio formation is the depositional record of the uplift of the Berkeley Hills block is clearly shown by the fact that for a considerable portion of its extent it is separable into two parts. The lower part is made up of detritus brought down in the early stages of the degradation of the new mountain front, before the canyons had cut back to the chert of the Monterey group, and therefore includes none of this chert. The upper part abounds in chert fragments derived from the Monterey and represents the degradation after the canyons had cut back to the belt of chert which marks for some distance the present crest of the uplifted block. As Alameda Creek in its transverse passage through the Berkeley Hills in the gorge near Niles, just east of the Haywards quadrangle, is an antecedent stream, formed before the uplift of the Berkeley Hills, the lower beds of its delta or alluvial fan probably correspond to the Alameda formation and the upper beds to the San Antonio formation, deposition having been continuous from one epoch into the other.

The remains of a notable vertebrate fauna, now extinct, in the San Antonio formation, particularly in its occurrence north of the San Francisco quadrangle, represent the life of this epoch.

MERRITT AND TEMESCAL EPOCH.

The abrupt cliff-like edge of the alluvial embankment of the San Antonio formation in the city of Oakland indicates that the region was depressed and attacked by the waves, so that a wave-cut terrace and sea cliff were here carved out of it. During this period of depression the Merritt sand of Oakland and Alameda was deposited. Since then the dissection of the main embankment of the San Antonio formation has given it a pronounced terraced effect and has supplied the materials of the Temescal formation, which rests upon the Merritt sand in the city of Oakland. Since the deposition of the Temescal formation the region has been slightly uplifted and shallow valleys have been cut in it and then submerged by a later subsidence, which produced the drowned effects in the topography about Lake Merritt and in the channel between Oakland and Alameda, but these later movements may have been local. It is noteworthy that the last depression appears to have continued down to the time of the occupation of the region by man. The base of a large shell mound near Emery, on the Oakland shore of the bay, is more than 2 feet below sea level. The bases of other Indian mounds on the shores of the bay are also below sea level, and as they were all probably started on dry land, their present position indicates very recent subsidence.[a]

RECENT UPLIFT AND DEPRESSION.

The record of uplift and depression which is read in the Quaternary deposits of the east side of the Bay of San Francisco and in their dissection is not matched on the west side. The alluvium which extends from the base of the steep slopes to the edge of the salt marshes of the bay is the equivalent of the Temescal formation, and the Alameda, San Antonio, and Merritt formations are absent. The dentate contour of the shore—a series of embayments separated by rocky promontories—which characterizes the bay side of the Marin Peninsula and of the San Francisco Peninsula as far south as San Bruno Point clearly points to a subsidence much more pronounced than that which occurred on the east side of the bay. If the missing formations were ever deposited on the west shore, and it seems probable that some of them were, they have been entirely submerged by the greater subsidence of this part of the bay.

The heavy bank of old alluvium on the west side of Crystal Springs Lake, at the southern border of the San Mateo quadrangle, which is the northern extension of the Santa Clara formation of the Santa Cruz quadrangle, is the product of degradation and fluviatile deposition during a period whose geologic age is in doubt.

Outside of the Golden Gate the striking wave-cut terrace at Bolinas affords unequivocal evidence of uplift, the minimum measure of which is the elevation of the terrace where it abuts upon its now degraded sea cliff. This elevation is about 250 feet. The uplift thus clearly indicated is extremely interesting in view of the absence of evidence of uplift on the shore of the Marin Peninsula northeast of the San Andreas rift and in view of the positive evidence of depression and the entire absence of evidence of uplift on the bay side of the Marin Peninsula. Similarly uplifted shore lines are absent on the Pacific side of the San Francisco Peninsula between the Golden Gate and Point San Pedro. South of this point, however, particularly south of Halfmoon Bay as far as Santa Cruz, elevated strands are prominent features of the coastal profile. It is noteworthy also that on the coast north of Tomales Bay elevated strands again become conspicuous, and on the east side of Tomales Bay itself there are raised shell beds, which stand 20 to 30 feet above the present shore line. Since the uplift of the Bolinas terrace there has been a slight depression of the Point Reyes Peninsula, as may be readily inferred from the drowning of the small streams flowing into Drake's Bay, near Point Reyes light. The evidence thus presented shows that the diastrophic movements of the region about the Bay of San Francisco in Quaternary time have been complex and uneven. The Marin Peninsula proper between Bolinas and the Bay of San Francisco has undergone marked depression, and with this depression may be associated the invasion of the Golden Gate by the sea. The east side of the bay in the vicinity of Oakland and Berkeley has been alternately lowered and raised, the net result of the movements being an uplift. The Point Reyes Peninsula has certainly been uplifted more than 250 feet and this uplift has been followed by a slight depression. On both coasts of the San Francisco Peninsula the evidence, though not so clear as that presented on the Marin Peninsula, indicates subsidence in late Quaternary time.

CHANGES IN DRAINAGE.

The courses of many of the streams in these quadrangles were modified during Quaternary time, and it would be interesting to trace their history in detail, but only a few of the more important changes will be mentioned.

The most notable event in the modification of the drainage of the region was the conversion of the valley lying between the Berkeley Hills and the higher part of the San Francisco-Marin Mountain block into an inlet of the ocean by the sinking of the coast. The drainage from the Great Valley of California and from the Coast Ranges north and south of San Francisco converged upon this valley and flowed through a short transverse canyon at the Golden Gate. The submergence admitted the sea to the valley and so created the great harbor of San Francisco Bay. By this change the seat of deposition of the sediments brought down by the rivers from the interior was transferred from a delta outside of the coast line to San Francisco Bay, which is in consequence gradually filling up.

Another remarkable change in the drainage of the region was the deflection to Alameda Creek of the waters that once

[a] Uhle, Max, The Emeryville shell mound: California Univ. Pub. Am. Archeology and Ethnology, vol. 7, No. 1, 1907. Nelson, N. C., The shell mounds of the San Francisco Bay region: Idem, No. 4, 1909.

flowed from Livermore Valley through San Ramon and Ygnacio valleys to Suisun Bay. The divide between the head of San Ramon Creek and the hydrographic basin of Alameda Creek, in the country east of the Concord quadrangle, is situated on the nearly level floor of Livermore Valley, which was the flood plain of the much larger predecessor of San Ramon Creek before it was beheaded, somewhat modified by recent alluviation. This change explains the disproportion between the large San Ramon Valley and the present small creek that flows through it.

San Pablo Creek once probably had a straight course across the western flank of Sobrante Ridge to San Pablo Bay in the vicinity of Pinole, just north of the San Francisco quadrangle. The Quaternary alluvium at Pinole, so rich in the bones of extinct animals, is doubtless in part the flood-plain deposit of the lower part of San Pablo Creek, carried there before its course was changed. The deflection of the stream's course from northwest to west near San Pablo is probably due to its capture by a small stream, consequent upon the uplift of the Berkeley Hills—a stream that eroded back rapidly in the soft clays of the Orinda formation.

Alameda Creek, which passes through the southern extension of the Berkeley Hills in a deep, narrow canyon and flows across the alluvial plain in the southern part of the Haywards quadrangle, has an interesting relation to the uplift of the Berkeley Hills. It heads on the slopes of Mount Hamilton and Mount Diablo and drains broad, low-lying valleys east of the Berkeley Hills. Its course across these hills between Sunol and Niles, in the Pleasanton quadrangle, was evidently established before their uplift, and the stream has persisted across the rising mountain block, cutting its rugged canyon deeper and deeper as the block rose. It is an excellent example of an antecedent stream. During most of the time in which it was thus entrenching itself across the rising mountain block Alameda Creek was much smaller than it is now, for the drainage of Livermore Valley, which once flowed north by way of San Ramon Valley, in the Concord quadrangle, and is now tributary to Alameda Creek, was captured by that creek late in Quaternary time. By this capture the hydrographic basin of Alameda Creek was more than doubled.

The convergence of a large part of the drainage of the Haywards and Concord quadrangles at Castro Valley, near Haywards, has probably been in large measure determined by a structural sag in the Berkeley Hills block, formed at the time of its uplift.

The drainage of the southwest slope of the Berkeley Hills has been described under the heading "Structure" and illustrated in part in figure 4. The streams on this slope originally flowed with steep gradients across a zone of marked deformation and faulting and were relatively straight. Later faulting along the old fault zone apparently offset to a small extent some of these streams, and other streams were deflected along the line of the fault in a longitudinal rift valley that was formed in part directly by faulting but chiefly by excessive erosion of the zone of crushed and mashed rock produced by faulting. The trench of Shepard and Diamond creeks is but slightly offset at the rift valley, whereas Viejo Creek has been deflected nearly a mile. Kohler Creek, which was probably once continuous with Hayes Creek, is now entirely separated from it and flows along the rift valley to Temescal Creek, a mile distant. Other streams in this vicinity have been more or less affected in a similar manner.

The remarkably straight drainage line of the San Andreas rift in the San Mateo quadrangle was begun probably in Quaternary time by the creation of a belt of soft, mashed rock on a zone of recurrent faulting, but the more profound rift valley extending from Bolinas Lagoon to Tomales Bay, with its equally straight drainage lines, is an inheritance from a much older geologic period, as may be inferred from the discussion of the faulting at that place under the heading "Structure."

ECONOMIC GEOLOGY.

AVAILABLE RESOURCES.

The mineral resources of the San Francisco district are chiefly building materials, such as clay, shale, limestone, rock suitable for crushing, gravel, and sand, although small quantities of gold, lead, copper, manganese asbestos, chromite, talc, magnesite, and quicksilver are found, and manganese ore and pyrite have been mined on a small scale. Volcanic ash has been quarried for use as polishing material and large quantities of salt are extracted from the sea water. The most valuable natural resource in the region, however, is water.

WATER.

Surface water, impounded by dams in the valleys of streams, has been extensively used to supply the cities on the shores of San Francisco Bay, and the conversion of valleys into reservoirs for the storage of rain water is likely to be greatly extended in the near future, particularly on the east side of the bay. Such utilization requires no special discussion here, though knowledge of geologic conditions can assist in determining dam sites that are suitable as to foundation and as free as possible from danger of disturbance by earthquake. A knowledge of the nature of the underlying formations and of the distribution of recent faults may also minimize the danger to projected pipe lines and tunnels, a fact that has been generally recognized since the earthquake of 1906.

The rain water that is stored in the pores and voids of open-textured formations, such as gravels, sands, and sandstones, is also a source of water supply. Sandstone or other porous rock that is exposed directly to the weather becomes filled with water until it is saturated up to a certain level or plane, which in the wet season may coincide locally with the surface of the ground but is generally beneath the surface. This level is known as the ground-water plane. The underground storage in this region is well exemplified in the hill lands, which are very generally composed of sandstone and hold water up to a large but variable proportion of their volume. This ground water tends to escape in springs at the lower levels of the hill slopes, and owing to this leakage the ground-water plane becomes lower and lower during the dry season; but as the frictional resistance to flow through the minute spaces in the rocks greatly retards the escape of the water the supply may endure through the dry season till the leakage is made good by replenishment during the following rainy season. The ground water in the hill lands of this region is most commonly tapped not by wells but by tunnels driven into the hillsides, and it is a valuable source of local supply where the consumption is small.

Many porous rocks that are well adapted for the storage of water are in large part buried by clays and other relatively impervious strata, but in places these pervious formations outcrop and surface water or rainfall at this outcropping edge sinks into and fills the open-textured rock. In valleys underlain by such formations it is generally possible to reach the saturated strata by boring through a mantle of impervious material. If the porous outcrop at which the water enters the rock is notably higher than the top of the bore hole the water will flow from the well, and if the water does not quite reach the surface, owing to the slight difference of level between the point of intake and the valley floor, it may be lifted by pumps. Underground water supply of this kind, whether the water overflows at the surface or not, is classed as artesian.

The Bay of San Francisco is a sunken valley which as it sank gradually became filled with detritus washed in by streams from the surrounding hills, the coarser and more pervious deposits having been from time to time buried by finer and less pervious silts and clays, part of them fluviatile or delta deposits and part of them marine clays or sands. The valley in which the bay lies is therefore an artesian basin. The irregular tongues of gravel that grow wider and thicker away from the mouths of the canyons are separated by sheets of clay and have been buried by impervious deposits, leaving the gravels exposed only near the mouths of the canyons, where the present streams flow over them. These buried gravel tongues are thickest and most numerous in the old deltas of the larger streams, but it is probable that in many places the gravels at the several stages of the infilling coalesce in the axis of the buried valley, so that the water which they contain is intercommunicating.

The largest stream that enters the valley from the surrounding hills, except of course the streams in the Great Valley, is Alameda Creek. It has also the largest buried delta, and this delta is the source of the greatest artesian-water supply in the valley. Alameda Creek drains the northern slopes of Mount Hamilton and the southern slopes of Mount Diablo, its drainage basin including about 600 square miles. It emerges from its gorge through the southward extension of Berkeley Hills at Niles, at an elevation of 80 feet above sea level. From this point the surface of its delta slopes gently downward in a very flat cone, whose western limit is the tidal marsh of the bay shore. Near the apex of the cone, around Niles, the surface is gravelly, for the coarse material brought down by the stream is dropped where the current is checked as the stream emerges from the narrow canyon. The finer material, however, is spread uniformly over the lower slopes of the delta as a deposit of clayey consistency. This clay mantle seals the water in the sands and gravels of the delta, and the upper edge of the clay determines the level at which the artesian water under natural conditions can stand—about 40 feet above sea level.

Numerous wells sunk in this delta show that an alternation of gravels, sands, and clays—some of the clays containing marine fossils of living species—extends for several hundred feet below sea level, but that the sequence of this alternation differs considerably, even in neighboring wells. Very few of the wells have completely pierced this great buried delta, but one well, on the margin of the salt marsh west of Alvarado, reached bedrock at 730 feet below sea level. The water supplying the wells is drawn from gravels which lie at several levels but all of which are connected with gravels at the apex of the modern delta, unless possibly they have been dislocated by faulting at the base of the Berkeley Hills. The fact that these gravels extend down to the present shore of the bay and, indeed, beneath the bay, as is shown by wells sunk off shore, indicates that the surface of the delta has been much steeper than it is now, except at periods of unusually active subsidence, during which the sea flooded its surface. That the water in the delta gravels is in free contact with the salt water of the bay is shown by the fact that when the wells at Alvarado are left unpumped their water rises and falls rhythmically with the flow and ebb of the tide, although the movement shows a lag of some hours due to the frictional resistance of the gravels. This fact suggests that the fresh water might become contaminated by the salt water, but under normal conditions contamination is prevented by the higher head of the artesian water and by its slow movement toward the bay in consequence of leakage through thin places in the mantle of clay. Most such leaks are under the bay, but some of them may be seen in the marshes south of Alvarado. Though this leakage suggests that all the water in the delta might eventually drain down nearly to sea level, that drainage is hindered by the frictional resistance of the gravels, because of which the artesian water must have a certain minimum gradient—probably about 5 feet to the mile—before it will flow at all. With less gradient the water would be practically stationary under normal conditions and its drop from wet season to wet season would be negligible. Notwithstanding the leakage to the bay the gradient therefore maintains the level of the water in the delta at a maximum of about 40 feet above sea level, a level which fortuitously coincides with that which would be determined by the upper margin of the clay mantle below Niles if no leakage affected the stored water. When wells were first sunk on the lower flanks of the delta the water flowed freely, but systematic draft on this supply by groups of wells pumped in series has greatly steepened the gradient and lowered the water plane until now all the water has to be lifted to the surface. If this local depression of the water plane is made too great by excessive pumping, salt water will flow in from the bay. Thus a limit is fixed on the extent to which such wells may be pumped. The gravels of the delta of Alameda Creek yield 7,000,000 to 10,000,000 gallons daily for the water supply of Oakland. Manufacturing concerns draw about 3,000,000 gallons more, and many single wells also tap the supply.

The artesian condition above outlined probably exists also, on a smaller scale, on all the streams emptying into the alluvium-filled parts of the Bay of San Francisco, and the filling of this sunken valley is in a broad sense simply an aggregation of a series of confluent or interdigitating deltas. In this sense the valley of the bay constitutes one large artesian basin. The numerous successful wells that have been sunk in it, particularly around the southern end of the bay, show that the conditions favorable to the storage of water are nearly coextensive with the area of the valley and that gravel beds containing water lie at many levels.

The conditions at the north end of the valley, on the south side of San Pablo Bay, are somewhat similar to those at the south end. A number of wells recently sunk near San Pablo have obtained a supply of water from gravelly and sandy strata alternating with clays, which have an aggregate thickness of about 500 feet. The situation of the deposits indicates that their superficial parts are the confluent deltas of San Pablo and Wildcat creeks, but the wells doubtless pierce these deposits and penetrate the underlying, slightly inclined strata of alternating gravels and clays of the Orinda formation.

The artesian basin of San Francisco Bay is probably susceptible of still more extended exploitation, and measures might possibly be taken to insure the permanence of this supply by directing surface drainage into the gravel beds that hold the water.

Another small but similar artesian basin, which, however, has been but little exploited, lies beneath Ygnacio Valley, in the Concord quadrangle, and its extension northward to Suisun Bay.

BRICK CLAYS.

Orinda formation.—The Orinda formation, a heterogeneous accumulation of fluviatile and lacustral deposits with local beds of volcanic ash, includes valuable beds of clay, the more important of which may be briefly indicated.

A large deposit lies near Glorietta and Bryant, in the Concord quadrangle. Midway between these two places the beds are about 75 feet thick, but they include a few layers of sandy clay and sandstone. The clay outcrops continuously for nearly a mile south of Glorietta, but beyond this point it is masked by soil. The deposit occurs also farther north, just beyond Bryant and north of Orinda. Throughout its known extent the deposit averages probably 40 feet in thickness, but its boundaries are obscure and this estimate is therefore not exact. At Bryant a second set of clay beds outcrops on the hillside west of those above described. This deposit aggregates about 30 feet in thickness but in places includes considerable sand.

At the northwest end of Pleasant Valley, near Lafayette, in the Concord quadrangle, there is an exposure of sandy clays, which extend more than a mile eastward. In its easternmost exposures the clay appears on the south side of the valley, where its estimated thickness is about 30 feet.

South of Lafayette, on the road leading eastward from Lafayette to Moraga Valley, there is a deposit of clay of good quality, which is 12 to 15 feet thick as exposed on the banks of the creek. North of the creek the deposit is apparently thicker.

On Las Trampas Creek east of Moraga Valley about 6 feet of good clay is exposed, but the extent and thickness of the deposit can not be determined without excavation. A belt of clay beds extends through Bolinger Canyon, but so far as they are now exposed they appear to be thin and to grade into clayey sandstones and conglomerates.

Near Danville several beds of good clay are exposed in the creek banks, their total thickness being about 20 feet. The greatest thickness of a single bed is 6 feet. There is also considerable sandy clay at the same locality.

Several other deposits of impure or sandy clay suitable for brickmaking occur in the Orinda area, and much of the Orinda soil in places where no outcrop of the strata is apparent is so clayey as to be available for brickmaking. Some of these clayey soils probably lie upon clays of good grade.

Siesta formation.—The Siesta formation is composed largely of clays, which extend from the head of Wildcat Creek, in the Concord quadrangle, southeastward to the end of Moraga Valley. The most extensive exposure of these clays is in Moraga Valley, where the belt of clay has a maximum width of about 1200 feet. The formation throughout its extent lies in a synclinal trough, and the width just given probably represents more than double the thickness of the clays. The clay beds are flanked on the east by conglomerate and on the west by sandstone. The clay beds outcrop for several hundred feet along the strike but are generally covered by a deep soil. The clay is of good quality and the supply is very large. The deposit might be opened easily by cuts in the hillside.

Alluvial and marsh clay.—On the lower of the delta slopes of Alameda, San Pablo, and Walnut creeks the soil is very clayey and beneath this soil there are extensive flat-lying deposits of clay. The depth of these deposits is variable, and at some places beds of sand are intercalated between beds of clay. Below these slopes, in the salt marshes around the bay, there are at many places extensive deposits of good clay, which could be exploited by dredging.

SHALE FOR MAKING BRICKS AND CEMENT.

The clay shale of the Knoxville formation, in its outcrop along the Berkely Hills, is available for making bricks and possibly also, in its purer forms, which contain little or no sand, for making cement. Most of this shale, however, in so far as is indicated by its outcrops, is more or less sandy.

LIMESTONE.

Deposits of limestone large and pure enough to be of commercial value are rare in the region about the Bay of San Francisco. The oldest limestone (Gavilan limestone) is older than the quartz diorite. Within the quadrangles here described this rock occurs apparently only as inclusions in the quartz diorite. One of these inclusions, on the west side of Pilarcitos Canyon, at the south edge of the San Mateo quadrangle, is limited to a few acres and is surrounded by quartz diorite. Similar areas occur at the head of Tomales Bay, on the west side of the valley, opposite Point Reyes station, just beyond the northern limit of the Tamalpais quadrangle. These limestones are coarse marbles containing variable amounts of metamorphic minerals, notably wollastonite and graphite. Most of the rock contains some magnesia and free silica. Limestone has been extensively quarried in the Gavilan formation at Santa Cruz and to a less extent in the Gabilan Range.

In the Franciscan group the foraminiferal limestone (the Calera limestone member of the Cahil sandstone) lies in an intermittent belt that extends across the San Mateo quadrangle from Calera Valley southeastward to Crystal Springs Lake, and a small outcrop of the same limestone lies in the northwest corner of the Tamalpais quadrangle. This limestone varies greatly in thickness and in its content of chert, which occurs in the form of lenses and nodules, so that, although in part very pure, it can be quarried profitably only on a large scale at favorable localities, where its thickness is near the maximum and its content of chert is at a minimum. The only place where this limestone is exploited in the San Mateo quadrangle is on the coast at Calera Valley, where it has been quarried for some years. (See Pl. III.) Farther south, in Permanente Canyon, the same rock has been regularly quarried for several years for use in the beet-sugar industry.

A few thin lentils of limestone occur in the Cretaceous rocks, but they have no commercial value. There are also many lentils of impure ferruginous and phosphatic limestone in the bituminous shales and cherts of the Monterey group.

In the Orinda and Siesta formations limestone lenses occur more or less persistently at several horizons, and similar beds of limestone are interstratified with the lavas of the Moraga formation. All these lenses are of lacustral origin and most of them are siliceous. The best that can be said of them as to their economic value is that some of them may prove to be of service for local use.

More recent than all of these are certain travertine deposits that occur at several localities and overlie several different formations. Small patches lie on the western slope of the Berkeley Hills north of Berkeley. On Lime Ridge, southeast of Concord, travertine occurs as a veneer in a few places on the hillsides, forming deposits, which to the inexpert eye appear much more extensive than they really are. This limestone is of good quality and the deceptive appearance it presents as to quantity has led to the establishment of cement mills at this locality.

CRUSHED ROCK.

The cities about the bay use a large quantity of crushed rock for both macadam and concrete. The choice of material for these uses is generally determined by convenience of situation and ease of transportation. Probably the rock most available and therefore most used for macadam and for concrete is the hard sandstone of the Franciscan group, which has been quarried on both sides of the bay for many years, notably at Telegraph Hill in San Francisco and at Temescal in Oakland. Quarries in this rock have been opened recently also on the bay shore of Marin County, and it might be quarried at many other localities, but it doubtless varies in quality, and considerable stripping must generally be done to determine the character of the rock below the zone of weathering. The radiolarian chert of the Franciscan group has also been used to some extent in the city of San Francisco for macadam, for which it is very serviceable for light traffic if kept thoroughly watered, but most of that which has been quarried is not well adapted for making concrete, because it is interlaminated with shale. Some beds of the radiolarian chert, however, are so massive or thick bedded and include so little shale that they might with advantage be used for concrete as well as macadam. The foraminiferal Calera limestone, which is quarried in a large way at Calera Valley, is used chiefly as crushed rock. Occasionally the spheroidal basalt and the metamorphic schist of the Franciscan group have been utilized, but very few quarries have been maintained for any considerable time in these rocks. The Leona rhyolite, which outcrops in a nearly continuous belt from Berkeley to Haywards along the west front of the Berkeley Hills, has for many years been quarried, particularly at Laundry Farm, back of Oakland, and has yielded a great quantity of macadam for the Oakland streets.

The chert and shale of the Monterey group have been used to some extent on roads in Contra Costa County and make a road bed that is well adapted to light traffic. This material contains little or no clay, packs well, and forms a road that is neither dusty in summer nor muddy in wet weather.

The basalts and some of the andesites of the Berkeley group would afford excellent material for both macadam and concrete but have not yet been much used. Another abundant source of crushed rock that has not been touched is the quartz diorite ("granite") of Montara Mountain and the Point Reyes Peninsula.

GRAVEL AND SAND.

Gravel and gravelly sand are much sought by contractors for making concrete in the cities about the Bay of San Francisco, but the supply is small, so that a considerable quantity is brought in from deposits beyond the area here described.

The largest local supply of gravel lies at the apex of the delta of Alameda Creek, at Niles, just east of the Haywards quadrangle. Another deposit is on the delta of Walnut Creek a short distance south of Concord, where pits show a few acres of clean fine gravel from 2 to 10 feet thick. The region is soil covered, and much more gravel may lie below the soil.

The wind-blown sand in San Francisco is used to some extent, but it is not sharp enough and is generally too fine for many of the purposes for which sand is sought. There is an inexhaustible supply of sand on the ocean beach for some miles south of the Golden Gate, but few attempts have been made to use it. The better grades of sharp beach sand are brought from the coast of Monterey County.

Some of the tidal flats on the east side of the bay afford sand that serves to supply in part the demand in Oakland and Berkeley.

ABRASIVE.

The volcanic ash in the Merced formation south of San Francisco has been quarried and used as a polisher. The ash is made up of particles of frothy glass and is free from quartz grains, so that it is very uniform in quality and is well adapted for polishing wood.

GREENSAND.

Some portions of the Martinez formation consist largely of greensand, which may possibly be used as a source of potash for incorporation in artificial fertilizers.

OIL.

Although the sandstones of the Monterey group are oil bearing in some parts of California, attempts to find oil in the region here described have been unsuccessful. Several wells have been sunk in the region east of San Pablo Valley, in the Concord quadrangle, but all of them proved to be dry. A small seepage of oil was obtained in a shaft sunk many years ago at the north end of San Pablo Ridge in the San Francisco quadrangle. The most promising seepages are those that escape from the bituminous shales of the Monterey group on the Point Reyes Peninsula near Duxbury Point.

SALT.

The winning of salt from sea water by evaporation on the marshes on both sides of the Bay of San Francisco has been a local industry for many years.

PYRITE.

The Leona rhyolite contains deposits of pyrite which have been mined for several years for making sulphuric acid. The mines are at Leona Heights, near Laundry Farm, southeast of Oakland. The pyrite occurs as rather massive bodies of irregular shape, having in some parts sharply defined and in others vaguely defined boundaries. The best-known deposit, at the "Leona Heights new mine," has been studied particularly by A. R. Whitman, from whose unpublished notes the following details are taken.

The ore has practically no gangue but contains here and there small horses of country rock. It consists of pyrite mixed with chalcopyrite and pyrrhotite and a little silica. It also contains very small quantities of gold and silver. Some native copper has also been found in older workings, and the mine water is charged with copper sulphate.

The deposits are metasomatic replacements of the rhyolite, formed at a time when the ground water stood higher with reference to the ore bodies than it does at present. The retreat of the ground water to lower levels, owing to the deformation and dissection of the region, has led to the partial oxidation of some of these deposits and the consequent production of gossans of hematite and limonite. The oxidation of the sulphides has given rise to other secondary minerals, of which melanterite, pisanite, boothite, chalcanthite, copiapite, epsomite, and alunogen have been described by Schaller.

It is worthy of note that these pyritic deposits are confined to the rhyolite and that the unoxidized rock contains minute crystals of pyrite, which are rather thickly but sporadically scattered through it, and also that the rhyolite is the only rock in the district containing disseminated pyrite crystals. A sample of the unoxidized rhyolite charged with pyrite was assayed and found to contain gold to the value of 16 cents to the ton.

It is probable not only that the ore replaced the rhyolite but that the materials that were originally disseminated through the rock have been concentrated during the process of replacement. The rhyolite has been decomposed by sulphuric acid produced by the oxidation of the disseminated pyrite near the surface of the rhyolite. The formation was originally much thicker than it is now, and as the surface was gradually lowered by erosion the process has been continuous. Theoretically, one result of the process, besides the chemical attack on the silicates, should be that, as the available oxygen became exhausted near the surface, the ferrous sulphate would descend to lower parts of the formation and be reduced in the ground water to sulphide. The course of these descending solutions and the sites favorable to the precipitation of the sulphides on reduction would be determined by the rock structure. The deposits are very similar in their essential features to larger and more cupriferous deposits in similar rocks elsewhere, many of which have been explained as the result of ascending magmatic water. The genesis of the deposits at Leona Heights, however, is apparently simpler; they may be ascribed to the action of ordinary meteoric waters. Other similar deposits of pyrite will probably be found in the body of the Leona rhyolite.

QUICKSILVER.

On the west slope of the Berkeley Hills, north of Berkeley, cinnabar has been found in a silicified rhyolite fault breccia that outcrops as a prominent knob. Assay of samples taken from the outcrop showed that the rock contains 0.5 per cent of quicksilver. On the slopes below this, however, loose fragments of much richer ore have been found. No attempt has been made to prospect the deposit.

MANGANESE.

Manganese ore in the form of psilomelane occurs at many places in the Coast Ranges, where it is associated with the radiolarian chert of the Franciscan group, and at some of these places the ore is sufficiently pure and abundant to warrant mining on a small scale. The only occurrences worthy of mention within the territory described in this folio are on Red Rock Island, in the Bay of San Francisco, and near Fort Baker, on the north side of the Golden Gate, in the San Francisco quadrangle. At the locality first named the ore occurs on the southwest side of the island as an integral part of the radiolarian chert. The chert here has a west-northwest strike and a nearly vertical dip, and consists of the usual rhythmical alternation of thin beds of hard, flinty to quartzose chert and partings of shale, the whole having a reddish color. Locally, however, the chert layers are sharply bent and contorted, and back from the shore at this place the prevailing dip is southerly, at high angles. A belt parallel to the strike of the chert includes interstratified layers of psilomelane, which, by reason of their black color, present a bold contrast to the adjoining rocks. Most of the layers are about one-fourth to one-half inch thick and replace locally the usual shale parting, but in places the psilomelane is much thicker. Some of the layers of the chert adjoining these layers of psilomelane are also so charged with that mineral as to be quite black, though they are still hard and siliceous. The psilomelane also occurs in minute particles in the shale between the chert beds, making it black. The borders of the belt in which these layers of psilomelane occur are not sharply defined, but the mineral has been mined in open cuts from 2 to 6 feet wide. The ore appears to be essentially a primary deposit, contemporaneous with the deposition of the silica that formed the cherts, although doubtless some of the psilomelane has since migrated into the adjoining beds. It is probably related in its genesis to the concretionary manganese nodules now accumulating on the sea floor in association with siliceous oozes, as shown by deep-sea dredging.

Near Fort Baker, in a road cut, the manganese ore is well exposed as a stratified deposit of hard, clean psilomelane about 18 inches thick, grading off in its upper part into a lean ore consisting of chert and shale highly charged with the black manganese mineral. There is no definite boundary between this lean ore and the normal radiolarian cherts, for the proportion of psilomelane simply decreases till it ceases to color the rock. The thickness of the ore-impregnated cherts above the layer of psilomelane is about 12 feet. This body of ore lies within a few feet of an intrusive contact of ellipsoidal basalt with the cherts, the contact plane being parallel to the bedding, and may be traced for 90 feet on the outcrop of the formation, which dips about 40° SW. In several samples assayed by D. C. Billick the psilomelane contains gold not exceeding 40 cents to the ton.

The chemical character of the manganese ore at Red Rock Island is shown in partial analysis 1 of the following table, which includes also, for comparison, analyses of other similar ores from neighboring parts of the Coast Ranges. All the analyses were made by Norman E. Smith in the laboratory of the University of California.

Analyses of psilomelane from California.

	1	2	3	4	5
MnO	61.66	54.98	56.78	69.69	67.29
O	8.75	7.88	8.45	15.88	12.40
BaO		4.66	8.31	Trace.	6.38
Fe_2O_3	3.58	} 3.74	} 1.80	4.16	Trace.
Al_2O_3	1.43				.22
MgO				1.10	
K_2O	2.59			3.41	
SiO_2	15.01	11.68	16.94	Trace.	Trace.
H_2O	4.88	13.13	7.26	3.99	7.88
	97.90	96.07	99.54	98.23	94.17
Specific gravity	3.76	3.31	3.72	3.72	3.5

1. Red Rock Island, Bay of San Francisco.
2. Howell Mountain, Napa County.
3. Penitencia Creek, Santa Clara County.
4. Bernal Heights, San Francisco.
5. Corral Hollow, Alameda County.

The shale partings north of the manganese ore outcrop on Red Rock Island are abnormally thick, generally measuring from half an inch to 2 inches, and at some places the shale is 1 to 2 feet thick. It has a soft, earthy consistency and a shaly structure and is prevailingly red, though the color grades locally into yellow. This shale was at one time mined as mineral paint. Its composition is shown in the following analysis, made by Irving Miller at the University of California.

Analysis of shale from Red Rock Island, San Francisco Bay, Cal.

SiO_2	50.58
TiO_2	.55
Al_2O_3	14.35
Fe_2O_3	15.64
FeO	.65
MnO	.36
CaO	1.77
MgO	3.08
Na_2O	.70
K_2O	3.84
H_2O (at 110° C.)	3.30
Ignition	5.19
Soluble	.38
	100.39

LEAD.

Where Euclid Avenue crosses Cordonices Creek in the city of Berkeley lumps of coarse crystalline galena have been found, some weighing over 100 pounds. The source of these lumps is not known, but they may have been derived from deposits in the Franciscan group.

GOLD.

Gold occurs in the black sands on the ocean beach south of San Francisco and many attempts have been made to recover it, but the quantity of black sand is too small to warrant the construction of a washing or leaching plant.

In the shales and metamorphic schists of the west flank of the Berkeley Hills there are numerous stringers and small veins of quartz, some of which carry gold. Fragments of quartz containing visible free gold have been found on the slopes north of Berkeley.

COPPER.

A little chalcopyrite has been found in a small vein in sandstone of the Franciscan group in the Tamalpais quadrangle on the east side of the rift valley between Tomales and Bolinas bays. The chalcopyrite and native copper which occur in the pyritic deposits of Leona Heights have already been mentioned.

ASBESTOS, CHROMITE, TALC, AND MAGNESITE.

The serpentine rocks, which occur in all of the quadrangles, contain asbestos, chromite, talc, and magnesite, but, so far as known, not in sufficient abundance to be of economic importance.

MINERALS.

The following minerals occur in the San Francisco, Tamalpais, San Mateo, Concord, and Haywards quadrangles. The list has been checked by Prof. A. S. Eakle.

Native sulphur.	Pyrolusite.	Glaucophane.	Talc.
Gold.	Limonite.	Crossite.	Titanite.
Native copper.	Brucite.	Garnet.	Apatite.
Native mercury.	Psilomelane.	Olivine.	Vivianite.
Galena.	Calcite.	Zircon.	Gypsum.
Cinnabar.	Magnesite.	Datolite.	Epsomite.
Pyrrhotite	Ankerite.	Epidote.	Melanterite.
Chalcopyrite.	Aragonite.	Lawsonite.	Pisanite.
Pyrite.	Malachite.	Gyrolite.	Boothite.
Halite.	Hydromagnesite.	Apophyllite.	Chalcanthite.
Quartz.	Albite.	Analcite.	Halotrichite.
Chalcedony.	Labradorite.	Natrolite.	Alunogen.
Jasper.	Enstatite.	Muscovite.	Copiapite.
Opal.	Hypersthene.	Biotite.	Lignite.
Cuprite.	Diopside.	Margarite.	Petroleum.
Hematite.	Diallage.	Prochlorite.	Bitumen.
Ilmenite.	Pectolite.	Glauconite.	
Magnetite.	Tremolite.	Serpentine.	
Chromite.	Actinolite.	Chrysotile.	

EARTHQUAKES AND CONSTRUCTION.

The well-known susceptibility of the region about San Francisco Bay to earthquakes naturally raises the question how, in the light of geologic knowledge, loss of life and property due to violent shocks may be guarded against or minimized. In considering this question it should be noted, first, that more than 99 per cent of the earthquakes that affect the region are harmless. They are tremors of the earth's crust due to the adjustments of minor stresses in the rocks far below the surface. In regions where such tremors are frequent, however, as in the region about San Francisco Bay, violent and destructive shocks occur also, though at comparatively long intervals, and it is to these greater shocks, of course, that attention is particularly directed.

Violent shocks are due to the sudden adjustment of major stresses in the earth's crust. These stresses accumulate through a long period of time and involve a slow torsional deformation of the portion of the crust immediately affected. The ultimate cause of these stresses can not yet be positively stated, although there has been much speculation upon that question. In the firm rocks of the earth's crust the torsional deformation is chiefly elastic and is sooner or later relieved by rupture. When rupture occurs there is an elastic rebound,[a] the part of the earth's crust on one side of the rupture plane or fault moving suddenly forward in the direction of the former slow creep due to stress and the part on the other side springing as suddenly back in the opposite direction. The quick dislocation of the rocks which is thus brought about causes a jar which is propagated as a vibratory movement through the earth, particularly around the outer shell or crust of the earth, giving rise to the commotion known as an earthquake. When such a major stress in the rocks has been thus relieved by faulting many years may elapse before it can reaccumulate sufficiently to overcome friction and cementation on the old plane of rupture and so produce another slip and another large earthquake, though many minor adjustments and consequent small shocks may occur in the affected zone. It thus happens that catastrophic earthquakes due to movement on any single fault or fault zone generally occur only at long intervals.

[a] See Reid, H. F., The elastic rebound theory of earthquakes: California Univ. Dept. Geology Bull., vol. 6, No. 19, 1911.

Now in any effort to mitigate the recurrent evils of catastrophic earthquakes in a region of dense population, like the one here considered, the first requirement is a knowledge of the location and character of all the faults which traverse it or the country adjacent to it. A long step has been taken in this direction in the geologic mapping of the five quadrangles described in the San Francisco folio and of the adjacent quadrangle to the south, described in the Santa Cruz folio by other geologists. In the study of these quadrangles many faults have come to light and are indicated on the maps. Future, more detailed studies will doubtless reveal others and will also add to our knowledge of the direction of movement, the amount of displacement, and the geologic age of the faults that are now known.

Next, among the many faults thus recognized it is necessary to discriminate between those upon which there is no probability of future movement and which are therefore harmless and those which lie in zones of active stress and which are therefore dangerous. Of the many faults discovered in the region of San Francisco Bay only two are certainly known to be zones of active stress. These are the San Andreas fault and the Haywards fault, each of which is a record of a catastrophic earthquake. Other zones of active stress may yet be discovered, but most of the faults are the expression of energies that have been long spent and are not in any sense a menace. It is, moreover, barely possible that the stresses in the San Andreas fault zone have been completely and permanently relieved by the fault movement of 1906. We have only one way of determining this, and that is by repeated geodetic surveys to discover whether or not the latitude and longitude or altitude of selected points in the zone are changing under stress creep. Such surveys would also afford the most certain way in general of discriminating between zones of active stress and zones in which stress has been completely relieved. In their absence we can judge of the probable danger of a fault only by the evidence of the recency of its last movement, and this evidence may be historic, or geomorphic, or geologic. If we have positive evidence of recent movement—evidence of any of these three kinds—then all structures such as roads, bridges, aqueducts, pipes, and tunnels, which cross the fault, are in danger of destruction, and every effort should be made in their design not only to minimize the destructive effect but also to supply auxiliary structures to tide over a period of repairs. This principle has been recognized, for example, in the construction of the aqueduct from Owens River to Los Angeles. This important structure parallels the Inyo fault, on which movement occurred in 1872, and crosses the San Andreas fault, on which movement occurred in 1857. The engineers who designed the structure have recognized the danger inherent in its situation by providing reservoirs on the city side of the danger zone, which will insure a supply of water pending repairs to any break that might be caused by a recurrence of faulting. Even where there is no reason to suspect recent movement on fault lines engineers should avoid them as far as possible in locating important works. This principle has been recognized by the engineers of the People's Water Co. in locating many dams and tunnels in the Concord and San Francisco quadrangles and by the engineers of the Spring Valley Water Co. in locating the foundation for the new Calaveras dam, south of Sunol.

Besides the dangers that arise from the rupture and displacement of the ground and that may either be avoided by wisely selecting the locations for important structures or be minimized by providing auxiliary structures and facilities for speedy repairs, there are other more general dangers due to the vibration of the ground, concerning which a word of caution may be of service. The principle to be observed by those who may design and locate large buildings or works in this region is that all structures which rest on solid rock are very much safer than those which rest on loose, unconsolidated ground, whether the ground is natural or artificial, and that loose ground saturated with water is the most dangerous of all. This principle has been recognized by the engineers of the city of San Francisco in the construction of the new salt-water fire-protection system, all the mains being laid so far as possible on firm rock. It has not been so well recognized, however, in the rebuilding of lower San Francisco, where, on the made ground, many buildings have been erected on foundations which, so far as earthquakes are considered, are most unstable. The deep piling which is commonly employed in constructing large foundations and the use of steel frames in modern construction, however, very largely offset the danger inherent in the foundations.

Another principle to be observed in any region subject to severe earthquake shocks is simplicity and unity of structure. Two structural types combined in the same building and not intimately and strongly tied together vibrate with different periods and mutually tend to destroy each other. This principle is perhaps not sufficiently recognized by all constructors who veneer steel frames with masonry. The masonry should invariably be thoroughly bonded to the steel. The failure to recognize this principle causes the overthrow of brick chimneys in ordinary frame buildings. The house and the chimney swing with different periods under the impulse imparted by the movement of the ground and the chimney is broken off, usually at the roof line. For residences the most earthquake-proof house is a frame structure that is firmly tied to a concrete foundation and that has no brick chimney. In general all buildings erected in a country subject to severe earthquakes should be made stronger than buildings erected elsewhere, and the best provision against partial destruction is a large margin of safety in strength.

Finally it may be remembered that, although the coast of California has never suffered in historic times from a sea-wave generated by a fault on the sea floor, such an event is not beyond the range of possibility. The only way to guard against this danger is to avoid placing buildings where large numbers of people congregate close to sea level.

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TOPOGRAPHY

CALIFORNIA
TAMALPAIS QUADRANGLE

Henry Gannett, Chief Topographer.
R.U. Goode, Geographer in charge.
Triangulation by U.S. Coast and Geodetic Survey.
Topography by R.B. Marshall and U.S. Coast and Geodetic Survey.
Surveyed in 1894-95.

TRUE NORTH
MAGNETIC NORTH
18½°
APPROXIMATE MEAN DECLINATION 1913.

Scale $\frac{1}{62500}$

1 ½ 0 1 2 3 4 Miles

1 ½ 0 1 2 3 4 5 Kilometers

Contour interval 25 feet.

Datum is mean sea level.

Edition of May 1897, reprinted Aug. 1913.

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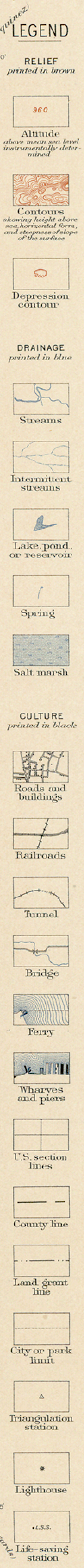
TOPOGRAPHY

CALIFORNIA
SAN FRANCISCO QUADRANGLE



A.H. Thompson, Geographer.
Willard D. Johnson, Topographer in charge.
Triangulation by U.S. Coast and Geodetic Survey.
Topography by U.S.C. and G.S., U.S. Eng. Corps, City Surveys, and by R.H. Chapman, R.B. Marshall, and W.H. Otis.
Surveyed in 1892-93-94.

APPROXIMATE MEAN DECLINATION 1913.

Scale 1/62500

Contour interval 25 feet.
Datum is mean sea level.

Edition of Feb. 1899, reprinted Aug. 1913.

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TOPOGRAPHY

CALIFORNIA
CONCORD QUADRANGLE

LEGEND

RELIEF
printed in brown

Altitude
above mean sea level instrumentally determined

Contours
showing height above sea, horizontal form, and steepness of slope of the surface

DRAINAGE
printed in blue

Streams

Intermittent streams

Lake pond or reservoir

Intermittent lake

Salt marsh

Fresh marsh

CULTURE
printed in black

Roads and buildings

Private or secondary road

Railroad

Bridge

U.S. township and section lines

County line

Land grant line

City limit

Triangulation station

Henry Gannett, Chief Topographer.
R.U. Goode, Geographer in charge.
Triangulation by U.S. Coast and Geodetic Survey.
Topography by W.D. Johnson and W.H. Otis.
Surveyed in 1893-94

TRUE NORTH — MAGNETIC NORTH — 18½°
APPROXIMATE MEAN DECLINATION 1913.

Scale $\frac{1}{62500}$

1 ½ 0 1 2 3 4 5 Miles

1 ½ 0 1 2 3 4 5 Kilometers

Contour interval 25 feet.
Datum is mean sea level.

DIAGRAM OF TOWNSHIP.

6	5	4	3	2	1
7	8	9	10	11	12
18	17	16	15	14	13
19	20	21	22	23	24
30	29	28	27	26	25
31	32	33	34	35	36

Edition of Nov. 1897, reprinted Aug. 1913.

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TOPOGRAPHY

CALIFORNIA
SAN MATEO QUADRANGLE

A.H. Thompson, Geographer.
Willard D. Johnson, Topographer in charge.
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Topography by R.B. Marshall, R.H. Mc.Kee, and U.S.C.&G.S.
Surveyed in 1892.

Edition of Feb. 1899, reprinted Aug. 1913.

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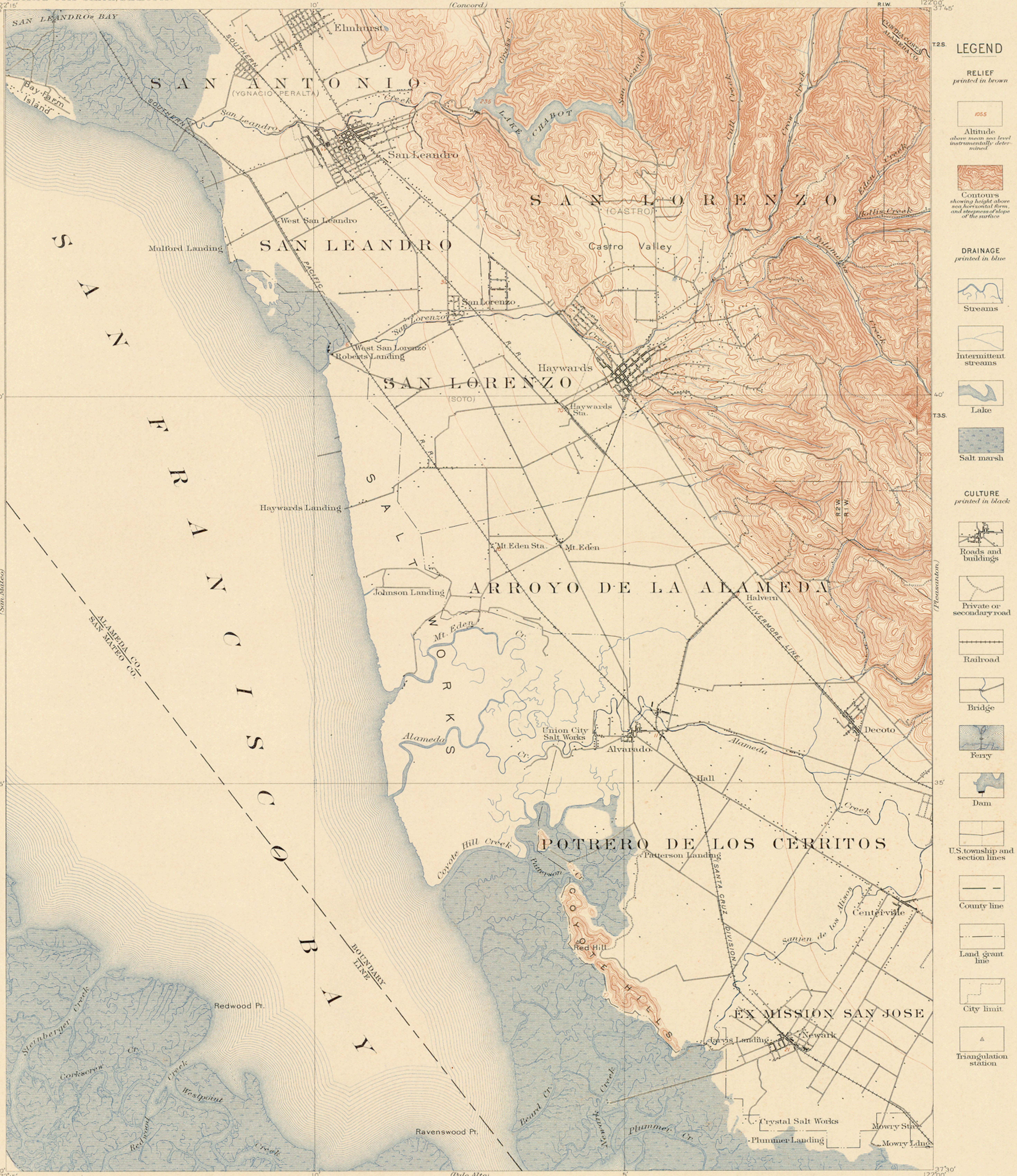
TOPOGRAPHY

CALIFORNIA
HAYWARDS QUADRANGLE



R. U. Goode, Geographer in charge.
Triangulation by U.S. Coast and Geodetic Survey.
Topography by L. C. Fletcher, R. B. Marshall, and U.S. Coast and Geodetic Survey.
Surveyed in 1896.

APPROXIMATE MEAN DECLINATION 1913.

Scale $\frac{1}{62500}$

Contour interval 25 feet.
Datum is mean sea level.

Edition of Jan. 1899, reprinted June 1913.

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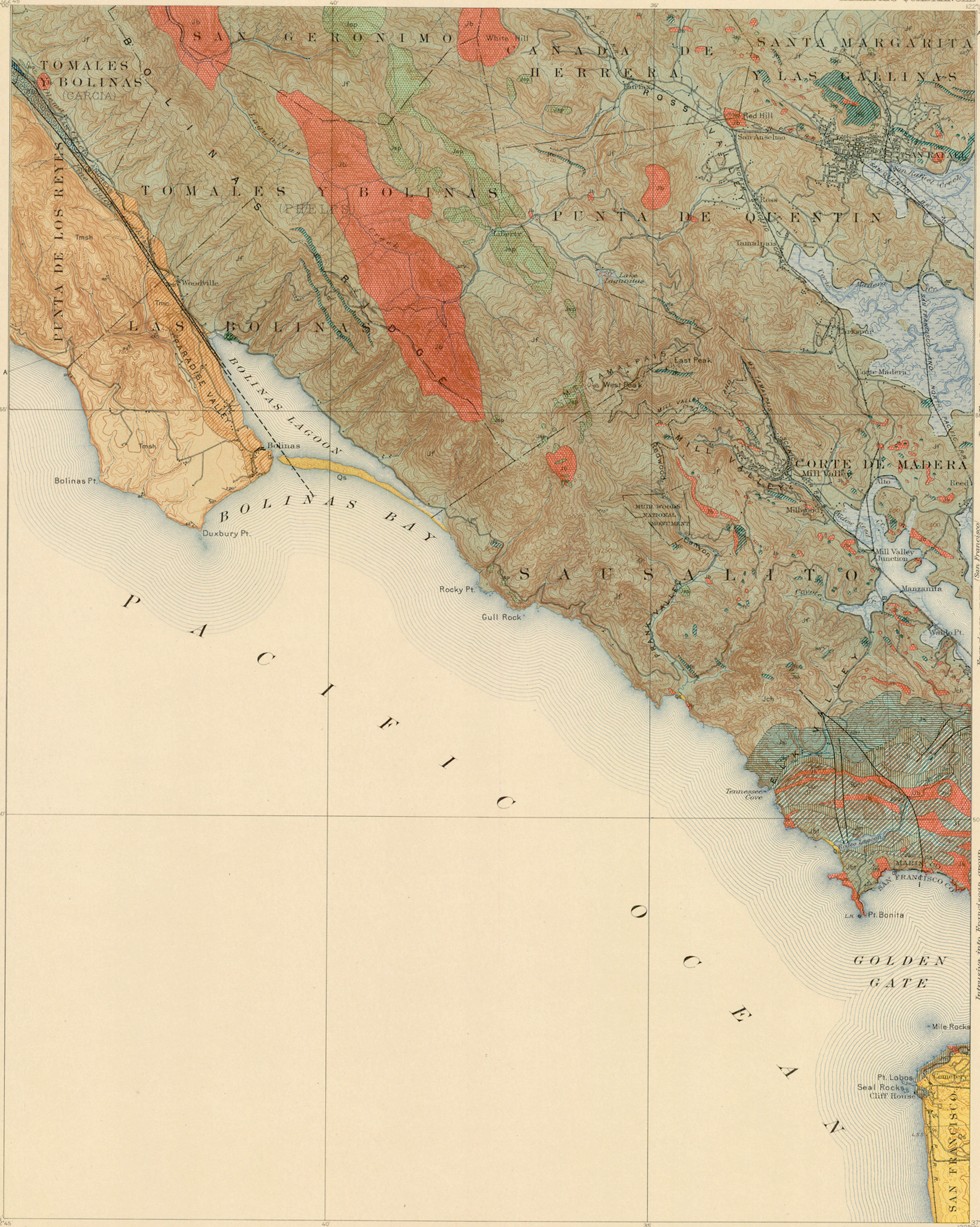
AREAL GEOLOGY

CALIFORNIA
TAMALPAIS QUADRANGLE



(Napa)

LEGEND

SEDIMENTARY ROCKS

(Areas of subaqueous deposits are shown by patterns of parallel lines, subaerial deposits by patterns of dots and circles)

QUATERNARY — Recent

Salt marsh deposits *(clay and silt)*

Qs — Sand dunes and beach sand

UNCONFORMITY

TERTIARY — Pliocene

Tmc — Merced formation *(chiefly marine sand; fault breccia represented by Tmb)*

UNCONFORMITY

TERTIARY — Miocene

Tmsh — Undifferentiated bituminous shales of the Monterey group

UNCONFORMITY

CRETACEOUS ? — Post Franciscan

Kk — Conglomerate, probably Knoxville formation

UNCONFORMITY

JURASSIC ? (pre-Knoxville) — Franciscan group (San Francisco)

Jbr — Bonita sandstone *(arkosic sandstone with subordinate amounts of shale and conglomerate)*

Ji — Ingleside chert *(alternations of thin layers of varicolored radiolarian chert, chiefly red, and earthy shale)*

Jm — Marin sandstone *(arkosic sandstone with subordinate amounts of shale and conglomerate)*

Js — Sausalito chert *(alternations of thin layers of varicolored radiolarian chert, chiefly red, and earthy shale)*

Jch — Cahil sandstone *(arkosic sandstone with subordinate amounts of shale and conglomerate)*

Jf — Undifferentiated sandstones of Franciscan group with radiolarian chert lentils of undetermined horizons, Jfc, and Calera limestone member, Jca *(fault breccia represented by Jfb)*

INTRUSIVE IGNEOUS ROCKS

(Areas of igneous rocks are shown by patterns of triangles and rhombs)

JURASSIC ? (pre-Knoxville) — Intrusive into Franciscan group

Jsp — Serpentinized peridotite with associated gabbro and pyroxenite

Jb — Basalt and diabase *(commonly show spheroidal or ellipsoidal structures)*

Faults

Concealed faults *(covered by younger deposits)*

Strike and dip of stratified rocks

Economic note: *Crushed stone can be obtained from sandstones and cherts of Franciscan group and intrusive basalt and diabase; limestone from Calera limestone member; sand from beach sand; brick clay from regolith from sandstones of Franciscan group; manganese occurs in chert of Franciscan group; small quantities of asbestos, chromite, talc, and magnesite in serpentinized peridotite; and water in Merced formation.*

Henry Gannett, Chief Topographer.
R. U. Goode, Geographer in charge.
Triangulation by U.S. Coast and Geodetic Survey.
Topography by R. B. Marshall and U.S. Coast and Geodetic Survey.
Surveyed in 1894-95.

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(San Mateo)

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AREAL GEOLOGY

CALIFORNIA
SAN FRANCISCO QUADRANGLE

LEGEND

SEDIMENTARY ROCKS
(continued)

UNCONFORMITY

CRETACEOUS

Upper Cretaceous
- Kc — **Chico formation** *(sandstone with subordinate amount of shale)*

Lower Cretaceous (Shasta)
- Kk — **Knoxville formation** *(dark carbonaceous shale, sandstone, fine pebbly conglomerate, and impure limestone)*

UNCONFORMITY

JURASSIC ? (pre-Knoxville)

Franciscan group
- Ji — **Ingleside chert** *(alternations of thin layers of varicolored radiolarian chert, chiefly red, and thinner earthy shales)*
- Jm — **Marin sandstone** *(arkosic sandstone with subordinate amounts of shale and conglomerate)*
- Jfm — **Metamorphic schist** *(sedimentary and igneous rocks altered by contact metamorphism chiefly to glaucophane schist)*
- Js — **Sausalito chert** *(alternations of thin layers of varicolored radiolarian chert, chiefly red, and thinner earthy shales)*
- Jf — **Undifferentiated sandstones of Franciscan group with radiolarian chert lentils, Jfc, of undetermined horizons**
- Jch — **Cahil sandstone** *(arkosic sandstone with subordinate amounts of shale and conglomerate)*

INTRUSIVE IGNEOUS ROCKS
(Areas of igneous rocks are shown by patterns of triangles and rhombs)

JURASSIC ? (pre-Knoxville)

Intrusive into Franciscan group
- Jso — **Silica-carbonate rock** *(aggregate of silica and various carbonates derived from alteration of serpentine)*
- Jsp — **Serpentinized peridotite with associated gabbro and pyroxenite** *(intrusive bodies)*
- Jb — **Basalt and diabase** *(commonly show spheroidal or ellipsoidal structures; locally variolitic; some inclusions of radiolarian chert)*

Faults

Concealed faults *(covered by younger deposits)*

T Overthrust side of thrust faults
D Downthrown side of faults
U Upthrown side of faults
Strike and dip of stratified rocks

Economic note: *Crushed stone can be obtained from sandstone, schist, and chert of Franciscan group, Northbrae rhyolite, rhyolite tuff in Campus formation, basalt and andesite of Berkeley group, and intrusive basalt and diabase; brick clay from Orinda and Temescal formations and the regolith from sandstones of Franciscan group; gravel and sand from Temescal formation and from tidal flats and beaches; quicksilver occurs in Northbrae rhyolite; manganese in chert of Franciscan group; small quantities of asbestos, chromite, talc, and magnesite in serpentinized peridotite; and water in sandstones of Chico formation, gravels of Orinda and Temescal formations, Merritt sand, and gravels beneath San Francisco Bay, probably in Alameda formation.*

Crushed-stone quarries

A.H.Thompson, Geographer.
Willard D. Johnson, Topographer in charge.
Triangulation by U.S.Coast and Geodetic Survey.
Topography by U.S.C. and G.S., U.S.Eng. Corps, City Surveys, and by R.H.Chapman, R.B.Marshall, and W.H.Otis.
Surveyed in 1892-93-94.

APPROXIMATE MEAN DECLINATION 1913.

Scale $\frac{1}{62500}$

Contour interval 25 feet.
Datum is mean sea level.
Edition of Sept. 1913.

Geology by Andrew C.Lawson, assisted at various times by students of the University of California.
Surveyed in 1891-1895, 1899, 1905, and 1911.

LEGEND

SEDIMENTARY ROCKS
(Areas of subaqueous deposits are shown by patterns of parallel lines, subaerial deposits by patterns of dots and circles)

QUATERNARY

Recent
- **Salt marsh deposits** *(clay and silt)*
- Qs — **Sand dunes and beach sand**
- Qtc — **Temescal formation** *(alluvium; probably includes some San Antonio formation where not separable)*

UNCONFORMITY

Pleistocene
- Qm — **Merritt sand** *(marine sand)*

UNCONFORMITY

- Qsac, Qsa — **San Antonio formation with chert-gravel member, Qsac** *(coarse alluvial fans; the later part of deposits, Qsac, contains angular chert fragments)*
- Qa — **Alameda formation** *(yellow marine clay with some intercalated fluviatile gravel)*

UNCONFORMITY

- Qc — **Campus formation** *(fresh-water clay, limestone, conglomerate, tuff, agglomerate, and andesite and basalt flows)*

UNCONFORMITY

TERTIARY

Pliocene (Concord) — *Berkeley group*
- Tm — **Moraga formation** *(chiefly andesite and basalt)*

UNCONFORMITY ?

- Tor — **Orinda formation** *(fresh-water conglomerate, sandstone, clay, limestone, and thin layers of tuff)*
- Tp — **Pinole tuff** *(pumiceous tuff, probably andesitic, deposited in fresh water; in part interbedded with Orinda formation)*
- Tnb — **Northbrae rhyolite** *(soda rhyolite lava flows possibly equivalent to Pinole tuff)*

UNCONFORMITY

Miocene — *Monterey group*
- Tb — **Briones sandstone** *(light-colored, coarse to pebbly quartzose sandstone)*
- Tr — **Rodeo shale** *(chiefly chalky bituminous shale, stained by iron, with some cherty beds)*
- Th — **Hambre sandstone** *(medium-textured, slightly ferruginous sandstone, with some sandy shale)*
- Tt — **Tice shale** *(white to pink bituminous shale, prevailingly chalky)*
- To — **Oursan sandstone** *(fine-grained, light-colored, soft sandstone)*
- Tc — **Claremont shale** *(white chalky bituminous shale and chert, with some white indurated tuff)*
- Ts — **Sobrante sandstone** *(fine-grained, light-colored, soft sandstone)*

UNCONFORMITY

Eocene
- Ttj — **Tejon formation** *(sandstone and shale)*

Legend is continued on the left margin.

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AREAL GEOLOGY

CALIFORNIA
CONCORD QUADRANGLE

LEGEND

SEDIMENTARY ROCKS (continued)

UNCONFORMITY

Eocene — TERTIARY

Ttj — Tejon formation (hard ferruginous and calcareous sandstones, with beds of shale and lenses of conglomerate at base)

UNCONFORMITY

Tmz — Martinez formation (sandstone in part glauconitic, shale, and some conglomerate)

UNCONFORMITY

Upper Cretaceous — CRETACEOUS

Kc, Ko — Chico formation with Oakland conglomerate member at base (massive yellowish sandstone and clay shale with conglomerate member, Ko, at base)

Lower Cretaceous

Kk — Knoxville shale (carbonaceous and arenaceous)

UNCONFORMITY

Franciscan group — JURASSIC ? (pre-Knoxville) (San Francisco)

Jfm — Metamorphic schist (sedimentary and igneous rocks altered by contact metamorphism chiefly to glaucophane schist)

Jf, Jfc — Undifferentiated sandstones of Franciscan group, with radiolarian chert lentils of undetermined horizons, Jfc

IGNEOUS ROCKS CHIEFLY INTRUSIVE

(Areas of igneous rocks are shown by patterns of triangles and rhombs)

Post-Cretaceous (Pliocene?) — TERTIARY

Tln — Leona rhyolite (lava flows of undetermined age)

Intrusive into Franciscan group — JURASSIC ? (pre-Knoxville)

Jsp — Serpentinized peridotite with associated gabbro and pyroxenite (serpentine in part altered to an aggregate of silica and various carbonates)

Jb — Basalt and diabase (commonly show spheroidal or ellipsoidal structures)

Faults

Concealed faults (covered by younger deposits)

T Indicates overthrust side of thrust faults
35° Strike and dip of stratified rocks
Strike of vertical strata

Crushed-stone quarries
LS Limestone quarry
PYRITE Mine
Gravel pit

Economic note: Crushed stone can be obtained from sandstone, chert, and schist of Franciscan group, cherty shale of Monterey group, Leona rhyolite, andesite and basalt of Berkeley group, and intrusive diabase and basalt; sandstone from Chico formation; brick clay from Orinda, Siesta, Knoxville, and Temescal formations and the regolith from sandstones of Franciscan group; lime from travertine and limestone lentils in Moraga, Orinda, and Siesta formations; abrasives from Pinole tuff; greensand for fertilizer from Martinez formation; pyrite for sulphuric acid from Leona rhyolite; water from sandstones of Chico formation, loose-textured rocks of Berkeley group and Campus formation, gravels of Alameda formation, Merritt sand, and gravelly portions of Temescal formation.

LEGEND

SEDIMENTARY ROCKS

(Areas of subaqueous deposits are shown by patterns of parallel lines, subaerial deposits by patterns of dots and circles)

Recent — QUATERNARY

Salt marsh deposits (clay and silt)

Qt — Travertine (calcareous spring deposits)

Qtc — Temescal formation (alluvium)

UNCONFORMITY

Pleistocene

Qm — Merritt sand (marine sand)

UNCONFORMITY

Qsac, Qsa — San Antonio formation with chert-gravel member, Qsac (coarse alluvial fans; the later part of deposits, Qsac, contains angular chert fragments)

Qa — Alameda formation (yellow marine clay with some intercalated fluviatile gravel)

UNCONFORMITY

Qc — Campus formation (fresh-water clay, limestone, conglomerate, tuff, agglomerate, and andesite and basalt flows)

UNCONFORMITY

Pliocene — Berkeley group — TERTIARY

Tbp — Bald Peak basalt (lava flows with lentils of fresh-water limestone; some dikes are included in mapping)

Tst — Siesta formation (fresh-water conglomerate, clay, sandstone, chert, limestone, lignite, and tuff)

UNCONFORMITY

Tm, Tmc — Moraga formation (andesite and basalt flows, with rhyolitic and basic tuffs, lentils of gravel, clay, and limestone, and thick beds of conglomerate, Tmc, near base)

Tml — Fresh-water limestone lentils at various horizons in the Moraga and Siesta formations (only the larger bodies shown)

UNCONFORMITY ?

Tor — Orinda formation (fresh-water conglomerate, sandstone, clay, limestone, and thin layers of tuff)

Tp — Pinole tuff (pumiceous tuff, probably andesitic, deposited in fresh water)

UNCONFORMITY

Miocene

Tsp — San Pablo formation (coarse gray to blue sandstone with admixture of tuffaceous material)

UNCONFORMITY

Miocene (Monterey group)

Thl, Tb — Briones sandstone with Hercules shale member, Thl (light-colored coarse to pebbly quartzose sandstone with chalky bituminous shale member, Thl)

Tr — Rodeo shale (chiefly chalky bituminous shale, stained by iron, with some cherty beds)

Th — Hambre sandstone (medium-textured, slightly ferruginous sandstone, with some sandy shale)

Tt — Tice shale (white to pink bituminous shale, prevailingly chalky)

To — Oursan sandstone (fine-grained, light-colored, soft sandstone)

Tc — Claremont shale (white chalky bituminous shale and yellowish chert rhythmically interbedded with thin shales; thin hard sandstones and lentils of ferruginous limestone)

Ts, Tsf — Sobrante sandstone (light-colored soft sandstone with darker ferruginous beds; includes layers of white pumiceous tuff, Tsf, near base)

Legend is continued on the left margin.

Henry Gannett, Chief Topographer.
R.U. Goode, Geographer in charge.
Triangulation by U.S. Coast and Geodetic Survey.
Topography by W.D. Johnson and W.H. Otis.
Surveyed in 1893-94.

APPROXIMATE MEAN DECLINATION 1913.

Scale $\frac{1}{62500}$

Miles · Kilometers

Contour interval 25 feet.
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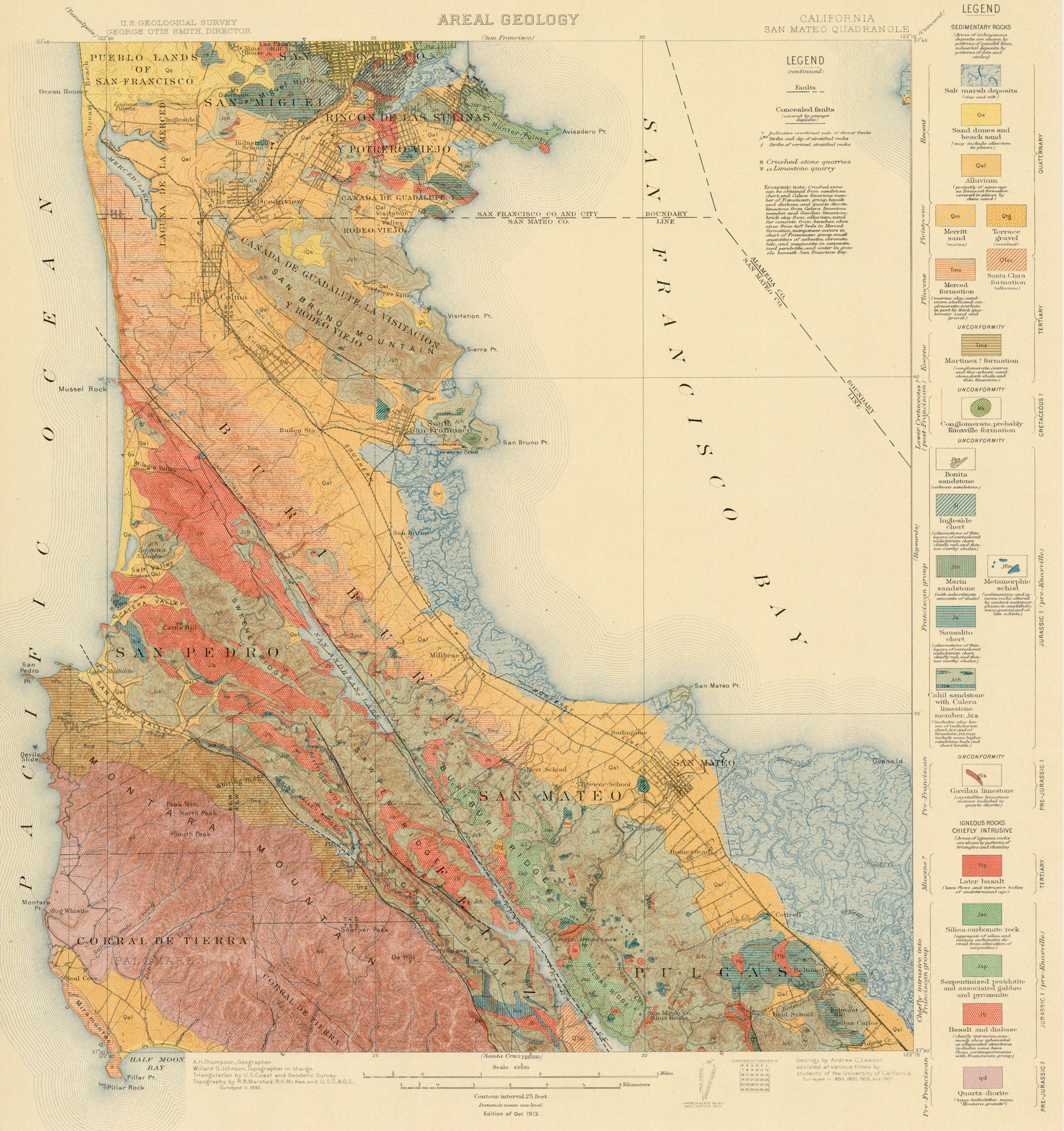
CALIFORNIA
SAN MATEO QUADRANGLE



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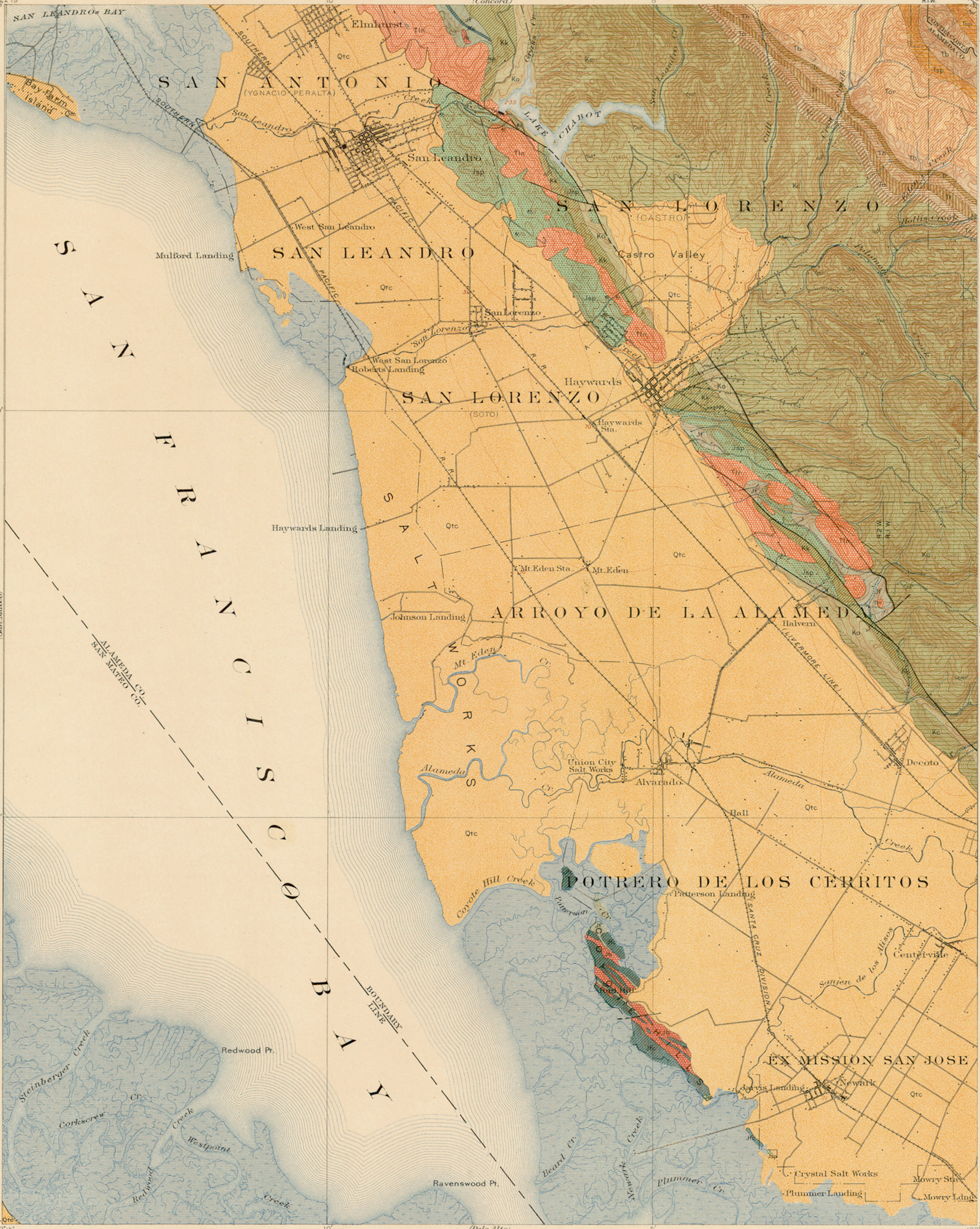

LEGEND

SEDIMENTARY ROCKS

(Areas of subaqueous deposits are shown by patterns of parallel lines, subaerial deposits by patterns of dots and circles)

QUATERNARY

Recent

- Salt-marsh deposits *(clay and silt)*
- Qtc — Temescal formation *(alluvium)*

UNCONFORMITY

Pleistocene

- Qm — Merritt sand *(marine)*

UNCONFORMITY

TERTIARY

Pliocene

- Tor — Orinda formation *(fresh-water conglomerate, sandstone, clay, limestone, and thin layers of tuff)*

UNCONFORMITY

Miocene ?

- Tsp — San Pablo formation *(coarse gray to blue sandstone with admixture of tuffaceous material)*

UNCONFORMITY

Miocene (Monterey group)

- Tb — Briones sandstone *(light-colored, coarse to pebbly quartzose sandstone)*
- Tr — Rodeo shale *(chiefly chalky bituminous shale, stained by iron, with some cherty beds)*
- Th — Hambre sandstone *(medium-textured, slightly ferruginous sandstone, with some sandy shale)*
- Tt — Tice shale *(white to pink bituminous shale, prevailingly chalky)*
- To — Oursan sandstone *(fine-grained, light-colored, soft sandstone)*
- Tc — Claremont shale *(white chalky bituminous shale and yellowish chert rhythmically interbedded with thin shales)*

UNCONFORMITY

CRETACEOUS

Upper Cretaceous

- Kc, Ko — Chico formation with Oakland conglomerate member at base *(massive sandstone and shale with lenses of conglomerate and limestone, and conglomerate member, Ko, at base)*

Lower Cretaceous (Shasta)

- Kk — Knoxville formation *(dark carbonaceous and arenaceous shale)*

UNCONFORMITY

JURASSIC ? (pre-Knoxville)

Franciscan group

- Jf — Undifferentiated sandstone of Franciscan group and radiolarian chert lentils of undetermined horizon, Jfc

IGNEOUS ROCKS CHIEFLY INTRUSIVE

(Areas of igneous rocks are shown by patterns of triangles and rhombs)

TERTIARY

Post-Cretaceous Pliocene ?

- Tln — Leona rhyolite *(lava flows of undetermined age)*

JURASSIC ? (pre-Knoxville)

Intrusive into Franciscan group

- Jsp — Serpentinized peridotite with associated gabbro and pyroxenite
- Jb — Basalt and diabase *(commonly show spheroidal or ellipsoidal structures)*

Faults

Concealed faults *(covered by younger deposits)*

65° Strike and dip of stratified rocks

Crushed-stone quarries

Economic note: *Crushed stone can be obtained from sandstone and chert of Franciscan group, cherty shale of Monterey group, Leona rhyolite, serpentine, and intrusive basalt and diabase; brick clay from Knoxville, Orinda, and Temescal formations and salt marshes; salt from sea water on marshes; manganese occurs in chert of Franciscan group; small quantities of asbestos, chromite, talc, and magnesite in serpentinized peridotite; and large quantities of water in gravels underlying the Temescal formation.*

R.U. Goode, Geographer in charge.
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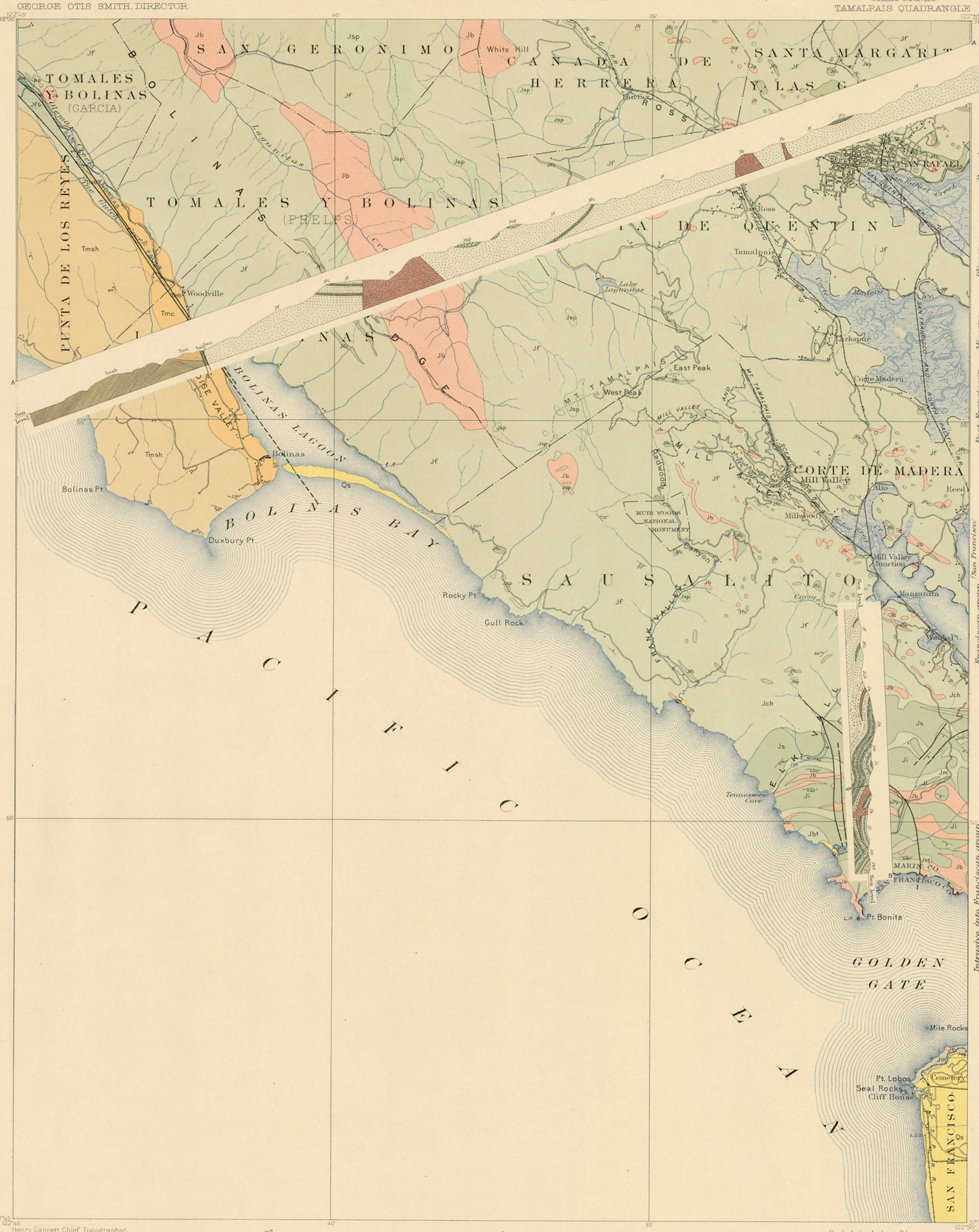
Surveyed 1896 to 1910.

STRUCTURE SECTIONS



LEGEND

SEDIMENTARY ROCKS

SHEET SYMBOL | SECTION SYMBOL

QUATERNARY — Recent

Salt marsh deposits (clay and silt)

Qs — Sand dunes and beach sand

UNCONFORMITY

TERTIARY — Pliocene

Tmb, Tmc — Merced formation (chiefly marine sand; fault breccia represented by Tmb)

UNCONFORMITY

TERTIARY — Miocene

Tmsh — Undifferentiated bituminous shales of the Monterey group

UNCONFORMITY

CRETACEOUS ? — Post-Franciscan

Kk — Conglomerate, probably Knoxville formation

UNCONFORMITY

JURASSIC ? (pre-Knoxville) — Franciscan group (San Francisco)

Jbt — Bonita sandstone (arkosic sandstone with subordinate amounts of shale and conglomerate)

Ji — Ingleside chert (alternations of thin layers of varicolored radiolarian chert, chiefly red, and earthy shale)

Jm — Marin sandstone (arkosic sandstone with subordinate amounts of shale and conglomerate)

Js — Sausalito chert (alternations of thin layers of varicolored radiolarian chert, chiefly red, and earthy shale)

Jch — Cahil sandstone (arkosic sandstone with subordinate amounts of shale and conglomerate)

Jf, Jfc, Jca, Jfb — Undifferentiated sandstones of Franciscan group with radiolarian chert lentils of undetermined horizons, Jfc, and Calera limestone member, Jca (fault breccia represented by Jfb)

INTRUSIVE IGNEOUS ROCKS

JURASSIC ? (pre-Knoxville) — Intrusive into Franciscan group

Jsp — Serpentinized peridotite with associated gabbro and pyroxenite

Jb — Basalt and diabase (commonly show spheroidal or ellipsoidal structures)

Faults

Concealed faults (covered by younger deposits)

20° Strike and dip of stratified rocks

Henry Gannett, Chief Topographer.
R.U. Goode, Geographer in charge.
Triangulation by U.S. Coast and Geodetic Survey.
Topography by R.B. Marshall and U.S. Coast and Geodetic Survey.
Surveyed in 1894-95.

APPROXIMATE MEAN DECLINATION 1913.

Scale $\frac{1}{62500}$

1 ½ 0 1 2 3 4 Miles

1 ½ 0 1 2 3 4 5 Kilometers

Edition of Dec. 1913.

Geology by Andrew C. Lawson, assisted at various times by students of the University of California.
Surveyed 1896 to 1910.

U.S. GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

STRUCTURE SECTIONS

CALIFORNIA
SAN FRANCISCO QUADRANGLE

A.H. Thompson, Geographer.
Willard D. Johnson, Topographer in charge.
Triangulation by U.S. Coast and Geodetic Survey.
Topography by U.S.C. and G.S., U.S. Eng. Corps, City Surveys, and by R.H. Chapman, R.B. Marshall, and W.H. Otis.
Surveyed in 1892-93-94.

TRUE NORTH — MAGNETIC NORTH 18½°
APPROXIMATE MEAN DECLINATION 1913.

Scale 1/62500

1 ½ 0 1 2 3 4 Miles

1 ½ 0 1 2 3 4 5 Kilometers

Edition of Dec. 1913.

Geology by Andrew C. Lawson, assisted at various times by students of the University of California.
Surveyed in 1891-1895, 1899, 1905, and 1911.

LEGEND

SEDIMENTARY ROCKS

SHEET SYMBOL / SECTION SYMBOL

QUATERNARY

Recent

Qs — **Salt marsh deposits** *(clay and silt)*

Qs — **Sand dunes and beach sand**

Qtc — **Temescal formation** *(alluvium; probably includes some San Antonio formation where not separable)*

UNCONFORMITY

Pleistocene

Qm — **Merritt sand** *(marine sand)*

UNCONFORMITY

Qsac / Qsa — **San Antonio formation with chert-gravel member, Qsac** *(coarse alluvial fans; the later part of deposits, Qsac, contains angular chert fragments)*

Qa — **Alameda formation** *(yellow marine clay with some intercalated fluviatile gravel)*

UNCONFORMITY

Qc — **Campus formation** *(fresh-water clay, limestone, conglomerate, tuff, agglomerate, and andesite and basalt flows)*

UNCONFORMITY

TERTIARY

Pliocene (Concord) — *Berkeley group*

Tm — **Moraga formation** *(chiefly andesite and basalt)*

UNCONFORMITY ?

Tor — **Orinda formation** *(fresh-water conglomerate, sandstone, clay, limestone, and thin layers of tuff)*

Tp — **Pinole tuff** *(pumiceous tuff, probably andesitic, deposited in fresh water; in part interbedded with Orinda formation)*

Tnb — **Northbrae rhyolite** *(soda rhyolite lava flows possibly equivalent to Pinole tuff)*

UNCONFORMITY

Miocene — *Monterey group*

Tb — **Briones sandstone** *(light-colored, coarse to pebbly quartzose sandstone)*

Tr — **Rodeo shale** *(chiefly chalky bituminous shale, stained by iron, with some cherty beds)*

Th — **Hambre sandstone** *(medium-textured, slightly ferruginous sandstone, with some sandy shale)*

Tt — **Tice shale** *(white to pink bituminous shale, prevailingly chalky)*

To — **Oursan sandstone** *(fine-grained, light-colored, soft sandstone)*

Tc — **Claremont shale** *(white chalky bituminous shale and chert, with some white indurated tuff)*

Ts — **Sobrante sandstone** *(fine-grained, light-colored, soft sandstone)*

UNCONFORMITY

Eocene

Ttj — **Tejon formation** *(sandstone and shale)*

Legend is continued on the left margin.

LEGEND

SEDIMENTARY ROCKS *(continued)*

SHEET SYMBOL / SECTION SYMBOL

UNCONFORMITY

CRETACEOUS

Upper Cretaceous

Kc — **Chico formation** *(sandstone with subordinate amount of shale)*

Lower Cretaceous (Shasta)

Kk — **Knoxville formation** *(dark carbonaceous shale, sandstone, fine pebbly conglomerate, and impure limestone)*

UNCONFORMITY

JURASSIC ? (pre-Knoxville) — *Franciscan group*

Ji — **Ingleside chert** *(alternations of thin layers of varicolored radiolarian chert, chiefly red, and thinner earthy shales)*

Jm — **Marin sandstone** *(arkosic sandstone with subordinate amounts of shale and conglomerate)*

Jfm — **Metamorphic schist** *(sedimentary and igneous rocks altered by contact metamorphism chiefly to glaucophane schist)*

Js — **Sausalito chert** *(alternations of thin layers of varicolored radiolarian chert, chiefly red, and thinner earthy shales)*

Jfc / Jf — **Undifferentiated sandstones of Franciscan group with radiolarian chert lentils, Jfc, of undetermined horizons**

Jch — **Cahil sandstone** *(arkosic sandstone with subordinate amounts of shale and conglomerate)*

INTRUSIVE IGNEOUS ROCKS

JURASSIC ? (pre-Knoxville) — *Intrusive into Franciscan group*

Jsc — **Silica-carbonate rock** *(aggregate of silica and various carbonates derived from alteration of serpentine)*

Jsp — **Serpentinized peridotite with associated gabbro and pyroxenite** *(intrusive bodies)*

Jb — **Basalt and diabase** *(commonly show spheroidal or ellipsoidal structures; locally variolitic; some inclusions of radiolarian chert)*

Faults

Concealed faults *(covered by younger deposits)*

Overthrust side of thrust faults

Strike and dip of stratified rocks

U.S. GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

STRUCTURE SECTIONS

CALIFORNIA
CONCORD QUADRANGLE

LEGEND

SEDIMENTARY ROCKS
(continued)

SHEET SYMBOL — SECTION SYMBOL

UNCONFORMITY

TERTIARY — *Eocene*

Ttj — **Tejon formation** *(hard ferruginous and calcareous sandstones, with beds of shale and lenses of conglomerate at base)*

UNCONFORMITY

Tmz — **Martinez formation** *(sandstone in part glauconitic, shale, and some conglomerate)*

UNCONFORMITY

CRETACEOUS — *Upper Cretaceous*

Kc, Ko — **Chico formation with Oakland conglomerate member at base** *(massive yellowish sandstone and clay shale with conglomerate member, Ko, at base)*

Lower Cretaceous

Kk — **Knoxville shale** *(carbonaceous and arenaceous)*

UNCONFORMITY

JURASSIC ? *(pre-Knoxville)* — *Franciscan group*

Jfm — **Metamorphic schist** *(sedimentary and igneous rocks altered by contact metamorphism chiefly to glaucophane schist)*

Jf, Jfc — **Undifferentiated sandstones of Franciscan group with radiolarian chert lentils of undetermined horizons, Jfc**

IGNEOUS ROCKS CHIEFLY INTRUSIVE

TERTIARY *(San Francisco)* — *Post-Cretaceous (Pliocene?)*

Tln — **Leona rhyolite** *(lava flows of undetermined age)*

JURASSIC ? *(pre-Knoxville)* — *Intrusive into Franciscan group*

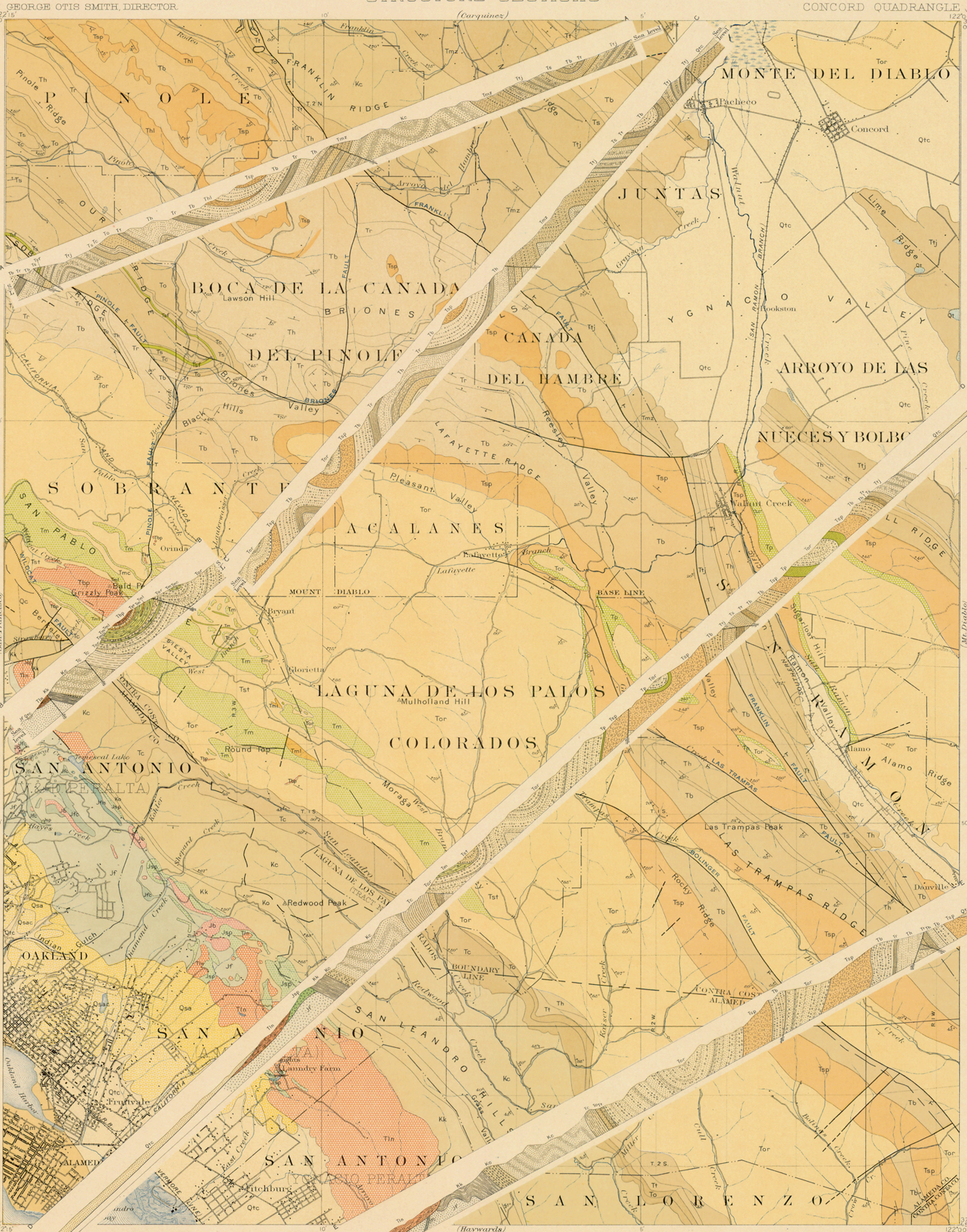
Jsp — **Serpentinized peridotite with associated gabbro and pyroxenite** *(serpentine in part altered to an aggregate of silica and various carbonates)*

Jb — **Basalt and diabase** *(commonly show spheroidal or ellipsoidal structures)*

Faults

Concealed faults *(covered by younger deposits)*

T indicates overthrust side of thrust faults
Strike and dip of stratified rocks
Strike of vertical strata



LEGEND

SEDIMENTARY ROCKS

SHEET SYMBOL — SECTION SYMBOL

QUATERNARY — *Recent*

Salt marsh deposits *(clay and silt)*

Qt — **Travertine** *(calcareous spring deposits)*

Qtc — **Temescal formation** *(alluvium)*

UNCONFORMITY

Pleistocene

Qm — Combined with Temescal formation on sections — **Merritt sand** *(marine sand)*

UNCONFORMITY

Qsac, Qsa — Combined with Temescal formation on sections — **San Antonio formation with chert-gravel member, Qsac** *(coarse alluvial fans; the later part of deposits, Qsac, contains angular chert fragments)*

Qa — **Alameda formation** *(yellow marine clay with some intercalated fluviatile gravel)*

UNCONFORMITY

Qc — **Campus formation** *(fresh-water clay, limestone, conglomerate, tuff, agglomerate, and andesite and basalt flows)*

UNCONFORMITY

TERTIARY — *(Mt. Diablo)* *Pliocene* — *Berkeley group*

Tbp — **Bald Peak basalt** *(lava flows with lentils of fresh-water limestone; some dikes are included in mapping)*

Tst — **Siesta formation** *(fresh-water conglomerate, clay, sandstone, chert, limestone, lignite, and tuff)*

UNCONFORMITY

Tm, Tmc — **Moraga formation** *(andesite and basalt flows, with rhyolitic and basic tuffs, lentils of gravel, clay, and limestone, and thick beds of conglomerate, Tmc, near base)*

Tml — **Fresh-water limestone lentils at various horizons in the Moraga and Siesta formations** *(only the larger bodies shown)*

UNCONFORMITY ?

Tor — **Orinda formation** *(fresh-water conglomerate, sandstone, clay, limestone, and thin layers of tuff)*

Tp — **Pinole tuff** *(pumiceous tuff, probably andesitic, deposited in fresh water)*

UNCONFORMITY

Miocene

Tsp — **San Pablo formation** *(coarse gray to blue sandstone with admixture of tuffaceous material)*

UNCONFORMITY

Miocene (Monterey group)

Thl, Tb — **Briones sandstone with Hercules shale member, Thl** *(light-colored coarse to pebbly quartzose sandstone with chalky bituminous shale member, Thl)*

Tr — **Rodeo shale** *(chiefly chalky bituminous shale, stained by iron, with some cherty beds)*

Th — **Hambre sandstone** *(medium-textured, slightly ferruginous sandstone, with some sandy shale)*

Tt — **Tice shale** *(white to pink bituminous shale, prevailingly chalky)*

To — **Oursan sandstone** *(fine-grained, light-colored, soft sandstone)*

Tc — **Claremont shale** *(white chalky bituminous shale and yellowish chert rhythmically interbedded with thin shales; thin hard sandstones and lentils of ferruginous limestone)*

Ts, Tsf — **Sobrante sandstone** *(light-colored soft sandstone with darker ferruginous beds; includes layers of white pumiceous tuff, Tsf, near base)*

Legend is continued on the left margin.

Henry Gannett, Chief Topographer.
R. U. Goode, Geographer in charge.
Triangulation by U.S. Coast and Geodetic Survey.
Topography by W. D. Johnson and W. H. Otis.
Surveyed in 1893–94.

TRUE NORTH — MAGNETIC NORTH — 18½°
APPROXIMATE MEAN DECLINATION 1913.

Scale $\frac{1}{62500}$

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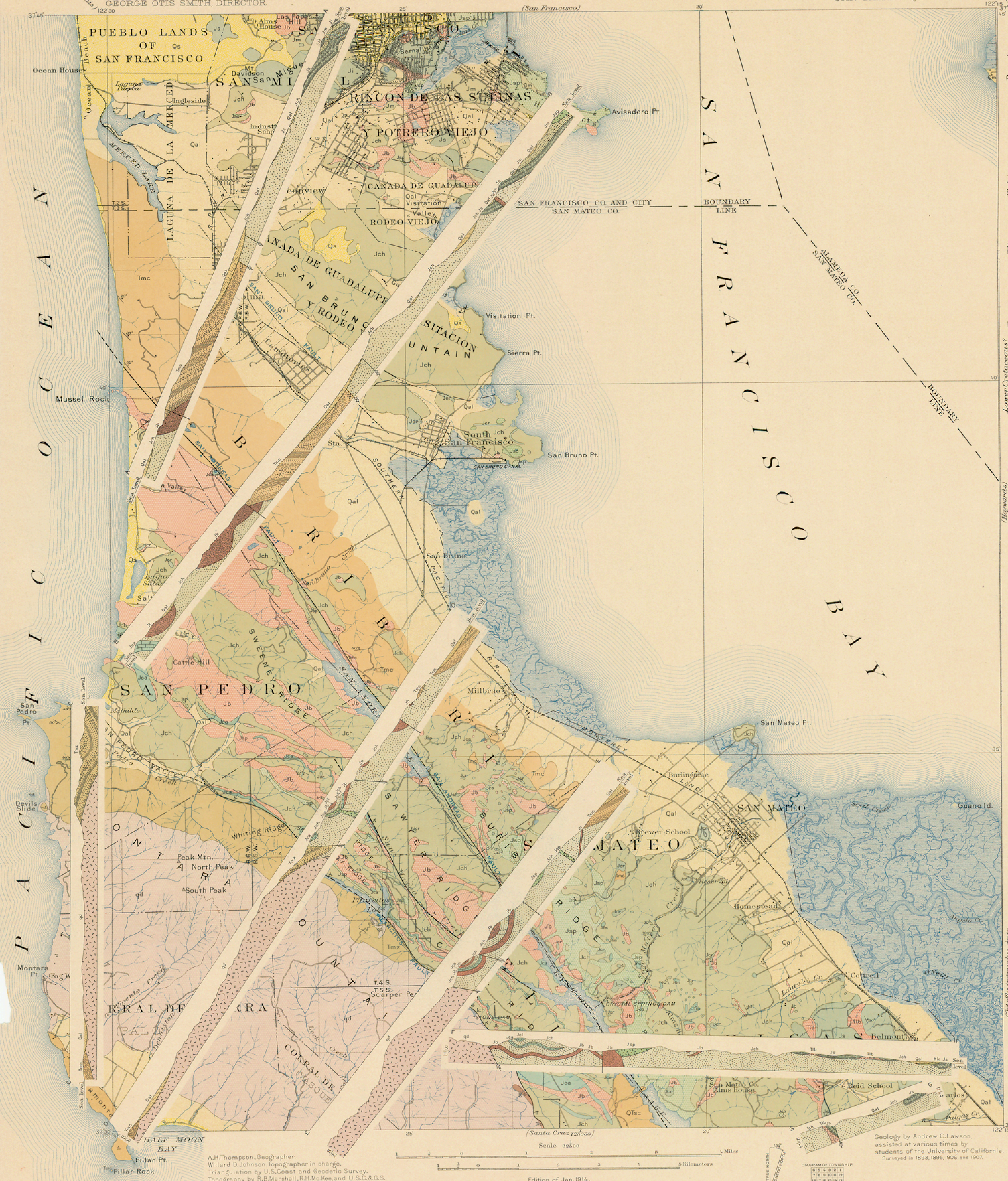
Edition of Jan. 1914.

Geology by Andrew C. Lawson and John C. Merriam, assisted at various times by students of the University of California. Surveyed in 1894, 1896, 1905, and 1911.

U.S. GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

STRUCTURE SECTIONS

CALIFORNIA
SAN MATEO QUADRANGLE



A.H.Thompson, Geographer.
Willard D. Johnson, Topographer in charge.
Triangulation by U.S. Coast and Geodetic Survey.
Topography by R.B. Marshall, R.H. McKee, and U.S.C.&G.S.
Surveyed in 1892.

Scale $\frac{1}{62500}$

Edition of Jan. 1914.

Geology by Andrew C. Lawson, assisted at various times by students of the University of California. Surveyed in 1893, 1895, 1906, and 1907.

APPROXIMATE MEAN DECLINATION 1913.

DIAGRAM OF TOWNSHIP

LEGEND

SEDIMENTARY ROCKS

SHEET SYMBOL / SECTION SYMBOL

QUATERNARY

Recent

Salt-marsh deposits (clay and silt)

Qs — Sand dunes and beach sand (may include alluvium in places). Combined with Qal on sections

Qal — Alluvium (probably of same age as Temescal formation; covered in places by dune sand)

Pleistocene

Qm — Merritt sand (marine)

Qtg — Terrace gravel (residual)

TERTIARY

Pliocene

Tmc — Merced formation (marine clay, sandstone, shale, and conglomerate overlain in part by thick Quaternary sand and gravel)

QTsc — Santa Clara formation (alluvium)

UNCONFORMITY

Eocene

Tmz — Martinez ? formation (conglomerate, coarse and fine arkosic sandstone, dark shale, and thin limestone)

UNCONFORMITY

CRETACEOUS ?

Lower Cretaceous ? (post-Franciscan)

Kk — Conglomerate, probably Knoxville formation

UNCONFORMITY

JURASSIC ? (pre-Knoxville)

Franciscan group (Haywards)

Jbs — Bonita sandstone (arkosic sandstone)

Ji — Ingleside chert (alternations of thin layers of varicolored radiolarian chert, chiefly red, and thinner earthy shales)

Jm — Marin sandstone (with subordinate amounts of shale)

Jfm — Metamorphic schist (sedimentary and igneous rocks altered by contact metamorphism to amphibole, mica, quartz, and albite schists)

Js — Sausalito chert (alternations of thin layers of varicolored radiolarian chert, chiefly red, and thinner earthy shales)

Jch, Jca — Cahil sandstone with Calera limestone member, Jca (includes also lenses of radiolarian chert, Jcr, and of limestone, Jcl, may include some higher sandstone beds and chert lentils)

UNCONFORMITY

PRE-JURASSIC ?

Pre-Franciscan

Gavilan limestone (crystalline limestone masses included in quartz diorite)

IGNEOUS ROCKS CHIEFLY INTRUSIVE

TERTIARY

Miocene ?

Tlb — Later basalt (lava flows and intrusive bodies of undetermined age)

JURASSIC ? (pre-Knoxville)

Chiefly intrusive into Franciscan group

Jsc — Silica-carbonate rock (aggregate of silica and various carbonates derived from alteration of serpentine)

Jsp — Serpentinized peridotite and associated gabbro and pyroxenite

Jb — Basalt and diabase (chiefly intrusive, commonly show spheroidal or ellipsoidal structures; includes some lava flows contemporaneous with Franciscan group)

PRE-JURASSIC ?

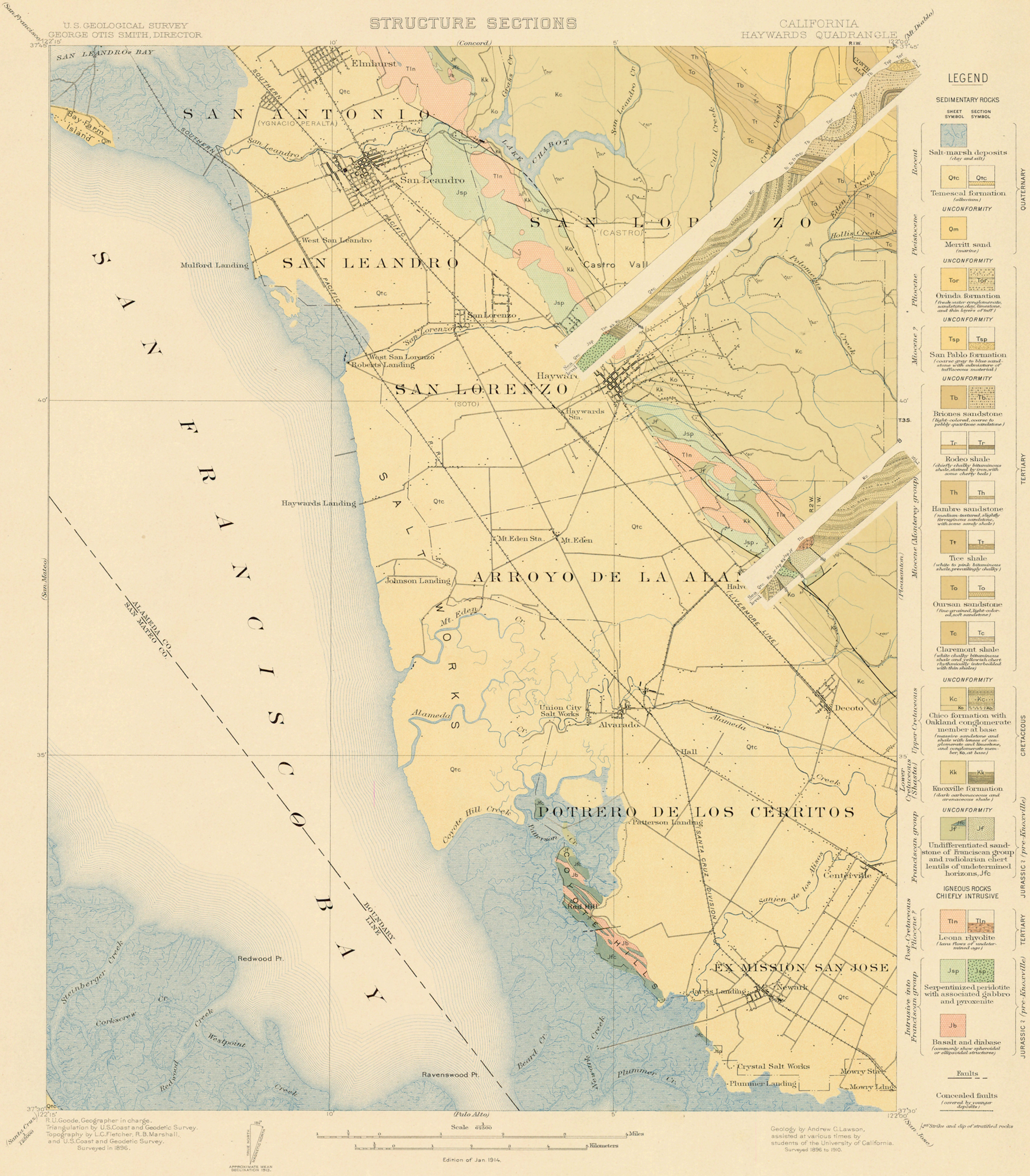
Pre-Franciscan

qd — Quartz-diorite (large batholithic mass; "Montara granite")

Faults

Concealed faults (covered by younger deposits)

Strike and dip of stratified rocks
Strike of vertical stratified rocks
T indicates overthrust side of thrust faults



R.U. Goode, Geographer in charge.
Triangulation by U.S. Coast and Geodetic Survey.
Topography by L.C. Fletcher, R.B. Marshall, and U.S. Coast and Geodetic Survey.
Surveyed in 1896.

Edition of Jan. 1914.

Geology by Andrew C. Lawson, assisted at various times by students of the University of California.
Surveyed 1896 to 1910.

COLUMNAR SECTION

GENERALIZED SECTION OF THE SEDIMENTARY ROCKS OF THE SAN FRANCISCO DISTRICT.

SCALE: 1 INCH=2000 FEET.

System.	Series.	Group.	Formation.	Symbol.	Columnar Section.	Average Thickness in Feet.	Character of Rocks.	Equivalents in Santa Cruz Quadrangle and Remarks.
QUATERNARY	RECENT		Temescal formation.	Qtc		20±	Mixed clay, sand, and angular fragments, with some gravel.	Alluvium.
			UNCONFORMITY					
	PLEISTOCENE		Merritt sand.	Qm		30±	Marine sand.	Note.—The fresh-water Santa Clara formation in the San Mateo quadrangle closely resembles the San Antonio formation. In the Santa Cruz folio it is treated as contemporaneous with the marine Merced formation.
			UNCONFORMITY					
			San Antonio formation.	Qsa		150±	Clay, sand, and angular fragments, composing coarse alluvial fans.	
			UNCONFORMITY					
			Alameda formation.	Qa		130±	Marine sand and clay, with intercalated fluviatile gravel and clay.	
			UNCONFORMITY					
			Campus formation.	Qc		600±	Fluviatile gravel, lacustral clay and limestone, andesitic and basaltic lava, and rhyolite tuff and agglomerate.	
			UNCONFORMITY					
TERTIARY	PLIOCENE	BERKELEY	Bald Peak basalt.	Tbp		400±	Lava flows with some lenses of fresh-water limestone.	
			Siesta formation.	Tst		200	Fresh-water clay, sandstone, conglomerate, limestone, chert, lignite, and tuff.	
			Moraga formation.	Tm		1200	Andesite and basalt flows, tuff, fresh-water conglomerate, and cherty limestone.	
			UNCONFORMITY					
			Merced formation (marine) and contemporaneous fresh-water Orinda formation.	Tmc Tor		5000–5800	Merced formation, 5800 feet of marine clay, sandstone, conglomerate, shell beds, and beds of tuff. Orinda formation, about 5000 feet of fresh-water conglomerate, sandstone, clay, and limestone, with a few beds of tuff.	Merced and Purisima formations. Note.—Only the Orinda formation is interstratified with Pinole tuff and Moraga formation and is therefore represented in the graphic columnar section. The Merced formation lies in a separate depression.
			Pinole tuff; also Northbrae rhyolite and Leona rhyolite of uncertain age.	Tp		1000	White andesitic pumiceous tuff, containing shells of fresh-water mollusks, interbedded with basal beds of Orinda formation.	Note.—Northbrae rhyolite lava, 100 feet thick, and the pyritic Leona rhyolite lava, about 500 feet thick, may possibly be contemporaneous with Pinole tuff.
			UNCONFORMITY					
	MIOCENE		San Pablo formation	Tsp		1700	Sandstone, in large part light blue, shale, and some tuff.	Santa Margarita formation.
			UNCONFORMITY					
			Basaltic flows.	Tlb		100±	Lava flows with associated intrusive basalt in southern part of San Mateo quadrangle only.	Diabase and basalt.
			UNCONFORMITY					
		MONTEREY	Briones sandstone with Hercules shale member near middle.	Tb Thl Tb		2300	Sandstone, including bituminous shale member 500 feet thick.	Monterey shale. Vaqueros sandstone. Note.—The bituminous shale formations of the Monterey group are made up in large part of microscopic organisms, chiefly diatoms, but the group contains also admixtures and beds of volcanic ash.
			Rodeo shale.	Tr		670	Chalky bituminous shale, slightly ferruginous and locally cherty.	
			Hambre sandstone.	Th		1200	Sandstone and sandy shale, slightly ferruginous.	
			Tice shale.	Tt		460	Prevailingly chalky cream-colored bituminous shale.	
			Oursan sandstone.	To		600	Fine-grained sandstone.	
			Claremont shale.	Tc		800	Bituminous shale and alternations of shale and chert with lenses of limestone and a few beds of sandstone.	
			Sobrante sandstone.	Ts		400	Fine-grained, light-colored, locally ferruginous sandstone.	
			UNCONFORMITY					
	EOCENE		Tejon formation.	Ttj		2000±	Hard, slightly ferruginous, light-colored to reddish sandstone, calcareous sandstone, and shale.	Represented by limestone inclusions in diabase.
			UNCONFORMITY					
			Martinez formation.	Tmz		2000±	Sandstone with some glauconitic layers and shale.	
			UNCONFORMITY					
CRETACEOUS	UPPER CRETACEOUS		Chico formation.	Kc		2000 6000	Sandstone and shale.	Chico formation.
			Oakland conglomerate member.	Ko			Conglomerate, 1000 feet thick.	
	LOWER CRETACEOUS		Knoxville formation.	Kk		1000±	Shale and sandstone with some thin beds of limestone.	Knoxville formation.
			UNCONFORMITY					
JURASSIC?		FRANCISCAN	Bonita sandstone.	Jbt		1400	Fine-grained gray sandstone with flakes of carbonaceous matter and thin seams of coal.	Franciscan formation. Note.—The Franciscan rocks throughout the region are intruded by basalt, diabase, and peridotite, the last largely changed to serpentine, and at many localities they are metamorphosed to glaucophane schist and other crystalline schists.
			Ingleside chert.	Ji		530	Rhythmically stratified, reddish radiolarian chert and shale.	
			Marin sandstone.	Jm		1000	Massive dark-gray sandstone, obscurely stratified.	
			Sausalito chert.	Js		900	Rhythmically stratified, reddish radiolarian chert and shale.	
			Cahil sandstone.	Jch		2560	Prevailingly massive, obscurely bedded sandstone, with some shale, limestone, and conglomerate.	
			Calera limestone member.	Jca			Foraminiferal limestone, with lenses of chert, 60 feet thick.	
			UNCONFORMITY					
PRE-JURASSIC ?		PRE-FRANCISCAN	Quartz diorite and included masses of Gavilan limestone.	qd			Medium-coarse quartz diorite with inclusions of limestone.	Quartz diorite.

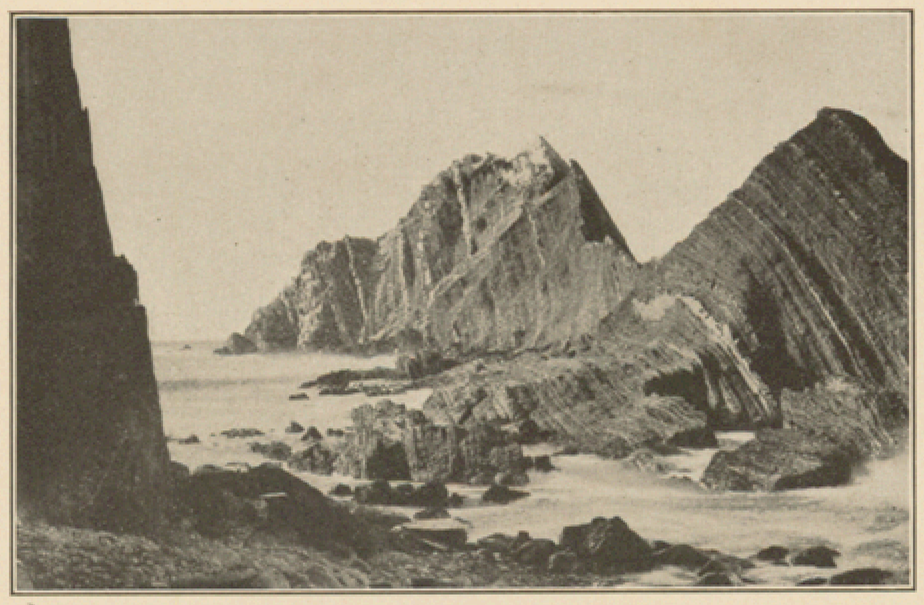


PLATE I.—STEEPLY TILTED ROCKS OF SAN PEDRO POINT, SAN MATEO QUADRANGLE.
Shales and sandstones of Martinez formation.

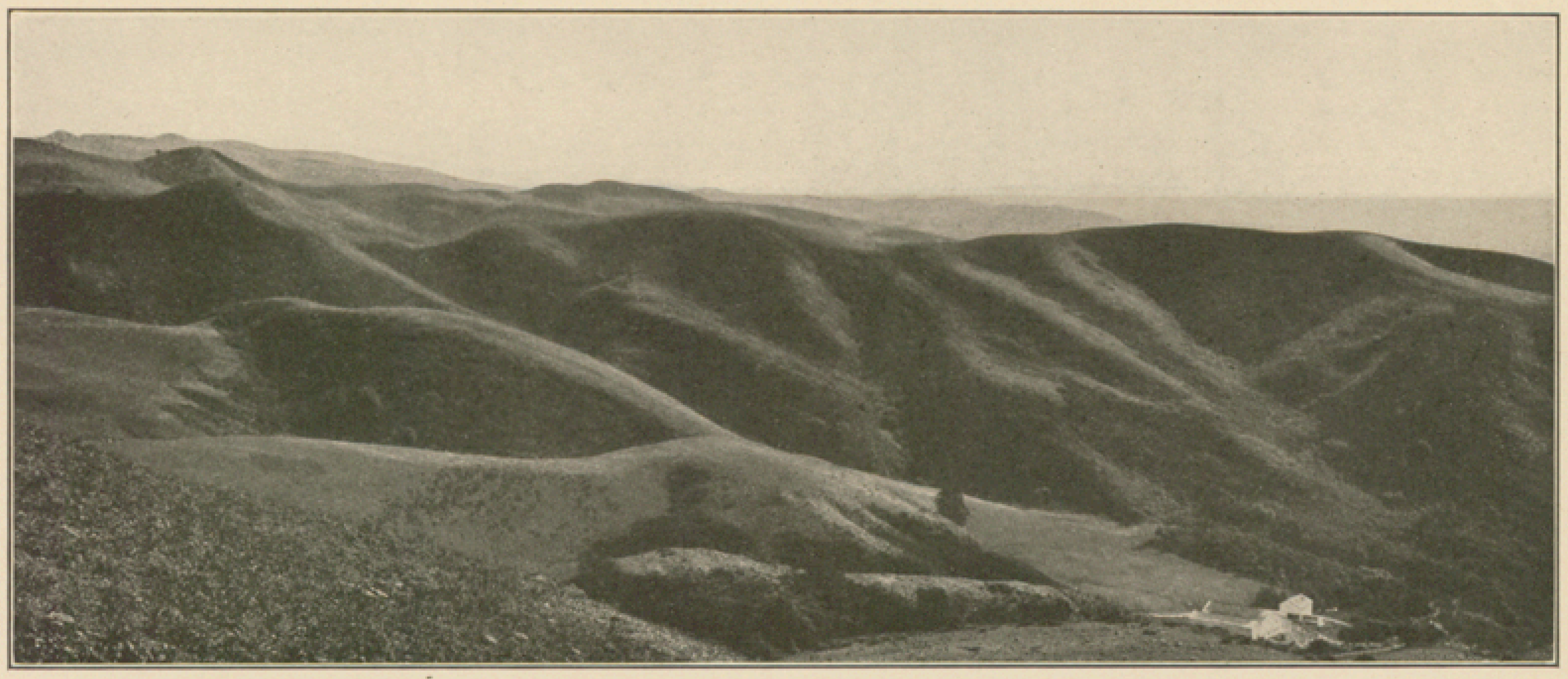


PLATE II.—WESTERN FRONT OF THE BERKELEY HILLS, VIEWED FROM THE NORTH ACROSS THE CANYON OF STRAWBERRY CREEK.
Characteristic Coast Range topography.

PLATE III.—CALERA LIMESTONE MEMBER OF CAHIL SANDSTONE, FRANCISCAN GROUP, CALERA POINT, SAN MATEO QUADRANGLE.
The limestone contains layers of dark chert.

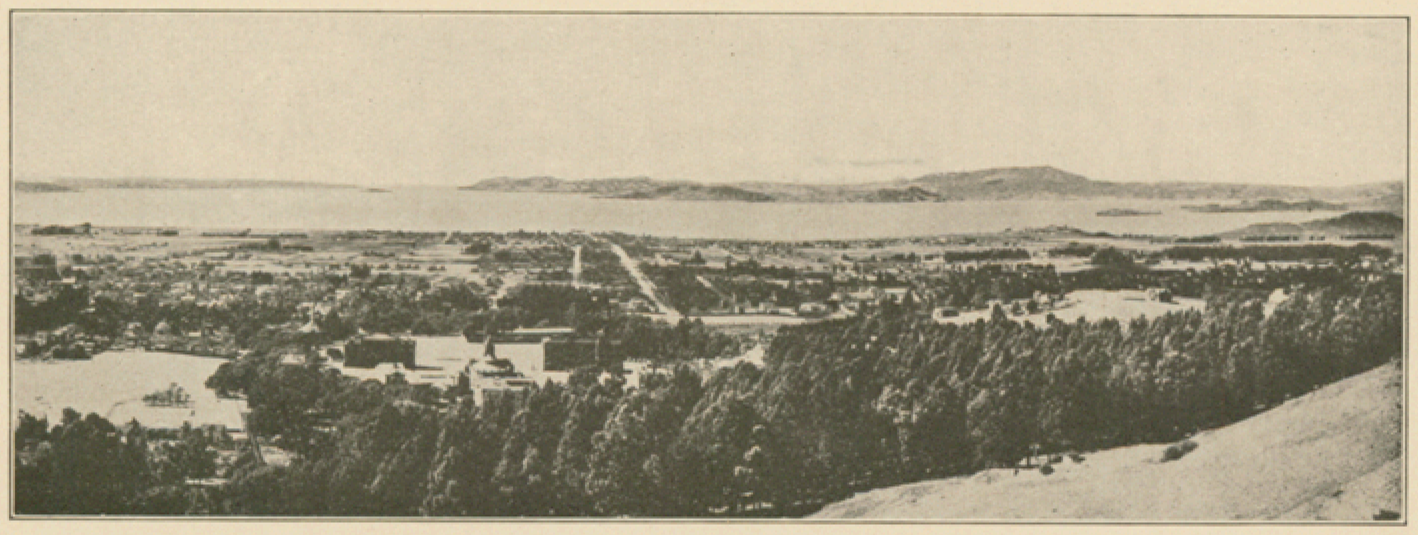


PLATE IV.—SAN FRANCISCO BAY, FROM THE BERKELEY HILLS.
Berkeley in the foreground. Mount Tamalpais at the right across the bay and the Golden Gate at the left of the center.

PLATE V.—ELLIPSOIDAL STRUCTURE IN INTRUSIVE BASALT, HUNTER POINT, SAN FRANCISCO.

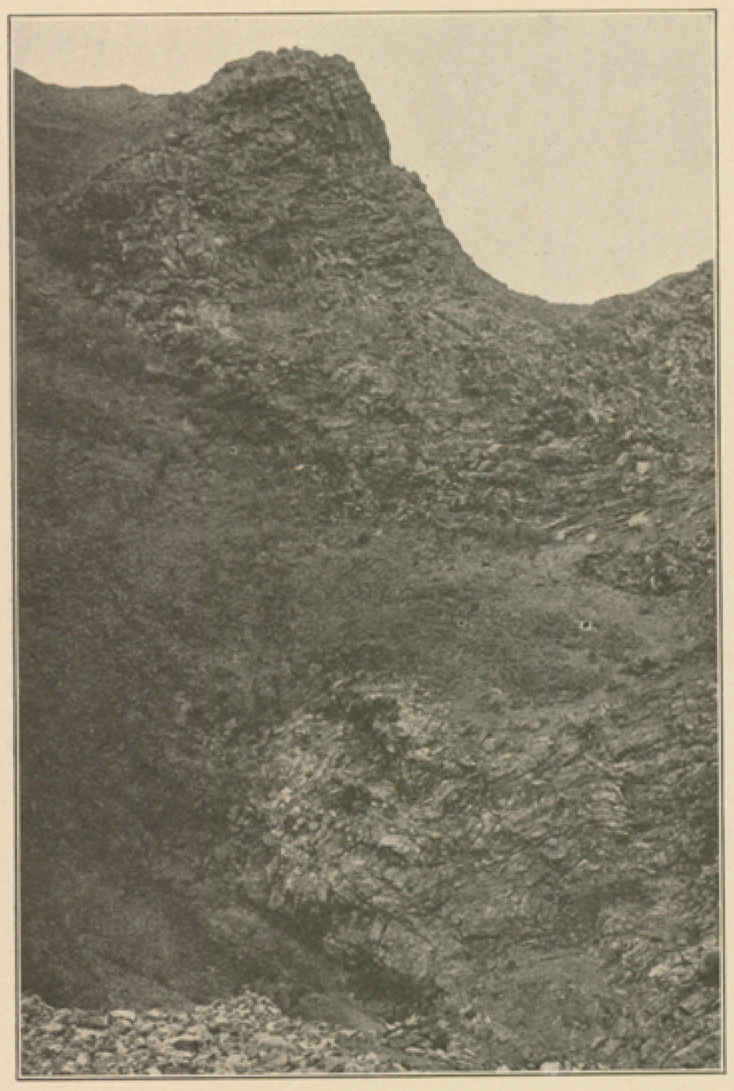


PLATE VI.—ELLIPSOIDAL BASALT INTRUSIVE INTO THIN-BEDDED RADIOLARIAN CHERT OF FRANCISCAN GROUP, HUNTER POINT, SAN FRANCISCO.
The layers of chert are much contorted by the intrusion.

PLATE VII.—THIN-BEDDED CHERT AND SHALE OF THE CLAREMONT FORMATION, MONTEREY GROUP, CLAREMONT CANYON, BERKELEY HILLS.
The layers of shale are much thinner than the layers of chert, which are white in the picture.

PLATE VIII.—MINUTELY FOLDED THIN-BEDDED RADIOLARIAN CHERT OF FRANCISCAN GROUP EXPOSED IN QUARRY IN GOLDEN GATE PARK, SAN FRANCISCO.

PLATE IX.—SAN ANDREAS RIFT VALLEY. VIEW SOUTHEASTWARD TOWARD CRYSTAL SPRINGS LAKE, SAN MATEO QUADRANGLE.
The straight valley follows the zone of weakened rocks along the San Andreas fault. Crystal Springs Lake in the distance

PLATE X.—TRACE OF SAN ANDREAS FAULT, MADE BY THE MOVEMENT WHICH CAUSED THE EARTHQUAKE OF 1906.
On the left is the rift valley, which extends from Bolinas Lagoon to Tomales Bay.

and still smaller ones *stages*. The age of a rock is expressed by the name of the time interval in which it was formed.

The sedimentary formations deposited during a period are grouped together into a *system*. The principal divisions of a system are called *series*. Any aggregate of formations less than a series is called a *group*.

Inasmuch as sedimentary deposits accumulate successively the younger rest on those that are older, and their relative ages may be determined by observing their positions. In many regions of intense disturbance, however, the beds have been overturned by folding or superposed by faulting, so that it may be difficult to determine their relative ages from their present positions; under such conditions fossils, if present, may indicate which of two or more formations is the oldest.

Many stratified rocks contain *fossils*, the remains or imprints of plants and animals which, at the time the strata were deposited, lived in bodies of water or were washed into them, or were buried in surficial deposits on the land. Such rocks are called fossiliferous. By studying fossils it has been found that the life of each period of the earth's history was to a great extent different from that of other periods. Only the simpler kinds of marine life existed when the oldest fossiliferous rocks were deposited. From time to time more complex kinds developed, and as the simpler ones lived on in modified forms life became more varied. But during each period there lived peculiar forms, which did not exist in earlier times and have not existed since; these are *characteristic types*, and they define the age of any bed of rock in which they are found. Other types passed on from period to period, and thus linked the systems together, forming a chain of life from the time of the oldest fossiliferous rocks to the present. Where two sedimentary formations are remote from each other and it is impossible to observe their relative positions, the characteristic fossil types found in them may determine which was deposited first. Fossil remains in the strata of different areas, provinces, and continents afford the most important means for combining local histories into a general earth history.

It is in many places difficult or impossible to determine the age of an igneous formation, but the relative age of such a formation can in general be ascertained by observing whether an associated sedimentary formation of known age is cut by the igneous mass or is deposited upon it. Similarly, the time at which metamorphic rocks were formed from the original masses may be shown by their relations to adjacent formations of known age; but the age recorded on the map is that of the original masses and not that of their metamorphism.

Symbols, colors, and patterns.—Each formation is shown on the map by a distinctive combination of color and pattern and is labeled by a special letter symbol.

Patterns composed of parallel straight lines are used to represent sedimentary formations deposited in the sea, in lakes, or in other bodies of standing water. Patterns of dots and circles represent alluvial, glacial, and eolian formations. Patterns of triangles and rhombs are used for igneous formations. Metamorphic rocks of unknown origin are represented by short dashes irregularly placed; if the rock is schist the dashes may be arranged in wavy lines parallel to the structure planes. Suitable combination patterns are used for metamorphic formations known to be of sedimentary or of igneous origin. The patterns of each class are printed in various colors. With the patterns of parallel lines, colors are used to indicate age, a particular color being assigned to each system.

The symbols consist each of two or more letters. If the age of a formation is known the symbol includes the system symbol, which is a capital letter or monogram; otherwise the symbols are composed of small letters.

The names of the systems and of series that have been given distinctive names, in order from youngest to oldest, with the color and symbol assigned to each system, are given in the subjoined table.

Symbols and colors assigned to the rock systems.

	System.	Series.	Symbol.	Color for sedimentary rocks.
Cenozoic	Quaternary	Recent Pleistocene	Q	Brownish yellow.
	Tertiary	Pliocene Miocene Oligocene Eocene	T	Yellow ocher.
Mesozoic	Cretaceous		K	Olive-green.
	Jurassic		J	Blue-green.
	Triassic		Ꞧ	Peacock-blue.
Paleozoic	Carboniferous	Permian Pennsylvanian Mississippian	C	Blue.
	Devonian		D	Blue-gray.
	Silurian		S	Blue-purple.
	Ordovician		O	Red-purple.
	Cambrian		Ꞓ	Brick-red.
	Algonkian		A	Brownish red.
	Archean		Æ	Gray-brown.

SURFACE FORMS.

Hills, valleys, and all other surface forms have been produced by geologic processes. For example, most valleys are the result of erosion by the streams that flow through them (see fig. 1), and the alluvial plains bordering many streams were built up by the streams; waves cut sea cliffs and, in cooperation with currents, build up sand spits and bars. Topographic forms thus constitute part of the record of the history of the earth.

Some forms are inseparably connected with deposition. The hooked spit shown in figure 1 is an illustration. To this class belong beaches, alluvial plains, lava streams, drumlins (smooth oval hills composed of till), and moraines (ridges of drift made at the edges of glaciers). Other forms are produced by erosion. The sea cliff is an illustration; it may be carved from any rock. To this class belong abandoned river channels, glacial furrows, and peneplains. In the making of a stream terrace an alluvial plain is first built and afterward partly eroded away. The shaping of a marine or lacustrine plain is usually a double process, hills being worn away (*degraded*) and valleys being filled up (*aggraded*).

All parts of the land surface are subject to the action of air, water, and ice, which slowly wear them down, and streams carry the waste material to the sea. As the process depends on the flow of water to the sea, it can not be carried below sea level, and the sea is therefore called the *base-level* of erosion. Lakes or large rivers may determine local base-levels for certain regions. When a large tract is for a long time undisturbed by uplift or subsidence it is degraded nearly to base-level, and the fairly even surface thus produced is called a *peneplain*. If the tract is afterward uplifted, the elevated peneplain becomes a record of the former close relation of the tract to base-level.

THE VARIOUS GEOLOGIC SHEETS.

Areal geology map.—The map showing the areas occupied by the various formations is called an *areal geology map*. On the margin is a *legend*, which is the key to the map. To ascertain the meaning of any color or pattern and its letter symbol the reader should look for that color, pattern, and symbol in the legend, where he will find the name and description of the formation. If it is desired to find any particular formation, its name should be sought in the legend and its color and pattern noted; then the areas on the map corresponding in color and pattern may be traced out. The legend is also a partial statement of the geologic history. In it the names of formations are arranged in columnar form, grouped primarily according to origin—sedimentary, igneous, and crystalline of unknown origin—and within each group they are placed in the order of age, so far as known, the youngest at the top.

Economic geology map.—The map representing the distribution of useful minerals and rocks and showing their relations to the topographic features and to the geologic formations is termed the *economic geology map*. The formations that appear on the areal geology map are usually shown on this map by fainter color patterns and the areas of productive formations are emphasized by strong colors. A mine symbol shows the location of each mine or quarry and is accompanied by the name of the principal mineral mined or stone quarried. If there are important mining industries or artesian basins in the area special maps to show these additional economic features are included in the folio.

Structure-section sheet.—In cliffs, canyons, shafts, and other natural and artificial cuttings the relations of different beds to one another may be seen. Any cutting that exhibits those relations is called a *section*, and the same term is applied to a diagram representing the relations. The arrangement of rocks in the earth is the earth's *structure*, and a section exhibiting this arrangement is called a *structure section*.

The geologist is not limited, however, to natural and artificial cuttings for his information concerning the earth's structure. Knowing the manner of formation of rocks and having traced out the relations among the beds on the surface, he can infer their relative positions after they pass beneath the surface and can draw sections representing the structure to a considerable depth. Such a section is illustrated in figure 2.

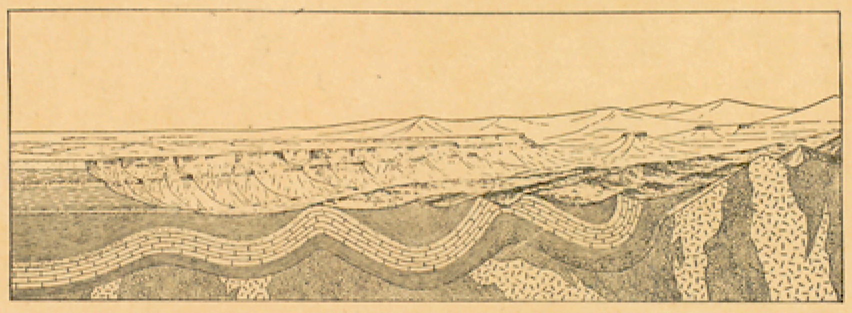


FIGURE 2.—Sketch showing a vertical section at the front and a landscape beyond.

The figure represents a landscape which is cut off sharply in the foreground on a vertical plane, so as to show the underground relations of the rocks. The kinds of rock are indicated by appropriate patterns of lines, dots, and dashes. These patterns admit of much variation, but those shown in figure 3 are used to represent the commoner kinds of rock.

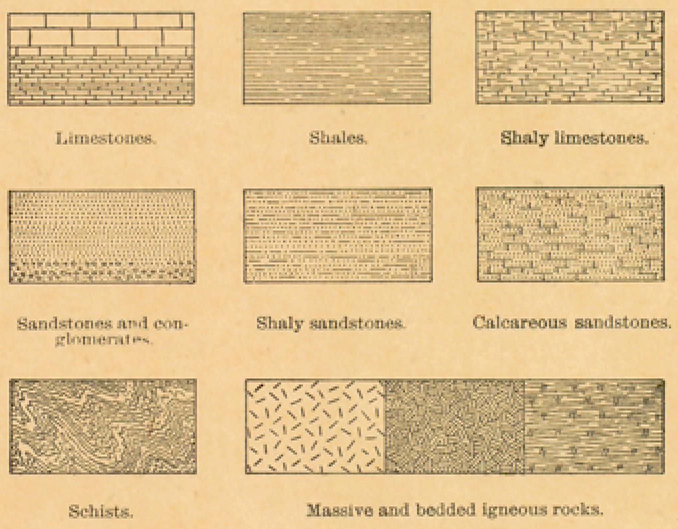


FIGURE 3.—Symbols used in sections to represent different kinds of rocks.

The plateau shown at the left of figure 2 presents toward the lower land an escarpment, or front, which is made up of sandstones, forming the cliffs, and shales, constituting the slopes. The broad belt of lower land is traversed by several ridges, which are seen in the section to correspond to the outcrops of a bed of sandstone that rises to the surface. The upturned edges of this bed form the ridges, and the intermediate valleys follow the outcrops of limestone and calcareous shale.

Where the edges of the strata appear at the surface their thickness can be measured and the angles at which they dip below the surface can be observed. Thus their positions underground can be inferred. The direction of the intersection of a bed with a horizontal plane is called the *strike*. The inclination of the bed to the horizontal plane, measured at right angles to the strike, is called the *dip*.

In many regions the strata are bent into troughs and arches, such as are seen in figure 2. The arches are called *anticlines* and the troughs *synclines*. As the sandstones, shales, and limestones were deposited beneath the sea in nearly flat sheets, the fact that they are now bent and folded is proof that forces have from time to time caused the earth's surface to wrinkle along certain zones. In places the strata are broken across and the parts have slipped past each other. Such breaks are termed *faults*. Two kinds of faults are shown in figure 4.

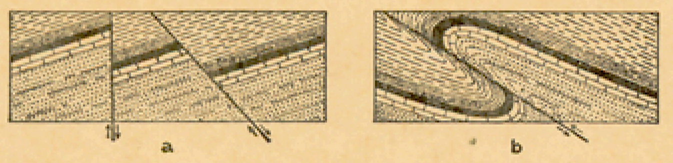


FIGURE 4.—Ideal sections of strata, showing (a) *normal* faults and (b) a *thrust* or *reverse* fault.

At the right of figure 2 the section shows schists that are traversed by igneous rocks. The schists are much contorted and their arrangement underground can not be inferred. Hence that portion of the section delineates what is probably true but is not known by observation or by well-founded inference.

The section also shows three sets of formations, distinguished by their underground relations. The uppermost set, seen at the left, is made up of sandstones and shales, which lie in a horizontal position. These strata were laid down under water but are now high above the sea, forming a plateau, and their change of elevation shows that a portion of the earth's mass has been uplifted. The strata of this set are parallel, a relation which is called *conformable*.

The second set of formations consists of strata that have been folded into arches and troughs. These strata were once continuous, but the crests of the arches have been removed by erosion. The beds, like those of the first set, are conformable.

The horizontal strata of the plateau rest upon the upturned, eroded edges of the beds of the second set shown at the left of the section. The overlying deposits are, from their position, evidently younger than the underlying deposits, and the bending and eroding of the older beds must have occurred between their deposition and the accumulation of the younger beds. The younger rocks are *unconformable* to the older, and the surface of contact is an *unconformity*.

The third set of formations consists of crystalline schists and igneous rocks. At some period of their history the schists were folded or plicated by pressure and traversed by eruptions of molten rock. But the pressure and intrusion of igneous rocks have not affected the overlying strata of the second set. Thus it is evident that a considerable interval elapsed between the formation of the schists and the beginning of deposition of the strata of the second set. During this interval the schists were metamorphosed, they were disturbed by eruptive activity, and they were deeply eroded. The contact between the second and third sets is another unconformity; it marks a time interval between two periods of rock formation.

The section and landscape in figure 2 are ideal, but they illustrate actual relations. The sections on the structure-section sheet are related to the maps as the section in the figure is related to the landscape. The profile of the surface in the section corresponds to the actual slopes of the ground along the section line, and the depth from the surface of any mineral-producing or water-bearing stratum that appears in the section may be measured by using the scale of the map.

Columnar section.—The geologic maps are usually accompanied by a *columnar section*, which contains a concise description of the sedimentary formations that occur in the quadrangle. It presents a summary of the facts relating to the character of the rocks, the thickness of the formations, and the order of accumulation of successive deposits.

The rocks are briefly described, and their characters are indicated in the columnar diagram. The thicknesses of formations are given in figures that state the least and greatest measurements, and the average thickness of each formation is shown in the column, which is drawn to scale. The order of accumulation of the sediments is shown in the columnar arrangement—the oldest being at the bottom, the youngest at the top.

The intervals of time that correspond to events of uplift and degradation and constitute interruptions of deposition are indicated graphically and by the word "unconformity."

GEORGE OTIS SMITH,
Director.

May, 1909.

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