DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

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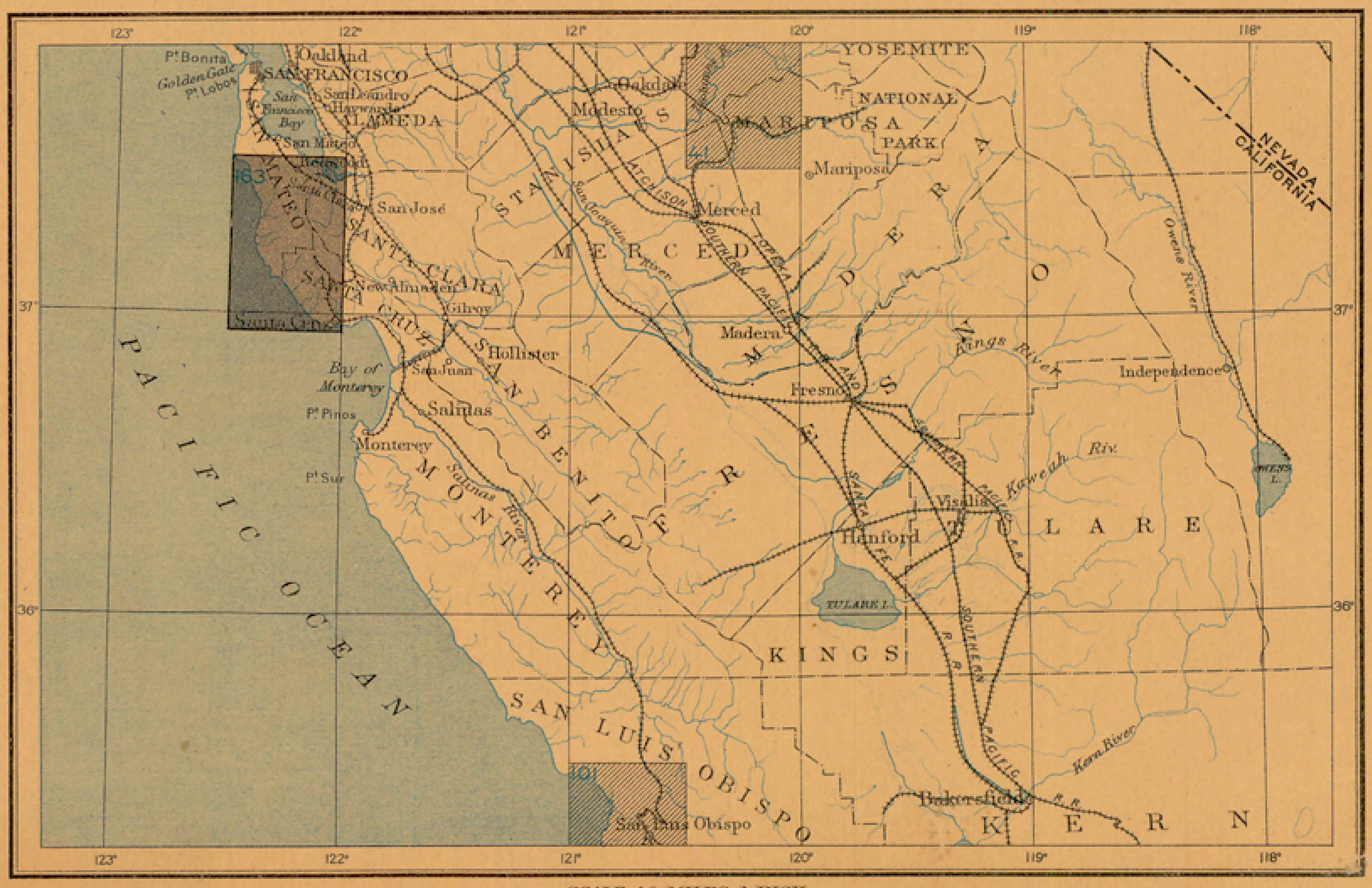
# GEOLOGIC ATLAS
## OF THE
# UNITED STATES

# SANTA CRUZ FOLIO
## CALIFORNIA

INDEX MAP



SCALE: 40 MILES=1 INCH

▨ SANTA CRUZ FOLIO

▨ OTHER PUBLISHED FOLIOS

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# EOLOGIC AND TOPOGRAPHIC ATLAS OF UNITED STATES

The Geological Survey is making a geologic map of the United States, which is being issued in parts, called folios. Each folio includes a topographic map and geologic maps of a small area of country, together with explanatory and descriptive texts.

## 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 which are most important 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 thru points of equal elevation above mean sea level, the altitudinal interval represented by the space between lines being the same throughout each map. These lines are called *contours*, and the uniform altitudinal space between each two contours is called the *contour interval*. Contours and elevations are printed in brown.

The manner in which contours express elevation, form, and grade is shown in the following sketch and corresponding contour map (fig. 1).

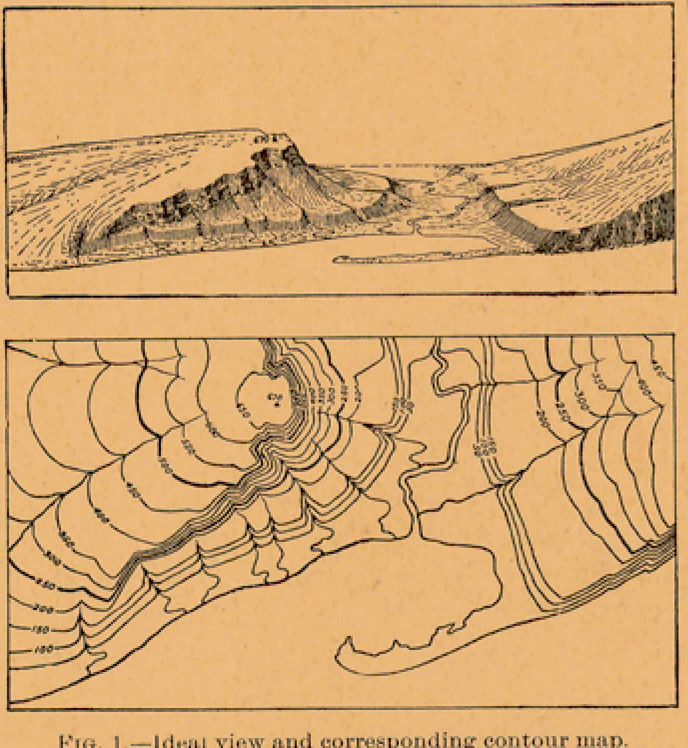

FIG. 1.—Ideal view and corresponding contour map.

The sketch represents a river valley between two hills. In the foreground is the sea, with a bay which is partly closed by a hooked sand bar. On each side of the valley is a terrace. From the terrace on the right a hill rises gradually, while from that on the left the ground ascends steeply, forming a precipice. Contrasted with this precipice is the gentle slope from its top toward the left. In the map each of these features is indicated, directly beneath its position in the sketch, by contours. The following explanation may make clearer the manner in which contours delineate elevation, form, and grade:

1. A contour indicates a certain height above sea level. In this illustration the contour interval is 50 feet; therefore the contours 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 sea; along the contour at 200 feet, all points that are 200 feet above sea; and so on. In the space between any two contours are found elevations above the lower and below the higher contour. Thus the contour at 150 feet falls just below the edge of the terrace, while 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 sea. The summit of the higher hill is stated to be 670 feet above sea; accordingly the contour at 650 feet surrounds it. In this illustration all the contours are numbered, and those for 250 and 500 feet are accentuated by being made heavier. Usually it is not desirable to number all the contours, and then the accentuating and numbering of certain of them—say every fifth one—suffice, for the heights of others may be ascertained by counting up or down from a numbered contour.

2. Contours define the forms of slopes. Since contours are continuous horizontal lines, they wind smoothly about smooth surfaces, recede into all reentrant angles of ravines, and project in passing about prominences. These relations of contour curves and angles to forms of the landscape can be traced in the map and sketch.

3. Contours show the approximate grade of any slope. The altitudinal space between two contours is the same, whether they lie along a cliff or on a gentle slope; but to rise 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.

For a flat or gently undulating country a small contour interval is used; for a steep or mountainous country a large interval is necessary. The smallest interval used on the atlas sheets of the Geological Survey is 5 feet. This is serviceable for regions like the Mississippi delta and the Dismal Swamp. In mapping great mountain masses, like those in Colorado, the interval may be 250 feet. For intermediate relief contour intervals of 10, 20, 25, 50, and 100 feet are used.

*Drainage.*—Watercourses are indicated by blue lines. If a stream flows the entire year the line is drawn unbroken, but if the channel is dry a part of the year the line is broken or dotted. Where a stream sinks and reappears at the surface, the supposed underground course is shown by a broken blue line. Lakes, marshes, and other bodies of water are also shown in blue, by appropriate conventional signs.

*Culture.*—The works of man, such as roads, railroads, and towns, together with boundaries of townships, counties, and States, are printed in black.

*Scales.*—The area of the United States (excluding Alaska and island possessions) is about 3,025,000 square miles. A map representing this area, drawn to the scale of 1 mile to the inch, would cover 3,025,000 square inches of paper, and to accommodate the map the paper would need to measure about 240 by 180 feet. Each square mile of ground surface would be represented by a square inch of map surface, and one linear mile on the ground would be represented by a linear inch on the map. This relation between distance in nature and corresponding distance on the map is called the *scale* of the map. In this case it is "1 mile to an inch." 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 an inch" is expressed by $\frac{1}{63,360}$.

Three scales are used on the atlas sheets of the Geological Survey; the smallest is $\frac{1}{250,000}$, the intermediate $\frac{1}{125,000}$, and the largest $\frac{1}{62,500}$. These correspond approximately to 4 miles, 2 miles, and 1 mile on the ground to an inch on the map. On the scale $\frac{1}{62,500}$ a square inch of map surface represents about 1 square mile of earth surface; on the scale $\frac{1}{125,000}$, about 4 square miles; and on the scale $\frac{1}{250,000}$, 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 in English inches, by a similar line indicating distance in the metric system, and by a fraction.

*Atlas sheets and quadrangles.*—The map 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 $\frac{1}{250,000}$ contains one square degree—i. e., a degree of latitude by a degree of longitude; each sheet on the scale of $\frac{1}{125,000}$ contains one-fourth of a square degree; each sheet on the scale of $\frac{1}{62,500}$ contains one-sixteenth of a square degree. The areas of the corresponding quadrangles are about 4000, 1000, and 250 square miles.

The atlas sheets, being only parts of one map of the United States, disregard political boundary lines, such as those of States, counties, and townships. 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 the names of adjacent sheets, if published, are printed.

*Uses of the topographic map.*—On the topographic map are delineated the relief, drainage, and culture of the quadrangle represented. It should portray to the observer every characteristic feature of the landscape. It should guide the traveler; serve the investor or owner who desires to ascertain the position and surroundings of property; save the engineer preliminary surveys in locating roads, railways, and irrigation reservoirs and ditches; provide educational material for schools and homes; and be useful as a map for local reference.

## 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 the structure sections show their underground relations, as 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.*—These are rocks which have cooled and consolidated from a state of fusion. Through rocks of all ages molten material has from time to time been forced upward in fissures or channels of various shapes and sizes, to or nearly to the surface. Rocks formed by the consolidation of the molten mass within these channels—that is, below the surface—are called *intrusive*. When the rock occupies a fissure with approximately parallel walls the mass is called a *dike*; when it fills a large and irregular conduit the mass is termed a *stock*. When the conduits for molten magmas traverse stratified rocks they often send off branches parallel to the bedding planes; the rock masses filling such fissures are called *sills* or *sheets* when comparatively thin, and *laccoliths* when occupying larger chambers produced by the force propelling the magmas upward. Within rock inclosures molten material cools slowly, with the result that intrusive rocks are generally of crystalline texture. When the channels reach the surface the molten material poured out thru them is called *lava*, and lavas often build up volcanic mountains. Igneous rocks thus formed upon the surface are called *extrusive*. Lavas cool rapidly in the air, and acquire a glassy or, more often, a partially crystalline condition in their outer parts, but are more fully crystalline in their inner portions. The outer parts of lava flows are usually more or less porous. Explosive action often accompanies volcanic eruptions, causing ejections of dust, ash, and larger fragments. These materials, when consolidated, constitute breccias, agglomerates, and tuffs. Volcanic ejecta may fall in bodies of water or may be carried into lakes or seas and form sedimentary rocks.

*Sedimentary rocks.*—These rocks are composed of the materials of older rocks which have been broken up and the fragments of which have been carried to a different place and deposited.

The chief agent of 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. In smaller portion the materials are carried in solution, and the deposits are then 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 deposits 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*. Rocks deposited in layers are said to be stratified.

The surface of the earth is not fixed, as it seems to be; it very slowly rises or sinks, with reference to the sea, over wide expanses; and as it rises or subsides the shore lines of the ocean are changed. As a result of the rising of the surface, marine sedimentary rocks may become part of the land, and extensive land areas are in fact occupied by such rocks.

Rocks exposed at the surface of the land are acted upon by air, water, ice, animals, and plants. They are gradually broken into fragments, and the more soluble parts are leached out, leaving the less soluble as a *residual* layer. Water washes residual material down the slopes, and it is eventually carried by rivers to the ocean or other bodies of standing water. Usually its journey is not continuous, but it is temporarily built into river bars and flood plains, where it is called *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 a variety of processes, rocks may become greatly changed in composition and in texture. When the newly acquired characteristics are more pronounced than the old ones such rocks are called *metamorphic*. In the process of metamorphism the substances of which a rock is composed may enter into new combinations, certain substances may be lost, or new substances may be added. There is often a complete gradation from the primary to the metamorphic form within a single rock mass. Such changes transform sandstone into quartzite, limestone into marble, and modify other rocks in various ways.

From time to time in geologic history igneous and sedimentary rocks have been deeply buried and later have been raised to the surface. In this process, through the agencies of pressure, movement, and chemical action, their original structure may be entirely lost and new structures appear. Often there is developed a system of division planes along which the rocks split easily, and these planes may cross the strata at any angle. This structure is called *cleavage*. Sometimes crystals of mica or other foliaceous minerals are developed with their laminæ approximately parallel; in such cases the structure is said to be schistose, or characterized by *schistosity*.

As a rule, the oldest rocks are most altered and the younger formations have escaped metamorphism, but to this rule there are important exceptions.

### 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, a rapid alternation of shale and limestone. When the passage from one kind of rocks to another is gradual it is sometimes 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 is constituted of one or more bodies either containing the same kind of igneous rock or having the same mode of occurrence. A metamorphic formation may consist of rock of uniform character or of several rocks having common characteristics.

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 the rocks were made is divided into several *periods*. Smaller time divisions are called *epochs*, and still smaller ones *stages*. The age of a rock is expressed by naming the time interval in which it was formed, when known.

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*.

(Continued on third page of cover.)

# DESCRIPTION OF THE SANTA CRUZ QUADRANGLE.

**By J. C. Branner, J. F. Newsom, and Ralph Arnold.**

## INTRODUCTION.

Most of the work on the geology of this quadrangle was done during the summer months of 1892 to 1904. During that time much assistance was received from the instructors and the students in Leland Stanford Junior University.

The work has at all times been done under the personal direction of Mr. Branner or Mr. Newsom. Most of the work in the Santa Clara Valley region has been done by Mr. Branner or under his immediate direction. Mr. Newsom has directed the work in a large part of the region west of the Stevens Creek fault. The diabase area near Langley Hill was mapped chiefly by Mr. Arnold, and the descriptions of the petrography of this and the other crystalline rocks were written by him. Mr. Arnold also mapped the marine Quaternary and terraces. The description of the Purisima formation is in part by Mr. Arnold and in part by Mr. Newsom. All paleontologic work, except where otherwise specified, has been done by Mr. Arnold.

## GEOGRAPHY.

*Location.*—The Santa Cruz quadrangle proper lies between latitudes 37° and 37° 30′ north and longitudes 122° and 122° 30′ west, but a strip of country south of latitude 37°, around the town of Santa Cruz, is shown on the maps and covered by the descriptions of this folio, because it is too small to form a quadrangle by itself. The whole area is here referred to as the Santa Cruz quadrangle. The total land area shown on the map is 712 square miles; the water area, including that in a strip 4 miles wide extending east and west across the quadrangle south of latitude 37°, covers 332 square miles. Near the northeast corner of the quadrangle is the southeast end of the Bay of San Francisco, covering an area of 15 square miles.

The quadrangle is situated entirely in California, and includes parts of four counties—San Mateo, Santa Cruz, Santa Clara, and Alameda.

*Relation to Coast Range and Pacific Ocean.*—The part of California in which the Santa Cruz quadrangle lies is commonly known as the Coast Ranges. This region is characterized by a series of parallel mountains and valleys that follow the Pacific coast from 35° to about 41° north latitude, just north of Cape Mendocino. These mountains and valleys have a general direction of N. 40° W. Southeast of San Francisco the Coast Ranges are divided by the Santa Clara–San Benito Valley into two well-defined groups—the Mount Hamilton division of the Diablo Range, standing between the Santa Clara Valley and the San Joaquin Valley, and the Santa Cruz Range, standing between the Santa Clara Valley and the ocean.

The quadrangle takes in the full width of the Santa Cruz Range, and includes also a part of the Santa Clara Valley and the south end of the Bay of San Francisco, while its western and southwestern parts extend out over the Pacific Ocean. The Santa Cruz Range crosses the quadrangle in a southeast-northwest direction. Northwestward the range narrows and disappears at the coast a few miles south of San Francisco; southeast of the quadrangle it forms the watershed between the Santa Clara–San Benito and Salinas valleys, though cut in two by Pajaro River near Sargents. Beyond that river it is locally known as the Gabilan Mountains, and still farther southeast it merges into the main Diablo Range about the headwaters of San Benito River.

### TOPOGRAPHY.

*Relief.*—The parallelism of the valleys and ridges so characteristic of the Coast Ranges as a whole is less apparent in the minor topography of the Santa Cruz quadrangle. Some of the larger valleys and ridges are parallel with one another and with the main system of Coast Range ridges, but this parallelism is less marked, or is absent, in the minor relief. The main ridge of the group within the area is known as Castle Rock Ridge along the boundary between Santa Clara and Santa Cruz counties, but the same ridge toward the northwest corner of the quadrangle is known as Cahil Ridge. This ridge is situated nearer to the Santa Clara Valley than to the sea; it runs southeast and northwest across the entire quadrangle and is the main watershed of the range. It forms an escarpment with a steep northeastern slope, bordered by the line of valleys lying along the San Andreas fault line; to the southwest, from the ridge's summit the general slope of the country toward the ocean is comparatively gradual, though the region is cut by many deep gulches, formed by the streams heading near the watershed and flowing directly to the sea.

The highest point in the range within the area of the map is Stanford Peak, on Castle Rock Ridge, 4 miles southwest of Saratoga; it has an elevation of a little more than 3200 feet. Both east and west of this point many of the main peaks rise higher than 2000 feet, and several are more than 2500 feet in height.

Little relation is apparent between the topographic features of the quadrangle and the geologic structure. Exceptions to this rule may be noted, however, in the cases of Ben Lomond Mountain, Butano Ridge, and Castle Rock Ridge, and of the valleys along certain of the important fault lines. Ben Lomond Mountain has been formed by the upward tilting of a granitic block along the Ben Lomond fault, forming a mountain with a sharp escarpment toward the northeast and a long, gentle slope toward the southwest. Butano Ridge is an anticlinal ridge formed by massive sandstone, the axis of the Butano anticline, a northwest-southeast flexure, being parallel with and about one-fourth mile north of the axis of the ridge. In its more prominent part Castle Rock Ridge is formed by massive sandstone which has been compressed into sharp anticlinal and synclinal folds immediately west of the San Andreas fault. The lines of the major faults of the quadrangle, viz, the Butano fault, the Ben Lomond fault, and the San Andreas fault, are marked by more or less continuous valleys. Some small valleys also have their directions controlled by the San Gregorio fault.

The areas in the quadrangle underlain by the formations from the Quaternary down to the base of the Purisima are usually characterized by well-rounded hills and evenly sloping valleys. The hillsides are generally covered with a deep coating of soil, and cliffs are rarely found on them. An unusual feature of the topography is the exceeding steepness of many of the soil-covered hillsides, slopes of 35° to 40° being not uncommon. In one place a soil and vegetation covered hillside with a slope of 50° from the horizontal was observed. With the exception of the area immediately around Black Mountain and Congress Springs the foothills of the range east of the San Andreas fault have well-rounded outlines. In the northeastern portion of the quadrangle is a gently sloping plain extending from the foothills to the marshes bordering San Francisco Bay.

The Monterey shale areas are usually characterized by steep, narrow V-shaped canyons and high ridges with steep slopes, while the massive sandstone beds of the Vaqueros and Butano formations generally produce a comparatively rugged topography with occasional prominent cliffs. The granite area of Ben Lomond Mountain in its more elevated portions also produces a rugged topography.

Filled U-shaped valleys are developed in many places along the sea coast. The valleys in the more elevated portion of the quadrangle, however, are V-shaped. Finely developed sea terraces occur along the coast from the mouth of Pescadero Creek to Santa Cruz, and less clearly defined terraces are found along the coast northward from the mouth of Pescadero Creek.

*Drainage.*—The streams on the northeast side of the main watershed flow into the Bay of San Francisco; on the west side they descend directly into the Pacific Ocean. The largest hydrographic basin in the quadrangle is that of San Lorenzo River, which enters the ocean at Santa Cruz and has a drainage area of 126 square miles. The next smaller hydrographic basins are those of Pescadero Creek, with an area of 60 square miles, and San Gregorio Creek, which has an area of 52 square miles. The mouths of these two streams are separated by only 4 miles of coast.

The streams on the west side of the range have cut back rapidly into the soft sediments which form the mass of the mountains, so that the lower parts of their channels are already fairly well graded. San Lorenzo River reaches the 500-foot level about 2 miles above the town of Boulder Creek—that is, about 16 miles from the mouth of the river. San Gregorio Creek reaches the 500-foot level about 9 miles from its mouth, while the 500-foot level on Pescadero Creek is reached about 14 miles above its mouth. The larger streams west of the range—San Lorenzo, San Gregorio, Pescadero, and Waddell creeks—are all perennial.

East of the main watershed the basins of the streams flowing into the Bay of San Francisco are smaller than those west of the range. The largest of them are the San Francisquito Creek basin, with an area of 37 square miles, and the Stevens Creek basin, with an area of 28 square miles.

The largest streams on the east side of the range are Stevens Creek, San Francisquito Creek, and Campbell Creek. These streams are perennial only in their upper portions. In summer and autumn they disappear soon after they emerge from the foothills upon the plain, the water entering the gravels that underlie the Santa Clara Valley.

The water from a portion of the San Francisquito drainage basin is caught in Searsville Lake. To the northwest, near the north boundary of the quadrangle and in the San Andreas fault valley, is Crystal Springs Lake, from which San Francisco draws a part of its water supply.

Where the streams debouch upon the plain of Santa Clara Valley they are characterized by broad alluvial fans of such low relief that their form can hardly be more than suggested by the 100-foot contour interval of the topographic map. San Francisquito Creek flows along the crest of a ridge that has been built by its alluvial deposits. To one looking along the Southern Pacific Railroad track toward that stream from either Menlo Park or Palo Alto station it is evident that the grade rises toward the creek.

An area of marshy lands borders the Bay of San Francisco at the northeast corner of the quadrangle, and very small and insignificant areas of marsh land occur where some of the larger streams enter the sea along the Pacific coast.

## DESCRIPTIVE GEOLOGY.

### *GEOLOGIC OUTLINE.*

The California Coast Ranges are young, geologically speaking, yet their history is complex. In other portions of California and Nevada there are Cambrian, Silurian, Carboniferous, Triassic, and Jurassic rocks; the oldest rocks in the Coast Ranges of which the age is definitely known are Lower Cretaceous. Above the basement complex of acidic plutonic rocks and metamorphic schists and limestones, the age of which is uncertain, there are represented within the Santa Cruz quadrangle alone fourteen recognizable formations. Nine distinct and far-reaching disturbances, as recorded by profound unconformities, not to mention many local readjustments, took place in the region during the deposition of these formations. Volcanism was active during several epochs, and in at least one of these lasted for a considerable time. Between different areas within the Coast Ranges the correlation of the geologic events, as recorded in the rocks, is made possible by the widespread distribution of certain geologic bench marks, such as characteristic faunas and formations. Correlations between the Coast Ranges and other geologic provinces, the Sierra Nevada for instance, are extremely difficult and hazardous because the history of each province is more or less distinct, though obviously related in regions of juncture.

The Santa Cruz quadrangle is characteristic of the Coast Ranges in general as regards geologic formations and, in a measure, topography as well, but in respect to vegetation and certain features of topography dependent on the humidity of the region it is quite different from many of the ranges farther south or farther inland. The broader features of the history are the same throughout the coastal belt, however, so that the descriptions following may be applied in general to the whole region from San Francisco south to the region of northern Santa Barbara County.

### *ROCKS OF THE QUADRANGLE.*

Sedimentary rocks, consisting of conglomerates, sandstones, and shales, of pre-Cretaceous, Cretaceous, Tertiary, and Quaternary age, are exposed in the Santa Cruz quadrangle, the relative areas of which are shown on the map. There are also two occurrences of diorite of importance and some minor areas of schist and limestone. In addition, diabases, lavas, and tuffs are of considerable importance in the central part of the quadrangle and in the region adjacent to Stanford University. Small areas of travertine are associated with the latter rocks locally.

The formations above the basement complex of granitic rocks, schists, and limestone consist of the following: Franciscan, probably of upper Jurassic age; Knoxville, Lower Cretaceous; Chico, Upper Cretaceous; limestone inclusions of Eocene age; Butano and San Lorenzo, Oligocene; Vaqueros, lower Miocene; Monterey, middle Miocene; Santa Margarita, upper Miocene; Purisima, upper Miocene to middle Pliocene; Merced and Santa Clara, upper Pliocene and lower Quaternary; and Quaternary deposits. Of these the most important are the Franciscan, Knoxville, Chico, Butano, Vaqueros, Monterey, and Purisima. Fossils characteristic of the various formations in the quadrangle are figured on illustration sheet 2. The following description will take up the different formations in the order of age, beginning with the oldest beds.

#### METAMORPHOSED SEDIMENTARY ROCKS.

Two series of metamorphosed sedimentary rocks are exposed in the quadrangle—one the Franciscan formation, the other of probably pre-Franciscan age. The supposed pre-Franciscan metamorphic rocks are confined to the region of the Ben Lomond quartz diorite batholith and probably owe their alteration to the intrusion of that igneous mass. The metamorphosed Franciscan formation is found in the Black Mountain area and in the belt which extends both northwest and southeast of the latter. There are also a few cases of local metamorphism of the Monterey shale by intruding diabases, but these are unimportant.

#### SUPPOSED PRE-JURASSIC ROCKS.

##### SCHIST AND LIMESTONE.

*Distribution.*—Northwest of Santa Cruz there are isolated patches of micaceous schist and highly crystalline white limestone or marble, lying above the quartz diorite mass that makes up the core of Ben Lomond Mountain. The schist and the limestone are interbedded in some places, notably in the quarries and along the road to the summit of Ben Lomond Mountain, 2 miles west of the town of Felton. The limestone areas are much smaller than the schist areas around them. The schist usually occurs between the limestone and the quartz diorite, and the latter is apparently younger than either the schist or the limestone. The relations of the schist and the limestone to the underlying quartz diorite and overlying sedimentary rocks are shown in section G-G on the structure-section sheet. The schist and the limestone have been much broken up and disturbed, apparently by the intrusion of the quartz diorite. It seems probable, therefore, that they are older than the underlying quartz diorite and that they owe their metamorphism in part at least to the intrusion of the quartz diorite mass. This view of their relations is borne out by the facts in other portions of the Coast Ranges. No fossils have ever been found in the limestone or the schist, the age of which is therefore unknown. They appear from their extreme metamorphism, however, to be older than the Franciscan formation, though the latter has not been seen in contact with them.

*Character of the schist.*—Weathering of the schist has in most places advanced more rapidly than denudation, as in the case of the associated quartz diorite, so that fresh specimens are difficult to obtain. Weathered exposures of the rock vary from brick red through brown to gray, the same colors also showing in the hand specimens. Alternating light and dark bands are often apparent in the less extremely weathered portions, the color depending on the relative amounts of mica, feldspar, and quartz. The rock is fine grained and compact, but splits more easily along the planes of schistosity, especially in the weathered portions. Certain facies of the schist contain garnet crystals up to three-eighths inch in diameter, these usually occurring in the centre of local quartzose segregations. Red iron oxide often stains the rock immediately around the garnet.

In thin sections the rock shows characteristic schistose texture and the consistency to warrant the name quartz-mica schist. White mica makes up as high as 70 per cent of the rock, the other constituents being biotite, quartz, plagioclase, and magnetite, with accessory zircon and apatite. In the garnetiferous varieties the longer axes of the mica crystals are quite uniformly tangent to the peripheries of the garnet crystals. The garnets are usually altered along cleavage cracks to iron oxide and quartz.

*Character of the limestone.*—Several qualities of the limestone, ranging from small impure layers interbedded with the schist to beautiful white marble, are found in the Ben Lomond Mountain metamorphic area. The purest marble consists of large, white, intergrowing calcite crystals showing the glossy cleavage faces in fractures. The striations or traces of the cleavage cracks common to calcite are unusually prominent on some of the faces. Another form of the limestone is a gray marble, very fine textured and somewhat mottled. Although much finer grained than the white marble, the minute crystal faces in this rock are discernible by the naked eye and glisten in reflected light. In thin sections the gray rock is seen to be composed almost entirely of calcite with minor quantities of magnetite. The impure limestones are fine grained, close textured, and vary from gray to greenish gray in color, with weathered surfaces grayish brown. Their luster is duller than that of the purer varieties. Under the microscope the rock is seen to consist of calcite together with much monoclinic pyroxene and some orthoclase. Mineralized layers are in places interbedded with almost mineral-free zones, pyrite usually being the sulphide present.

### JURASSIC (?) SYSTEM.

#### FRANCISCAN FORMATION.

*Distribution.*—The Franciscan formation is distributed intermittently along a broad band extending in a northwesterly direction from about the middle of the east side of the quadrangle to about the middle of the north end. The most important areas are those west and southwest of Redwood and the band which extends from the region northwest of Black Mountain southeastward to the eastern edge of the quadrangle. A small area is also exposed north of Portola.

A difference of opinion exists as to the age of the sandstone and shale beds lying in the area mapped as Franciscan west of Redwood and east of the San Andreas fault. Messrs. Branner and Newsom believe these rocks to be largely Knoxville, at least those beds which they believe overlie the Franciscan cherts. The same beds are believed to be Franciscan by A. C. Lawson, who mapped the type Franciscan on the San Francisco Peninsula to the north. G. D. Louderback and Ralph Arnold, acting as a committee to harmonize the mapping of the two areas, held to the theory that the disputed beds were of Franciscan age, and their decision was accepted tentatively for present mapping purposes.

*Character.*—The formation is characteristically metamorphic, although large areas of unaltered rocks are found within it. It consists of sandstone, shale, limestone, chert, schist, and gneiss. It is associated at many places with serpentine, which intrudes it in the form of dikes and large masses.

The sandstone as a rule is moderately fine grained, although it is sometimes coarse and occasionally even pebbly. Its color is gray, weathering to brown, and it is usually characterized by small bits of hardened shale included in it. Quartz is the principal constituent, but mica, hornblende, and feldspar in varying proportions also enter into its composition. The rock is usually well lithified, the grains fracturing rather than parting from the matrix when it is broken. These varieties are appropriately termed quartzite. The sandstone is generally massive, though often thin bedded. It is fractured, squeezed, and slickensided, causing local incipient recrystallization; quartz veins and veinlets are locally abundant. Some exposures stand out in bold relief, while at other localities the rock weathers into good rich soil.

There is much less shale than sandstone in the formation. The shale is hard and brittle. In color it is gray, greenish gray to bluish gray, and almost black, and often shows manganese or iron oxide stains along the joint planes. Like the sandstone, it is much crushed, jointed, and slickensided. It breaks with a semiconchoidal fracture and much of it resembles slate.

Small quantities of limestone are found in the Franciscan. The principal area is on the slope of Black Mountain, where it is mined for burning into lime. It is a fine-grained, semicrystalline rock, light to dark gray in color, and contains small specks of what appears to be magnetite. The rock is hard, and breaks with a conchoidal fracture and sharp edges. Its relations to the adjacent rocks are not definitely known, but it is believed to be interbedded with them.

The chert occurs in lenses and in masses of considerable size, and is found principally interbedded with the sandstone toward the base of the formation. The principal areas are southwest of Redwood and in the region of Black Mountain. It is distinctly stratified, the beds being from a fraction of an inch to several inches in thickness; locally it appears massive. It is very brittle and weathers into small, irregular, angular fragments. Red and brown are the prevailing colors, but green, bluish gray, yellowish, white, or variegated cherts are also found. Thin sections show the chert to range between masses of amorphous silica and aggregates of quartz grains. The silica is believed to be derived largely from Radiolaria, sponge spicules, and other siliceous organic remains. The beds of chert are separated by thin films of fine soft shale or clay, of the same color as the associated chert. The thinly laminated facies of the chert are often locally intricately contorted and are usually much jointed and slickensided. Some of the most rugged topographic features are due to the chert. The soil derived from it is usually poor.

The schists and gneisses of the Franciscan present a wide range of petrographic characters and various stages of alteration, from sandstone and shale showing weakly schistose structure to mica schists showing sheets of mica. They do not occur in large areas but rather as irregular patches, which, owing to their great resistant properties, jut out prominently from the surrounding and more easily weathered sandstone and shale. The schists are hard and usually tough, and fracture into angular blocks or along the planes of schistosity. In color they vary from blue to gray and green, weathering reddish and brownish. The most prominent petrographic characteristic of the schists and gneisses of the Franciscan is the occurrence in them of the blue amphibole, glaucophane, which varies in amount from a few scattered needles in the shales to an abundant constituent of the glaucophane schists. The following are some of the varieties of schist and gneiss found in the Santa Cruz quadrangle:

(*a*) Glaucophane-lawsonite schist, composed almost exclusively of lawsonite and glaucophane, the latter in fine needles forming a compact groundmass in which are embedded rectangular prisms of lawsonite. Sphene and talc are also present, but neither garnet nor epidote occurs in any quantity in this type. This schist occurs on the Hellman ranch, 3 miles west of Redwood.

(*b*) Quartz-glaucophane-lawsonite schist, similar to the last, but more acidic, and containing in addition to the quartz and other constitutents the greenish mineral carinthine. Found near the Schrader farm, 2 miles west of Redwood.

(*c*) Actinolite schist, of which the principal constituents are chlorite and the green prismatic actinolite known as smaragdite. Glaucophane is also present in varying amounts, as is also carinthine, while titanite is common and in many places abundant. This type occurs near the Hopkins reservoir, 3 miles southwest of Redwood.

(*d*) Mica schist, of a decidedly acidic type. This schist is interbedded with layers rich in quartz, such as altered quartzites and cherts, and probably represents clay shale layers in original siliceous sediments. Muscovite and biotite are the principal constituents, garnet is almost invariably present, while epidote and actinolite occur but rarely.

(*e*) Lawsonite gneiss, in which one of the prominent minerals is lawsonite. It is massive and banded, showing a groundmass of lawsonite crystals, with a thick felt of compact prisms of glaucophane. Titanite and garnet are scattered throughout, and the whole is seamed with quartz veins. Analyses of this rock indicate that it was originally a quartz diorite. It is found 3 miles southwest of Redwood.

*Metamorphism in the Franciscan.*[a]—Little is definitely known concerning the causes of metamorphism in the Franciscan formation. The many occurrences of the altered rocks in intimate association with unaltered sediments which to all appearances should be fully as susceptible to alteration constitute one of the puzzling facts observed.

It has been shown that metamorphism on a small scale has been developed in chert at the contact with serpentine and other basic intrusives, and in sandstone and shale by recrystallization due directly to crushing, but these cases help little toward accounting for the great mass of metamorphics in the formation. There are in the Coast Ranges extensive schist masses near which neither serpentine nor other intrusives have been found; and in many localities where such schists are near serpentine they occur in much greater masses than the igneous rocks to which the metamorphism might be ascribed. From this it would seem illogical to assume that the formation of schist within the Franciscan is due in every case to contact with basic intrusive rocks. There are also numerous contacts of such basic intrusives with sediments where no schists have been formed.

On the other hand, it might be assumed that dynamic metamorphism has been the cause of the formation of the schists, for the Franciscan is usually crushed, and zones of shearing are common in it. But while the metamorphic rocks are extensively developed for several hundred miles in the Coast Ranges, from Oregon to San Diego, there are no continuous masses of schists or other metamorphics. In fact, small patches are the rule rather than the exception. Thus the cause of the metamorphism can hardly have been regional. And it is hard to see how this agency can have been intermittent or local in its action, since the rocks of the Franciscan are crushed and sheared almost everywhere, even where no metamorphic minerals have been developed in them. Yet, in a sense, the phenomenon is regional—that is, confined to a petrographic region, or, more properly, a region of one sort of geologic activity.

An interesting fact in relation to metamorphism in the Franciscan of the Coast Ranges as compared with metamorphism in other parts of North America is that neither in the Rocky Mountain, the Lake Superior, nor the Appalachian region are glaucophane schists (so common in the Coast Ranges) developed, although amphibole and garnet schists are common. Nor yet in the Sierra Nevada of California, where schist masses, both of dynamic and of contact origin, are common, is any glaucophane schist known; and there, too, extensive masses of peridotite occur, and altered sediments of the same chemical character as in the Coast Ranges, but of totally different petrographic character. Altered quartzites are abundant in the Sierra Nevada, also altered clay shales and altered diabase tuffs; but the quartzites have been changed to sericite schists, the clay shales to andalusite schists, and the diabase tuffs and the peridotites to amphibolites, all without glaucophane. What is more puzzling, the metamorphism in the Sierra Nevada and that in the Coast Ranges seem to have been contemporaneous.

*Age.*—No identifiable fossils have been found in the Franciscan formation, but in the Knoxville beds, which unconformably overlie it throughout the Coast Ranges, there are fossils indicating lowest Cretaceous or upper Jurassic. It has therefore been assumed that the Franciscan is at least as old as the Jurassic. The rocks below the Franciscan are of unknown age, so that its lower limit is indeterminable.

## SEDIMENTARY ROCKS.

### CRETACEOUS SYSTEM.

The Cretaceous rocks form one of the most important and widespread systems on the Pacific coast. Three formations are commonly recognized as belonging to the Cretaceous in California—the Knoxville, or Lower Cretaceous; the Horsetown, or Middle Cretaceous; and the Chico, or Upper Cretaceous. The Knoxville is known from central Oregon to southern California, the Horsetown only in Oregon and northern California, and the Chico, the most widespread and most easily recognized of the three, from Vancouver Island to the Peninsula of Lower California. The Knoxville and Chico have been recognized in the Santa Cruz quadrangle, but the Horsetown or its equivalent is apparently lacking.

#### KNOXVILLE FORMATION.

*Distribution.*—The beds of Knoxville age cover only small areas in the Santa Cruz quadrangle and are confined to the northeastern or Santa Clara Valley side of the mountain range. On the map only two or three small areas, just west of Redwood, are represented as of Knoxville age. Because of the difficulty or impossibility of separating the Knoxville from some of the Franciscan, and because of the lack of fossils for identification of the formations, some of the Knoxville has been included with the Franciscan in the area southeast of Searsville Lake, in the Black Mountain area, and in the Franciscan region south and west of Saratoga.

*Character.*—The Knoxville formation in the Santa Cruz quadrangle consists of conglomerate, sandstone, and shale. Within the areas mapped as this formation the conglomerate is the prevailing type, minor quantities of sandstone being the only other rock present. West of Redwood the only known example of the fossil-bearing Knoxville is a conglomeratic bowlder of pebbles of dark-colored jasper that was found at the forks of Pulgas Creek. As no exposure of this conglomerate has been seen in place its thickness and relative position in the formation are unknown. On the hill above the forks of Pulgas Creek, 3 miles west of Redwood, where the bowlder of fossiliferous conglomerate was found, is a series of conglomerates with minor quantities of sandstone, resting unconformably upon the Franciscan. The conglomerate consists of bowlders, cobbles, and pebbles of jasper, quartzite, limestone, typical Franciscan sandstone, and glaucophane schist, and with the interbedded coarse sandstone is probably over 100 feet in thickness. The source of the material in this exposure of supposed Knoxville and in the other small areas in the same general locality is believed to be the underlying Franciscan, which contains types of practically all the rocks found in the conglomerate.

The beds recognized as Knoxville in the region of Black Mountain consist of a fine-grained, very hard, tough black shale. As previously mentioned this facies of the Knoxville has not been separated on the map from the Franciscan.

*Fossils.*—Recognizable fossils have thus far been found in the Knoxville at only three places in this quadrangle, mostly in the conglomerate west of Redwood. They consist of a few well-preserved aucellas (*Aucella crassicollis* Keyserling) and an

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[a] This discussion, together with the notes on the glaucophane-bearing rocks just described, is largely copied from Smith, James Perrin, The paragenesis of the minerals in the glaucophane-bearing rocks of California: Proc. Am. Philos. Soc., vol. 45, 1907, pp. 183–242.

*Amberlya dilleri* Stanton (see illustration sheet II), found in the conglomerates on the Brittain place, 3 miles west of Redwood, and one fragment of a cephalopod, which J. P. Smith has identified as *Hoplites*, found on an adjoining tract on the south side of Belmont Hill. Several specimens of *Aucella piochii* Gabb and *Aucella crassicollis* Keyserling have also been found in bowlders in the upper or northern part of Stevens Creek gorge. It is this fact that bears out the statement that a part of the Black Mountain area represented on the map as of Franciscan age really belongs to the Knoxville. This occurrence of *Aucella piochii* Gabb and *Aucella crassicollis* Keyserling in the same bed is the first to be recorded; heretofore, wherever these fossils were found closely associated, the latter was invariably in beds at least a short distance above the former. It is believed by Branner and Newsom that many of the rocks west of Redwood mapped as Franciscan are of Knoxville age.

### CHICO FORMATION.

*Distribution.*—An area of Chico rocks is exposed along the coast, extending from the mouth of Pescadero Creek southward to Año Nuevo Bay, a distance of 12 miles. This area varies in width from one-half mile to 2½ miles, and is locally covered by a thin layer of Quaternary gravel and sand. At the southwest end of the area, in the region of Año Nuevo Point, the strata are completely covered by sand dunes, except immediately along the shore. Areas of supposed Chico are found in the low hills west of Redwood and near Stanford University.

*Character.*—The Chico strata along the coast are made up for the most part of hard siliceous shale, sandstone, and massive, coarse conglomerate. The general dip of the beds, for a distance of 3 miles along the coast south of the mouth of Pescadero Creek, is toward the southwest and the section apparently exposes about 9400 feet of strata. These strata dip at high angles, however, and may be repeated by folds, or to some extent by faults, thereby making the thickness appear greater than it is. This is the case 2 miles north of Pigeon Point, where massive conglomerate is faulted into contact with sandstone and shale.

The upper portion of the formation is characterized by massive, coarse conglomerate with interbedded sandstone. The conglomerate shows evidences of much crushing, faulted and crushed pebbles being plentiful in it. It is most prominent south of the last-mentioned fault in the region about Pigeon Point (see fig. 4, illustration sheet I), but it also extends southeastward along the coast line to a place 2 miles southeast of Franklin Point, a total distance of more than 5 miles.

Farther south, notably at Año Nuevo Island and outcropping along the shore for a mile north and east of that island, there is a body of hard, flinty, evenly bedded shale which is shown on the map as Chico. It dips toward the southwest at angles varying from 10° to 50°. This shale has an exposed thickness of more than 750 feet, and is presumably older than the Chico conglomerate exposed on the shore 1½ miles north of Año Nuevo Island, for fragments of shale apparently identical with the shale at Año Nuevo Island have been found in the conglomerate.

*Areas of supposed Chico.*—Three miles west of Redwood the Franciscan strata are overlain unconformably by coarse yellow sandstones that are referred provisionally to the Chico. This particular area covers nearly 2 square miles. Toward the south and east the Chico covers several square miles between Stanford University and the village of Woodside. Southwest of Stanford University the Chico rocks form the yellow hills in the vicinity of Blue Goose and the rolling hills of the university golf links. Just below the Stanford University reservoir on Bear Creek the Chico contains a basal conglomerate made up largely of serpentine and resting unconformably against serpentine in place. This bed can be traced for a mile or two toward the southeast, and at a few places it contains lumps or concretions of limestone. This limestone includes abundant fragments of microscopic marine organisms, but none of them have thus far been identified.

*Fossils.*—In the clay pit by the roadside immediately south of Stanford University campus a fossil was found and identified by J. P. Smith as *Baculites chicoensis* Trask. A single specimen of *Baculites* has been found as an inclusion in the tuffs at Frenchmans Lake, near Stanford University. It is inferred that the basalt with which this tuff belongs came up through the Chico hereabout.

In addition to *Baculites chicoensis* Trask the following fauna has been found in the Chico of this quadrangle. All the species are from the rocks along the coast from Pescadero Creek to Año Nuevo Point, and all are characteristic of the Chico except *Arca vancouverensis* Meek, which is also found in the Horsetown formation (Middle Cretaceous). A few of the more common forms are shown on illustration sheet II.

*Pelecypoda.*

Anatina tryoniana Gabb.
Arca vancouverensis Meek.
Cucullæa bowersiana Cooper.
Glycymeris veatchii Gabb.
Inoceramus subundatus Meek.
Mactra stantoni Arnold.
Nucula truncata Gabb.
Ostrea brewerii (?) Gabb.
Panopea concentrica Gabb.
Pholadomya subelongata Meek.
Pinna calamitoidea Shumard.
Trigonia evansana Meek.
Trigonia leana Gabb.

*Gasteropoda.*

Cinulia obliqua Gabb.
Lunatia n. sp. *p*.
Margaritella n. sp.
Perissolax brevirostris Gabb.
Turritella pescaderoensis Arnold.

*Cephalopoda.*

Baculites chicoensis Trask.

*Crustacea.*

Archæopus antennatus Rathbun.

## TERTIARY SYSTEM.

### GENERAL STATEMENT.

Most of the mountains of the Santa Cruz quadrangle are made up of strata belonging to the Tertiary system, which rests unconformably on the older formations wherever contacts have been observed. The deposits are mostly marine, though some gravels of importance in the northeast corner of the quadrangle, bordering the eastern foothills of the Santa Cruz Range and forming the floor of the Santa Clara Valley, are largely of fresh-water origin. The Tertiary strata are composed chiefly of shales and sandstones, with some gravels. The sandstones usually contain much clay, and the shales vary from pure diatom shale to clay shale and sandy shale. At many places the beds grade into one another, both vertically and horizontally. These impure varieties of Tertiary sandstones and shales are generally not firmly cemented and are therefore very susceptible to weathering influences. However, the area contains some comparatively pure shales and sandstones, notably the diatomaceous shale at the southwest side of the quadrangle, known as the Monterey, the soft white sandstone of the Santa Margarita southeast of the town of Ben Lomond, the sandstone lying at the base of the Monterey shale west of Ben Lomond Mountain, the sandstone that makes up a part of Castle Rock Ridge, and some of the sandstone in Butano Ridge.

A noteworthy feature of the impure sandstones and shales which cover so large a part of this quadrangle is the protective influence of water upon them. Where the strata remain constantly wet, along the sea shore or in the stream beds, they are for the most part hard and resist erosion. Where, however, they are exposed above water level and are subject to daily changes of temperature and other atmospheric agencies they disintegrate rapidly.

The Tertiary system is represented by nine more or less distinct formations in the Santa Cruz quadrangle. These formations are distinguished in part by their lithologic characters and in part by the fossils found in them. Beginning with the lowest, and using local names in part, they are: Limestone inclusions of Eocene age, the Butano sandstone, the San Lorenzo formation, the Vaqueros sandstone, the Monterey shale, the Santa Margarita formation, the Purisima formation, the Merced formation, and the Santa Clara formation.

### EOCENE.

#### LIMESTONE INCLUSIONS IN DIABASE.

*Distribution and character.*—The diabase exposed north of the headwaters of Pescadero Creek has brought up some considerable inclusions of impure limestone which, from the fossils found in them, appear to be of Eocene age. The limestone is light brown in color, usually rather soft except where silicification has begun, and appears to be made up of broken marine shells, a little argillaceous material, and small fragments of what may be tuff. The thickness of the limestone is nowhere more than 100 or 200 feet.

On Langley and Mindego hills, 2½ miles northeast and southeast, respectively, of the village of La Honda, are two other small areas of calcareous sandstone, supposed to be of the same age as that exposed north of the headwaters of Pescadero Creek.

*Fossils.*—The fauna of the limestone in the Pescadero Creek exposure above referred to is different from that of any of the other known formations of California. Some of its species, such as *Patella mateoensis* Arnold, *Fissurella perrini* Arnold, *Tritonium newsomi* Arnold, and *Pecten proavus* Arnold, are closely allied to Chico (Cretaceous) forms, while *Ostrea* cf. *idriaensis* Gabb is found only in the Tejon (middle Eocene), and *Terebratulina tejonensis* Stanton only in the Martinez (lower Eocene). In view of the affinities of the above species and also of the several new ones, it appears probable that the fauna represents either a new horizon of the lower Eocene or a local development of the Martinez (lower Eocene) fauna. The following species, with the exceptions noted above, are characteristic of this formation. Several are shown on illustration sheet II.

*Echinoidea.*

Cidaris merriami Arnold.

*Brachiopoda.*

Terebratalia, n. sp. *m*.
Terebratalia, n. sp. *p*.
Terebratulina tejonensis Stanton.

*Pelecypoda.*

Ostrea (cf.) idriaensis Gabb.
Pecten proavus Arnold.
Semele gayi Arnold.

*Gasteropoda.*

Chlorostoma, n. sp. *c*.
Cylindrites brevis (?) Gabb.
Dentalium.
Fissurella perrini Arnold.
Hipponyx carpenteri Arnold.
Odostomia. n. sp. *b*.
Patella mateoensis Arnold.
Patella, n. sp. *b*.
Thylacodes, n. sp. *w*.
Tritonium newsomi Arnold.

### OLIGOCENE.

#### BUTANO SANDSTONE.

*Distribution.*—The Butano sandstone outcrops in a triangular area, the eastern point of which is at San Lorenzo River, 4 miles north of the town of Boulder Creek. Here the very top of the Butano sandstone is exposed at the axis of the southeastward-plunging Butano anticline. The sandstone disappears toward the east under the San Lorenzo shale, which lies conformably above it. The axis of the Butano anticline rises northwestward, and the San Lorenzo shale, which formerly passed over it, has been removed by erosion, leaving an exposed area of Butano sandstone, which increases in width toward the northwest until, in the eastern part of T. 8 S., R. 4 W., it is 4½ miles wide. A thickness of 2100 feet of Butano sandstone is exposed in a distance of a mile and a quarter between Pescadero Creek and the crest of Butano Ridge. The increasing width of the sandstone area toward the west is due not so much to the thickness of the formation as to minor folds and faults southwest of the Butano anticline.

At the west end of the Butano Ridge area just described the Butano sandstone is overlain unconformably by white diatomaceous shale, which extends from east of Pescadero to Santa Cruz and which is supposed to be the equivalent of the Monterey shale.

The most prominent topographic feature of the Butano sandstone area, and one of the most prominent in the quadrangle, is Butano Ridge. This is a high northwest-southeast anticlinal ridge with a length of 10 miles and a maximum elevation of 2319 feet. The axis of the Butano anticlinal fold is parallel with the crest of Butano Ridge and is usually from one-fourth to one-half mile north of the ridge's crest. Throughout its length the ridge is flanked on the north by Pescadero Creek, which has cut its valley in the highly folded and faulted shale at the north side of the Butano anticline.

*Character.*—The Butano sandstone is made up almost entirely of medium- to coarse-grained, massive, brown and buff sandstone. Minor pebbly beds occur with the sandstone, and toward the top of the formation some beds of dark-colored shale are also intercalated.

*Supposed Butano rocks.*—About one-half mile south of the mouth of Pescadero Creek is an excellent exposure of an unconformity. (See fig. 5, illustration sheet I.) The lower strata are steeply inclined, thin-bedded Chico (Cretaceous) sandstone; overlying these and dipping N. 20° W. are alternating beds of hard, coarse conglomerate and coarse arkose sandstone supposed to represent the base of the Butano sandstone. The conglomerate consists of waterworn pebbles of granite, quartz, and dark-colored quartzite and porphyry, the latter two being the commonest. The maximum diameter of the bowlders is about 3 feet. Nearer Pescadero Creek bowlders of waterworn Cretaceous sandstone up to 10 feet in diameter occur in the conglomerate. The sandstone associated with the conglomerate is bluish gray and exceedingly hard where subjected to continual wetting, but is yellowish in color and weathers rather soft in positions out of reach of the waves. False bedding is common in the sandstone. A well-developed system of joints perpendicular to the bedding planes also affects them. The exposures of the supposed Butano rocks extend north from the unconformity to the mouth of Pescadero Creek, where they disappear under the creek. At several places throughout this stretch the line of unconformity, as indicated by the huge waterworn bowlders of the Cretaceous, approaches the surface.

*Fossils.*—No fossils have been observed in the typical Butano sandstone, and whether it is of Eocene or Oligocene age is purely conjectural. On account of its conformable position below the San Lorenzo, which is believed to be well up in the Oligocene, the Butano sandstone is placed in the same epoch. A few fossils have been found in the sandstone of the supposed Butano about three-eighths of a mile south of the mouth of Pescadero Creek. These include a *Pecten* closely allied to *P. sanctæcruzensis* Arnold, a fragment of a huge *Venericardia*, a large *Turritella*, and an echinoderm suggesting *Clypeaster*.

#### SAN LORENZO FORMATION.

*Distribution.* — The San Lorenzo formation of shale and fine sand outcrops in the region north of Ben Lomond Mountain and between the latter and Castle Rock Ridge. Its areal distribution is controlled by the northwest-southeast folds which are the prominent structural features between Ben Lomond Mountain at the southwest and Castle Rock Ridge at the northeast. Owing to these folds the San Lorenzo beds outcrop in northwest-southeast bands, except in the Big Basin area, where they flank the southern side of the Butano sandstone area and form an east-west band 2½ miles wide. The best sections of the San Lorenzo formation are exposed along San Lorenzo River, Kings Creek, and Bear Creek, where those streams cut across the eastward extension of the Butano Ridge anticline. On Kings Creek a thickness of 2500 feet of San Lorenzo strata (mostly shales) is exposed. A thickness of 2400 feet of the San Lorenzo is exposed along San Lorenzo River from 2 to 3½ miles northwest of the town of Boulder Creek, while from 2 to 3 miles northeast of that town 1300 feet appear where Bear Creek cuts through the eastward extension of the Butano anticlinal fold.

*Character.*—In the Big Basin area the San Lorenzo formation is composed chiefly of fine-grained soft sandstone with some interbedded shale. The sandstone disintegrates rapidly when exposed to the weather. Where exposed in creek beds and saturated with water it is generally soft and massive, rarely showing bedding planes; for this reason and because of absence of good exposures the structure of the formations in the Big Basin area can not be determined in detail. At the west side of the Big Basin the San Lorenzo formation is overlain unconformably by sandstone at the base of Miocene shale which are tentatively regarded as the Vaqueros sandstone and Monterey shale.

Eastward from the Big Basin area the San Lorenzo strata become finer grained and more shaly, until they reach their typical development on San Lorenzo River, Kings Creek, Bear Creek, and the headwaters of Newell Creek, where they consist of clayey to fine, gray, arenaceous shale with intercalated fine, yellowish to brownish sandstone layers.

The San Lorenzo formation lies conformably above the Butano sandstone and in general conformably below the Vaqueros sandstone. It derives its name from San Lorenzo River, along the upper branches of which it attains its maximum known development.

*Fossils and age of the San Lorenzo.*—The fauna of the San Lorenzo is for the most part new. The position of the formation below the lower Miocene, taken in connection with the affinity of many of its fossils, such as *Pleurotoma perissolaxoides* Arnold, *Fusus ashleyi* Arnold, *Aturia ziczac* Sowerby, etc., to the Eocene or Oligocene fossils of this or the Atlantic coast, has led to its correlation with a portion of the Oligocene. Beds containing a fauna similar to that of the San Lorenzo formation are known at only one other locality—Porter, Chehalis County, Wash.—although the lowest part of the so-called Oligocene-Miocene series in Washington and Oregon is probably contemporaneous with at least a part of the San Lorenzo. As would be expected in a formation composed in this area principally of shale, the known fauna of the San Lorenzo consists largely of off-shore forms. This fact accounts in a measure for the dissimilarity between the San Lorenzo fauna and that of the overlying sandy and conglomeratic Vaqueros (lower Miocene) formation. The sandy transition beds between the two formations contain some San Lorenzo and some Vaqueros species. *Pecten peckhami* Gabb and *Yoldia impressa* Conrad, found in the San Lorenzo, also occur abundantly in the Monterey (middle Miocene), but not in the intervening Vaqueros (lower Miocene). In the following list the species characteristic of the San Lorenzo, many of which are shown on illustration sheet II, are marked with an asterisk (*).

*Echinoidea.*

Cidaris branneri Arnold.

*Pelecypoda.*

Callista (cf.) vespertina Conrad.
*Cardium cooperi Gabb var. lorenzanum Arnold.
Leda n. sp. *s.*
*Malletia chehalisensis Arnold.
*Modiolus ynezianus Arnold.
*Neaera (cf.) pectinata Carpenter.
*Nucula (Acila) dalli Arnold.
Pecten peckhami Gabb.
*Pecten sanctæcruzensis Arnold.
Solen sp. *a.*
Tellina albaria Conrad.
Tellina lorenzanum Arnold.
Thracia (cf.) trapezoides Conrad.
Yoldia impressa Conrad.

*Gasteropoda.*

*Architectonica lorenzoensis Arnold.
Dentalium substriatum Conrad.
Fusus corpulentus Conrad.
Fusus geniculus Conrad.
*Fusus hecoxi Arnold.
*Fusus sanctæcrucis Arnold.
Galerus excentricus (?) Gabb.
Haminea petrosa Conrad.
Natica oregonensis Conrad.
*Lirofusus ashleyi Arnold.
*Pleurotoma newsomi Arnold.
*Pleurotoma perissolaxoides Arnold.
*Pleurotoma sanctæcrucis Arnold.
Sigaretus scopulosus Conrad.
*Strepsidura californica Arnold.
*Turcicula santacruzana Arnold.

*Cephalopoda.*

Aturia ziczac Sowerby.

*Transitional Oligocene-Miocene.*—The fine massive sandstones on Twobar Creek lying above the typical San Lorenzo (Oligocene) formation but below the Vaqueros (lower Miocene) sandstone contain a fauna allied to those of both the beds below and the beds above. The fauna appears, however, to be more closely related to that of the San Lorenzo and the rocks are mapped with that formation. Among the species common to the latter and to the transitional beds are: *Sigaretus scopulosus* Conrad, *Nucula dalli* Arnold, *Yoldia impressa* Conrad, *Leda* n. sp. *s.*, *Pecten sanctæcruzensis* Arnold, *Marcia oregonensis* Conrad, *Cardium cooperi Gabb* var. *lorenzanum* Arnold, *Tellina lorenzoensis* Arnold, *Solen* sp. *a*, etc. Those common to the transitional beds and the Vaqueros (lower Miocene) are: *Pecten branneri* Arnold, *Marcia oregonensis* Conrad, *Chione* cf. *mathewsonii* Gabb, *Thracia* cf. *trapezoides* Conrad, etc.

## MIOCENE.

### VAQUEROS SANDSTONE.

*Distribution.*—The Vaqueros sandstone, of lower Miocene age, is one of the most important formations of the quadrangle. Its areal distribution is controlled largely by the northwest-southeast structural lines usual in the quadrangle, and the areas covered by it therefore consist for the most part of northwest-southeast bands. The largest of these bands is that coincident with Cahil and Castle Rock ridges, extending northwest and southeast almost entirely across the quadrangle.

A considerable area of Vaqueros laps up against Ben Lomond Mountain on its northeastern side. It is seen resting on an erosion surface of the diorite where the contact is exposed on Clear Creek a mile south of the town of Boulder Creek. Between Ben Lomond Mountain and Castle Rock Ridge the upturned edges of the Vaqueros are exposed by northwest-southeast folds. A thin sandstone at the base of bituminous Miocene shales (regarded as Monterey) southwest of Ben Lomond Ridge, Big Basin, and Butano Ridge is included on the map with the Vaqueros sandstone.

*Character.*—The sandstone varies in texture from fine-grained beds to conglomerate, but is usually medium grained. Generally it is brown or buff in color, and varies from soft to very hard. The beds are massive, and even where comparatively soft are more resistant to weathering than are the underlying formations, and consequently when cut through by streams they produce a rugged topography with deep, narrow ravines. They reach their maximum development in Castle Rock Ridge—the highest ridge in the quadrangle. The precipitous slopes of Castle Rock Ridge around the headwaters of San Lorenzo River and Kings and Bear creeks are due almost entirely to the local development of the Vaqueros sandstone. In the region about the towns of Boulder Creek and Ben Lomond the Monterey shale, overlying the Vaqueros sandstone, becomes sandy and grades into sandstone where near-shore deposition occurred in Monterey time. This makes it impossible in some places to trace the line of contact between the Vaqueros and Monterey formations, and for this reason it is very probable that the area mapped as Vaqueros may include near-shore portions of the Monterey.

Where all of the Vaqueros is exposed in the Newell Creek canyon 3 miles east of the town of Boulder Creek it is approximately 2000 feet thick. Along San Lorenzo River and on Bear Creek near the town of Boulder Creek thicknesses of 2200 to 2400 feet of Vaqueros sandstone are exposed. The formation has a thickness of 2700 feet in Castle Rock Ridge near the headwaters of Kings Creek and Bear Creek.

*Relation to other formations.*—The Vaqueros in general lies conformably above the San Lorenzo formation, and there is often a gradual change from one formation to the other, with no clear line of demarcation between them. But while the San Lorenzo formation is made up chiefly of shale and fine-grained impure sandstone, the Vaqueros formation is composed principally of medium and coarse-grained sandstone, showing that the conditions of deposition were different during the two periods. Southwest of Ben Lomond Ridge, Big Basin, and Butano Ridge the thin sandstone at the base of the supposed Monterey shale, tentatively included with the Vaqueros, overlaps unconformably the San Lorenzo, the Butano, and the pre-Cretaceous diorite.

The relation of the Vaqueros sandstone to the overlying beds is not so clear as are its relations to the underlying strata. Around the northwest end of Butano Ridge the diatomaceous shale (supposed Monterey) rests directly on the Butano, and the thin sandstone (regarded as possibly Vaqueros), is absent. Elsewhere in the quadrangle there is commonly a marked difference in the dips of the Monterey strata and those of the Vaqueros sandstone, and an unconformity is therefore believed to exist generally between the two formations. Inasmuch, however, as the line of contact nearly always occurs in densely wooded or chaparral-covered regions and where the rocks are much crushed and folded, it is not possible to say with certainty that there is at all places an unconformity between the Vaqueros sandstone and the overlying strata.

The sandstone beds underlying the diatomaceous shale west of Ben Lomond Mountain are shown as Vaqueros on the map. These are conformable with the Monterey shale, and are thought to be of Vaqueros age. That they are the true equivalents of the massive Vaqueros sandstone of the area from Ben Lomond Mountain to Castle Rock Ridge is not known.

*Fossils and age.*—There are few localities where the Vaqueros sandstone is fossiliferous, but at those places the rocks yield an abundant fauna of unmistakable lower Miocene age. As would be expected in a formation composed largely of conglomerates and coarse sandstones, the Vaqueros contains a shallow-water or littoral fauna. Some of the Vaqueros species are unique, some extend downward into the underlying transitional zone, many are found also in the upper Miocene, still others extend into the transitional Miocene-Pliocene, and a few are known to occur in the recent fauna of the west American coast. The fauna is characterized by a great abundance of individuals of several species of the genus *Agasoma* and the occurrence within it of such unique forms as *Turritella ineziana* Conrad, *Cuma biplicata* Gabb, *Pecten magnolia* Conrad, *Tivela inezinana* Conrad, etc., many of which are shown on illustration sheet II. The teeth of several species of sharks and other large fish also appear to be characteristic of this horizon. A partial list of Vaqueros fossils follows. Those marked with an asterisk (*) are supposed to be characteristic of the formation.

*Brachiopoda.*

Terebratalia aff. occidentalis Dall.

*Pelecypoda.*

* Arca microdonta Conrad.
* Cardium vaquerosensis Arnold.
* Chione temblorensis F. M. Anderson.
* Chione mathewsonii Gabb.
* Dosinia conradi Gabb.
Dosinia ponderosa Gray.
* Glycymeris branneri Arnold.
* Leda cahillensis Arnold.
* Mytilus mathewsonii Gabb.
* Ostrea n. sp. *v.*
Panopea (cf.) generosa Gould.
Pecten andersoni Arnold.
Pecten branneri Arnold.
Pecten estrellanus Conrad.
Pecten magnolia Conrad.
Phacoides acutilineatus Conrad.
Phacoides richthofeni Gabb.
* Pinna alamedensis Yates.
* Tivela inezinana Conrad.
Yoldia submontereyensis Arnold.

*Gasteropoda.*

* Agasoma kernianum Cooper.
* Agasoma santacruzana Arnold.
* Conus oweniana F. M. Anderson.
Crepidula princeps Conrad.
* Cuma biplicata Gabb.
Galerus inornatus Gabb.
* Neverita callosa Conrad.
Sigaretus scopulosus Conrad.
* Turritella inezinana Conrad.
* Turritella ocoyana Conrad.

*Pisces.*

Galeocerdo productus Agassiz.
Lamna clavata Agassiz.

### MONTEREY SHALE.

*Distribution.*—As with the previously described Tertiary formations, the areal distribution of the Monterey is controlled largely by the northwest-southeast structural lines of the region. A study of the areal geology map sufficiently shows the distribution of the formation. During Monterey time the sea probably covered at least the southwestern two-thirds of what is at present the land area of the quadrangle. The largest area of Monterey shale in the quadrangle is that flanking the west side of the Santa Cruz Range and extending from the city of Santa Cruz northwestward for 30 miles, to a point slightly north of Pescadero Creek.

*Character.*—In the Santa Cruz quadrangle the Monterey shale consists chiefly of diatomaceous shale with here and there intercalated sandstone beds. In the region northwest of Santa Cruz the sandstones interbedded with the diatomaceous shale (of supposed Monterey age) are largely bituminous (See fig. 11, illustration sheet I.) The diatomaceous shale composes the greater part of the formation and occurs in various grades of purity, from the very light shales composed almost entirely of diatom skeletons to those containing so large proportions of clay and fine sands as to almost or quite lose their diatomaceous character. In the region northwest of Santa Cruz the Monterey shale is ordinarily spoken of as "chalk rock." The shale usually weathers to white or buff color, but unweathered surfaces often present a dark-gray, drab, or chocolate color.

In the region along the coast from Santa Cruz north to Pescadero Creek there are usually sandstone beds varying from 50 to 200 or 300 feet in thickness beneath the Monterey. This sandstone, which reaches its maximum development about the asphalt quarries and about Bonnie Doon northwest of Santa Cruz, apparently lies conformably below the shale. It contains fossils that are common in Miocene and transition Oligocene-Miocene formations. Whether this sandstone is the equivalent of part of the Vaqueros sandstone or whether it should be considered a part of the Monterey shale is unknown. It is shown on the map as Vaqueros sandstone.

While the Monterey shale readily breaks up under the influence of the weather to small angular fragments, it does not form a rich or a deep soil. It is therefore more resistant to erosive agencies than is the more massive sandstone and shale of the overlying Purisima formation. In many places it is quite as resistant as the underlying Vaqueros sandstone, and it is much more so than the massive shale and fine-grained sandstone that make up the San Lorenzo formation. For these reasons the topography of the Monterey is characterized generally by sharp, narrow canyons and high ridges with steep slopes.

The Monterey shale along the west side of Cahil and Castle Rock ridges has been highly folded and faulted, being so crushed in some places that it is impossible to determine its detailed structure. From the headwaters of Peters Creek to the headwaters of Tunitas Creek the formation has been cut by many intrusions of diabase. These intrusions reach such prominence in the region about Langley and Mindego hills that all continuity of the sedimentary beds has been destroyed. In this region the Monterey shale closely resembles lithologically the impure mud shale of the San Lorenzo formation rather than the diatomaceous variety of the Monterey.

Deposits of petroleum of economic importance occur in sands intercalated in what is believed to be the Monterey shale below the Purisima formation in Purisima Canyon about 2 miles from the ocean.

*Relations to other formations.*—The Monterey appears generally to lie unconformably upon the underlying formations. It rests unconformably upon the Butano sandstone northwest of Butano Ridge. It appears to lie unconformably upon the Vaqueros sandstone in the region between Ben Lomond Mountain and Castle Rock Ridge. Farther northwest, in the region of Langley and Mindego hills and west of Cahil Ridge, its relations to the underlying formations are not clear.

As has already been pointed out, the diatomaceous shale of supposed Monterey age at the south and west sides of Ben Lomond Mountain lies conformably over a thin sandstone series which may there be the equivalent of the Vaqueros sandstone.

There is a slight unconformity between the supposed Monterey shale and the overlying Santa Margarita formation at the city of Santa Cruz, and this unconformity may exist between the two formations wherever the Santa Margarita overlies the Monterey in the southeastern portion of the quadrangle.

Along the coast the Monterey and Purisima formations are brought into contact by a fault extending from the vicinity of Año Nuevo Bay northwestward to the north side of Pescadero Creek near Pescadero. North of Pescadero Creek sedimentation appears to have been continuous from Monterey time well into Purisima time, probably until its end. The Purisima formation is known to lie unconformably upon the Monterey shale in the region northwest of La Honda.

To sum up, it appears that subsequent to Monterey time a portion of the present land area of the quadrangle was raised above sea level, while at other places sedimentation still continued, and that afterward, during Purisima time, subsidence caused the Santa Margarita and in places the Purisima to overlap the eroded Monterey beds, and at other places to appear conformable with them.

*Fossils and age.*—Locally the Monterey shale contains abundant fossils, leaving no doubt as to its age. This is especially true of the formation in the region north of Santa Cruz, where it is exposed along Newell and Zayante creeks.

Some of the areas of diatomaceous shale supposed to be of Monterey age have thus far yielded no determinable fossils. No fossils have been obtained from the northernmost Monterey area shown on the map, viz, that immediately west of the north end of Cahil Ridge; neither have enough determinable fossils been found in the large diatomaceous shale area which flanks the west side of the Santa Cruz Range from Pescadero Creek southeastward to Santa Cruz to indicate its age definitely. These two areas are mapped as Monterey solely because of their lithologic character and their stratigraphic relations to the overlying and underlying strata.

Few species are known in the formation, but this paucity in the number of species is partly compensated for by the abundance and rather widespread distribution of *Pecten peckhami* Gabb, *Yoldia impressa* Conrad, *Arca obispoana* Conrad, and *Tellina congesta* Conrad. The first two of these are found sparingly also in the San Lorenzo formation (Oligocene); nevertheless, their great abundance in the Monterey make them more or less useful for purposes of correlation. A few of the more common species are shown on illustration sheet II. The fauna of the Monterey shale comprises the following species. Those marked by an asterisk (*) are supposed to be characteristic of the formation.

*Echinoidea.*

*Cidaris sp. *a.*

*Pelecypoda.*

*Arca obispoana Conrad.
Chione mathewsonii Gabb.
*Corbula sp. *a.*
*Diplodonta (aff.) serricata Reeve.
*Mactra montereyana Arnold.
*Marcia oregonensis Conrad.
Pecten andersoni Arnold.
Pecten peckhami Gabb.
*Semele sp. *a.*
Siliqua sp. *a.*
*Tellina congesta Conrad.
*Venericardia montereyana Arnold.
Yoldia impressa Conrad.

*Gasteropoda.*

Haminea petrosa Conrad.

### SANTA MARGARITA FORMATION.

*Distribution.*—The region of Scott Valley, north of Santa Cruz, is occupied by a distinctive formation consisting of pure white sand overlain by white shale. This formation, which is known as the Santa Margarita, extends northward to the region about the town of Boulder Creek and east of the town of Ben Lomond.

*Character of the sandstone.*—The formation in places rests unconformably on the Monterey. It consists of about 200 feet of coarse, white, incoherent sand with bedded conglomerates near the bottom. These conglomerates consist for the most part of dioritic bowlders derived from the diorite immediately underlying the formation in certain areas in this part of the quadrangle. Owing to their incoherency the sand beds weather easily, affording large quantities of loose white sand, which form hills that strikingly resemble sand dunes.

In the Ben Lomond area, where the sandstones are very pure and soft and are capped by harder shales, the hills generally have steep slopes and the soils are poor. The same is true of the exposures along the western side of Scott Valley, where the shale-capped hills have the general appearance of small buttes.

Certain grotesque concretionary columns, known locally as "the Ruins," occur in the white sand on the Locke place in Scott Valley. These columns show a remarkable alignment, suggesting the parallel walls of a house. They are the result of a weathering away of the soft sandstone surrounding locally hardened portions along joint cracks.

*Character of the shale.*—Throughout much of the extent of the Santa Margarita formation the white sands are overlain by a thickness of about 100 feet of fine, thin-bedded, more or less indurated shale. East and southeast of the town of Ben Lomond and southward to Scott Valley this shale is the youngest bed exposed, but south and southeast of Scott Valley it grades into softer, more sandy strata which dip under the later Purisima sediments.

*Relation to other formations.*—In the region north of Scott Valley the unconformity between the Santa Margarita and the earlier Miocene is very noticeable, the basal conglomerate of the Santa Margarita resting on the upturned and eroded edges of the Monterey shale. East of Ben Lomond, however, the unconformity is not so apparent, the white sands appearing to lie with about the same dip as the subjacent Monterey. Throughout most of the Scott Valley region the Santa Margarita rests directly on the quartz diorite, the line of contact being in places obscure, owing to the arkose character of the basal member of the Santa Margarita.

The relation of the Santa Margarita to younger formations is not so well known, but it is believed from observation outside the quadrangle that the Purisima conformably overlies the Santa Margarita. The contemporaneity of the upper part of the Santa Margarita with certain of the lower strata mapped as Purisima is, however a possibility.

*Fossils and age.*—The correlation of the white sand of the Santa Cruz quadrangle with the typical Santa Margarita of the upper Salinas Valley is based upon the stratigraphic, lithologic, and paleontologic similarity existing between the two. It is true that but two species of fossils, *Pecten crassicardo* Conrad and *Astrodapsis antiselli* Conrad, have been found in the white sands, but the great abundance of the latter species, coupled with the fact that it is unknown outside of the Santa Margarita horizon in this part of California, lends great weight to its evidence. *Amphiura sanctæcrucis* Arnold, a species of "brittle star," or *Ophiuroidea*, is found in the shale overlying the white sand. This and *Astrodapsis antiselli* are shown on illustration sheet II.

### PURISIMA FORMATION.

*General statement.*—A large portion of the Santa Cruz quadrangle is occupied by an apparently continuous series of sediments composed of heavy conglomerate, sandstone, breccia, impure shaly sandstone, impure soft mud shale, and white diatomaceous shale like the Monterey shale. For these the name Purisima formation has been selected, from the typical development of the formation near the mouth of Purisima Creek, San Mateo County. The Purisima formation, as here defined, includes a thick mass of sediments representing upper Miocene and much of Pliocene time; they appear to be conformable, and no area was found where they could be subdivided.

It will be observed that three general periods of sedimentation occurred in Purisima time—a basal sandstone-forming period, a middle diatom-growing period, and an upper sandstone-forming period.

*Distribution.*—The principal area of Purisima rocks exposed in the quadrangle extends along the west slope of the range from Halfmoon Bay to Año Nuevo Bay. A triangular area with its base to the northwest extends inland along the north side of Butano Ridge almost to the head of Pescadero Creek. From this point as its apex the triangle widens out toward the northwest, flanking and in part forming the southwest slope of the range. There are also small outlying Purisima areas on the east slope of the range southwest of the village of Portola and 2 miles southwest of the village of Westside, and there is an important area south and southwest of Stanford University.

*General character.*—In the typical Purisima sandstones are almost invariably found at the base of the formation. Along Pescadero Creek, and from the headwaters of Pescadero Creek northwestward throughout the area where the diabase is prominent, sandstone and conglomerate composed largely of diabase grains and pebbles occur near the base of the formation. These beds are almost invariably of a characteristic greenish color, due to the weathered diabase materials of which they are composed. Farther from the diabase area the basal sandstone becomes finer grained and loses its distinctive greenish color. West of Cahil Ridge it contains many angular fragments of the older Monterey shale.

The conglomerate and sandstone along Pescadero Creek near Jones Gulch range in thickness from 25 to 150 or 200 feet. The lower sandstones of the formation reach a maximum development of 2700 feet north of Pescadero Creek, about 3 miles northeast of the town of Pescadero.

The sandstones occurring at the base, as well as those at the top, of the Purisima formation are almost invariably soft and crush easily; in color they are generally buff or brown.

Light-colored diatomaceous shale occurs in the Purisima formation at various places. This often resembles to a marked degree the diatomaceous shale of the Monterey. It varies, as would be expected, from almost pure diatom shale to impure clay shale, which, as shore conditions are approached, in turn grades into fine sandstone. The shale reaches its highest development in the area between Pescadero and San Gregorio creeks and east of the fault which extends from the mouth of San Gregorio Creek to Año Nuevo Bay. Immediately east of this fault and between the two creeks above mentioned the white shale has a thickness of approximately 1000 feet and makes up the middle part of the Purisima formation.

The topmost beds in the Purisima area extending from Año Nuevo Bay to Halfmoon Bay and passing inland north of Pescadero Creek are composed of loosely cemented sandstones, generally of brown or buff color. In the region north of San Gregorio Creek these strata have an exposed thickness of 1500 feet. On Tunitas Creek they are about 5000 feet thick. In this locality the strata are apparently free from faulting. The upper Purisima sandstones are almost invariably fossiliferous. They often contain hard layers and nodules, due to the cementing materials derived from the fossils.

The thickness of the Purisima formation is most variable. A thickness of 5400 feet is exposed along a north-south section extending from 2½ miles northeast of Pescadero to Madera Creek, where the whole formation appears to be represented and is apparently free from faults. On Tunitas Creek its thickness is 5000 feet, apparently only the upper portion of the formation being exposed. The upper Purisima strata have an exposed thickness of 1500 feet north of San Gregorio Creek.

*Local facies.*—The Purisima formation has many local facies, which make its adequate description impossible without reference to specific localities.

The sandstone overlying the basalt in the region south and southwest of Stanford University, which is mapped as Purisima but is believed to be older, as is stated farther on, is fossiliferous and quartzose in character and about 300 feet or more in thickness. For the most part this sandstone is rather soft and has poorly defined bedding. Certain of the beds, especially those near the base, contain the remains of numerous barnacles (*Balanus concavus* Bronn), the lime of which hardens the sandstone in some places.

In the vicinity of Halfmoon Bay the conglomerate rests upon the Miocene sandstone and Miocene diabase and is generally composed of bowlders and pebbles of diabase with some shale and pebbles of pre-Miocene rocks. Above this conglomerate is a series of rather fine, hard shale beds, and on top of the shale is a fine, soft sandstone. The sandstone contains fossils nearly everywhere, so far as it has been examined, and the shales contain fossils in a few localities. This same section appears to prevail over most of the territory from Halfmoon Bay to San Gregorio Creek and possibly as far south as Pescadero Creek. Along the coast from the vicinity of Purisima southward as far as Año Nuevo Bay the formation is almost wholly sandstone. This sandstone, as a rule, is soft, but contains hard layers a few inches thick, in which are found numerous well-preserved fossils. Probably the finest exposures of these fossiliferous beds are in the vicinity of Purisima, north of San Gregorio Creek, and north of Pescadero Creek. Another extremely fossiliferous locality is that along the coast 2 miles east of Point Año Nuevo, where two distinct horizons of Pliocene are distinguishable.

The conglomerate at the base of the Purisima along Pescadero Creek in the vicinity of Jones Gulch consists of fine, black, somewhat siliceous pebbles and sands rather firmly cemented and containing a fauna somewhat older than that of any of the horizons of the soft sandstones of the formation. A green sand is also found at about the same horizon as that of the dark-colored conglomerate in this same vicinity.

The shale capping the white sandstone of the Santa Margarita south of Scott Valley is in turn overlain by soft, fine sands, more coherent than the underlying white sand. In some places, notably in the vicinity of Capitola, just east of the limits of the quadrangle, these soft sands are very fossiliferous. At certain localities the base of the series is composed of a fine, rather hard, massive, shaly sandstone. This condition prevails south of Mindego Hill on the Alpine road. In this region the fine shaly sandstone is found to rest directly upon the eroded surface of the diabase, some of the larger diabase bowlders extending up into the shaly sandstone, with no conglomerate or coarse material whatever between them and the overlying shale.

*Relation to soils and topography.*—With the exception of some of the shales the Purisima strata are generally soft, crushing and weathering easily and forming a deep, rich soil where they contain much organic matter, as is the case throughout most of the area extending from Año Nuevo Bay to Halfmoon Bay. Rounded fertile hills and comparatively broad, open valleys are characteristic of this portion of the Purisima area.

Where the harder shale is the surface rock the hills are generally higher, with steeper slopes and narrower valleys, than they are over the sandstone areas. With the exception of the regions covered with Quaternary deposits the most fertile lands along the coast from Halfmoon Bay to Santa Cruz are those formed from the Purisima sediments.

*Relation to other formations.*—The Purisima beds usually lie unconformably above the Monterey shale and in places rest on the Vaqueros sandstone; upward they grade into beds having a fauna similar to that of the Merced formation. The upper limit of the Purisima may be defined as the base of the Merced, as exposed in the type section of Merced on Sevenmile Beach beyond the north border of the quadrangle. Although an unconformity usually marks the contact between the Monterey and the Purisima, this is not invariably the case, for in some localities, notably north of Pescadero Creek and about 5 miles from the coast, the Purisima seems to grade directly into the Monterey, with no noticeable unconformity.

In the vicinity of La Honda and the Alpine Creek country south of Mindego Hill the contact between the Purisima and the Monterey is marked by a zone of broken shale, and in some places this breccia contains marine fossils, probably indicating a beach condition in the region during the early part of Purisima time.

In the vicinity of Santa Cruz fine massive sandstone rests directly upon the eroded surface of the Monterey shale, the contact stratum consisting of only a few inches of waterworn pebbles, which in some places contain fragments of cetacean bones. Although these beds are mapped with the Santa Margarita they are regarded, because of their lithologic character, as probably Purisima. The strike of these beds and that of the underlying Miocene are the same, and the difference in dip between the two is only about 8°, the younger beds having the lesser dip. The same conditions are also found in some places along the upper portions of Pescadero Creek and in several localities in the region just east of the quadrangle in Soquel Creek.

Wherever noted in the quadrangle the Quaternary deposits rest unconformably upon the Purisima. The fauna of the Quaternary is entirely different from that of the uppermost beds of the Purisima, thus probably indicating a considerable time interval between the deposition of the latest Purisima beds and the terracing and deposition of the Quaternary.

*Fossils and age.*—The Purisima is the most uniformly fossiliferous formation found in the Santa Cruz quadrangle, nearly all of its outcrops yielding fossils more or less readily determinable. The fauna of the lower part of the Purisima shows a strong affinity to the Miocene, while that of the great bulk of its sediments is certainly Pliocene.

Beds immediately overlying the basalt in the area southwest of Stanford University, locally known as the barnacle beds, represent, as indicated by their fauna, a horizon lower than any in the known Purisima west of the range. The relations existing between these beds, mapped with the Purisima, and the Santa Margarita formation are not known, although both are known to be younger than the Monterey (middle Miocene) shale and older than the typical Purisima. It would be well to differentiate these lowest beds on the map and give them a new formation name, but owing to their similarity to other beds in the same general area containing a fauna of upper Pliocene species such treatment becomes impossible.

The fauna of the barnacle beds is distinctive, although it contains many species found in the formations both below and above it. It may be the equivalent of a portion of the Miocene beds which in Contra Costa County lie just above the Monterey shale. *Fusus stanfordensis* Arnold, *Trochita costellata* Conrad, *Fissuridea* sp. *a*, *Arca canalis* Conrad, and *Marcia gibbosus* Gabb are some of the species found in the barnacle beds which are not known at any of the horizons below it; while *Agasoma stanfordensis* Arnold, *Fusus stanfordensis* Arnold, *Chione mathewsonii* Gabb, etc., are species which are not known to occur in any of the horizons above it. On illustration sheet II are shown several of the more common species. A typical fauna from the barnacle beds is as follows;

*Pelecypoda.*

Arca (cf.) obispoana Conrad.
Arca canalis Conrad.
Callista sp. *a*.
Chione securis Shumard.
Chione mathewsonii Gabb.
Dosinia mathewsonii Gabb.
Dosinia ponderosa Gray.
Leda taphria Dall.
Mactra albaria Conrad.
Marcia gibbosus Gabb.
Panopea generosa Gould.
Pecten andersoni Arnold.
Periploma sanctæcrucis Arnold.
Phacoides acutilineatus Conrad.
Solen sicarius Gould.
Tapes truncata (?) Gabb.
Yoldia supramontereyensis Arnold.

*Gasteropoda.*

Agasoma stanfordensis Arnold.
Fusus stanfordensis Arnold.
Galerus inornatus Gabb.
Megatabennus (cf.) bimaculatus Dall.
Natica (cf.) ocoyana Conrad.
Trochita costellata Conrad.

The Purisima formation is younger than the Monterey, and also younger than the latest of the diabase and basalt intrusions of the quadrangle. It is probably upper Miocene and lower Pliocene, possibly extending up into the middle Pliocene. The fauna of the lower beds of the Purisima exposed along Pescadero Creek in the vicinity of the mouth of Jones Gulch indicates a horizon which is probably upper Miocene or transitional between upper Miocene and Lower Pliocene. The fauna of the soft sandstone beds in the vicinity of Pescadero and Purisima represents a horizon well down in the Pliocene, or, taken in association with the Pescadero Creek fauna, probably represents the transition from Miocene to Pliocene. The fauna of the lower part of the beds at Año Nuevo Creek is similar to to that of the beds north of Pescadero and at Purisima, but its upper part, showing many species which are found commonly in the Merced formation at Merced beach, has been mapped as Merced. Thus the Purisima, taken as a whole, covers a rather long vertical range and may possibly, on careful study, be divided into two or more recognizable formations.

The fauna of the lower part of the typical Purisima is developed in Pescadero Creek near Jones Gulch. The fauna of that portion of the Purisima lying along the northeastern flanks of the main divide, as the beds exposed on the Halliday ranch and at the quarry where Stevens Creek enters the Santa Clara Valley, appears also to belong to this lower horizon, although the fauna of these latter strata is markedly different from that found in the Pescadero Creek-Jones Gulch rocks. Both of these latter faunas are also different from that of the barnacle beds and are probably younger. The Halliday ranch strata are unusually rich in *Fusus* and *Chione*, while the Pescadero Creek-Jones Gulch locality yields numerous *Natica*, *Crepidula*, etc. Some of the characteristic fossils of the typical Purisima are shown on illustration sheet II. The following species have been found in the lower horizon of the typical Purisima. Those species marked by an asterisk (*) are not found in the upper or distinctly Pliocene portion of the Purisima in this region.

*Pelecypoda*

Arca canalis Conrad.
Arca trilineata Conrad.
Cardium meekianum Gabb.
*Chione (aff.) gnidia Broderip and Sowerby.
Clidiophora punctata Conrad.
Macoma nasuta Conrad.
Mactra albaria Conrad.
*Marcia oregonensis Conrad.
Nucula castrensis Hinds.
Panopea generosa Gould.
Pecten healeyi Arnold.
*Pecten oweni Arnold.
Pecten purisimaensis Arnold.
*Pecten wattsi Arnold.
Phacoides acutilineatus Conrad.
Solen sicarius Gould.
Tapes staleyi Gabb.
*Venus pertenuis Gabb.

*Gasteropoda.*

*Chlorostoma stantoni Dall var. lahondaensis Arnold.
*Chrysodomus imperialis Dall.
Chrysodomus liratus Martyn.
Chrysodomus stantoni Arnold.
Crepidula princeps Conrad.
*Fusus portolaensis Arnold.
Lunatia lewisii Gould.
Nassa californiana Conrad.
Natica clausa Broderip and Sowerby.
*Neptunea (aff.) humerosa Gabb.
Olivella intorta Carpenter.
Olivella pedroana Conrad.
Solariella peramabilis Carpenter.
Thais crispata Chemnitz.
Tornatina culcitella Gould.

The upper portion of the Purisima usually consists of fine, soft sandstone, which in many cases is ill suited to the preservation of fossils. At those localities where the formation yields only molds and casts in the fine sandstone one usually finds numerous specimens of *Nucula castrensis* Hinds and *Phacoides acutilineatus* Conrad. The best preserved fossils are found in the sandstone cliffs along the ocean, where *Crepidula princeps* Conrad, *Pecten purisimaensis* Arnold, *Pecten healeyi* Arnold, and *Cardium meekianum* Gabb are the commonest fossils. Following is a list of the fossils from the upper portion of the Purisima:

*Echinoidea.*

Scutella perrini Weaver.

*Pelecypoda.*

Arca canalis Conrad.
Arca trilineata Conrad.
Cardium meekianum Gabb.
Cryptomya ovalis Conrad.
Marcia gibbosus Gabb.
Mactra californica Conrad.
Modiolus directus Dall.
Nucula castrensis Hinds.
Panomya ampla Dall.
Pecten healeyi Arnold.
Pecten nutteri Arnold.
Pecten purisimaensis Arnold.
Phacoides acutilineatus Conrad.
Phacoides nuttalli Conrad, var. antecedens Arnold.
Schizothærus pajaroanus Conrad.
Tapes staleyi Gabb.
Tapes tenerrima Carpenter.
Thracia trapezoides Conrad.
Yoldia cooperi Gabb.
Yoldia (aff.) scissurata Dall.

*Gasteropoda.*

Astyris richthofeni Gabb.
Bathytoma carpenteriana Gabb var. fernandoana Arnold.
Chrysodomus stantoni Arnold.
Crepidula princeps Conrad.
Drillia (aff.) graciosana Arnold.
Galerus inornatus Gabb.
Lunatia lewisii Gould.
Miopleiona oregonensis Dall.
Nassa californiana Conrad.
Natica clausa Broderip and Sowerby.
Olivella pedroana Conrad.
Pleurotoma perversa Gabb.
Priene oregonensis Redfield.
Serpulorbis squamigerus Carpenter.
Sigaretus debilis Gould.

### PLIOCENE.

#### MERCED FORMATION.

*Distribution.*—The Merced formation, so remarkably developed at Sevenmile Beach, south of Lake Merced, only a few miles north of the Santa Cruz quadrangle, is barely represented in the latter. Pillar Point, at the extreme northwest corner of the quadrangle, contains the principal area of Merced strata shown on the map. Another important outcrop of the same formation lies conformably above the Purisima in the bluff immediately south of the mouth of Año Nuevo Creek. This outcrop, though of limited extent, is of much importance as showing the relations existing between the Merced and the underlying Purisima. Characteristic lower Merced fossils have also been found immediately southwest of Felt Lake, 2½ miles south-southwest of Stanford University; near the forks of the Page Mill road, 3 miles south-southwest of Mayfield; and at a locality about 1½ miles southeast of the last. It was impossible to properly differentiate the small areas represented by the last three localities from the older beds to the northeast, so that the former have been included in the Purisima on the map.

*Character.*—In the vicinity of Pillar Point the Merced strata consist of several hundred feet of dark shale, interbedded with coarse arkosic sandstone carrying well-preserved fossils. The beds are tilted at various angles and appear to have undergone at least as much distortion as the nearest beds of Purisima age, which occur more than 2 miles to the east, in the region north of the town of Halfmoon Bay. Less than 100 feet of soft yellowish brown sandstone, interbedded every 4 to 10 feet with hard calcareous layers, make up the Merced south of Año Nuevo Creek. The hard layers contain an abundant fauna similar to that in the lower part of the Merced at the type locality. Another richly fossiliferous outcrop of Merced occurs just east of the quadrangle, on the coast between Santa Cruz and Capitola. Here the beds also lie conformably above the Purisima. At all of the localities in the quadrangle where the two occur together the Merced is unconformably overlain by the Quaternary.

*Fossils and age.*—The typical Merced is marine and includes the upper part of the Pliocene and extends into the lower Quaternary. Only the lowest portion of the Merced is represented in this quadrangle. The greater part of the Pliocene is represented by the fresh-water Santa Clara formation. The typical Merced fauna is distinguishable from that of the upper portion of the Purisima more by the absence of certain forms common in the latter than by the presence within the Merced of any unique species. An exception to this is the abundance of the characteristic echinoderm *Scutella interlineata* Stimpson in the typical Merced and its absence or doubtful occurrence in the Purisima. A few of the typical Merced species are shown on illustration sheet II. The fauna of the lowest Merced horizon as developed in the Santa Cruz quadrangle is as follows:

*Echinoidea.*

Scutella interlineata Stimpson.

*Pelecypoda.*

Arca canalis Conrad.
Arca trilineata Gabb.
Cardium meekianum Gabb.
Cryptomya californica Conrad.
Macoma nasuta Conrad.
Mactra californica Conrad.
Mactra albaria Conrad.
Modiolus directus Dall.
Nucula castrensis Hinds.
Pecten latiauritus Conrad.
Siliqua patula Dixon.
Solen sicarius Gould.
Tapes staleyi Gabb.

*Gasteropoda.*

Astyris richthofeni Gabb.
Chrysodomus stantoni Arnold.
Crepidula princeps Conrad.
Lunatia lewisii Gould.
Margarita pupilla Gould.
Nassa californiana Conrad.
Nassa mendica Gould.
Nassa perpinguis Hinds.
Olivella biplicata Sowerby.
Olivella intorta Carpenter.
Olivella pedroana Conrad.
Thais ostrina Gould.
Thais trancosana Arnold.

#### SANTA CLARA FORMATION.

*Distribution and character.*—During at least a portion of the time in which the gravel, sand, and the finer sediment of the Merced were being deposited in the ocean somewhat similar sediments were being laid down in great fresh-water lakes on the opposite side of the Santa Cruz Range. These fresh-water deposits are now exposed in a narrow band which extends from the region of Crystal Springs Lake southeastward through the Portola Valley, thence up Corte de Madera Creek and over the divide into Stevens Creek canyon. Another important area of similar deposits occurs northwest of Saratoga. The fresh-water beds are largely gravels, through which are interbedded minor quantities of soft marly sands and clays. Some thin beds of lignite are also found at one horizon in the series. It is impossible to compute the thickness of the formation, as at no one place is much of it exposed. It seem probable, however, that the series is at least 500 feet thick.

*Correlation and relation to other formations.*—There is no question as to the contemporaneity of the greater part of the Santa Clara formation and the Paso Robles formation described in the San Luis folio (No. 101). At no place has it been possible to find the exact contact between the Santa Clara and the underlying Purisima formation, but it seems likely that the two formations are conformable. The line separating the Santa Clara formation from the Quaternary gravels on the map is largely arbitrary and based on physiographic evidence, it being impossible at all but a few places to separate the upper beds of the Santa Clara from the Quaternary. In at least one locality, however, the recent gravels may be seen resting unconformably on the Santa Clara.

*Fossils and age.*—In age the Santa Clara probably represents the upper Pliocene and lower Quaternary. Its fauna consists of but a few fresh-water species. These, however, are fairly abundant at some localities, notably at one place in the bed of Corte de Madera Creek in the Portola Valley, and in the area northwest of Saratoga. The following fossils have been collected from the Santa Clara formation within the quadrangle:

Anodonta wahlametensis Lea.
Paludestrina sp. *a*.
Paludestrina sp. *b*.
Amnicola sp. *a*.
Amnicola sp. *b*.

### QUATERNARY SYSTEM.

#### GENERAL STATEMENT.

The Quaternary in the Santa Cruz quadrangle has been a period of intermittent uplift and depression. The record of the changes that have taken place during it is found in the wave-cut and stream terraces and in the marine and fresh-water deposits which occur in different parts of the quadrangle. Quaternary sediments in the region of the coast, as mapped in this folio, form a border which extends almost continuously from Halfmoon Bay to Santa Cruz. Most of the terraces are capped or covered by these Quaternary sediments (see figs. 6, 7, and 8 on illustration sheet I), but in some places, notably in the vicinity of Pescadero, Bolsa, and Pigeon points, these sediments have been removed from portions of the terrace.

#### TERRACES.

*Terraces of marine origin.*—The wave-cut terraces offer impressive evidence of what has taken place. These are best developed in the region of Santa Cruz and are viewed to best advantage from a mile or two off shore from the town. In that region four and in some places five of these great steps are cut back into the hills, each terrace being practically horizontal except for its general seaward slope. The lowest terrace ranges from 20 to 100 feet above sea level; the second is approximately 250 feet; the third, 500 feet; and the fourth, 800 feet. The width of the lowest terrace averages about a mile, the second about one-half mile, and the others much less. The lowest terrace has been very little dissected except by the larger streams. The smaller streams have cut down through the second terrace to a level with the first, and flow out over the first in a narrow and shallow trench. The second terrace is much more dissected than the first or lowest, and the third and fourth are still more dissected, and in some places are entirely obliterated. Evidences of terraces still higher than that at 800 feet are to be found in the Santa Cruz region, and even the top of Ben Lomond Mountain, at an elevation of about 2000 feet, offers evidence of having been planed off and then covered by waterworn gravels.

Wave-cut terraces are also developed in the vicinity of Halfmoon Bay and from there southward along the coast. These terraces are unequally elevated at different points along the coast. This inequality of uplift is shown in the two terraces which begin at Halfmoon Bay and extend southward nearly to San Gregorio Creek. The lowest terrace at Halfmoon Bay is 1½ miles wide, sloping gently upward toward the hills. It has an elevation of about 60 feet at the foot of the escarpment which marks the old sea cliff of the upper terrace. The surface of the terrace rises gradually southward and at the mouth of Tunitas Creek has an elevation of about 150 feet. At Halfmoon Bay the upper terrace is about 100 feet above sea level, and it rises to about 400 feet in the vicinity of Tunitas Creek. It is thus evident that during the period between the formation of the upper and lower terraces the upper or older terrace was uplifted 40 feet at Halfmoon Bay, while it was raised 250 feet at Tunitas Creek. Furthermore, during its rise to 100 feet at Halfmoon Bay it was raised to about 400 feet at Tunitas Creek. During the first period of uplift the rise was about six times as much at Tunitas Creek as at Halfmoon Bay, while during the second it was only about two and a half times as much at the former place as at the latter. Another interesting fact in connection with the differential uplift is that the region of maximum elevation of the terraces coincides with the axis of an anticlinal fold of the rocks from which the terrace is cut. In other words, the old axis of the anticlinal fold, which presumably was formed at the end of the Purisima epoch, continued to be the line of greatest uplift in Pleistocene time.

Terraces are not prominent between Tunitas Creek and Waddell Creek except in the region about Año Nuevo Point, where the lowest terrace reaches its maximum width (about 2 miles) and where there is a second well-marked terrace with its top about 150 feet high. From Franklin Point to Año Nuevo Point the terrace is covered with shifting sand dunes (see fig. 7, illustration sheet I), which are underlain in most of the region between the two points by fossiliferous Quaternary gravel and unfossiliferous deposits of broken shale.

*Terraces of stream origin.*—Stream terraces which can be correlated with the wave-cut terraces of the coast are found along the sides of most of the larger streams which flow into the ocean from the territory under discussion. This is true for San Lorenzo River and San Gregorio, Pescadero, and Pilarcitos creeks, besides several other less important ones. The lower or latest of these stream terraces are trenched but little by the smaller streams which flow across them. These smaller streams empty into the major streams of the valley at steep inclines or over waterfalls. Not a very long period of time has elapsed, therefore, since the uplift of these valleys to their present positions.

### TERRACE DEPOSITS.

*Deposits on marine terraces.*—Under this heading are described all the Quaternary deposits along the coast from Halfmoon Bay to Santa Cruz. In the vicinity of Halfmoon Bay the Quaternary deposits resting on the youngest or lowest terrace consist mostly of thin-bedded sand and broken shale. The sand has an average thickness of about 15 feet and is probably of marine origin. On top of it rests a layer of shale fragments which in most places is about 5 feet thick and which is probably of fresh-water origin. It is derived directly from the shales which form the hills back of the first terrace, and is brought down onto the terrace by some of the small streams which flow across the latter into the ocean.

The terrace from Halfmoon Bay to Purisima is covered by waterworn gravel and sand from 2 to 25 feet in thickness, becoming thicker southward from Halfmoon Bay. In the vicinity of Purisima the Quaternary is about 25 feet thick and consists of alternating sand and coarse gravel, the latter predominating.

A peculiar relation exists between two Quaternary deposits in the vicinity of Purisima, the detritus from the second terrace here overlapping the bedded marine deposits of the first. The Quaternary deposits at the mouth of Lobitos Creek consist of about 25 to 35 feet of horizontally bedded, rather coarse gravel and sand, while at Tunitas Creek they are about 50 feet thick and were deposited in an old creek valley which has been since raised to its present height.

The 400-foot terrace at Tunitas Creek is covered by a thin layer of gravel, and the slopes between it and the low or 150-foot terrace are also covered in some places 2 or 3 feet deep by gravel. This is indicative of a third or intermediate terrace which, though not prominent at present, was probably developed and obliterated before the completion of the present lowest terrace.

The Quaternary deposits on the south side of San Gregorio Creek attain a thickness at one place of about 60 feet. The development of the deposits in this vicinity seems to have been greater than at any other place. South of this great development of Quaternary the deposits thin out and consist almost wholly of large bowlders of soft sandstone cemented together with sand. The Quaternary deposits along the top of the bluff from San Gregorio Creek to the mouth of Pomponio Creek consist for the most part of shale fragments with some harder pebbles. In this vicinity, at the contact with the sandstone of the Purisima there is generally a stratum of material coarser than the rest of the deposit, which is usually overlain by fine sand or clay.

The Quaternary deposits south of Pescadero consist chiefly of thin layers of gravel or sandy clay resting on the old rocks of the Chico formation. At the Pescadero pebbly beach the pebbles are derived from the Quaternary layer, 10 to 12 feet in thickness, the latter being derived in turn from the Chico conglomerate which outcrops in the vicinity. *Pholas* holes are common in several places in the old terrace surfaces along this part of the coast.

From Arroyo de los Frijoles to Pigeon Point the Quaternary consists of more or less disconnected patches of gravel and reddish yellow sand which are found overlying the eroded edges of the old sandstones and conglomerates. At many places within the area mapped as Quaternary between Pescadero Creek and Pigeon Point the Chico formation outcrops.

Quaternary deposits of small pebbles and sand reach a thickness of 20 feet about a mile east of Pigeon Point, and a mile and a quarter southeast of the same point their base contains many *Pholas*-bored bowlders. The underlying sandstone of the Chico formation is also full of holes bored by this same mollusk.

From Gazos Creek to Franklin Point and beyond the Quaternary varies in thickness from a few inches to 10 feet. It consists of a pebbly layer containing large *Pholas*-bored bowlders, the bottom overlain by reddish yellow sand and clay.

For half a mile southeast from the mouth of Whitehouse Creek there is a good development of Quaternary deposits, consisting of 10 to 15 feet of waterworn fragments of shale and sandstone, which probably came from the hills to the east. *Pholas*-bored sandstone bowlders and the underlying sandstone in place are also seen along the contact. A fossiliferous Quaternary bed about 2 feet thick is exposed at the base of the formation in the sea cliff about Point Año Nuevo. Above the fossiliferous layer is a sandy stratum about 4 feet thick, which in turn is overlain by broken shale and, lastly, soil.

The surface of Año Nuevo Point is covered for the most part by sand dunes. From a point one-half mile southeast of the mouth of Año Nuevo Creek to the valley at the mouth of Waddell Creek the Quaternary deposits of worn shale fragments and finer material occur in more or less disconnected patches along the top of the bluff, which in some places rises to a height of about 300 feet. These patches seem to be the remnants of detritus at the base of a terrace which once extended out into the ocean, but which has since been eroded away. The patches extend only a short distance back from the bluff. They are represented on the map by two or three large spots.

At the mouth of Scott Creek the Quaternary consists of 8 to 10 feet of coarse gravel overlain by 40 feet of reddish-yellow sand. The present stream cuts through these deposits and has washed them away from one side of its old channel. From the mouth of Scott Creek to Santa Cruz the Quaternary sediments consist chiefly of sand and broken shale in beds having a total thickness of about 10 feet. These deposits are wholly lacking in some places, however, notably near the sloping edges of the streams which cut down into the underlying Miocene shale. So thin is the Quaternary on this part of the terrace that even the smaller streams appear to have cut down through it. Waterworn pebbles of diorite and other hard rocks were found on top of the second or 250-foot terrace, but no connected areas of deposits were noted at any point on this upper bench. *Pholas*-bored fragments of shale were found at several points on the first and second terraces.

The Quaternary forms an almost continuous layer at the top of the sea cliff from Terrace Point to the eastern limit of the quadrangle. In places, especially in the vicinity of the Santa Cruz pier, this Quaternary layer is only a few inches thick. East of the mouth of San Lorenzo River the Quaternary deposits are from 5 to 15 feet thick, and consist of thin, horizontally bedded sand, overlain by a thin stratum of dark-colored soil.

*Deposits of fresh-water origin.*—In the Santa Clara Valley region the Quaternary deposits consist chiefly of alluvial fan deposits. There is, however, some scattered coarser gravel of probable Quaternary age in the foothills. The alluvial fans have been a large factor in the past in filling the Bay of San Francisco. These deposits steadily encroach upon the low-lying marsh lands that fringe the bay shore. They vary in thickness from a fraction of an inch along the edges of the salt marshes to many feet at the foothills where the streams debouch upon the plain. A veneer of recent stream deposits is thus being formed over the Quaternary salt-water deposits of San Francisco Bay. The depth to which the Santa Clara Valley has been filled by Quaternary deposits is not known.

*Travertine deposits.*—Deposits of travertine of Quaternary age are found on the hill slopes and along the streams at many localities in the region of the diabase tuffs and intrusions, but are too small to be mapped.

*Local movements in the Quaternary.*—Evidence offered by the deposits exposed in the sea cliff at the mouths of several of the old stream channels indicates alternating conditions of elevation and depression. At the mouths of Tunitas, Año Nuevo, and Scott creeks and several other streams emptying into the ocean the old broad stream channels are filled to a depth in some instances of 40 feet with gravel, breccia, and sand. These deposits have been cut through by the present streams, which now empty into the ocean through more or less narrow gorges. In some places the gorge has been cut through the Quaternary and into the older underlying rocks; in others the stream has cut only partly through the Quaternary sediments and enters the ocean through a lagoon. The meaning of this is not hard to decipher. During a previous elevation, when the precipitation was presumably heavier than at present, the streams cut out wide channels; then followed a depression during which these channels were filled with the gravel, breccia, and sand. Following this came the present period of elevation, in which the streams have cut down through the deposits in their old channels and now enter the sea in narrower gorges than those previously used. Where the present streams cut into the older underlying rocks the uplift has probably been greater than the previous one; where the streams enter the ocean through lagoons the uplift has been less. These two cases are further illustrations of the uneven uplift of the coast.

Most of the larger streams which drain the west slope of the Santa Cruz Range from Santa Cruz to Pescadero Creek flow through valleys, which, near the coast, are filled in with recent material, showing a comparatively recent subsidence in that region of probably 50 to 100 feet.

There appears to have been less recent sinking in the region from Purisima to San Gregorio than along the coast line farther southeast, since in the former region the streams enter the ocean either over waterfalls or in shallow valleys, flowing on or near to the underlying rock.

*Marine fossils.*—Along the tops of nearly all the terraces the rock-boring mollusks, *Pholas,* have drilled their holes in the rocks in place, and these holes now remain as evidence of the marine origin of the terraces. *Pholas*-bored bowlders are also common in many of the basal Quaternary conglomerates which rest on the surfaces of the terrace. Marine fossils associated with such bowlders are found abundantly in the lowest Quaternary layer at Año Nuevo Point. Evidences of Indian kitchen middens (shell heaps marking spots where the aborigines used to congregate for feasts and powwows) are found in the soil along the top of the bluffs at this point. Fossiliferous Quaternary deposits are also found in the vicinity of Santa Cruz Point, where they are about 2 feet thick and consist of coarse *Pholas*-bored gravels and shale fragments.

The Quaternary beds are characterized by a fauna of which nearly, if not all, of the species are still found living on the adjacent coast. The fossils are usually poorly preserved, but in some cases are identifiable. The following species have been found in the local Pleistocene deposits:

#### *Pelecypoda.*

Macoma nasuta Conrad.
Pecten (Hinnites) giganteus Gray.
Pholadidea penita Conrad.
Rupellaria lamellifera Conrad.
Saxidomus gracilis Gould.
Zirphæa gabbi Tryon.

#### *Gasteropoda.*

Amphissa corrugata Reeve.
Astyris gausapata Gould.
Bela fidicula Gould.
Bittium filosum Gould.
Bittium rugatum Conrad.
Calliostoma costatum Martyn.
Fusus luteopictus Dall.
Margarita parcipicta Carpenter.
Margarita pupilla Gould.
Nassa mendica Gould.
Nassa perpinguis Hinds.
Natica clausa Broderip and Sowerby.
Ocinebra interfossa Carpenter.
Ocinebra lurida Middendorf.
Ocinebra lurida var. aspera Baird.
Ocinebra lurida var. cancellina Philippi.
Ocinebra lurida var. munda Carpenter.
Ocinebra perita Hinds.
Odostomia nuciformis Carpenter.
Odostomia nuciformis var. avellana Carpenter.
Phasianella compta Gould.
Spiroglyphus littuella Mörch.
Thais canaliculata Duclos.

### MAMMALIAN REMAINS.

In the reworked and later Quaternary gravels there are occasionally found the remains of large extinct mammals. Near Corte de Madera Creek, 2 miles southeast of Stanford University, the tusk of an elephant was found in this gravel at a depth of 7 feet. A mile southeast of Mountain View the tooth of a mastodon was found in the loose worked gravel and coarse sand at a depth of 33 feet. The surface of the ground at this place is 115 feet above tide level.

A well-preserved jaw of *Elephas columbi* was found in coarse sand and gravel near Aptos, just east of Santa Cruz. A tooth of the last-named species was also found in some gravel on the top of the second terrace in the region immediately northwest of Santa Cruz.

## IGNEOUS ROCKS.

*General statement.*—The igneous rocks of the quadrangle, which occupy a relatively small area, as compared with the sedimentary formations, are, in chronologic order, quartz diorite, pegmatite, older diabase and serpentine, and diabase, basalt, and basalt tuffs. The largest areas are those of quartz diorite on Ben Lomond Mountain and of diabase in the region of Langley and Mindego hills. The quartz diorite occurs as a great boss, is of pre-Franciscan age, and is intruded by small dikes of pegmatite. The serpentine and older diabase occur as intrusive dikes and masses in the Franciscan and are of pre-Tertiary age. The basalt and younger diabase occur as dikes and in the form of tuff, and are of Miocene age.

### PRE-FRANCISCAN.

#### QUARTZ DIORITE.

*Distribution.*—Quartz diorite is important as forming the core of Ben Lomond Mountain, one of the most important eminences of the quadrangle. Here it outcrops over extensive areas. The same or a closely allied rock occurs at the north border of the quadrangle east of Halfmoon Bay, and in the vicinity of Scott Valley, north of Santa Cruz. All the exposures are probably a part of the same great mass which forms the heart of the outer ridge of the Coast Range from the San Francisco Peninsula southward into Monterey County and which is referred to in the San Luis folio (No. 101) as the "plutonic basement." In the region east of Halfmoon Bay the quartz diorite is overlain unconformably by the Franciscan; in the Ben Lomond area it is younger than the associated schist and limestone, although it is overlain by them. It is also overlain by the Vaqueros and Monterey in the Ben Lomond region and by the Santa Margarita in the vicinity of Scott Valley. All that is known of its age is that it is pre-Franciscan, which itself is pre-Cretaceous.

*Character.*—Owing to the usual weathered condition of the quartz diorite where exposed, it forms no sharp relief. The rock varies in color from light to dark gray when comparatively fresh, weathering to rusty brown. In hand specimens the texture is seen to be medium coarse to rather fine grained. Locally the rock is porphyritic, and some of the feldspar phenocrysts attain a length of five-eighths inch, while again segregations of fine-grained, usually darker material will be found in the mass. The finest grained rock comes from the top of Ben Lomond Mountain, while the coarsest is found on the west side of the same ridge. The fracture of the rock is rough, and many of the exposed crystals show lustrous faces. Light-colored pegmatite dikes and quartz veins intersect the quartz diorite in many places. Some of the quartz veins locally carry small quantities of gold.

Under the microscope the rock exhibits characteristic hypautomorphic granular texture. The plagioclase feldspar is by far the most important mineral, making up from 55 to 65 per cent of the rock. The other constituents vary in relative abundance, the order in some slides being biotite, quartz, and hornblende, in others quartz, biotite, and hornblende, and in still others hornblende, quartz, and biotite. Only traces of orthoclase occur in the sections. The accessory minerals are zircon, apatite, and magnetite; some of the secondary products are kaolin, white mica, epidote, and red iron oxide.

The quartz diorite is believed to have been the metamorphosing agent of the schists and limestone associated with it, but no definite information concerning this theory was obtained in the course of the field work.

### PEGMATITE.

Intruding the quartz diorite at various places throughout its range are pegmatite dikes of lighter color and more acidic composition than the country rock. The dikes are usually small and the texture of the rock is coarse. The principal constituent is feldspar, largely plagioclase, which occurs in large crystals, the faces of which show a characteristic glossy luster on fractured surfaces. Quartz and biotite are also present in the pegmatite in minor quantities.

## POST-FRANCISCAN–PRE-TERTIARY.

### SERPENTINE.

Serpentine occurs as intrusive dikes in all of the more important areas of Franciscan rocks in the quadrangle, furnishing a bare, rugged surface in most exposures. The rock is usually fine grained and close textured, and is variously colored from bright blue to shades of green. Many small seams of asbestos cut the main mass of the rock, and there are also certain talcose varieties which are usually found in the vicinity of faults. Manganese and chrome iron occur as segregations in the rock, and in certain localities sulphides of iron and copper are found in it. Its relations to associated rocks indicate that it is post-Franciscan and pre-Tertiary in age.

Under the microscope the rock is seen to be composed almost entirely of serpentine, although in one of the sections a large flake of what appeared to be biotite was noticed. The serpentine is probably the alteration product of augite and olivine, and the original dike rock from which the serpentine was derived was doubtless a peridotite.

### OLDER DIABASE.

A dike of more or less altered greenish diabase occurs along the San Andreas fault, extending from near the head of Stevens Creek southeastward to the border of the quadrangle. In places instead of outcropping as a single dike it branches and occurs as a number of small ones. It was not possible to map the dike and its various branches in detail, and for this reason a portion of the area indicated as older diabase on the map is in reality composed of the rocks into which the dike rock has been intruded. A small area of the same rock also outcrops southeast of Table Mountain. Occurring as it does along a faulted zone in which many movements have taken place since its origin, the relations of the dike to the associated rocks are obscure. It is intrusive in the Franciscan, but in no later rocks; it is therefore known to be post-Franciscan and is believed to be pre-Tertiary. At the only place where it is known to be in contact with the Vaqueros (Miocene) the latter shows no evidence of metamorphism and the diabase is believed to be faulted up against the Vaqueros.

In common with most of the rocks along the fault zone, the dike rock has little individuality in its field appearance to distinguish it from the mass of the Franciscan in this region. It weathers in fairly resistant, rather angular croppings, greenish gray to greenish brown in color. Fresh surfaces show a somewhat wavy, mottled gray color, usually stained by iron oxide. On Lyndon Creek, almost at the edge of the quadrangle, sulphides carrying some copper are present in the dike.

In hand specimens the rock is rather compact, greenish gray, and exhibits extremely local variation in grain, varying from fine to rather coarse. The finer-grained facies show a few dark phenocrysts, while in the coarser varieties the individual crystals of feldspar and basic minerals are plainly visible. Some of the coarse-grained specimens which show hypautomorphic texture would ordinarily be termed diorite if dissociated from the diabasic type. The rock breaks with a rough fracture. Various textures from ophitic to hypautomorphic are seen in thin sections of the diabase. Plagioclase, largely andesine, in typical lath-shaped crystals, forms from 50 to 60 per cent of the mass, the other principal constituent being augite, which is usually much altered to hornblende and chlorite. Secondary white mica and kaolin, together with magnetite and some leucoxene, are also present.

## MIOCENE.

### DIABASE AND BASALT.

*Distribution.*—Diabase and basalt are among the most important of the igneous rocks of the Santa Cruz quadrangle. The exposures of the diabase have been traced for a distance of approximately 32 miles in a generally southeasterly direction from a point near the San Mateo-Halfmoon Bay road, on Pilarcitos Creek, in San Mateo County, to a point on the headwaters of Lompico Creek, 4 miles east of the town of Boulder Creek, in Santa Cruz County. There is also a basaltic outflow exposed near Stanford University, which is probably closely related genetically to the diabase. The largest exposed areas of the diabase are in the vicinity of Langley and Mindego hills east of La Honda, and on the ridges between the headwaters of Pescadero Creek and San Lorenzo River. The region of igneous intrusion presents at the surface a chain of more or less connected patches of diabase, extending approximately parallel to the coast, and also parallel to but southwest of the major axis of the Santa Cruz Mountains. The continuity of the dikes is hidden by overlying strata and by dislocated masses of country rock and soil to such an extent that the exact relations of the various facies are difficult to ascertain.

*Relations to other formations.*—The diabase proper breaks through beds of Vaqueros (lower Miocene) and possibly Monterey (middle Miocene) age, while the associated diabase tuff is interbedded with strata containing a typical Vaqueros (lower Miocene) fauna and lies below the Monterey shale. The basalt outflow exposed near Stanford University overlies and metamorphoses beds of lower Miocene age, and is overlain by beds containing a fauna believed to be well down in the upper Miocene. This evidence indicates the middle Miocene age of the basalt and its probable contemporaneity with the diabase of Mindego and Langley hills. Both the intrusive diabase and the tuff are in many places overlain by the Purisima (lower Pliocene) strata, which show a distinct erosion line at their base, and also often by a basal conglomerate made up of diabase pebbles. An uplifted mass of impure limestone containing a fauna that indicates its probable lower Eocene age occurs in the diabase area between the headwaters of Pescadero Creek and San Lorenzo River. This limestone has been described in a previous paragraph. (See p. 3.)

The masses of diabase follow the bedding, particularly in the shale of the lower Miocene, and it is between shale beds that most of the diabase exposures occur. There are some very striking exceptions to the sheetlike occurrences of the diabase, but in general the ready parting of the shale along the bedding planes seems to have offered the line of weakness which the intrusive rock followed. Inclusions of sandstone and shale are plentiful and vary from pieces the size of a walnut to masses weighing hundreds of tons, but no alteration of the sandstone has been noted, except in the beds underlying the basalt near Stanford University. Some well-preserved vertebrate bones and teeth (*Oxyrhina tumula* Agassiz) were found in a sandstone inclusion 2 feet in diameter about one-half mile north of the Alpine schoolhouse. The inclusions of shale are usually somewhat metamorphosed, but the metamorphism is not radical, changes in color and texture being the chief phenomena. An inclusion of shale 4 inches thick, metamorphosed to a hard, brittle flint, was found in the diabase on Oil Creek. Similar occurrences were noted at several other localities in the quadrangle.

Studied in the field the formation presents three facies. One is the diabasic, the second the basaltic, and the third the tuffs. The distinction between the diabasic and the basaltic is made purely on the physical appearance of the two. No great chemical difference exists, but the crystallization, color, texture, and manner of weathering are so radically different that, while no separation is attempted on the map, a distinction is necessary in describing the rocks microscopically. Small dikes of diabase younger than the large masses intrude certain of the principal diabase dikes.

*Diabase.*—The diabasic rock seems to be confined to the masses which make the north and east boundaries of the area between the south fork of Tunitas Creek on the north and Langley Hill on the south. The rock is well exposed near the summit of the ridge on the road which crosses the range 2½ miles south of Sierra Morena. Here the course of the dike is plainly marked by the large rounded bowlders on the hillsides. The rocks weather in such a way as to give particular prominence to the feldspars, causing the mass to present the appearance of a gabbro. The soil derived from its disintegration closely resembles granite soil. It is made up of granular particles having a slight reddish tint and varying in diameter from one-fourth inch to one-sixteenth inch.

The diabasic rock is a medium-grained light-gray crystalline aggregate in which three components are very readily distinguishable. One, augite, is present in dark patches intruded by the others and showing distinct glistening cleavages. Magnetite can be detected in large flat plates and smaller grains dark and lustrous. The most evident component is the feldspar. It occurs in long, white, rodlike crystals, giving a reticulated appearance to the mass; it is banded and contains inclusions of magnetite and augite.

In thin sections the rock is seen to be composed of the following principal constituents, given in the order of their crystallization: Magnetite, ilmenite, apatite, olivine, feldspar, augite, and analcite. The last is never present as an original constituent, so far as could be determined, but is certainly in many cases, and probably in all cases, a secondary product. Of the secondary minerals, serpentine, chlorite, iron ores, calcite, and natrolite have been noted.

*Basalt.*—The basaltic rocks differ from those of diabasic habit in that they are dark and show the white feldspars indistinctly, the predominating crystals being augite and olivine. The finer-grained varieties make up the tuffs and some of the dikes of the Langley Hill–Mindego Hill igneous area. Many of them are amygdaloidal, and cavities of considerable size are frequently encountered. One cavity filled with quartz measured 4 inches along its greatest diameter. Calcite, chalcedony, and serpentine fill the cavities in many localities, and on Bogess and Harrington creeks basalt in place was found with its vesicles filled with petroleum. An interesting occurrence is the presence in many places of nests of glassy analcite crystals, filling the amygdaloidal cavities and joints and seams in the rock. In thin section the basaltic facies of the igneous mass presents a more difficult problem than the diabasic, because it is universally more weathered. The typical section shows a few phenocrysts of olivine and augite in a fine-grained groundmass of lath-shaped feldspar, microscopic augite and olivine, ilmenite, magnetite, and the secondary products, calcite, serpentine, chlorite, iddingsite, iron oxides, natrolite, and analcite.

### TUFF.

The tuffs associated with the diabase are confined to the Langley Hill–Mindego Hill igneous mass, of which they form the major portion. Within this area are also found diabase, of both the diabasic and the basaltic kinds, limestone beds, limestone dikes, shale, and sandstone. It is to be regretted that all of the rocks within this area can not be differentiated on the map, as their areal distribution would throw much light on the structure of the territory within which they occur. Beds of sandstone containing a typical Vaqueros (lower Miocene) fauna (given previously) are found between layers of the tuff, while the shale containing *Pecten peckhami,* when associated with the tuffs, is always found above them. This places most of the tuffs in the Vaqueros, with a possibility of their extending into the Monterey (middle Miocene). Basaltic layers are found in such relation to the tuff as would indicate the contemporaneity of the two. This theory is strengthened by the fact that this characteristic basaltic facies, with the exception of the outflow near Stanford University, has been found only within the Langley Hill–Mindego Hill igneous area, to which the tuff is confined. The true diabase is later than the basaltic facies and associated tuffs, as it is intrusive both in the tuffs and in shale beds overlying them. The Purisima formation overlies unconformably both the tuffs and their overlying shale beds.

The tuffs vary in composition from coherent aggregates of basaltic diabase fragments to almost pure limestone, sandstone, and shale, depending on the conditions under which they were formed. The observed fragments of igneous rock are composed of the basaltic facies of the diabase. This is to be expected, as the extrusive forms of the rock would naturally be finer grained than the intrusive ones. The material in which the fragments of igneous rock are embedded is generally more or less limy, showing that the fragments were deposited in water at least deep enough to be the habitat of lime-forming organisms. The theory that most of the tuffs were deposited in comparatively deep water is strengthened by the fact that the fragments in most of the beds are angular, which would not be the case had the tuffs been deposited near enough the surface of the water to be affected by the action of the waves. In one case, however, a 20-foot bed of tuff composed of waterworn fragments was seen interbedded with the angular material.

Typical tuff is found in thick beds all along the southwestern side and part of the northeastern side of the Langley Hill–Mindego Hill igneous area. The fragments composing the tuff are of dark-colored basaltic diabase, angular in outline and varying in size from the smallest grains to large masses weighing several hundred pounds. The thin sections of these fragments show them to be badly weathered, a few feldspars, a little augite, and the magnetite and ilmenite being the only recognizable original constituents. The fragments are embedded in a limy matrix, varying in composition from pure limestone to a limy shale. Spheroidal weathering of the tuffs was noticed in one or two instances. Small organic remains are often found associated with the rock fragments in some of the more limy tuffs. Much, and sometimes all, of the lime occurs in a secondary form, as veins of calcite surrounding the fragments or cutting through the tuff. Pure calcite crystals weighing several ounces are sometimes found in the tuff. This calcite is derived principally from the original lime beds in which the tuff was deposited, but a little of it may come from a weathering of the feldspars of the basaltic fragments. Patches of isolated calcite are also found in most of the sections of both the basaltic and the diabasic rocks.

## CLASTIC DIKES.

### LIMESTONE DIKES.

One of the most interesting phenomena in the Langley Hill–Mindego Hill igneous area is the occurrence of limestone dikes in the tuff beds. The best exposures of these dikes are found in the ridge to the north of the Langley ranch house. Fig. 1 shows a transverse section and fig. 2 a longitudinal section of this ridge. Similar dikes occur in the tuff which makes up the ridge running southeast from the top of Langley Hill, and also in the tuff exposed along the Searsville–La Honda road north of La Honda.

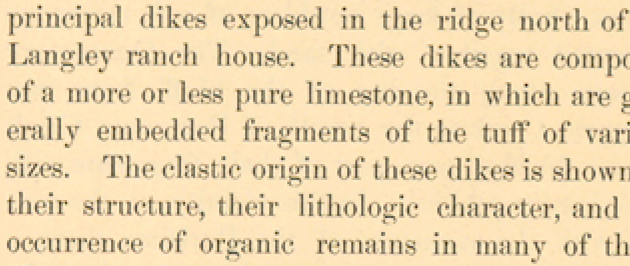


FIG. 1.—North-south section through the Langley ranch, north of Langley Hill, showing the stratigraphic relations of the limestone beds to tuffs and Miocene shales.

Fig. 2 shows the relative position and size of the principal dikes exposed in the ridge north of the Langley ranch house. These dikes are composed of a more or less pure limestone, in which are generally embedded fragments of the tuff of various sizes. The clastic origin of these dikes is shown by their structure, their lithologic character, and the occurrence of organic remains in many of them. The dikes vary in width from a fraction of an inch to more than 30 feet, and in length from a few inches to at least 150 feet. Some of them show a kind of flow structure; and a few of them show two systems of joint planes at right angles to each other and both perpendicular to the surfaces of the dikes. The surfaces of the dikes are irregular, giving a more or less wavy line in section, but the planes of

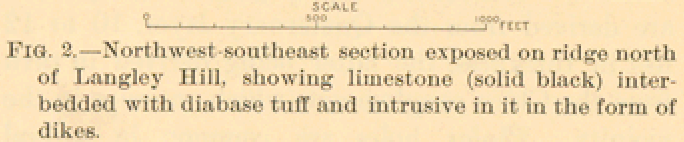


FIG. 2.—Northwest-southeast section exposed on ridge north of Langley Hill, showing limestone (solid black) interbedded with diabase tuff and intrusive in it in the form of dikes.

contact of most of the dikes are approximately perpendicular to the bedding planes of the tuff and interbedded calcareous layers. Some of the dikes extend into the diabase which has intruded the tuff beds. Chalcedony, quartz, and calcite form veins and fill cavities all through the tuff, the calcareous tufa beds, and the limestone dikes. The minerals deposited from solution are of later origin than the limestone dikes.

The origin of the limestone dikes is easily accounted for, when the relations of the containing and associated terranes are considered. The series of beds in which the dikes occur north of the Langley house have an upward sequence of sandstone, tuff, calcareous shales, and then alternating thick beds of tuff, comparatively thin beds of limestone, and calcareous tuff, the whole capped by sandy tuff, above which are shale and sandstone beds. (See fig. 1.) Soon after the deposition of this series, and before the tuffs and limestones had become very coherent, diabase was intruded between the lower sandstone layer and the overlying tuffs. The intrusive sheet fractured the tuff along lines approximately perpendicular to the bedding planes of the series, and the unconsolidated ooze and calcareous tufa of the interbedded layers flowed into the fissures, thus forming the dikes.

### SANDSTONE DIKES.

A number of sandstone dikes occur at the bituminous rock quarries 6 miles northwest of Santa Cruz, and also along the coast line from 5 to 13 miles west of that town.

*Dikes at rock quarries.*—The dikes at the bituminous rock quarries are all composed of bituminous sand, and their connection with the underlying beds from which they have been derived can be clearly seen in nearly all cases. (See fig. 3.) The bituminous rock itself is plastic under a gentle continuous pressure, but is brittle to a blow.

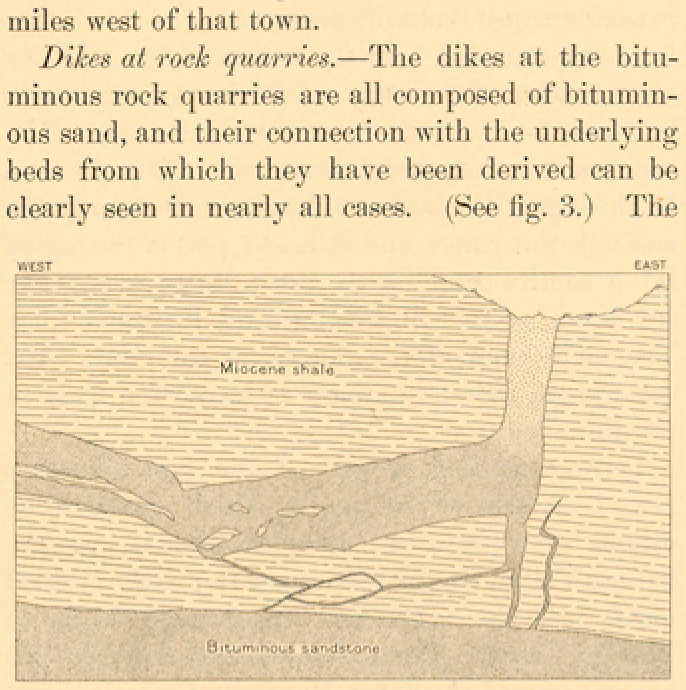


FIG. 3.—Bituminous sandstone dike intruded in Miocene shale overlying bituminous sandstone bed, north end of the Point quarry of the City Street Improvement Company, 6 miles northwest of Santa Cruz. Height represented in sketch is about 50 feet.

In thickness the dikes vary from mere films along joint planes to intruded masses 10 feet thick. Some of the thinnest of the intrusions composed of bituminized sands follow joint planes for 30 or 40 feet from the parent sandstone bed below. In some instances the dikes branch and the branches again coalesce.

*Dikes along the coast.*—Most of the sandstone dikes outcropping along the coast line occur in the white diatomaceous shales from the mouth of Baldwin Creek, 5 miles west of Santa Cruz, to the mouth of Respini Creek, 8½ miles west of that city. One dike occurs at the mouth of Scott Creek, 13 miles west of Santa Cruz. It is believed that most of the dikes along the coast were derived from sand beds which underlie the shale in this region. They are composed of both bituminized and unbituminized sands, and vary in size from mere films an inch or less in thickness to sand masses as much as 600 feet across. The dike near the mouth of Baldwin Creek, which has several minor branches, and the larger one near Laguna Creek are shown on illustration sheet I. Three of the larger sandstone dikes will be described.

At a point half a mile northwest of the mouth of Laguna Creek there is a dike of soft yellowish-gray and brown sandstone. The sand mass is exposed for 225 feet along the bottom of the sea cliff, which is about 50 feet high. (See fig. 10, illustration sheet I.) At its east end the mass cuts through shale to the top of the cliff in a chimney-shaped mass 40 feet across. Throughout this mass of soft sand are irregular wavy bands indicating flow structure. The sandstone is practically free from the odor of bitumen. The line of contact between the adjacent overlying shale and the sand at the west end of the exposure is irregular. Dikes of shale occur in the sand mass near the west end of the exposure.

The largest of the sandstone dikes along the coast occurs at the mouth of Respini Creek, having an exposed width of 600 feet along the sea cliff and extending one-fourth of a mile inland. It is composed of rather fine-grained yellowish-brown and gray sand, free from bitumen. The sandstone varies from soft, friable, semisolidified material, from which the cementing material, if ever present, has been leached, to a hard, compact stone. The surface of the intrusion is much pitted by the action of the waves and by the weather and is broken by many joint planes. At places it presents a peculiar wavy banded structure, some of the bands being harder than others. The hardness of some of the thin layers that resist the action of the weather is apparently due to iron oxide as a cementing material. At other places there are groups of vertical columns of hard, gray, jointed sandstone, extending to the top of the cliff. Adjacent to these columns, of which there are many groups, the sandstone of the dike is soft and has the peculiar wavy banded structure mentioned above. The wavy layers exposed in this dike strongly suggest flowage of the sand in a liquid medium, and the columns are apparently the filled necks of channels through the sand mass, through which liquids and sands were forced up from below and around which the sands were deposited, thus finally building up the entire mass of the dike.

Just north of the mouth of Respini Creek is a large V-shaped sandstone intrusion, with a width of 190 feet at the top of the sea cliff, which is 45 feet high, and a width of 30 feet at the bottom. It is composed of light-brown and gray sandstone in alternating layers or bands varying in thickness from 1 to 2 or 3 inches. The entire surface is given a rough and pitted appearance by the leaching away of one or the other sets of these layers, at some places the brown layers proving the softer, at other places the gray. Some of the sand layers have a very faint bituminous odor, but the intrusion for the most part is free from that substance. The sand layers slope toward the center of the exposure, forming a trough, with a smaller trough at the west side.

It is noticeable that the larger dikes along the coast west of Santa Cruz are comparatively free from bituminous matter, while most of the smaller ones, and especially those which do not extend to the top of the sea cliff, are highly charged with it. Most of the dikes of this region were undoubtedly intruded from below.

*Origin of dikes.*—The underlying sandstones were probably at one time oil bearing, as indicated by their bituminous outcrops at the asphalt rock quarries and elsewhere in the district. They are at present practically barren of petroleum wherever they have been penetrated by borings. The bituminized sands of the smaller dikes along the coast lead to the conclusion that the former oil-bearing sands were forced into joints in the shale and that the residues from the oil entrapped with the sands in these crevices are still found in the dikes. The larger crevices probably formed the avenues of escape for the petroleum (provided it was originally present in the underlying beds), and afterward for the water of the underlying sands, the sands being at the same time carried up into the crevices. The escaping water must have removed the oil and oil residues if such were ever present in the dikes.

## STRUCTURE.

### GENERAL STATEMENT.

The structure of the Santa Cruz quadrangle is complex. In many places the strata are intensely folded, faulted, and crushed. The dense growth of timber and underbrush over much of the area, and especially over the more complex part of it, makes the working out of the detailed structure impossible. The structure is further obscured by the thick covering of soil and by landslides, which are common in the regions of the greatest faulting and folding. Observations for determining the structure over much of the area can be secured only in the stream beds, and it is often impossible to connect the structures exposed in parallel streams only a mile or two apart. For these reasons it has not been possible to work out all the minor details of structure in the quadrangle. The major structural lines, however, are fairly well determined.

Attention should be called to the fact that the faults shown on the map rarely occur as well-defined lines of fracture, but are rather in the nature of faulted and crushed zones varying in width from a hundred feet to a quarter of a mile or more, and it is therefore difficult to represent them correctly on the map.

Faulting, folding, and crushing have doubtless been going on in the area under discussion since early geologic times. The oldest sedimentaries exposed—the metamorphics of Ben Lomond Mountain and the Franciscan rocks—have been crushed into intricately folded and faulted masses, the details of structure of which it is impracticable to work out. It is impossible to say with certainty at what date the folding and crushing occurred, but much of it probably was prior to Eocene or Miocene time.

The Cretaceous rocks likewise bear evidence of intense crushing, much of which probably occurred before Eocene time. The Oligocene and Miocene strata extending southeast-northwest through the central part of the quadrangle have been intensely crushed and folded. Thus there was a post-Miocene period of intense movement, which was the last period of intense folding and faulting, for the Pliocene strata do not show evidences of so intense movement as do the older formations. The post-Pliocene movements have been in the nature of uplifts and gentle folds with considerable faulting, as an inspection of the structure sections will show.

There seems to be no reasonable doubt that the major fault lines of the quadrangle were established at least as early as the end of the middle Miocene time, and probably much earlier. It appears probable also that various movements have occurred along these lines, and that fault blocks that have been uplifted at one time have at another time been depressed along the same line.

The faulting and folding have been most intense along the main northwest-southeast dividing ridge of the quadrangle. This dividing ridge has been the main axis of movement in the Santa Cruz Range. The rocks along and near the crest of the ridge are invariably much folded, faulted, and crushed. Away from the ridge toward both the northeast and the southwest, the evidences of movement become less pronounced. Much folding and faulting have also occurred in the Miocene and older rocks in the region north of Ben Lomond Mountain, and also northeastward between that mountain and Castle Rock Ridge.

### FAULTS.

Innumerable small faults occur in the Santa Cruz quadrangle, but the nature of the rocks, the thick covering of soil usually to be found, and the dense growth of underbrush make it impossible to trace them out in detail, and therefore no attempt is made to map any except the larger and more important fractures which have had a controlling influence on the topography or on the distribution of the strata. The principal faults of the quadrangle are thought to be, for the most part, reverse faults, as is to be expected in a highly folded region, or faults along which the movement has been largely horizontal.

There are two systems of faulting in the quadrangle, viz, that which may be called the major fault system, to which the San Andreas, San Gregorio, and Butano faults belong, and the minor fault system, to which belong the faults along the west slope and near the top of Castle Rock Ridge, and also the Zayante fault. The nature and effect of of these faults is shown in the structure sections. The major faults (with the exception of the north end of the Ben Lomond fault) have directions N. 20°–45° W., while the minor faults trend N. 60°–75° W.

The most important structural feature of the quadrangle is the great fault passing through Portola. This fault, which extends many miles beyond this quadrangle and is known throughout its length as the San Andreas fault, enters the north side of the quadrangle in the valley occupied by Crystal Springs Lake and passes southeastward across the area to the center of the eastern boundary about 5 miles southeast of Saratoga. It is locally referred to as the Portola and the Stevens Creek fault. At some places it is made up of two or more parallel fractures; at other places it forms a highly crushed zone half a mile wide A series of northwest-southeast valleys has been formed along the fault line. Crystal Springs Lake lies in the San Andreas fault valley, while the valleys of West Union Creek, Corte de Madera Creek, and Stevens Creek all follow the fault. Its effect on the topography is very marked for many miles both to the northwest and to the southeast of the Santa Cruz quadrangle.

From the northern edge of the quadrangle to the head of Stevens Creek this fault consists of at least two more or less parallel fractures from half a mile to a mile apart. (See sections A–A and C–C.) Between these fractures a long, narrow block has been dropped, letting down the Quaternary gravel into the troughlike depression which is bordered on the southwest by Miocene and on the northeast by Cretaceous and Franciscan rocks.

The San Andreas fault forms most of the dividing line between the Tertiary rocks to the southwest and the Cretaceous and Franciscan rocks to the northeast. It appears probable that this fault line has been a line of weakness since early Tertiary time and perhaps since pre-Tertiary time. While many movements have probably occurred along it, sometimes with the downthrow on the east side and sometimes on the west, the sum total of these movements has resulted in an uplift on the east with a downthrow on the west. It appears probable, however, that the latest movement along this line has been one in which the rocks on the east side of the fracture have gone down.

The total uplift on the east is not known. Judging, however, from the thickness of Tertiary rocks on the west which are not represented on the east side of the fracture, the displacement must be several thousand feet. (See section D–D.) Some minor fractures branch off from the San Andreas fault at acute angles.

The earthquake of April 18, 1906, is supposed to have been caused by a movement that took place at that time along the San Andreas fault. The displacement was chiefly horizontal, amounting to a maximum of 8½ feet within this quadrangle, the northeast side moving relatively toward the southeast. At several places there were evidences of vertical displacement of from 1 to 3 or 4 feet, but these appear to have been due to purely local conditions. The intensity within the area was as high as IX½ of the Rossi-Forel scale on the fault line, but it fell away rapidly on both sides. Through the Santa Cruz Mountains to the west the intensity fell to VI½, and even as low as VI near the coast northwest of Santa Cruz. In the low grounds in Santa Cruz the intensity rose again to VIII or more, and at Halfmoon Bay it rose to IX in the loose ground upon which the town is built. On the northeast side of the fault the intensity fell away quite as rapidly as it did on the southwest, so that the intensity was only about VII½ at a distance of 2½ miles from the fault line. On reaching the loose materials of the flat valley floor, however, the intensity rose abruptly to IX. This line of high intensity passes through San Mateo, Belmont, Redwood City, Stanford University, and most of Mountain View, and passes off the east side of the quadrangle directly east of Saratoga. East of this line of high intensity the intensity falls rapidly, so that along the west side of the Bay of San Francisco it was only VII½. A detailed statement of the data collected in this area is given in the report of the State Earthquake Investigation Commission.

Another northwest-southeast fault with the downthrow on the west side and a displacement of several hundred feet occurs along the west slope of Cahil Ridge. (See sections A–A and C–C.) This fracture is in a general way parallel with the San Andreas fault, and is along the same general line of weakness.

Running almost parallel with the San Andreas fault, but from 12 to 15 miles southwest of it, is the San Gregorio fault, with the upthrow on the northeast side. (See sections C–C and D–D.) This fracture is exposed on the coast line 1½ miles northwest of San Gregorio, and, running to the southeast, it strikes the coast again at Año Nuevo Bay. In the region between Pescadero and San Gregorio creeks it brings the uppermost Purisima strata in contact with the lower beds of that formation, a displacement of somewhat more than 2000 feet, and farther southeast it brings the uppermost Purisima beds in contact with the Monterey shale.

Three other faults of importance have been traced—the Ben Lomond fault, the Butano fault, and the Zayante fault. In the first two of these the downthrow is on the northeast side of the fracture, while in the Zayante fault the downthrow is on the southwest side.

The Ben Lomond fault skirts the east and north sides of Ben Lomond Mountain for a distance of 15 miles, and is the fracture along which the Ben Lomond Mountain block was tilted up. (See sections E–E, F–F, and G–G.) At its southeast end the displacement is only a few hundred feet, but at the north end of Ben Lomond Mountain the displacement appears to be over 2000 feet. To the uptilting of the Ben Lomond block at the east and north is due the bold escarpment of that mountain on those sides, and likewise its comparatively long and gentle slope toward the southwest.

The Butano fault lies immediately northeast of Butano Ridge through its entire extent. (See sections D–D, E–E, and F–F.) It crosses San Lorenzo River 5½ miles north of the town of Boulder Creek. Thence it appears to follow a highly crushed belt of the San Lorenzo strata, toward the southeast. Pescadero Creek has cut out its valley along the crushed zone of the Butano fault from its headwaters to the northwest end of Butano Ridge. The Butano fault cuts diagonally across the region lying between the San Andreas and the San Gregorio faults, and approaches both of those fractures at an acute angle. The downthrow is on the north side of the fracture, and where the fault crosses San Lorenzo River the displacement appears to be over 2000 feet.

The Zayante fault extends from a point near the town of Boulder Creek slightly south of east to the eastern edge of the quadrangle, in the valley of Zayante Creek. (See section G–G.) The crushed zone along this fracture is exposed along Love, Newell, and Lompico creeks and the north fork of Zayante Creek. The downthrown block is southwest of the fracture. Data for the estimation of the displacement are lacking; but the crushed and disturbed nature of the strata along the line of fracture indicates that the movement has been considerable.

### FOLDS.

As has been remarked, the folding over much of the quadrangle has been intense and in many places it is impossible to determine the structure in detail. The major folds, however, have their locations and characters shown in the cross sections. They have practically parallel axes with a general direction of about N. 60° W. These axes of folding are nearly parallel with the lines of the minor faults (the Zayante, Butano, and Castle Rock Ridge faults), but they are cut across diagonally by the San Andreas, the San Gregorio, and a part of the Ben Lomond faults.

The older rocks of the quadrangle are invariably much more crushed and folded than the newer, and there is little doubt that folding and faulting have been going on more or less continuously since pre-Cretaceous time. But little is known of the axes of the folds which were produced prior to the Tertiary; whether these were in a general way coincident in position with the Tertiary axes is not known.

Three uplifts with accompanying folding and faulting occurred in Tertiary time. The main axes appear to have been along the same general northwest-southeast lines during each of these periods, but they did not coincide in all cases, as is seen west of Big Basin and at the west end of Butano Ridge, where the Monterey shale, with a general westward dip, overlaps the upturned edges of the San Lorenzo and Butano formations, which are folded along northwest-southeast axes.

The series of Chico strata from the mouth of Pescadero Creek to Año Nuevo Point have been folded along northwest-southeast axes, in a general way parallel to the axes of folding of the Tertiary strata farther east.

Fairly well defined folds occur between the crest of Castle Rock Ridge and Ben Lomond Mountain. (See sections E–E, F–F, and G–G.) Castle Rock Ridge itself is made up, in its most prominent part, of an overturned anticline with an accompanying syncline, as indicated on sections E–E and F–F. The strata between the Castle Rock Ridge and the Butano fault generally stand at high angles. Southwest of the Butano fault is a series of anticlinal and synclinal folds with northwest-southeast axes. The most important of these is the Butano anticline, which is well defined from the northwest end of Butano Ridge to Lompico Creek, a distance of 18 miles.

The later Tertiary formations that border the coast line from Santa Cruz to Halfmoon Bay, the Monterey and the Purisima, are generally but slightly folded. In a general way the beds of these formations dip gently toward the sea. (See sections E–E, F–F, and G–G.)

The axes of the folds lying between Ben Lomond Mountain and the Butano fault and its southeastward continuation pitch to the southeast, as is plainly shown by the areal geology map and cross sections D–D to G–G. The axes of the chief folds between the Butano fault and Castle Rock Ridge, Mindego Hill, and La Honda pitch to the northwest, as shown in sections C–C to F–F. Along the southwest slope of Ben Lomond Mountain is a monoclinal fold, the axis of which is approximately horizontal. In the northern portion of the quadrangle (except in the Purisima area, noted above) and in the region of the older rocks lying immediately east of the San Andreas fault, the structure of the Tertiary and older rocks is obscure and the positions of the axes of the folds occurring there are not known.

Movements in the nature of uplift or depression with little or no deformation took place at various times. These are treated under the next heading, "Geologic history."

Metamorphism has affected the Franciscan formation through its entire range, but the causes of this metamorphism and its exact character are little known. This subject is discussed more fully in the section relating to the Franciscan formation (p. 2).

## GEOLOGIC HISTORY.

### PRE-FRANCISCAN TIME.

The oldest rocks exposed in the Santa Cruz quadrangle appear to be the schist, white marble, and other metamorphosed sedimentary rocks which lie upon the quartz diorite in the region northwest of Santa Cruz. The age of these rocks is unknown; it is safe to say, however, that they are very old, and may have been deposited in Paleozoic or pre-Paleozoic time. They are believed to be older than the Franciscan, though in the Santa Cruz quadrangle no Franciscan rocks are found lying upon them. It seems probable that after these strata were deposited in the sea they were intruded by the quartz diorite mass which makes up Ben Lomond Mountain, and were greatly disturbed and metamorphosed. This intrusion is therefore believed to be the second important event of which there is a record in the quadrangle.

After the intrusion of the quartz diorite an uplift occurred and most of the metamorphosed sediments were removed, leaving only a few remnants of limestone and schist. How long this erosion interval lasted is unknown. The rocks deposited upon the quartz diorite and metamorphic rocks are of Tertiary age; a hiatus and an unconformity therefore constitute the only record of the time between the intrusion of the diorite and the deposition of the Tertiary beds in the region of Ben Lomond Mountain.

The oldest unmetamorphosed rocks resting against the quartz diorite are massive sandstones of supposed Oligocene age at the north end of Ben Lomond Mountain. The Miocene rests upon the quartz diorite and metamorphosed sediments on its southern and western slopes. This area was therefore either a land area up to the Tertiary period or else was uplifted and had lost by erosion its pre-Tertiary sediments, except the metamorphic rocks above referred to.

### FRANCISCAN TIME.

The area of Franciscan rocks exposed in the Santa Cruz quadrangle is too small and the geology too complex to afford any clear conception of the physical geography and history of that period. The rocks of the series—jasper, limestone, metamorphic sediments, and eruptives—occur in such confusion, so faulted, altered, and decomposed, that their sequence has not been clearly made out. The jasper and limestone are contemporaneous, and as the limestone contains the remains of Foraminifera the two rocks must be marine deposits laid down in waters of moderate depths.

### CRETACEOUS TIME.

So far as we now know, Cretaceous time is represented in this quadrangle only by rocks of Knoxville and Chico age. The Knoxville sediments are conglomerates, sandstones, and shales. The abundance of pebbles of jasper and eruptive rocks in the Knoxville basal conglomerates shows that the land areas were to a considerable extent made up of Franciscan eruptives and jaspers. Facts gathered through the Coast Ranges suggest that during the time of the deposition of the Knoxville beds the region now lying between the Sierra Nevada and the ocean was a sound or series of sounds containing islands—a region somewhat like that along the present southern coast of Alaska and British Columbia. About the islands and along the shores the pebbles and bowlders of the conglomerate beds were worn and deposited, and subsequent depressions were followed by deposits of sands and clays.

### TERTIARY TIME.

The Tertiary strata appear to rest unconformably upon all older strata in the quadrangle, and an erosion interval and deformation must therefore have occurred between Cretaceous and Tertiary time in this area.

With the exception of the diatomaceous shale, which was probably formed in comparatively deep and clear water, the Tertiary sediments of the quadrangle consist of sandstone, conglomerate, clay shale, and gravel. These deposits indicate near-shore conditions, and the thickness of the Tertiary strata indicates a plentiful supply of sediment. At least three uplifts with accompanying folding, faulting, and erosion, followed by subsidence, occurred during the Tertiary.

At the beginning of Tertiary time land masses were probably in existence northeast of the San Andreas fault, southwest of the San Gregorio fault, and southwest of the Ben Lomond fault. Whether these areas were islands or were connected with a large land mass is not known; they must have been of considerable size, however, to supply the great thickness of sediments which was derived from them. An arm of the sea or an embayment extended between these three land areas. In this body of water limestone of Eocene age, the Butano sandstone (supposed Oligocene), the San Lorenzo shale (Oligocene), and the Vaqueros sandstone (lower Miocene) were deposited, all (except possibly the Eocene) in conformable sequence.

*Post-Vaqueros uplift.*—After the deposition of the Vaqueros sandstone at least a portion of the region appears to have been raised, and was probably folded and faulted; in parts of the area considerable erosion appears to have taken place.

*Pre-Monterey subsidence.*—After the lower Miocene erosion a subsidence occurred, causing the region between the San Gregorio and San Andreas faults to sink beneath the sea. It is possible that the area west of the San Gregorio fault also sank beneath the sea at this time. During this period of submergence the Monterey diatomaceous shale was deposited over much of the area, indicating that open-sea conditions prevailed.

During this time there was an active volcano in the region where Langley Hill now stands. The sea on the southwest extended a little east of the present site of the village of La Honda. The volcano was not far from the seashore, and from this poured out streams of lava, while enormous quantities of volcanic cinders were thrown into the air. Some of the cinders fell into the sea, some fell on the land, and others fell on the shore, where the angular fragments were worn by the waves. After the cessation of this volcanic activity the diatomaceous silts again began to accumulate over the sea floor.

During probably late Monterey time there was a volcano in what are now the foothills 2 miles south of Stanford University. This volcano was near the sea and some of the cinders from its craters fell into the water. A sheet of lava flowed about 3 miles toward the northwest and stopped near Menlo Heights. Some of this lava flowed over the bottom of a shallow sea, possibly over mud flats, for in its movement it gathered up and squeezed into cracks in its lower side soft mud filled with marine shells. The excavation for a reservoir on the hilltop south of Stanford University was made in the lava, and in the bottom fossiliferous sediments were found in the cracks of the eruptive. Near the ancient crater the lava is 400 feet thick; where it is cut through in a well on Menlo Heights its margin is only 20 feet thick.

These lavas, and indeed the craters themselves, sank slowly beneath the Miocene sea and were soon afterward covered by sediments mingled with the shells of marine mollusks.

*Post-Monterey uplift.*—The next event of importance was the uplift of the submerged area. This was accompanied by much folding, faulting, and crushing in the region near Cahil and Castle Rock ridges and between Ben Lomond Mountain and Castle Rock Ridge, but the region southwest of the Ben Lomond fault was not much folded at this time. During this period many diabase intrusions occurred along the line of the main dividing ridge, those of most importance being near Langley and Mindego hills. The Monterey or post-Monterey uplift was followed by a considerable period of erosion.

*Purisima subsidence.*—The post-Monterey erosion was followed by a subsidence, during which the Purisima sediments were deposited along a sinking shore, forming an overlapping series. This overlapping of the older sediments by the newer ones toward the ancient shore line is especially noticeable in the region north and northwest of Purisima Creek. The extent of the Purisima subsidence is unknown. It seems probable, however, that the Purisima sediments never extended far beyond the present mapped limits of that formation. Had they formerly extended over the entire region, it seems almost certain that outliers of Purisima strata would be found far removed from the main areas. The conclusion is therefore drawn that Cahil and Castle Rock ridges, Ben Lomond Mountain, Butano Ridge and adjacent ridges, and at least a part of the region lying southwest of Castle Rock Ridge were above sea level, in part at least, during Purisima time. The main lines of the ranges in the Santa Cruz quadrangle therefore appear to have been fixed in pre-Purisima time.

During at least a part of the post-Monterey period an arm of the sea, in which unique conditions were prevalent, occupied what is now the Salinas Valley, south of Monterey Bay, and extended north into the Santa Cruz quadrangle as far as Boulder Creek. The sediments laid down in this bay are termed the Santa Margarita formation, and probably represent late middle Miocene time. The relation between this bay and the waters in which the lower portion of the Purisima were deposited is not known.

*Post-Purisima uplift.*—At the end of Purisima time occurred an uplift which appears to have been accompanied by little intense folding. The Purisima beds generally, while considerably faulted and folded, have not been subjected to the great folding and crushing which the pre-Purisima rocks have undergone.

It is possible that the adjacent land areas were worn down nearly to base level during Purisima time. Cahil Ridge presents an even sky line that suggests a peneplain surface. The westward slope of Cahil Ridge is somewhat gradual, but is so dissected that whether or not it is a tilted peneplaned block can not be stated. If reduction toward base-level did occur in Purisima time the peneplain then formed was broken up by later faulting, especially along the line of the San Andreas, Butano, and Ben Lomond faults.

So far as we know, the most important of these movements were along the lines of the San Andreas fault zone. On the west side of this fracture, which extends many miles to the northwest and southeast, a great block of the region was uplifted. It was probably at this time that a partial barrier was formed across the outlet to the sea of the drainage from the Sacramento and San Joaquin valleys, causing these streams to form an inland fresh-water lake or series of lakes in what is at present San Francisco Bay and Santa Clara and adjacent valleys. Fresh-water conditions also extended to and partly filled the Sacramento and San Joaquin valleys. Evidence of this fresh-water body is found in the fresh-water fauna of the gravel, clay, and sand that flank the Santa Cruz and Mount Hamilton ranges. This fresh-water lake in all probability extended southeastward from the Santa Clara Valley to the San Benito Valley. It appears probable that during the post-Purisima uplift the west side of the fault block east of the San Andreas fault was raised and helped to form the watershed between the inland fresh-water sea and the ocean.

Fresh-water lakes were extensively formed elsewhere in the Coast Ranges at about this period. Such a large lake existed in the middle and upper Salinas Valley, taking the place of the bay in which the Santa Margarita formation was laid down.

### QUATERNARY TIME.

*Subsidence.*—At the end of the period of uplift above referred to, which probably extended well into the Quaternary, a general subsidence of the region took place, accompanied by faulting and considerable folding. Probably the faulting at this time was chiefly along the old lines of weaknesses. At this period the gravels which had been formed in the preceding epoch were more or less folded. The strip of gravel extending along the line of the San Andreas fault from Crystal Springs Lake to the west side of Black Mountain—halfway across the quadrangle—was probably faulted into its present position at this time.

At some places the land area sank from 1500 to 2000 feet lower than it is at present. On Ben Lomond Mountain there are undoubted remnants of wave-cut terraces up to an elevation of 1500 feet, and what are believed to be terrace remnants up to as least the 2000-foot level. Whether this depression affected the whole area of the quadrangle is not known.

The outlets which were being cut down from the inland lakes to the sea prior to this subsidence were submerged and the region of the Santa Clara Valley and some of the adjacent valleys became inland salt-water bodies.

*Uplift and oscillations.*—At the end of the subsidence in the Quaternary period uplift again occurred, and the coast region was in part at least lifted to a higher plane than it now occupies. This uplift was by stages, as is attested by the series of wave-cut terraces exposed at many places along the coast. Following this elevation was a slight sinking of the shore line, as is attested by the submerged and filled-in valleys which open seaward along the coast from Pescadero Creek to Santa Cruz. The filled-in portions of the valleys extend a mile or more up the streams, the distance varying with the size of the stream. The present slopes indicate that in some cases these valleys have been filled to a depth of a hundred feet or more. Whether the land along the coast is at present sinking, stationary, or moving upward is not known. In the region about San Gregorio it appears to be rising, as the streams there have generally cut deep, narrow gullies in the recent materials which clog their valleys, and appear to have been recently rejuvenated. The recent movements along the coast line have been differential, as is attested by the fact that the lowest sea terrace ranges in height from but a few feet above tide to a hundred feet. Similar differences in elevation have been observed in other and higher terraces, especially in the region of San Gregorio and Purisima. The axes of elevation of the lowest terrace correspond with old axes of disturbance along the coast, and it is certain that faulting and possibly folding are now going on in the Santa Cruz Range, along some of the old lines of weakness.

The uplift of the lower terraces, especially from Santa Cruz to the mouth of Waddell Creek, has been geologically recent, as is shown by the narrow V-shaped canyons through which the streams in that region invariably flow.

During and since the last coastal oscillations the Bay of San Francisco has been gradually silting up with débris brought in by the land streams. The same streams are also building out alluvial fans over the salt and brackish-water deposits around the edge of the valley. These alluvial fans encroach upon the salt-water deposits at the bay shore and have covered the edges of the valley with recent stream deposits, which at some places have a thickness of 100 to 200 feet. The fresh-water gravel, sand, and clay become thinner and thinner as the bay shore is approached, and completely disappear at the edges and in some places to the landward of the salt marshes.

## ECONOMIC GEOLOGY.

After its soils the most important geologic products found in the Santa Cruz quadrangle are deposits of limestone and bituminous rock. Gold, petroleum, building stone, road materials, diatomaceous shale, and sand deposits also occur, but these materials are of comparatively little importance.

### GOLD.

Placer gold has been found in small quantities in the gravels of Stevens Creek and in some of the small streams on the eastern slope of Ben Lomond Mountain, but there is no likelihood of gold being found in paying quantities at any place in the quadrangle.

### BITUMINOUS ROCK.

The bituminous rock of the Santa Cruz quadrangle is a porous, loose sandstone impregnated with asphaltum—a petroleum residue. The most important deposits in the quadrangle are those on the southwest slope of Ben Lomond Mountain, from 4 to 6 miles northwest of Santa Cruz. The bituminous rocks are sandstone beds lying near the base of the diatomaceous shale, which is referred to the Monterey. Most of the sandstone beds which immediately underlie or are intercalated with the diatomaceous shale of this locality are more or less bituminous. The structure is monoclinal, with a gentle southwest dip, hence the asphalt-bearing strata crop out along the eastern fringe of the diatomaceous shale, and along the sides of the southwestward-flowing streams where these have cut down nearly or quite to the bottom of the shale.

The bituminous rock is being worked rather extensively at the quarries of the City Street Improvement Company, 6 miles northwest of Santa Cruz. Here the bituminous rock bed is almost horizontal near the tops of the ridges, has a total thickness of 50 feet, and is overlain by 50 to 100 feet of much-fractured diatomaceous shale. (See fig. 11, illustration sheet I.) While the character of the bituminous bed varies somewhat, the following section of the bed as exposed at what is known as the Point quarry will give an idea of its general relations in this district:

*Section at Point quarry.*

| | Feet. |
|---|---|
| Fractured diatomaceous shale | 75 |
| High-grade bituminous sandstone | 30 |
| Low-grade bituminous sandstone | 10 |
| High-grade bituminous sandstone | 10 |
| Soft, pure white sandstone (thickness unknown). | |

Where exposed to the weather for a long time, as on the outcropping edges of the bituminous rock in ravines, the rock turns first to a lead gray and finally to a much lighter color.

The zone of the bituminous rock is exposed near the base of the diatomaceous shale from Santa Cruz northwestward as far as the western side of the Big Basin, a distance of more than 20 miles. Throughout this distance the dip of the lower part of the diatomaceous shale and of the immediately underlying sandstone is gently to the west and southwest. At many places through this district the sandstone beds are more or less bituminous but at only the one locality mentioned above have they been found to be of commercial value.

Development work has been carried on at the various quarries during a considerable period of time, and much asphalt rock has been removed. Only those portions of the rock are saved which contain a high percentage of asphalt, at least as high as is ordinarily used for paving. This heavily charged rock is shipped and utilized directly for paving and other purposes.

### PETROLEUM.

Wells have been bored for oil at various places in the Santa Cruz quadrangle, but petroleum has been found in commercial quantities only in a limited area southeast of Purisima. Here small quantities of a light oil of excellent quality are obtained from sandstone beds believed to be intercalated with the Monterey shale a short distance below the base of the Purisima formation. Oil wells bored along the coast west of Santa Cruz, to penetrate at depths the strata which bear bituminous rock at their outcrops, failed to develop any commercial supply of oil. Wells have also penetrated the Purisima and Monterey strata a mile east of the town of Ben Lomond, and also the Monterey beds on Oil Creek, almost at the center of the quadrangle, but always without satisfactory results.

Apparently the most promising locality for prospecting for oil is that along the coast west and southwest from the outcropping bituminous rock beds, since those beds pass down under overlying shale in that region. Wells drilled here, however, failed to find oil, and it is supposed that the oil which must formerly have existed in the sandstones of the region has been drained off through large fractures which extended from the surface of the shale down to the underlying sandstone. Many sandstone dikes, some of them of large size, occur along the coast in this region. These were formed from the underlying oil-bearing sandstones, and the larger ones probably represent the channels through which the oil from the underlying strata escaped.

### BUILDING STONE.

The sandstone and other sedimentary rocks of the quadrangle are usually too soft or too much fractured to make good building stone. Buff sandstone in the Chico formation similar to that used in the buildings of Stanford University occurs near and southeast of Searsville, but the localities are at present inaccessible and the stone is not quarried.

The quartz diorite of Ben Lomond Mountain and other areas in the quadrangle might be utilized for building purposes, but thus far these areas have been too distant from a market and inaccessible, and no attempt has been made to use the stone.

### ROAD MATERIALS.

The west side of the Santa Clara Valley has a fairly good road metal in the limestone and chert occurring in the Franciscan strata. The hard nodules of the serpentine masses and the basalt of the area south of Stanford University are also used, but are not sufficiently resistant to make first-class roads when used alone. Of the materials used the chert is the best and makes excellent roads. Unfortunately, however, it is of very meager occurrence.

### LIMESTONE.

Considerable deposits of pure, highly crystallized limestone or marble occur on Ben Lomond Mountain northwest of Santa Cruz, and west of the town of Felton. This stone is extensively quarried and burned into lime and is the chief source of lime for this part of the State. The stone could also be utilized, in connection with clay or shale, for the manufacture of Portland cement, and a cement plant is now in operation near Davenport Landing using clay from the Monterey to mix with the pure limestone.

There are also many small limestone bodies in the Franciscan rocks on the east side of the Cahil-Castle Rock divide, but in these areas the limestone is generally much less pure than that found in the vicinity of Santa Cruz. This rock is being quarried near the head of Permanente Creek, where several thousand tons of crushed limestone are produced annually and shipped to beet-sugar factories.

### DIATOMACEOUS SHALE.

Diatomaceous shale is found in great quantities in the quadrangle, and could be used for polishing powder, for packing steam pipes, and for filters. Usually, however, it is too impure to compete with the purer varieties which abound elsewhere.

### SAND.

Much nearly pure sand is found at the base of the Santa Margarita formation east of the town of Ben Lomond and in the region of Scott Valley. Examination of this sand bed in detail might disclose portions of sufficient purity to be used in the manufacture of glass.

### SOILS.

The richest soils of the quadrangle are those of the Santa Clara Valley, which are derived from the hills adjacent on the southwest and from the underlying gravels of Pliocene and Quaternary age. The Purisima formation generally produces a deep and fertile soil. This is especially true where the formation is made up of fossiliferous impure sandstone and shale, as is the case over most of its area from Año Nuevo Bay northward. Where the Purisima or the Santa Margarita is composed of diatomaceous shale and very pure sandstone, as is the case north of Santa Cruz, it produces an exceedingly poor soil. The Monterey shale, being made up almost entirely of siliceous material, produces a poor and thin soil. The soils produced by the Vaqueros sandstone are usually poor, as that formation is composed for the most part of comparatively pure sandstone. The shale of the San Lorenzo formation decays readily and produces good soil, but little of it is cultivated for the area covered by this formation is cut by sharp ridges and deep, narrow ravines. The Butano sandstone produces a sandy soil which under cultivation would quickly become impoverished. This area is covered with a dense growth of redwoods and other timber and underbrush, which thrive in the sandy soil.

The soils in the Ben Lomond Mountain and Halfmoon Bay areas of quartz diorite are thin and poor, as are also those in the areas of serpentine wherever they occur. In the area of Franciscan rocks, however, rich soils are often produced by the decay of the limestones, greenstones, and metamorphic rocks which abound there.

### WATER RESOURCES.

The Santa Cruz quadrangle has but few springs, and most of these are small. Some on the east face of Castle Rock and Cahil ridges are charged with sulphur and soda, at least one group, Congress Springs, furnishing water for bottling and medicinal uses. During the dry summer season the streams on the east side of the range become dry, as do also many of the smaller creeks on the west side of the range. The west side of the range is much better watered, however, than the east side. The region drained by the headwaters of San Lorenzo River and Waddell and Pescadero creeks is the best watered portion of the quadrangle.

This region is kept moist during much of the summer season by the dense fogs which drift from the sea up the valleys. In the rainy season the moist currents pass up these valleys and cause a heavy rainfall around the heads of San Lorenzo River and Waddell and Pescadero creeks. This rainfall, combined with the dense fogs which are common in the Big Basin region and in the region covered by the headwaters of the above-named streams, made possible the dense growth of redwoods that formerly covered the whole of the central portion of the quadrangle.

In the Santa Clara Valley the most important water supply is that found in the gravel beds which underlie practically the whole valley floor.

Flowing wells are obtained by penetrating these gravels in the lower portion of the Santa Clara plain, bordering the Bay of San Francisco.

Reservoirs have been constructed at several places in the valley which follows the line of the San Andreas fault. These reservoirs collect a portion of the waters from the east side of Cahil and Castle Rock ridges. The most important are Crystal Springs and Searsville lakes. The former is at the north edge of the quadrangle and is used as a source of supply for San Francisco. The latter collects the waters from the upper portion of the drainage basin of San Francisquito Creek. A few small and unimportant reservoirs for local use only have been built elsewhere on the east side of the main watershed.

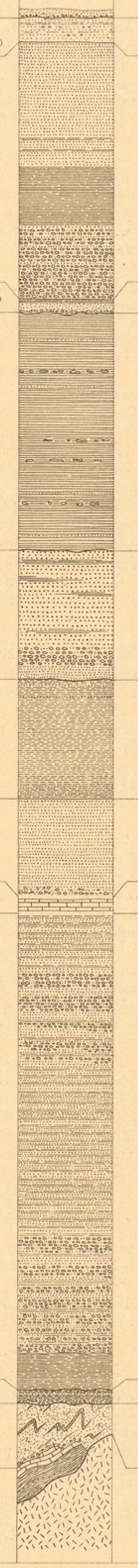
The run-off from Stevens Creek and Campbell Creek drainage basins is considerable during the winter months, and these streams form a possible future source of water supply that may be of some importance.

April, 1908.

# COLUMNAR SECTION

## COLUMNAR SECTION OF THE SEDIMENTARY ROCKS OF THE SANTA CRUZ QUADRANGLE.

SCALE: 1 INCH = 2000 FEET.



| System. | Series. | Formation Name. | Symbol. | Columnar Section. | Thickness in Feet. | Character of Rocks. |
|---|---|---|---|---|---|---|
| QUATERNARY | | Alluvium, terrace deposits, and dune sand. | Qal<br>Qt | | 0–50+ | Sand, gravel, and clay. |
| TERTIARY | PLIOCENE | Santa Clara formation.<br>(Merced formation along the coast.) | Tsc<br>(Tmc) | | 500±<br>(300±) | Coarse gravel, sand, and sandy clay, locally lignitic, of fresh-water origin. Represented along the coast by marine sandstone and sandy shale of Merced formation. |
| | | Purisima formation. | Tp | | 5400+ | Conglomerate and sandstone at the base, thin-bedded shale in the middle, and soft light yellowish brown heavy-bedded sand toward the top. |
| | MIOCENE | Santa Margarita formation. | Tsm | | 300± | Coarse white incoherent sand, conglomeratic at the base, overlain by thin-bedded hard shale. |
| | | UNCONFORMITY | | | | |
| | | Monterey shale. | Tm | | 5000± | Thinly laminated shale, largely diatomaceous, containing intercalated sandstone and calcareous concretionary layers. Locally bituminous and lignitic. Conformable with the Vaqueros on the west side of Ben Lomond Mountain. |
| | | UNCONFORMITY | | | | |
| | | Vaqueros sandstone. | Tv | | 2700± | Coarse brown sandstone, conglomeratic toward the base, interbedded with dark earthy shale in certain areas. Fine sandstone of transitional Oligocene-Miocene age locally at the base. |
| | | UNCONFORMITY | | | | |
| | OLIGOCENE | San Lorenzo formation. | Tsl | | 2500± | Fine clay shale with interbedded brown sandstone toward top and bottom. |
| | | Butano sandstone. | Tb | | 2100± | Massive brown and buff sandstones with conglomerate at the base. |
| | | SEQUENCE CONCEALED | | | | |
| | EOCENE | Limestone in diabase. | (Tl) | | 200± | Impure fossiliferous limestone inclusions in diabase dikes on the west flank of the Cahil-Castle Rock divide. |
| | | SEQUENCE CONCEALED | | | | |
| CRETACEOUS | UPPER CRETACEOUS | Chico formation. | Kc | | 0,000± | Thick-bedded coarse conglomerate, massive to thin-bedded sandstone, and sandy shale. |
| | | | | | (750) | Hard, flinty, even-bedded shale. |
| | | UNCONFORMITY | | | | |
| | LOWER CRET. | Knoxville formation. | Kk | | 100± | Conglomerate and sandstone; also dark thin-bedded clay shale, mapped with the Franciscan formation in Monte Bello Ridge. |
| | | UNCONFORMITY | | | | |
| JURASSIC? | | Franciscan formation. | fc | | 1000± | Chiefly an earthy sandstone in which are minor quantities of dark shale similar to the Knoxville. Contains jasper lentils and some schist. |
| | | UNCONFORMITY | | | | |
| PRE-JURASSIC? | | Schist and limestone. | ls<br>sch | | | |
| | | Intrusive quartz diorite. | qd | | 1000± | Quartz-mica schist and crystalline limestone. Intruded by quartz diorite which is cut by dikes of pegmatite and by quartz veins that are locally mineralized. |

U.S. GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

# TOPOGRAPHY

## CALIFORNIA
## SANTA CRUZ QUADRANGLE

| | | | | | |
|---|---|---|---|---|---|
| 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 |

Contour interval 100 feet.
*Datum is mean sea level.*

R.U. Goode, Geographer in charge.
Triangulation by U.S. Coast and Geodetic Survey.
Topography by E.C. Barnard, R.B. Marshall,
A.B. Searle, and U.S. Coast and Geodetic Survey.
Surveyed in 1895 and 1899.

Edition of June 1902, reprinted with corrections Oct. 1908.

## LEGEND

### RELIEF
*printed in brown*

1440
Figures
*showing heights above mean sea level instrumentally determined*

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

Beach sand

### DRAINAGE
*printed in blue*

Streams

Intermittent streams

Lakes ponds and reservoirs

Intermittent lakes

Salt marshes

Fresh marshes

### CULTURE
*printed in black*

Roads and buildings

Private and secondary roads

Trails

Railroads

U.S. township and section lines

County lines

Land grant lines

△
Triangulation stations

BM
×
Bench marks

LH
Lighthouses

U.S. GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

# AREAL GEOLOGY

CALIFORNIA
SANTA CRUZ QUADRANGLE

R.U. Goode, Geographer in charge.
Triangulation by U.S. Coast and Geodetic Survey.
Topography by E.C. Barnard, R.B. Marshall,
A.B. Searle, and U.S. Coast and Geodetic Survey.
Surveyed in 1895 and 1899.

APPROXIMATE MEAN DECLINATION 1900.

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 |

Scale $\frac{1}{125000}$

Contour interval 100 feet.

*Datum is mean sea level.*

Edition of Oct. 1908.

## LEGEND

### SEDIMENTARY ROCKS

*(Areas of subaqueous deposits are shown by patterns of parallel lines, subaerial deposits by patterns of dots and circles; metamorphism is indicated by hachures combined with the line patterns)*

QUATERNARY

Qt — **Terrace deposits** *(marine and dune sand and detrital deposits)*

Qal — **Alluvium** *(on flats bordering San Francisco Bay, merges with Santa Clara formation)*

UNCONFORMITY — UNCONFORMITY

TERTIARY

*Pliocene*

Tmc — **Merced formation** *(marine sandstone and shale, with occasional hard fossiliferous layers)*

Tsc — **Santa Clara formation** *(gravel, sand, and clay, chiefly of fresh-water origin; merges with recent alluvium and boundary is indefinite)*

Tp — **Purisima formation** *(conglomerate, sandstone, and shale, in part diatomaceous, includes some older strata east of Cahill-Castle Rock divide)*

*Miocene*

Tsms / Tsm — **Santa Margarita formation** *(clean white sand, largely unconsolidated, with shale, Tsms, at the top; includes some Purisima near coast)*

UNCONFORMITY

Tm — **Monterey shale** *(soft to flinty shale, largely diatomaceous, and massive sandstone locally bituminous near the base)*

UNCONFORMITY

Tv — **Vaqueros sandstone** *(heavy-bedded sandstone and conglomerate, interbedded, especially toward the top, with minor dark shale)*

UNCONFORMITY

*Oligocene*

Tsl — **San Lorenzo formation** *(clayey shale with intercalated fine-grained sandstone)*

Tb — **Butano sandstone** *(massive brown and buff sandstone)*

UNCONFORMITY

*Eocene*

Tl — **Limestone inclusions in diabase**

UNCONFORMITY

CRETACEOUS

Kc — **Chico formation** *(heavy-bedded sandstone and conglomerate, with small amount of shale)*

UNCONFORMITY

Kk — **Knoxville formation** *(hard, dark-colored shale, sandstone, and conglomerate)*

UNCONFORMITY

PRE-CRETACEOUS

*Jurassic?*

fc — **Franciscan formation** *(sandstone, shale, and some conglomerate, with lenticular masses of limestone, jasper, chert, schist, and greenstone)*

UNCONFORMITY

*Pre-Franciscan?*

ls — **Limestone** *(white to light-gray crystalline limestone)*

sch — **Schist** *(dark-colored micaceous schist, includes minor quantities of crystalline limestone and thin-bedded quartzite)*

### IGNEOUS ROCKS

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

TERTIARY

*Miocene (Pre-Santa Margarita)*

db — **Diabase and basalt** *(intrusive diabase, basalt flows and intrusions, and tuffs)*

PRE-TERTIARY

*Post-Franciscan*

odb — **Older diabase** *(somewhat altered diabase dike)*

sp — **Serpentine** *(altered intrusive masses and dikes of basic rocks)*

PRE-CRETACEOUS

*Pre-Franciscan?*

qd — **Quartz diorite** *(fine to medium grained)*

**Faults**

**Concealed faults** *(covered by younger deposits)*

*Strike and dip of stratified rocks*
*Anticlinal axes*

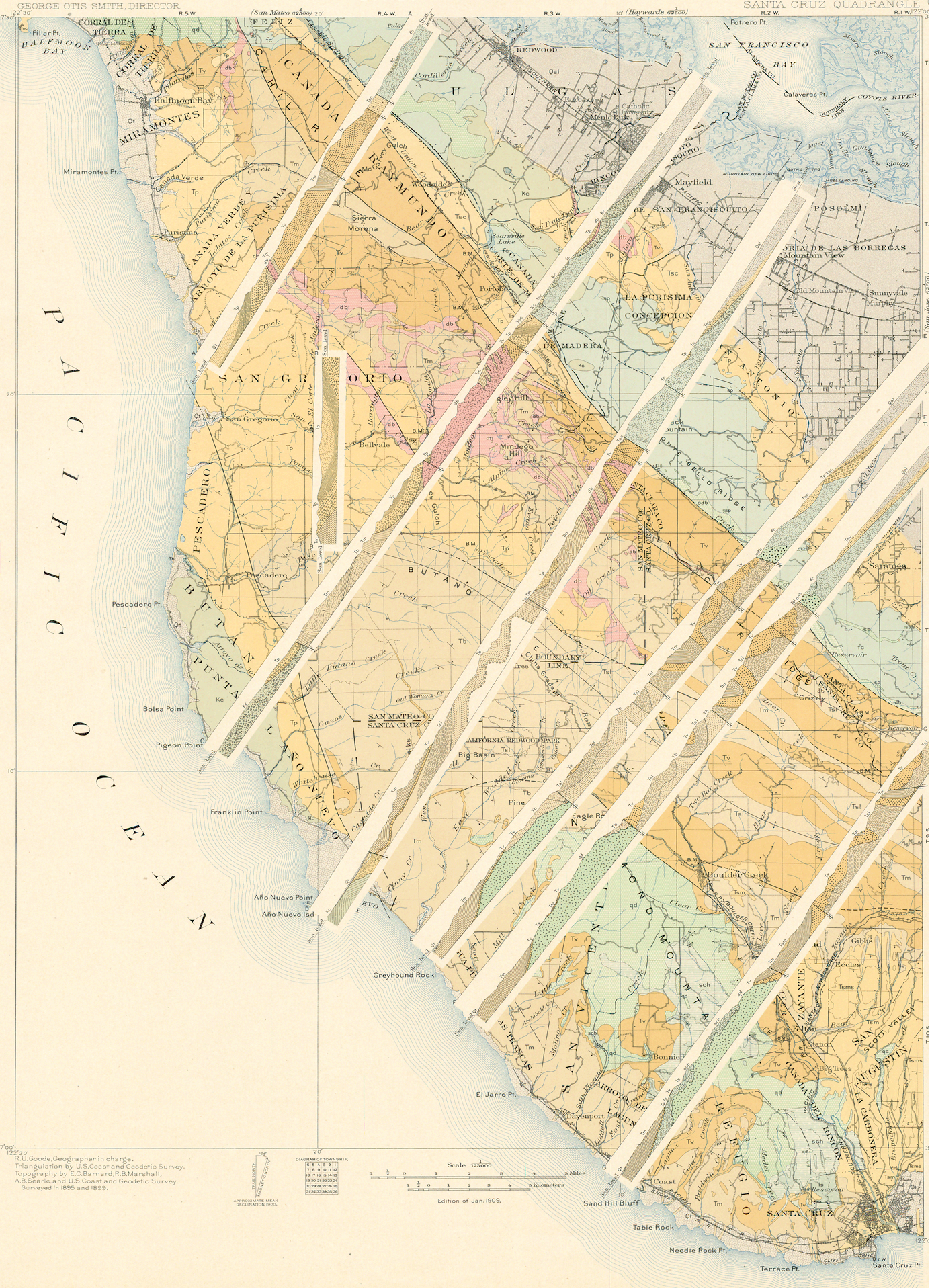
⚒ *Mines and quarries*

Geology by J.C. Branner,
J.F. Newsome, and Ralph Arnold.
Surveyed in 1896–1905.

U.S. GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

# STRUCTURE SECTIONS

CALIFORNIA
SANTA CRUZ QUADRANGLE



## LEGEND

### SEDIMENTARY ROCKS

| SHEET SYMBOL | SECTION SYMBOL | | SHEET SYMBOL | SECTION SYMBOL | | |
|---|---|---|---|---|---|---|
| Qt | Qt | **Terrace deposits** *(marine and dune sand and detrital deposits)* | Qal | Qal | **Alluvium** *(on flats bordering San Francisco Bay, merges with Santa Clara formation)* | QUATERNARY |
| Tmc | Tmc | **Merced formation** *(marine sandstone and shale, with occasional hard fossiliferous layers)* | Tsc | Tsc | **Santa Clara formation** *(gravel, sand, and clay, chiefly of fresh-water origin; merges with recent alluvium and boundary is indefinite)* | Pliocene |

UNCONFORMITY UNCONFORMITY

*Pliocene*

| SHEET SYMBOL | SECTION SYMBOL | | Epoch | Period |
|---|---|---|---|---|
| Tp | Tp | **Purisima formation** *(conglomerate, sandstone, and shale, in part diatomaceous; includes some older strata east of Cahill-Castle Rock divide)* | Miocene | TERTIARY |
| Tsms<br>Tsm | Tsm | **Santa Margarita formation** *(clean white sand, largely unconsolidated, with shale, Tsms, at the top; includes some Purisima near coast)* | Miocene | TERTIARY |
| UNCONFORMITY | | | | |
| Tm | Tm | **Monterey shale** *(soft to flinty shale, largely diatomaceous, and massive sandstone locally bituminous near the base)* | Miocene | TERTIARY |
| UNCONFORMITY | | | | |
| Tv | Tv | **Vaqueros sandstone** *(heavy-bedded sandstone and conglomerate, interbedded, especially toward the top, with minor dark shale)* | Miocene | TERTIARY |
| UNCONFORMITY | | | | |
| Tsl | Tsl | **San Lorenzo formation** *(clayey shale with intercalated fine-grained sandstone)* | Oligocene | TERTIARY |
| Tb | Tb | **Butano sandstone** *(massive, brown and buff sandstone)* | Oligocene | TERTIARY |
| UNCONFORMITY | | | | |
| Tl | | **Limestone inclusions in diabase** | Eocene | TERTIARY |
| UNCONFORMITY | | | | |
| Kc | Kc | **Chico formation** *(heavy-bedded sandstone and conglomerate, with small amount of shale)* | | CRETACEOUS |
| UNCONFORMITY | | | | |
| Kk | | **Knoxville formation** *(hard, dark-colored shale, sandstone, and conglomerate)* | | CRETACEOUS |
| UNCONFORMITY | | | | |
| fc | fc | **Franciscan formation** *(sandstone, shale, and some conglomerate with lenticular masses of limestone, jasper, chert, schist, and greenstone)* | Jurassic? | PRE-CRETACEOUS |
| UNCONFORMITY | | | | |
| ls | ls | **Limestone** *(white to light-gray crystalline limestone)* | Pre-Franciscan? | PRE-CRETACEOUS |
| sch | sch | **Schist** *(dark-colored micaceous schist; includes minor quantities of crystalline limestone and thin-bedded quartzite)* | Pre-Franciscan? | PRE-CRETACEOUS |

### IGNEOUS ROCKS

| SHEET SYMBOL | SECTION SYMBOL | | Epoch | Period |
|---|---|---|---|---|
| db | db | **Diabase and basalt** *(intrusive diabase, basalt flows and intrusions, and tuffs)* | Miocene (Pre-Santa Margarita) | TERTIARY |
| odb | odb | **Older diabase** *(somewhat altered diabase dike)* | Post-Franciscan | PRE-TERTIARY |
| sp | | **Serpentine** *(altered intrusive masses and dikes of basic rocks)* | Post-Franciscan | PRE-TERTIARY |
| qd | qd | **Quartz diorite** *(fine to medium grained)* | (Pre Franciscan?) | PRE-CRETACEOUS |

Faults ▬ ‒ ‒

Concealed faults
*(covered by younger deposits)*

*Strike and dip of stratified rocks*
*Anticlinal axes*

R.U. Goode, Geographer in charge.
Triangulation by U.S. Coast and Geodetic Survey.
Topography by E.C. Barnard, R.B. Marshall,
A.B. Searle, and U.S. Coast and Geodetic Survey.
Surveyed in 1895 and 1899.

TRUE NORTH MAGNETIC NORTH 18°
APPROXIMATE MEAN DECLINATION 1900.

DIAGRAM OF TOWNSHIP.

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Scale $\frac{1}{125000}$
1 ½ 0 1 2 3 4 5 Miles
1 ½ 0 1 2 3 4 5 Kilometers

Edition of Jan. 1909.

Geology by J.C. Branner,
J.F. Newsom, and Ralph Arnold.
Surveyed in 1896 – 1905.

# ILLUSTRATIONS I

FIG. 4.—CONGLOMERATE OF CHICO FORMATION ON THE COAST 2½ MILES NORTH OF PIGEON POINT, SAN MATEO COUNTY, LOOKING NORTHWEST.

FIG. 5.—UNCONFORMITY BETWEEN THE UPTURNED CHICO FORMATION ON THE RIGHT AND THE BUTANO SANDSTONE (OLIGOCENE) ON THE LEFT.

On the coast one-half mile south of the mouth of Pescadero Creek, San Mateo County.

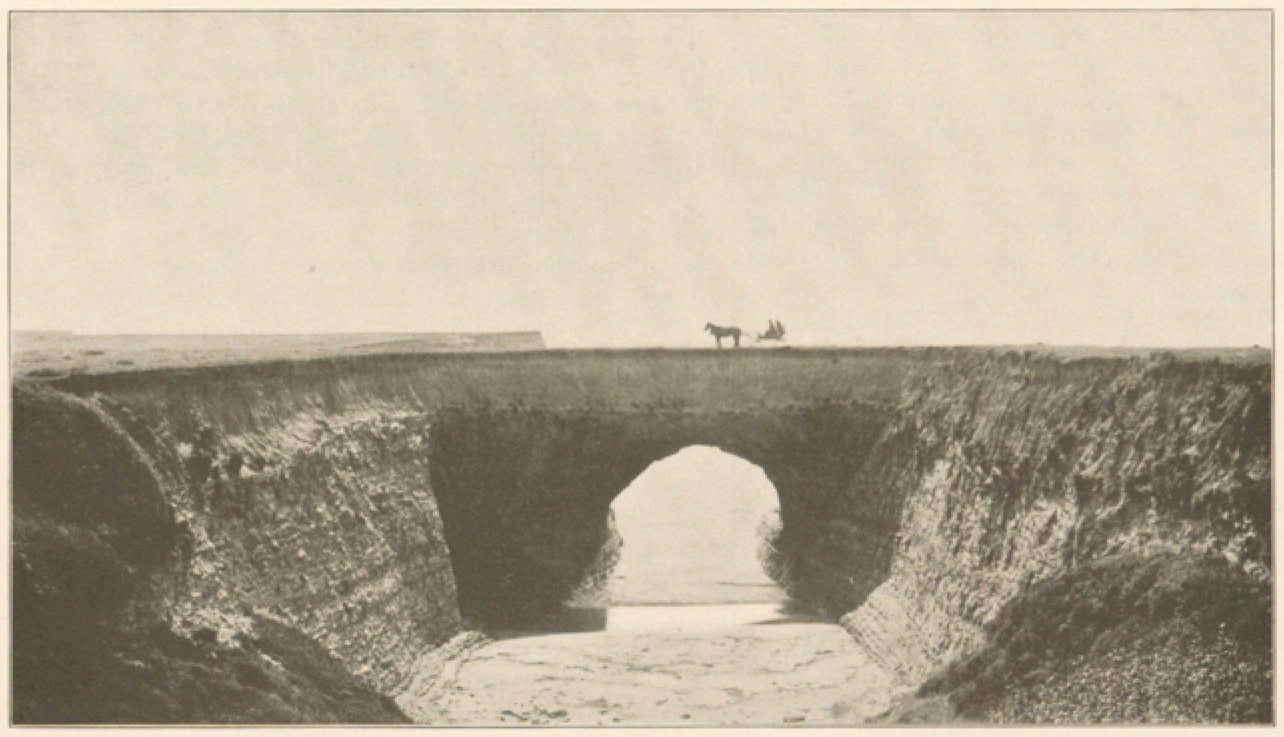

FIG. 6.—NATURAL BRIDGE IN MONTEREY SHALE, WHICH IS OVERLAIN BY 15 FEET OF QUATERNARY DEPOSITS FORMING THE SURFACE OF THE LOWEST MARINE TERRACE.

On the coast, 3 miles west of Santa Cruz.

FIG. 7.—VIEW LOOKING EAST FROM THE TOP OF THE 40-FOOT MARINE TERRACE 1 MILE EAST OF POINT AÑO NUEVO, SAN MATEO COUNTY.

Vertical bluff on the left shows truncated beds of Purisima formation overlain by Quaternary deposits, the top of which forms the surface of the terrace. Merced formation in the white bluffs on the right; white Miocene shales form the hills in the distance.

FIG. 8.—WAVE EROSION IN THE MIOCENE SHALE WEST OF SANTA CRUZ.

Erosion by the waves is fastest along joint lines in the shale, as shown by the parallel channels in the foreground. Quaternary sand and clay rest on the shale in the right middle distance, forming the surface of the lowest marine terrace.

FIG. 9.—EAST END OF SANDSTONE DIKE WEST OF THE MOUTH OF BALDWIN CREEK, SHOWING SEVERAL BRANCHES OF THE DIKE.

Exposed only at low tide.

FIG. 10.—SANDSTONE DIKE WEST OF THE MOUTH OF LAGUNA CREEK.

The dike is a soft sandstone, almost free from bitumen, and is therefore much less resistant to wave action than the shales, as is shown by the narrow trench in the foreground.

FIG. 11.—BITUMINOUS SANDSTONE BED OVERLAIN BY WHITE MONTEREY (MIOCENE) SHALE, QUARRY OF THE CITY STREET IMPROVEMENT COMPANY.

Six miles northwest of Santa Cruz.

# FOSSILS COMMONLY FOUND IN OR CHARACTERISTIC OF THE FORMATIONS IN THE SANTA CRUZ QUADRANGLE.

## SHOWN ON ILLUSTRATION SHEET II.

(Unless otherwise stated, all figures are natural size. L. S. J. U. refers to Leland Stanford Junior University collection; U. S. N. M., to United States National Museum.)

### KNOXVILLE FORMATION (LOWER CRETACEOUS).

1. *Aucella crassicollis* Keyserling. L. S. J. U., No. 1014. Right valve; altitude 35 mm. Shape of shell variable. From the fine conglomerate west of Redwood and in the black shale on Stevens Creek.

2. *Amberlya dilleri* Stanton. L. S. J. U., No. 1011. Back view; altitude 16 mm. Twice natural size. Rare at same horizon as No. 1.

### CHICO FORMATION (UPPER CRETACEOUS).

3. *Mactra stantoni* Arnold. U. S. N. M., No. 31001. Type; left valve; altitude 33 mm. Common in sandstones north of Pigeon Point.

4. *Glycymeris veatchii* Gabb. L. S. J. U., No. 1004. Umbones and hinge area; latitude 66 mm. At same locality as preceding.

5. *Trigonia evansiana* Meek. U. S. N. M., No. 31002. Umbones and hinge area; length of specimen 109 mm. Found in sandstones southeast of Pigeon Point. A somewhat similar form, *T. leana* Gabb, having nodose ribs, occurs with this species.

6. *Arca vancouverensis* Meek. U. S. N. M., No. 31003. Left valve; longitude 31 mm. Enlarged 1½ times. Common in sandstone southeast of Pigeon Point.

7. *Turritella pescaderoensis* Arnold. L. S. J. U., No. 999. Type; back view; altitude 46 mm. From conglomerate north of Bolsa Point.

### EOCENE.

8. *Pecten (Chlamys) proavus* Arnold. U. S. N. M., No, 164930. Type; decorticated left valve; altitude 38 mm. Occurs in impure limestones at head of Pescadero Creek.

9, 9a. *Hipponyx carpenteri* Arnold. U. S. N. M., No. 165433. Type; top and side views of nearly perfect specimen. Enlarged three times. Found with the preceding.

10. *Patella mateoensis* Arnold. U. S. N. M., No. 165437. Type; top view; longitude 7 mm. Enlarged three times. Found with the preceding.

11. *Fissurella perrini* Arnold. U. S. N. M., No. 165434. Type; top view of slightly imperfect specimen; longitude 16 mm. Twice natural size. Not a common species.

12. *Tritonium newsomi* Arnold. U. S. N. M., No. 165436. Type; back view; altitude 16 mm. Twice natural size. Found with the preceding.

13. *Cidaris merriami* Arnold. U. S. N. M., No. 165438. Type; fragment of spine; longitude 21 mm. Twice natural size. Abundant with the preceding.

14, 14a. *Terebratulina tejonensis* Stanton. U. S. N. M., No. 165432; L. S. J. U., No. 1023. Ventral valve and dorsal valve; altitudes 15 and 11 mm. Twice natural size. Common with the preceding.

15. *Semele gayi* Arnold. U. S. N. M., No. 165435. Type; right valve; latitude 14 mm. Twice natural size. Occurs with the preceding.

### SAN LORENZO FORMATION (OLIGOCENE).

16. *Tellina lorenzoensis* Arnold. U. S. N. M., No. 165439. Plastotype; left valve; longitude 40 mm. Abundant in the San Lorenzo, especially on the headwaters of Waddell Creek.

17. *Cardium cooperi* Gabb var. *lorenzanum* Arnold. L. S. J. U., No. 1077. Right valve; altitude 8 mm. Enlarged three times. Found commonly in the San Lorenzo shales and fine sandstones; also in Oligocene of Washington.

18. *Pecten (Pecten) sanctæcruzensis* Arnold. L. S. J. U., No. 1102. Plastotype; left valve; altitude 52 mm. Not uncommon in the Oligocene and transition Oligocene-Miocene beds.

19. *Fusus sanctæcrucis* Arnold. L. S. J. U., No. 1037. Plastotype; aperture of imperfect and decorticated specimen; altitude 43 mm. Found in the upper part of the formation.

20. *Haminea petrosa* Conrad. U. S. N. M., No. 165454. back view of slightly imperfect specimen; longitude 7 mm. Enlarged three times. Found at most fossiliferous localities of the San Lorenzo.

21. *Pleurotoma sanctæcrucis* Arnold. U. S. N. M., No. 165445. Plastotype; cast of imperfect mold; altitude 8.5 mm. Twice natural size. A characteristic species of this formation.

22. *Dentalium substriatum* Conrad. U. S. N. M., No. 165453. Lateral view of fragment; altitude 12 mm. Twice natural size. Common in the shales.

23. *Strepsidura californica* Arnold. U. S. N. M., No. 165450. Type; back view; altitude 33 mm. Not common in the shales and fine sandstones. Sometimes grows to twice the size of this specimen. Found also in Oligocene at Porter, Wash.

24. *Turcicula sanctacruzana* Arnold. U. S. N. M., No. 165442. Type: front of nearly perfect specimen; altitude 36 mm. A most beautiful and characteristic species; from the shales on San Lorenzo River.

25. *Pleurotoma newsomi* Arnold. U. S. N. M., No. 165440. Plastotype; back view; altitude 19 mm. Twice natural size. From the fine, soft sandstones.

26. *Fusus hecoxi* Arnold. U. S. N. M., No. 165446. Type; back view of imperfect specimen; altitude 35 mm. Found in the fine gray shale at the type locality of the formation on San Lorenzo River.

27. *Cidaris branneri* Arnold. L. S. J. U., No. 1056. Plastotype; lateral view of nearly perfect specimen; longitude 20 mm. Twice natural size. Occurs in upper part of formation.

28. *Architectonica lorenzoensis* Arnold. U. S. N. M., No. 165448. Plastotype; top view of nearly perfect specimen; maximum diameter 11 mm. Twice natural size. From the soft, fine sandstones.

29. *Nucula (Acila) dalli* Arnold. U. S. N. M., No. 165452. Plastotype; left valve; longitude 35 mm. This species is common in the shales of the San Lorenzo and has also been foond in the supposed Monterey between the mouths of Waddell and Año Nuevo creeks.

30. *Aturia ziczac* Sowerby. L. S. J. U., No. 1089. The figure shows the only authentic fragment of this species so far found in the quadrangle. This form is closely allied to *Nautilus*, the figure showing the chambered aspect, with suture lines plainly exposed. Supposed to be characteristic of the Oligocene; found here in beds supposed to be upper San Lorenzo. Altitude of fragment 27 mm.

31. *Lirofusus ashleyi* Arnold. U. S. N. M., No. 165449. Type; back view of nearly perfect specimen; altitude 12.5 mm. Twice natural size. From the fine gray shale on San Lorenzo River.

32. *Malletia chehalisensis* Arnold. L. S. J. U., No. 1062. Right valve; slightly imperfect; longitude (restored), 12.5 mm. Found at several localities in this formation; also in the Oligocene of Oregon and Washington.

33. *Pleurotoma perissolaxoides* Arnold. U. S. N. M., No. 165451. Plastotype; back view of nearly perfect cast; altitude 12.5 mm. Twice natural size. From the fine sandstones.

### VAQUEROS FORMATION (LOWER MIOCENE).

34. *Cardium (Trachycardium) vaquerosensis* Arnold. U. S. N. M., No. 165457. Type; imperfect right valve; longitude 65 mm. A characteristic species of the lower Miocene. Grows to more than 150 mm. (6 inches) in length.

35. *Glycymeris branneri* Arnold. U. S. N. M., No. 165455. Type; left valve; altitude 64 mm. Abundant in the lower Miocene, especially in Mindego Canyon.

36. *Leda cahillensis* Arnold. L. S. J. U., No. 1065. Type; left valve; longitude 7 mm. Enlarged three times. In Miocene sandstones west of Woodside.

37. *Pecten (Lyropecten) magnolia* Conrad. Collection, Univ. California. Right valve; altitude 145 mm. Characteristic of the Vaqueros formation; abundant at most fossiliferous localities.

38. *Turritella ineziana* Conrad (*Turritella hoffmanni* Gabb of most authors). U. S. N. M., No. 165459. Back view of imperfect but characteristic specimen; altitude 73 mm. Common in and characteristic of the lower Miocene (Vaqueros).

39. *Chione temblorensis* Anderson. U. S. N. M., No. 165474. Left valve; altitude 122 mm. Reduced one-half. Common in the Vaqueros; usually associated with the two preceding.

40. *Agasoma kernianum* Cooper. U. S. N. M., No. 165456. Back view of a specimen from Kern County; altitude 45 mm. A common species in the lower Miocene, or "*Agasoma* horizon," of the quadrangle.

41. *Terebratalia (aff.) occidentalis* Dall. L. S. J. U., No. 1091. Internal cast of dorsal valve; longitude 31 mm. Common in the Miocene of Tuff Hill, southeast of Stanford University.

42. *Yoldia submontereyensis* Arnold. U. S. N. M., No. 165459. Plastotype; right valve; longitude 32 mm. Common throughout the lower Miocene (Vaqueros).

43. *Turritella ocoyana* Conrad. U. S. N. M., No. 165474. Cast of a fragment of one of these long-spired shells; altitude 31 mm. Common in and characteristic of certain portions of the lower Miocene.

44. *Agasoma santacruzana* Arnold. L. S. J. U., No. 1072. Type; back view of young specimen; altitude 26 mm. Twice natural size. Another very common species in the "*Agasoma* horizon" (lower Miocene) of this quadrangle; found also at Coalinga, Fresno County.

45. *Pecten (Chlamys) branneri* Arnold. L. S. J. U., No. 1092. Plastotype; cast of fragment of a left valve; hinge line 33 mm. A common species in the Miocene of Tuff Hill; found also in the transition Oligocene-Miocene in Two Bar Creek.

46. *Tivela ineziana* Conrad. U. S. N. M., No. 165458. Slightly broken right valve; longitude 61 mm. A characteristic and common Vaqueros species.

### MONTEREY FORMATION (MIDDLE MIOCENE).

47. *Mactra montereyana* Arnold. U. S. N. M., No. 165463. Type; longitude of each valve 31 mm. A not uncommon form in the Monterey; usually distorted.

48. *Venericardia montereyana* Arnold. U. S. N. M., No. 165464. Type; left valve; longitude 10 mm. Twice natural size. Not uncommon in the Monterey shale; usually distorted.

49. *Yoldia impressa* Conrad. U. S. N. M., No. 165465. Cast of distorted (longitudinally elongated) right valve, showing teeth of left valve above; longitude 26 mm. Nearly all the fossils in the Monterey shale are distorted. The normal form of this common species is much broader, and pointed at the end broken in this specimen.

50. *Arca obispoana* Conrad. U. S. N. M., No. 165462. Cast of right and left valves; longitude of more nearly perfect specimen, 42 mm. Common in the Monterey shale about Felton and Newell Creek, and also in the Salinas and adjacent valleys.

51. *Pecten (Propeamusium) stanfordensis* Arnold. Collection, Delos Arnold. Type; cast of right valve and mold of left, altitude 7 mm. Enlarged three times. Common in shale of supposed Monterey age on the Burke ranch, southwest of Stanford University.

52. *Pecten (Pseudamusium) peckhami* Gabb. U. S. N. M., No. 164839. Casts of right and left valve in matrix. Common in the Monterey of the Coast Range; also occasionally found in the San Lorenzo formation, and even as low as the Eocene.

### BARNACLE BEDS, LOWEST PURISIMA (?) (UPPER MIOCENE).

53. *Periploma sanctæcrucis* Arnold. L. S. J. U., No. 1074. Type; partly decorticated right valve; longitude 43 mm. Not an uncommon species at this horizon.

54. *Agasoma stanfordensis* Arnold. L. S. J. U., No. 1087. Type; back view of cast of imperfect specimen; altitude 52 mm. Supposed to be characteristic of this horizon.

55. *Fusus stanfordensis* Arnold. L. S. J. U., No. 1081. Back view of sandstone cast of nearly perfect specimen; altitude 49 mm. Supposed to be characteristic of this horizon.

56. *Yoldia supramontereyensis* Arnold. L. S. J. U., No. 1067. Type; imperfect left valve; longitude 40 mm. This species is characterized by its long curved "beak."

57. *Leda taphria* Dall. L. S. J. U., No. 1069. Cast of right valve; longitude 18 mm. Twice natural size. Not uncommon at this horizon; also occurs recent.

### SANTA MARGARITA FORMATION (UPPER MIOCENE).

58. *Astrodapsis antiselli* Conrad. U. S. N. M., No. 165466. Top view; longitude 54 mm. Supposed to be characteristic of the Santa Margarita horizon; found abundantly in the white Santa Margarita sandstone of the Scott Valley region. Figured specimen from Salinas Valley.

59. *Amphiura sanctæcrucis* Arnold. U. S. N. M., No. 165431. Paratype; nearly perfect mold of ventral side of one of these beautiful animals. Among the few fossils found in the shale overlying the white sand of Scott Valley.

### PURISIMA AND MERCED FORMATIONS (UPPER MIOCENE AND PLIOCENE).

60. *Pecten (Patinopecten) purisimaensis* Arnold. Collection, Delos Arnold. Type; right valve; altitude 123 mm. Reduced one-half. The left valve has much narrower, lower ribs and broad interspaces. Common in the Purisima formation below the *Pecten healeyi* horizon.

61. *Cardium meekianum* Gabb. L. S. J. U., No. 1098. Decorticated left valve; altitude 73 mm. A common form in the Purisima and other upper Miocene and Pliocene formations.

62. *Arca schizotoma* Dall. L. S. J. U., No. 1090. A nearly perfect right valve; longitude 56 mm. A very common species in the Pliocene. Closely allied to *A. trilineata* Conrad and *A. canalis* Conrad.

63. *Chlorostoma stantoni* Dall var. *lahondaensis* Arnold. L. S. J. U., No. 1079. Back view of type; a slightly imperfect specimen; altitude 21 mm. Appears to be characteristic of the middle fauna of the Purisima.

64. *Miopleiona oregonensis* Dall. U. S. N. M., No. 165469. Aperture view of a nearly perfect specimen; altitude 78 mm. This species appears to be characteristic of the middle and upper Purisima in this quadrangle.

65. *Chrysodomus stantoni* Arnold. L. S. J. U., No. 1088, Paratype; the canal and upper whorls are broken off in this specimen; altitude 79 mm. A common form all through the Pliocene.

66. *Schizothærus pajaroanus* Conrad. U. S. N. M., No. 165467. Left valve; longitude 72 mm. A common species in the Pliocene.

67. *Pecten (Patinopecten) healeyi* Arnold. Collection, Delos Arnold. Imperfect right valve; hinge line 50 mm. Reduced one-half. Very common at one horizon in the Purisima near San Gregorio and Pescadero.

68. *Fusus portolaensis* Arnold. L. S. J. U., No. 1080. Paratype; aperture view of imperfect specimen; altitude 58 mm. Common in the Purisima on the east side of the range.

69. *Cryptomya ovalis* Conrad. L. S. J. U., No. 1097. Left valve; longitude 28.5 mm. A common form all through the Purisima.

70. *Phacoides annullatus* Reeve. U. S. N. M., No. 165470. Right valve; longitude 50 mm. A common species in the Purisima and Merced; also occurs recent.

71. *Nucula (Acila) castrensis* Hinds. U. S. N. M., No. 165471. Left valve; longitude 15 mm. Twice natural size. A common species in the Pliocene; found also in the Quaternary.

72. *Tapes staleyi* Gabb. L. S. J. U., No. 1094. Right valve; longitude 46 mm. A common species in the Pliocene.

### SPECIES FOUND MORE COMMONLY IN THE MERCED FORMATION (UPPER PLIOCENE).

73. *Nassa californiana* Conrad. L. S. J. U., No. 1095. Aperture view; altitude 31 mm. A common species in the Pliocene.

74. *Thais trancosana* Arnold. L. S. J. U., No. 1082. Type; aperture view of imperfect specimen; altitude 23 mm. Found in the Merced.

75. *Thais ostrina* Gould. L. S. J. U., No. 1096. Aperture view of imperfect specimen; altitude 23 mm. Found in the Merced; also recent.

76. *Bittium asperum* Gabb. U. S. N. M., No. 165472. Aperture view of slightly imperfect specimen; altitude 26 mm. Enlarged three times. Common in the Pliocene.

77. *Astyris richthofeni* Gabb. U. S. N. M., No. 165468. Aperture view; altitude 8 mm. Enlarged three times. Common in the Pliocene.

78. *Littorina petricola* Dall. L. S. J. U., No. 1099. Aperture view of imperfect specimen; altitude 10 mm. Found in the Merced.

### SANTA CLARA FORMATION (FRESH-WATER PLIOCENE AND QUATERNARY).

79. *Anodonta wahlametensis* Lea. L. S. J. U., No. 1100. Slightly imperfect right valve; longitude 75 mm. From the Santa Clara formation, associated with several kinds of small snails, such as *Amnicola*, etc.

# ILLUSTRATIONS II

MONTEREY SHALE (MIDDLE MIOCENE).

SANTA CLARA FORMATION (FRESH-WATER PLIOCENE AND QUATERNARY).

PURISIMA AND MERCED FORMATIONS (PLIOCENE).

SANTA MARGARITA FORMATION (UPPER MIOCENE).

VAQUEROS SANDSTONE (LOWER MIOCENE).

BARNACLE BEDS, LOWEST PURISIMA(?) (UPPER MIOCENE).

CHICO FORMATION (UPPER CRETACEOUS).

KNOXVILLE FORMATION (LOWER CRETACEOUS).

LIMESTONE OF EOCENE AGE.

SAN LORENZO FORMATION (OLIGOCENE).

As sedimentary deposits or strata accumulate the younger rest on those that are older, and the relative ages of the deposits may be determined by observing their positions. This relationship holds except in regions of intense disturbance; in such regions sometimes the beds have been reversed, and it is often difficult to determine their relative ages from their positions; then *fossils*, or the remains and imprints of plants and animals, indicate which of two or more formations is the oldest.

Stratified rocks often contain the remains or imprints of plants and animals which, at the time the strata were deposited, lived in the sea or were washed from the land into lakes or seas, 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. When 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 found 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 often difficult or impossible to determine the age of an igneous formation, but the relative age of such a formation can sometimes 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 is sometimes 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 of their metamorphism.

*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.

*Symbols and colors assigned to the rock systems.*

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

Patterns composed of parallel straight lines are used to represent sedimentary formations deposited in the sea or in lakes. 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 by which formations are labeled 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 recognized series, in proper order (from new to old), with the color and symbol assigned to each system, are given in the preceding table.

## SURFACE FORMS.

Hills and 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 thru them (see fig. 1), and the alluvial plains bordering many streams were built up by the streams; sea cliffs are made by the eroding action of waves, and sand spits are built up by waves. Topographic forms thus constitute part of the record of the history of the earth.

Some forms are produced in the making of deposits and are inseparably connected with them. The hooked spit, shown in fig. 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, and these are, in origin, independent of the associated material. 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 afterwards 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. When a large tract is for a long time undisturbed by uplift or subsidence it is degraded nearly to base-level, and the even surface thus produced is called a *peneplain.* If the tract is afterwards uplifted the peneplain at the top is a record of the former relation of the tract to sea level.

## THE VARIOUS GEOLOGIC SHEETS.

*Areal geology map.*—This map shows the areas occupied by the various formations. On the margin is a *legend*, which is the key to the map. To ascertain the meaning of any colored 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 given formation, its name should be sought in the legend and its color and pattern noted, when 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 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.*—This map represents the distribution of useful minerals and rocks, showing their relations to the topographic features and to the geologic formations. The formations which appear on the areal geology map are usually shown on this map by fainter color patterns. The areal geology, thus printed, affords a subdued background upon which the areas of productive formations may be emphasized by strong colors. A mine symbol is printed at each mine or quarry, accompanied by the name of the principal mineral mined or stone quarried. For regions where there are important mining industries or where artesian basins exist special maps are prepared, to show these additional economic features.

*Structure-section sheet.*—This sheet exhibits the relations of the formations beneath the surface. In cliffs, canyons, shafts, and other natural and artificial cuttings, the relations of different beds to one another may be seen. Any cutting which 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 the 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 of the earth to a considerable depth. Such a section exhibits what would be seen in the side of a cutting many miles long and several thousand feet deep. This is illustrated in the following figure:

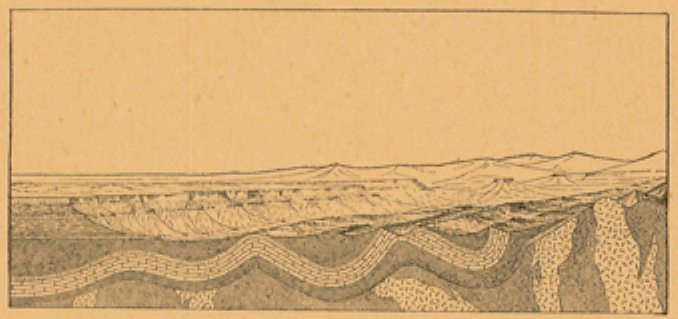

Fig. 2.—Sketch showing a vertical section at the front and a landscape beyond.

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 symbols of lines, dots, and dashes. These symbols admit of much variation, but the following are generally used in sections to represent the commoner kinds of rock:

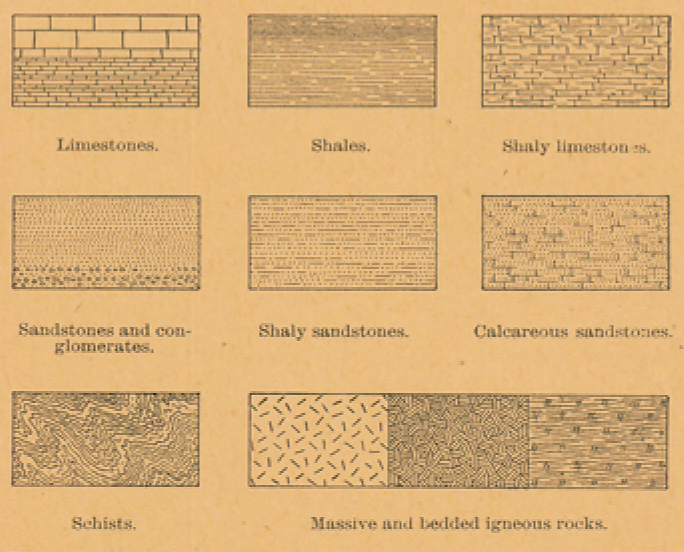

Fig. 3.—Symbols used in sections to represent different kinds of rocks.

The plateau in fig. 2 presents toward the lower land an escarpment, or front, which is made up of sandstones, forming the cliffs, and shales, constituting the slopes, as shown at the extreme left of the section. 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 that the intersection of a bed with a horizontal plane will take is called the *strike.* The inclination of the bed to the horizontal plane, measured at right angles to the strike, is called the *dip.*

Strata are frequently curved in troughs and arches, such as are seen in fig. 2. The arches are called *anticlines* and the troughs *synclines.* But the sandstones, shales, and limestones were deposited beneath the sea in nearly flat sheets; 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 fig. 4.

On the right of the sketch, fig. 2, the section is composed of schists which are traversed by masses of igneous rock. 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 well-founded inference.

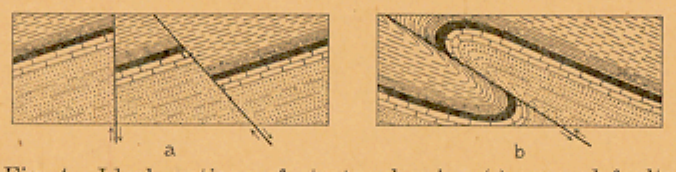

Fig. 4.—Ideal sections of strata, showing (a) *normal* faults and (b) a *thrust* fault.

The section in fig. 2 shows three sets of formations, distinguished by their underground relations. The uppermost of these, seen at the left of the section, is a set of sandstones and shales, which lie in a horizontal position. These sedimentary strata 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 raised from a lower to a higher level. The strata of this set are parallel, a relation which is called *conformable.*

The second set of formations consists of strata which form arches and troughs. These strata were once continuous, but the crests of the arches have been removed by degradation. 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 at the left of the section. The overlying deposits are, from their positions, evidently younger than the underlying formations, and the bending and degradation of the older strata must have occurred between the deposition of the older beds and the accumulation of the younger. When younger rocks thus rest upon an eroded surface of older rocks the relation between the two is an *unconformable* one, and their 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 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 suffered metamorphism; they were the scene of 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 fig. 2 are ideal, but they illustrate relations which actually occur. 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 which appears in the section may be measured by using the scale of the map.

*Columnar section sheet.*—This sheet contains a concise description of the sedimentary formations which 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 which state the least and greatest measurements, and the average thickness of each is shown in the column, which is drawn to a scale—usually 1000 feet to 1 inch. The order of accumulation of the sediments is shown in the columnar arrangement—the oldest formation at the bottom, the youngest at the top.

The intervals of time which 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, 1908.

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