DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

GEOLOGIC ATLAS

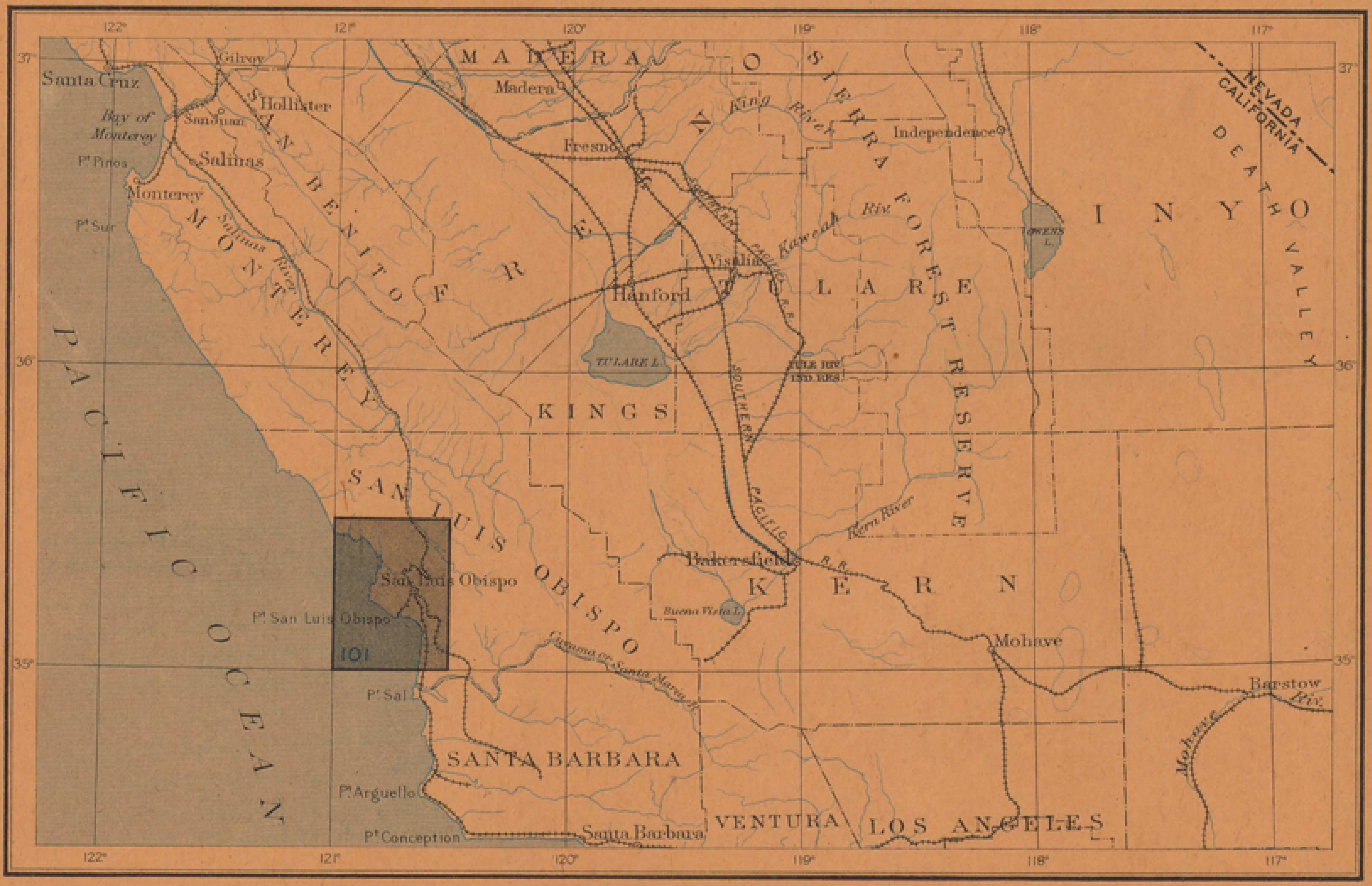
OF THE

UNITED STATES

SAN LUIS FOLIO

CALIFORNIA

INDEX MAP



SCALE: 40 MILES=1 INCH

AREA OF THE SAN LUIS FOLIO

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LIBRARY EDITION

SAN LUIS FOLIO
NO. 101

WASHINGTON, D. C.
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GEORGE W. STOSE, EDITOR OF GEOLOGIC MAPS   S. J. KUBEL, CHIEF ENGRAVER
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EXPLANATION.

The Geological Survey is making a geologic map of the United States, which necessitates the preparation of a topographic base map. The two are being issued together in the form of an atlas, the parts of which are called folios. Each folio consists of a topographic base 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 horizontal outline, or contour, of all slopes, and to indicate their grade or degree of steepness. This is done by lines connecting points of equal elevation above mean sea level, the lines being drawn at regular vertical intervals. These lines are called *contours*, and the uniform vertical 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.—Ideal sketch 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 in a precipice. Contrasted with this precipice is the gentle descent of the slope at 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 approximately a certain height above sea level. In this illustration the contour interval is 50 feet; therefore the contours are drawn at 50, 100, 150, 200 feet, and so on, above sea level. Along the contour at 250 feet lie all points of the surface 250 feet above sea; and similarly with any other contour. In the space between any two contours are found all 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 nearly all the contours are numbered. Where this is not possible, certain contours—say every fifth one—are accentuated and numbered; the heights of others may then be ascertained by counting up or down from a numbered contour.

2. Contours define the forms of slopes. Since contours are continuous horizontal lines conforming to the surface of the ground, they wind smoothly about smooth surfaces, recede into all reentrant angles of ravines, and project in passing about prominences. The 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 vertical 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 used 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.—Water courses are indicated by blue lines. If the streams flow the year round 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, and artificial details, are printed in black.

Scales.—The area of the United States (excluding Alaska) is about 3,025,000 square miles. On a map with the scale of 1 mile to the inch this would cover 3,025,000 square inches, and to accommodate it the paper dimensions would need to be 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 of "1 mile to an inch" is expressed by $\frac{1}{63,360}$. Both of these methods are used on the maps of the Geological Survey.

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 and corresponds nearly to 1 square mile; on the scale $\frac{1}{125,500}$, to about 4 square miles; and on the scale $\frac{1}{250,000}$, to about 16 square miles. At the bottom of each atlas sheet the scale is expressed in three different ways, one being a graduated line representing miles and parts of miles in English inches, another indicating distance in the metric system, and a third giving the fractional scale.

Atlas sheets and quadrangles.—The map is being published in atlas sheets of convenient size, which are bounded by parallels and meridians. The corresponding four-cornered portions of territory 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-quarter of a square degree; each sheet on a 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, respectively.

The atlas sheets, being only parts of one map of the United States, are laid out without regard to the boundary lines of the States, counties, or 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 sheet.—Within the limits of scale the topographic sheet is an accurate and characteristic delineation of the relief, drainage, and culture of the district represented. Viewing the landscape, map in hand, every characteristic feature of sufficient magnitude should be recognizable. It should guide the traveler; serve the investor or owner who desires to ascertain the position and surroundings of property to be bought or sold; save the engineer preliminary surveys in locating roads, railways, and irrigation ditches; provide educational material for schools and homes; and serve many of the purposes of a map for local reference.

THE GEOLOGIC MAP.

The maps representing areal geology show by colors and conventional signs, on the topographic base map, the distribution of rock formations on the surface of the earth, and the structure-section map shows their underground relations, as far as known and in such detail as the scale permits.

KINDS OF ROCKS.

Rocks are of many kinds. The original crust of the earth was probably composed of *igneous rocks*, and all other rocks have been derived from them in one way or another.

Atmospheric agencies gradually break up igneous rocks, forming superficial, or *surficial*, deposits of clay, sand, and gravel. Deposits of this class have been formed on land surfaces since the earliest geologic time. Through the transporting agencies of streams the surficial materials of all ages and origins are carried to the sea, where, along with material derived from the land by the action of the waves on the coast, they form *sedimentary rocks*. These are usually hardened into conglomerate, sandstone, shale, and limestone, but they may remain unconsolidated and still be called "rocks" by the geologist, though popularly known as gravel, sand, and clay.

From time to time in geologic history igneous and sedimentary rocks have been deeply buried, consolidated, and raised again above the surface of the water. In these processes, through the agencies of pressure, movement, and chemical action, they are often greatly altered, and in this condition they are called *metamorphic rocks*.

Igneous rocks.—These are rocks which have cooled and consolidated from a liquid state. As has been explained, sedimentary rocks were deposited on the original igneous rocks. Through the igneous and sedimentary rocks of all ages molten material has from time to time been forced upward to or near the surface, and there consolidated. When the channels or vents into which this molten material is forced do not reach the surface, it may consolidate in cracks or fissures crossing the bedding planes, thus forming dikes, or spread out between the strata in large bodies, called sheets or laccoliths, or form large irregular cross-cutting masses, called stocks. Such rocks are called *intrusive*. Within their rock inclosures they cool slowly, and hence are generally of crystalline texture. When the channels reach the surface the lavas often flow out and build up volcanoes. These lavas cool rapidly in the air, acquiring a glassy or, more often, a partially crystalline condition. They are usually more or less porous. The igneous rocks thus formed upon the surface are called *extrusive*. Explosive action often accompanies volcanic eruptions, causing ejections of dust or ash and larger fragments. These materials when consolidated constitute breccias, agglomerates, and tuffs. The ash when carried into lakes or seas may become stratified, so as to have the structure of sedimentary rocks.

The age of an igneous rock is often difficult or impossible to determine. When it cuts across a sedimentary rock it is younger than that rock, and when a sedimentary rock is deposited over it the igneous rock is the older.

Under the influence of dynamic and chemical forces an igneous rock may be metamorphosed. The alteration may involve only a rearrangement of its minute particles or it may be accompanied by a change in chemical and mineralogic composition. Further, the structure of the rock may be changed by the development of planes of division, so that it splits in one direction more easily than in others. Thus a granite may pass into a gneiss, and from that into a mica-schist.

Sedimentary rocks.—These comprise all rocks which have been deposited under water, whether in sea, lake, or stream. They form a very large part of the dry land.

When the materials of which sedimentary rocks are composed are carried as solid particles by water and deposited as gravel, sand, or mud, the deposit is called a mechanical sediment. These may become hardened into conglomerate, sandstone, or shale. When the material is carried in solution by the water and is deposited without the aid of life, it is called a chemical sediment; if deposited with the aid of life, it is called an organic sediment. The more important rocks formed from chemical and organic deposits are limestone, chert, gypsum, salt, iron ore, peat, lignite, and coal. Any one of the above sedimentary deposits may be separately formed, or the different materials may be intermingled in many ways, producing a great variety of rocks.

Sedimentary rocks are usually made up of layers or beds which can be easily separated. These layers are called *strata*. Rocks deposited in successive 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 over wide expanses, and as it rises or subsides the shore lines of the ocean are changed: areas of deposition may rise above the water and become land areas, and land areas may sink below the water and become areas of deposition. If North America were gradually to sink a thousand feet the sea would flow over the Atlantic coast and the Mississippi and Ohio valleys from the Gulf of Mexico to the Great Lakes; the Appalachian Mountains would become an archipelago, and the ocean's shore would traverse Wisconsin, Iowa, and Kansas, and extend thence to Texas. More extensive changes than this have repeatedly occurred in the past.

The character of the original sediments may be changed by chemical and dynamic action so as to produce metamorphic rocks. In the metamorphism of a sedimentary rock, just as in the metamorphism of an igneous rock, the substances of which it is composed may enter into new combinations, or new substances may be added. When these processes are complete the sedimentary rock becomes crystalline. Such changes transform sandstone to quartzite, limestone to marble, and modify other rocks according to their composition. A system of parallel division planes is often produced, which may cross the original beds or strata at any angle. Rocks divided by such planes are called slates or schists.

Rocks of any period of the earth's history may be more or less altered, but the younger formations have generally escaped marked metamorphism, and the oldest sediments known, though generally the most altered, in some localities remain essentially unchanged.

Surficial rocks.—These embrace the soils, clays, sands, gravels, and bowlders that cover the surface, whether derived from the breaking up or disintegration of the underlying rocks by atmospheric agencies or from glacial action. Surficial rocks that are due to disintegration are produced chiefly by the action of air, water, frost, animals, and plants. They consist mainly of the least soluble parts of the rocks, which remain after the more soluble parts have been leached out, and hence are known as residual products. Soils and subsoils are the most important. Residual accumulations are often washed or blown into valleys or other depressions, where they lodge and form deposits that grade into the sedimentary class. Surficial rocks that are due to glacial action are formed of the products of disintegration, together with bowlders and fragments of rock rubbed from the surface and ground together. These are spread irregularly over the territory occupied by the ice, and form a mixture of clay, pebbles, and bowlders which is known as till. It may occur as a sheet or be bunched into hills and ridges, forming moraines, drumlins, and other special forms. Much of this mixed material was washed away from the ice, assorted by water, and

DESCRIPTION OF THE SAN LUIS QUADRANGLE.

By H. W. Fairbanks.

INTRODUCTION.

The San Luis quadrangle includes the territory between the meridians 120° 30′ and 121° west longitude and the parallels 35° and 35° 30′ north latitude. It is about 34.5 miles long and 28 miles wide, and has an area of about 974 square miles. The coast line of the Pacific Ocean extends diagonally across the quadrangle from northwest to southeast, so that its total land surface is not more than 570 square miles. It embraces the west-central portion of San Luis Obispo County, Cal., and lies entirely within the Coast Ranges.

GEOGRAPHY.

TOPOGRAPHY.

COAST RANGES.

The Coast Ranges of California embrace that series of mountains which lies between the Great Valley and the Pacific Ocean. On the north they merge into the Klamath Mountains, and on the south they terminate in the San Emigdio Mountains, a high and rugged group which stands at the meeting point of the Sierra Nevada and the Sierra Madre of southern California. The valleys and mountain ridges of the Coast Range system trend in general a little more easterly and westerly than the coast line, so that along the coast are alternately broad sandy bays and rocky headlands that make a sharp angle with the coast line.

As a rule the river valleys open to the ocean in a northwesterly direction. San Francisco Bay is the most important exception. Here a depression across the mountains from the Great Valley permits a number of streams having the normal northwest-southeast course to enter the ocean directly through a common mouth.

The lower reaches of the valleys of the Coast Ranges are formed of broad alluvial plains, and near the ocean are frequently penetrated by tidal lagoons. Farther up, the valleys narrow and finally terminate in steep mountain canyons.

On both the north and the south, where the Coast Ranges blend with the adjoining mountains, a height of 5000 to 8000 feet is attained, while through the central portions the elevations do not generally exceed 3000 to 4000 feet. There are some portions of the Santa Lucia Range which reach 4500 feet; and San Lucia Peak, the highest point of the central Coast Ranges, attains an elevation of nearly 6000 feet. The crests of the mountain ridges which make up this system are in many cases remarkable for their even sky lines.

TOPOGRAPHY OF SAN LUIS QUADRANGLE.

Relief.—Three mountain ridges extend across the San Luis quadrangle from southeast to northwest—the San Luis Range in the south, the Santa Lucia Range in the middle, and the westward extension of the San Jose Range in the northeast. Of these the Santa Lucia Range is by far the most important. For a hundred miles northwest of this quadrangle it continues as the dominant mountain block of the Coast Ranges. Through much of this distance the range rises boldly from the Pacific Ocean, forming the most picturesque portion of the California coast. It terminates at Point Pinos, in northern Monterey County. To the southeast the range blends with the San Jose Range and the irregular mountain platform in northern Santa Barbara County.

The Santa Lucia Range forms the divide between those streams which flow directly into the Pacific and those which drain into Salinas River. The portion of the range in the San Luis quadrangle is divided topographically into two somewhat diverse parts by Cuesta Pass, a low gap affording an important line of communication between the interior valleys and the coast. Southeast of the pass the range attains an elevation of over 2800 feet, presenting a fairly even sky line. Viewed from a point on its crest, it appears as a platform about 2 miles wide, cut up into a series of sharp ridges by deep V-shaped canyons. The most important of these canyons is known as Lopez. It traverses the range longitudinally for some miles, and through most of its course has reached a graded condition.

Northwest of Cuesta Pass the summit of the range is not so uniform, owing to the diversity of formations present, but the width is greater, being nearly 4 miles. The central portion is formed almost wholly of soft Toro shale and the valleys consequently exhibit a more advanced stage of development. In this region the Santa Lucia Range has practically two crests, owing to the fact that the shale is bordered for a number of miles by igneous rocks whose greater resistance to erosion has preserved the abruptness of the outer slopes of the range. The streams pass from the open valleys in the interior of the range either directly to the ocean or to Salinas River through deep, narrow gorges.

The broad granite mountains in the northeastern portion of the quadrangle reach an elevation of nearly 2000 feet, but do not seem to be so high because of the elevated valleys about them. The mountains rise rather gradually to a sky line of striking regularity and evenness. They are trenched by numerous canyons, all narrow and not generally advanced beyond the V-stage. The ancient peneplain of which the summit of these mountains is a remnant appears to good advantage from almost any point along the foothills of the Santa Lucia Range.

The San Luis Range projects into the ocean in the form of a broad and prominent headland south of Estero Bay. Beginning on the west at Point Buchon, the range extends across the quadrangle with a somewhat more easterly course than the Santa Lucia Range, from which it is separated by San Luis and Los Osos valleys, in which are the San Luis buttes. The western and higher part of the range, which consists of a series of sharp ridges reaching an elevation of 1800 feet, is intersected by narrow V-shaped canyons. Toward the east the range decreases in height, and where it is crossed by San Luis Obispo Creek has an elevation of less than 1000 feet. East of the creek the range descends to 700 feet, and its eastern prolongation forms a broad ridge which finally blends with the Santa Lucia Range a little to the east of the southern portion of the quadrangle.

Los Osos and San Luis valleys, with their broad stretches of nearly level land, distinctly separate the San Luis Range from the Santa Lucia Range and the buttes shortly to be described. Southeast of the town of San Luis Obispo, San Luis Valley extends up to the foot of the steep southerly face which the Santa Lucia Range here presents, but northwest of the town, extending across the quadrangle and for some distance beyond, the main range is bordered by a series of rolling hills occupying a strip 4 to 5 miles wide and ranging in elevation from 1500 feet along the main face of the range to 400 feet near the ocean.

South of the town of San Luis Obispo there begins a line of peaks and ridges which extends northwestward for about 16 miles. (See fig. 4 on illustration sheet.) It terminates in Morro Rock, lying in the ocean off Morro Bay. These elevations form the northern boundary of Los Osos and a part of San Luis valleys, and are separated from the Santa Lucia Range by the lesser valleys and rolling hills. This series of buttes constitutes the most striking topographic feature of the quadrangle. There are about 12, and they range in altitude from 400 to 1600 feet. Many of them are almost completely isolated and rise from the open valleys with bold and frequently precipitous rocky faces. Morro Rock, the most northerly of these buttes, rises from the ocean as a bare rounded mass of rock nearly 600 feet high, forming the most striking scenic feature on the coast of California. (See figs. 2 and 5.) The rock is so steep that it can be scaled at only one point. Hollister Peak rises from a base but little above tide water to a height of over 1400 feet, and presents on its northern face almost vertical cliffs.

Generally the mountains and foothills are separated from the coast by a gently sloping platform which rises from a height of 40 to 80 feet in the ocean cliffs to 100 to 200 feet at its upper margin. The surficial portion of this platform is formed of the wash from the hills, spread on one or more wave-cut terraces. At some points the San Luis Range rises so boldly that this platform is absent. At Port Harford the spurs of the range terminate in cliffs several hundred feet high. In the extreme southern portion of the quadrangle, between Arroyo Grande and Santa Maria valleys, there is a gently sloping, plateau-like area of recent origin; it rises gradually from the ocean to a height of more than 450 feet at its eastern edge, overlooking Nipomo Valley. This is not a wave-cut surface like the coastal plains already described, but was formed by sedimentation during the last submergence of the coast, and was elevated and modified by erosion and wind action.

Drainage.—The principal hydrographic basin within the quadrangle is that of Salinas River. This stream rises about 30 miles to the southeast, in the mountains at the junction of the Santa Lucia and San Jose ranges. Passing across the northeast corner of the quadrangle, it pursues a comparatively straight course to the sea, emptying into Monterey Bay, 150 miles away. Throughout the greater portion of its course this river flows through an open valley which is in many places finely terraced.

Salinas River exhibits some rather unusual features within this quadrangle. Instead of flowing in the valley-like depression which lies between the granite mountains on the northeast and the Santa Lucia Range on the southwest, and which might topographically be considered as the extension of the valley of the stream to the northwest, the river occupies a winding canyon in the granite. This canyon is narrow and in places is 600 feet deep. The course of the stream is generally not more than a mile distant from the open and practically continuous valley already referred to.

The greater number and more important of the tributaries of Salinas River head to the southwest, in the Santa Lucia Range. These streams issue from the main mountain range through canyons, but their valleys rapidly widen and soon practically coalesce. Thus Rinconada Creek, Santa Margarita Creek, and Trout Creek valleys are separated by low divides only and together form the real continuation of what is known lower down as Salinas Valley. Santa Margarita and Trout creeks join the Salinas where it issues from the granite, but Rinconada Creek leaves a broad valley and flows with steeper grade to join the Salinas in the granite. This peculiar stream arrangement is not to be explained by the great differences in the hardness of the different rocks of the region; it is a clear case of superimposed drainage, and its origin will be more fully explained under the heading "Topographic development."

The streams on the southern side of the Santa Lucia Range also present peculiarities in topography, but these can not adequately be discussed until after the geological history of the region has been presented. The largest of the streams on the southern side is the Arroyo Grande. Like the Salinas, it is a graded stream throughout the greater portion of its course. The upper portion occupies a deep longitudinal V-shaped canyon. Here it has adapted its course to structural conditions, but farther down it turns at a right angle toward the southwest and cuts across the rock structures, presenting a broader and broader valley until it reaches the ocean. The lower portion of Arroyo Grande Valley is perhaps the most fertile and highly cultivated land in the quadrangle. The stream crosses the extreme eastern end of the topographic depression known as San Luis Valley, the drainage of the streams within this valley and that of the Arroyo Grande being separated by a very low divide.

The next stream to the northwest is the Corral de Piedra, which rises in the Santa Lucia Range in two main forks that cross the nearly level San Luis Valley and, uniting within the San Luis Range, continue across it through a rather narrow valley to the sea.

Passing northwestward through the broad, flat San Luis Valley, one reaches San Luis Obispo Creek, a somewhat larger stream, whose basin is separated by an almost imperceptible divide from that of the Corral de Piedra. San Luis Obispo Creek rises in the Santa Lucia Range and, flowing southwesterly across San Luis Valley in a channel but slightly depressed below the general level, cuts through the San Luis Range to the sea. The range is here 4 miles wide and 800 to 900 feet high. The rocks on either rim of the range are hard, and there the canyon is narrow. In the middle they are softer, and there the canyon has widened to a valley half a mile across.

San Luis Valley, where San Luis Obispo Creek enters the mountains, has an elevation of only 100 feet. The valley gradually rises toward the west to a broad, open gap, from which there is in turn a gentle descent to the broad valley known as Los Osos and to Morro Bay. The divide has an elevation of but 180 feet above tide water. Viewing the topography of this region in its broad outlines, one naturally wonders why Corral de Piedra and San Luis Obispo creeks did not take advantage of this depression and flow westward into Morro Bay rather than cut channels through a broad range of hills. In fact, it might be legitimately asked whether these streams did not at some time flow in this direction. A close examination, however, makes it clear that the present drainage is a long-established one; the tributaries of the two streams converge normally to the main lines of drainage as they are now maintained.

All the streams which enter the ocean within the San Luis quadrangle, as well as along the other portions of the California coast, meander in their lower courses over alluvial bottom lands which have been formed in valleys that were eroded to a greater depth when the land stood higher with relation to the ocean level. At the mouth of San Luis Obispo Creek its valley has been flooded for half a mile, and, as is the case with many of the larger streams, there is a tidal lagoon. (See fig. 7.)

Morro Bay is one of the most interesting of the coastal features of the San Luis quadrangle. It is the flooded lower portion of Los Osos Valley, across the entrance of which the waves and currents have thrown up a sand bar. (See fig. 2.) Aided by the wind, this bar has been built up until it is now 50 feet high in places and one-fourth of a mile across. The position of Morro Rock at the northern edge of the drowned valley has determined the outlet of the bay at that point. The Los Osos drainage area is comparatively small, but during the evolution of the present coastal features Chorro Creek, heading in the Santa Lucia Range, was deflected so as to pass between two of the buttes into Morro Bay. This stream is rapidly filling the bay with alluvium. The work has been especially rapid since the country began to be settled and the surface of the soil to be disturbed.

CLIMATE AND VEGETATION.

The climate of the coastal portion of California is influenced less by latitude than by nearness to a great body of water. The prevailing winds blow from a westerly direction, and these, passing over the expanse of the Pacific, whose waters vary but little in temperature through the whole year, cool the adjoining lands in summer and warm them in winter.

The greater portion of the rainfall along the middle California coast occurs during the winter months, the summers being long and dry. This is due to the fact that cyclonic disturbances of the atmosphere, with which precipitation is associated, do not occur during the summer months.

As a rule the storms originate in the north Pacific, and, passing southward and eastward, reach the land. As fall approaches these storms extend farther and farther south, until the whole coast as far as Mexico receives rain. The frequency of the storms and the amount of precipitation decrease from north to south.

The position and height of the mountain ranges form another factor in the climate of California. The Coast Ranges, extending across the course of the prevailing storms, are much better watered on their western slopes than on their eastern, the larger part of the available moisture being condensed on the side from which the storms come.

During summer regular winds blow in upon the land from the northwest, and for several months these are accompanied by cool, damp fogs. The wind usually reaches its greatest velocity in the afternoon, and is most marked in the large valleys which open northwestward to the coast. The air in the interior becomes greatly heated during the long summer days, and through the gaps in the mountains along the coast the cool, fog-laden air rushes in from the sea as through funnels. The fogs thus sweep inland 40 to 50 miles, tempering the climate and preventing as rapid evaporation from the land as would otherwise occur. These conditions permit the raising of certain crops in the fog belt without irrigation.

Within the San Luis quadrangle the rainfall is naturally heavier on the western slopes of the San Luis and Santa Lucia ranges. At the town of San Luis Obispo the average annual rainfall for the years during which a record has been kept is 21 inches. The amount for different years varies greatly, from a maximum of 40 inches to a minimum of 5 inches.

In Salinas Valley, east of the Santa Lucia Range, the rainfall is less, and it continues to decrease beyond each succeeding mountain ridge in the direction of San Joaquin Valley. With increase of distance from the coast there is an increase in summer temperature and a decrease in winter.

The higher and steeper portions of the three mountain ridges which traverse the quadrangle are generally covered with a dense growth of low shrubs or chaparral. Among the more common ones are the chamiso, California lilac, scrub oak, and manzanita. The distribution of some of these is clearly affected by the nature of the residual soil. Where the soil is heavy and sufficiently rich, grasses or wild oats frequently replace the brush, even on the steep slopes.

The sycamore marks the springs and water-courses, especially over the region on the coast side of the Santa Lucia Range. In some of the stream bottoms, particularly that of the Arroyo Grande, it forms dense groves. The live oak and laurel are generally confined to well-watered areas where the soil is rich. Willows and alders mark the canyons and marshy places.

A few scattered yellow pines are found on some of the higher portions of the Santa Lucia Range. Cypress is found in a few of the canyons north of San Luis Obispo, particularly at the head of Chorro Creek.

The rolling hills south of the Santa Lucia Range are nearly free from trees. North of the range the valleys are higher and drier and are thickly dotted with oaks, of which the white oak is the most abundant. The Digger pine is a common tree east of the Santa Lucia Range.

The soils are the poorest and vegetation is most scanty where the serpentine rocks outcrop, although, owing to the extent to which this formation has been seamed and sheared, these areas are abundantly supplied with water. Springs are particularly numerous and large along the fault lines. The San Luis formation is also well supplied with springs, especially where dikes are numerous. The granite area is the driest portion of the quadrangle. The granite does not appear to be fissured to any considerable degree, and most of the water it receives runs off. Springs are not numerous in the Toro formation nor in the Monterey shale, although the deep canyons in the latter generally contain running water the year round.

The sandy areas of the Pismo formation are surprisingly rich in springs. This is because of the porous nature of the sandstone, which absorbs water like a sponge and gives it off slowly during summer.

The San Luis formation, which consists so largely of an earthy sandstone, together with the basic rocks intruded in it, produces in decay the richest and deepest residual soils of the region. They support a luxuriant growth of grasses.

GENERAL GEOLOGY.

SEDIMENTARY ROCKS.

The geologic history of the Coast Ranges is complex. Periods of depression beneath the ocean with accumulation of sediments have alternated with elevation and erosion. In some cases these oscillations have progressed quietly, in others they have been accompanied by igneous action on an extensive scale. Intrusive masses almost innumerable have been forced through the crust in the form of sheets or dikes; have reached the surface in the form of lavas; or, thrown into the air with explosive violence, have fallen in the form of pumice and volcanic ashes.

So often have these disturbances taken place within the Coast Ranges, and so extensive have been the areas affected, that seldom are two formations found in conformable juxtaposition. Within the San Luis quadrangle there are seven sedimentary formations, separated by five unconformities marking periods of elevation and erosion. The periods of elevation were often so long that sediments thousands of feet in thickness were removed by erosion; indeed, in certain areas thus exposed whole formations disappeared in this manner; so that the sedimentary series is at present more or less fragmentary at every point.

The sedimentary formations in this portion of the Coast Ranges cover the time from Jurassic (?) to the present. They include both marine and fresh-water deposits, though chiefly the former. With the exception of narrow bands between certain of the igneous rocks and the sedimentary formations, the sediments have undergone but little metamorphism. In addition to the unaltered formations of the San Luis quadrangle, there is in certain portions of the Coast Ranges, notably in the northern portion of the Santa Lucia Range, an older and thoroughly metamorphosed formation, the exact position of which in the geological scale is unknown. The lack of sedimentary formations between this older one and the unaltered series makes it evident that previous to the Jurassic the region was elevated above the sea for an exceedingly long period, but that since then it has been elevated and depressed many times.

Several areas of crystalline rocks extend in a northwest-southeast direction through the central and southern Coast Ranges. The rocks consist partly of granite and partly of crystalline schist and marble. The schists and marble represent thoroughly metamorphosed remnants of a sedimentary formation of unknown age. The formation is older than the granite, in which it is inclosed, and the granite is older than the Jurassic sediments.

One of the crystalline areas crosses the northeast corner of the San Luis quadrangle, but the portion within its boundaries does not, so far as is known, contain any remnant of these early sediments.

JURATRIAS (?) SYSTEM.

San Luis formation.—The oldest sedimentary beds within the San Luis quadrangle consist of sandstone and shale with lenticular beds of radiolarian jasper and a very little conglomerate. The formation is named from San Luis Valley. These beds have been folded and faulted in a very complex manner and have been penetrated at various times by dikes of igneous rocks in great abundance and variety. They belong to the Franciscan group, which is extensively developed in the Coast Range region. With the exception of the crystalline complex already referred to, this group forms the basement upon which the succeeding formations rest. It is separated from the earlier as well as later beds by important unconformities.

The position of the Franciscan group in the geologic scale is not readily determinable, partly because of the scarcity of fossils and partly because of the difficulty experienced in ascertaining its relation to the Knoxville group, the lowest recognized Cretaceous. The formation has been shown to occur unconformably beneath the Knoxville, and the paleontologic evidence, though very incomplete, is sufficient to make it clear that the beds can not be older than the Jurassic. The group occupies the same relation to the Knoxville in the Coast Ranges as do the Mariposa slates in the Sierra Nevada and Klamath Mountains to the Knoxville on their borders, and is therefore provisionally referred to the Jurassic.

The strata of the San Luis formation are most prominently exposed through the central portion of the quadrangle along a general northwest-southeast line. They occupy the southern foothills of the Santa Lucia Range, the northern slope of the San Luis Range, and much of the valleys between the two. A small area appears on the coast north of Port Harford, and a long narrow strip along the eastern slope of the Santa Lucia Range.

The fossil remains found in this formation within the quadrangle are limited to Radiolaria and Mollusca. The former are widely distributed in the jasper lenses. They appear as little roundish dots, in some of which a definite structure can be seen with the aid of a hand glass. Molluscan remains were discovered at only one point—on the coast 6 miles northwest of Port Harford. One species, a little pecten-like form, occurs at this locality in immense numbers. It is distributed through a stratum of black slate about 50 feet thick. The beds stand vertical and are inclosed between dikes of diabase. The *Pecten* from these slates has been examined by Mr. T. W. Stanton, who reports as follows: "The collection consists of a number of distorted specimens of a single species of *Pecten*, which is of a type that might be either Jurassic, Cretaceous, or Tertiary. It should be compared with *Pecten pedroanus* (Trask), a Miocene species originally described as a *Plagiostoma* and assigned to the Cretaceous. The strange and interesting thing about this formation is that none of the molluscan remains yet found in it are referable to forms that have been described from the Pacific coast, while they are practically indeterminate as far as settling definitely the age of the formation is concerned."

The San Luis formation as a whole consists of shallow-water sediments, for nearly or quite three-fourths of it is sandstone. The remaining portion consists of shale, lenticular beds of radiolarian jasper, and a very little conglomerate. The whole has been upturned, folded, and faulted in a very complex manner, and penetrated at various periods by dikes of igneous rocks in great variety and abundance. In certain portions the eruptives of pre-Knoxville age form fully a third of the surface area of the complex. All these rocks except the jaspers and contact schists decay and weather away rapidly, leaving rounded hills covered with a fertile soil. For this reason the portions of the quadrangle covered by this formation were especially difficult to map.

The Franciscan group occurs extensively in the Coast Ranges. It reaches at least as far north as the Klamath Mountain region, and as far south as eastern Santa Barbara County, where it passes beneath the Cretaceous and other later formations. The character of the rocks is much the same throughout their occurrence. Sandstone, jasper lenses, and igneous intrusions are almost everywhere prominent. In marked contrast with the younger rocks, the strata of the San Luis formation have been sharply folded, shattered, and crushed together, through mountain-making movements as well as igneous intrusions. The softer layers have been crushed and portions of the harder ones embedded in them. Where the sandstones are thick bedded they are generally more or less seamed and slickensided. In the vicinity of igneous masses they are frequently penetrated by interlacing calcite veinlets. Over wide areas a greater or less degree of silicification has taken place, as shown by the quartz veinlets wholly or partly filling minute cracks and fissures in the sandstone. It has been found impossible within the San Luis quadrangle to measure the thickness of the formation or to determine with any certainty in a given section which are the lowest and which the uppermost beds.

Within this quadrangle the base of the formation is not exposed. Farther north, however, on the western slope of the Santa Lucia Range as well as in the Santa Cruz Mountains, it is seen resting upon the granite with a thick basal conglomerate. No formation is known between the San Luis formation and the crystalline basement complex. The latter, then, must represent the ancient land over which the sea gradually crept as the San Luis formation was deposited.

The sandstones of the San Luis formation are usually thick bedded, so that in poor exposures, especially if the rock has undergone much fissuring, it is impossible to determine the strike and dip. The outcrop of the formation along the coast northwest of Port Harford exhibits well the relative proportion of sandstone. This rock, together with thin beds of shale and lenses of jasper, stands vertical for a distance across the strike of nearly 2 miles, giving a section approximately 10,000 feet thick. Although the formation here exhibits less deformation than usual, the sandstone is seamed to such a degree that in most places it is unfit for building purposes, many of the seams appearing only under the influence of weathering.

A microscopic examination of the sandstone shows that it contains an unusually small proportion of quartz grains. The same fact is shown in the nature of the soils to which it gives rise. Fragments of feldspar crystals, quartz, mica scales, and dark ferruginous material form the bulk of the sandstone. Locally it has been metamorphosed, so that secondary minerals appear.

As already indicated, the basal beds of the formation are not exposed within the quadrangle. The conglomerates which undoubtedly exist at its base are deeply buried. Faulting along Salinas River near the edge of the granite area has thrown down the formation, so that its base is not exposed. At various points in the area occupied by the San Luis formation a thin bed of conglomerate was noted, but whether there is more than one horizon could not be determined. An unimportant bed appears at the fossil-bearing locality northwest of Port Harford. The conglomerate is interbedded with sandstones and shales. It contains pebbles of granitic rocks, quartzite, and jasper.

A stratum of sandstone containing scattered pebbles which is exposed on Villa Creek about a mile above its mouth contains a bowlder of glaucophane-schist 2 feet in diameter in the same matrix with the pebbles. Its presence here would seem to indicate either the existence of earlier glaucophane-schists very similar to those produced by igneous contact, or erosion and redeposition in San Luis time after the schists had been formed.

Rather thick beds of shale are exposed in several localities. The largest area is on the eastern slope of the Santa Lucia Range, opposite Rinconada Valley. Here the shales are not much hardened and are rather difficult to distinguish from those so characteristic of the Toro formation.

Jasper lentils.—This term is applied to beds of banded siliceous or flinty rock which occur in more or less discontinuous or lens-shaped bodies in the San Luis formation, and which have been separately mapped. These strata sometimes reach a thickness of 100 feet, and individual outcrops may be a mile or more in length. The beds are probably at times continuous for a longer distance, but the outcrop becomes so narrow that they can not be traced. Generally the bodies are smaller and more decidedly lens shaped. They are made up of hundreds of bands, from half an inch to several inches in thickness. These are in many cases strictly jasper, in others flinty and more earthy. In color they vary from light creamy tints through green, brown, and deep red. The different colors seem to be due to varying proportions of iron oxides, and in some cases to manganese. This mineral, when present, is always associated with the jasper. The prevailing color of the jaspers, particularly the deeper-tinted ones, is due to the nearness of igneous rocks. The jasper horizons have offered conditions especially favorable for intrusion of igneous masses, which so frequently penetrated the rocks of this formation. The jasper bands, because of the ease with which they may be parted, have offered easy passage for mineral-bearing solutions as well as for igneous masses. The bands are generally wavy and are often highly contorted, fractured, and intersected by a network of quartz or chalcedonic veinlets. They are separated by softer and more earthy material, and in some cases the jasper itself becomes earthy. The term "chert" might be used for the more impure varieties, but does not seem appropriate for the great mass of this rock. (See figs. 6 and 8.)

Under the microscope the jasper appears to be a mixture of crystalline and amorphous silica, and a chemical test shows the presence of iron, and often a little alumina and magnesia. In many hand specimens as well as in microscopic sections generally the rock is seen to be more or less thickly dotted with little circular or elliptical areas. In some cases it is clearly seen to be made up almost wholly of these minute forms. In specimens which have not undergone too much change the structure of the radiolarian skeleton is often seen with considerable distinctness. It is reasonable to suppose that originally the radiolaria were present in all phases of the rock, but that in the changes which it has undergone the structure of the little organisms has in large measure disappeared.

The ancient sea in which the beds were deposited must at times have swarmed with microscopic organisms possessing siliceous tests, so thick are the beds in which their skeletons are found. The strange feature connected with these beds is their association with sandstone. The change from a detrital rock of shallow-water formation to the jasper is abrupt. No radiolaria have yet been detected in the sandstone, while in the jasper detrital material of shore origin is entirely absent. There must have been comparatively abrupt alterations either in the currents or in the depth of the sea and the position of the shore line.

Owing to their hardness the jasper beds resist erosion more than the other portions of the San Luis formation, and consequently are generally found at the summit of low hills and ridges. As to the exact number of jasper horizons in the formation and their relative position little can be determined. In certain portions of the formation where there is reason for believing that we are dealing with but one limb of a compressed fold, there are at least half a dozen prominent strata of jasper distributed through 2000 to 3000 feet of the sediments. A portion of the formation which is almost exclusively sandstone contains but little if any jasper, but what part of the formation this is can not be told. Farther north, on the slope of the Santa Lucia Range, jasper occurs within 1500 feet of the base of the formation. There the succession from the base upward is conglomerate and sandstone, fossil-bearing slates, jasper, and sandstone.

There occurs within the San Luis quadrangle, as in other portions of the Coast Ranges, an interesting schist associated with the San Luis formation. In all fairly good exposures these bodies of schist are seen to have a lenticular form. Their thickness ranges from a foot or less up to 100 feet, and their length at times reaches 200 feet or more. This rock is of a prevailingly bluish tint and, owing to its resistant nature, often forms prominent outcrops. Its relation to the rest of the San Luis formation is often obscure, but wherever exposures are sufficiently good it is seen to lie at the contact between sandstone or shale and one of the basic igneous rocks which have so commonly intruded the beds. Similar schists in other parts of the Coast Ranges have been regarded as sediments metamorphosed by intrusive igneous rocks, and hence have been called contact metamorphics, or glaucophane-schists, from the predominance of the mineral glaucophane.

The phenomena exhibited by these rocks in many places within the quadrangle sustain the view that they are metamorphosed sediments. Although it is difficult to understand why the metamorphism should be so irregular in its action, resulting in such prominent bodies of schist in some places and scarcely any in others, the facts that the schists are always associated with one of the basic intrusions, and that the contact rock often exhibits a gradual transition from the fully crystalline state near the igneous mass to the uncrystalline sandstone or shale farther away, make it evident that the schist has been produced through contact metamorphism.

Glaucophane (a blue amphibole), the predominant constituent, gives this rock its characteristic tint, but other minerals are frequently present in abundance. Among those of importance are quartz, chlorite, a pearly mica, garnet, and at one place in Reservoir Canyon, lawsonite.

The exceeding abundance of these contact rocks throughout those portions of the Franciscan group where the pre-Knoxville basic eruptives are the most numerous confirms the view that most, if not all, of the latter are not contemporaneous lava flows, but later intrusions. The frequent occurrence of amygdaloidal facies among these igneous rocks might otherwise lend probability to the view that they were contemporaneous flows.

CRETACEOUS SYSTEM.

Strata of Cretaceous age in California include three main groups—the Knoxville, Horsetown, and Chico. Two of these, the Knoxville and the Chico, are widely distributed throughout the Coast Ranges; and their representatives, the Toro and Atascadero formations, are found within this quadrangle. Nothing corresponding to the Horsetown group has been recognized here, and probably the horizon is represented by an erosion unconformity.

It has been thought that the Cretaceous sediments in California formed a conformable series from top to bottom, but, in the central Coast Ranges at least, this period was broken two or more times by igneous outbursts, with one long interval of elevation and erosion.

Toro formation.—The Toro formation, within the San Luis quadrangle, consists of more than 3000 feet of dark shale and thin-bedded sandstone. The formation is named from a creek which flows across it. The shale forms almost the whole of the bottom and middle portions. The sandstone is more abundant toward the top. The formation is not supplied with many fossils, for, excepting one specimen of an ammonite, the only species found is one belonging to the genus *Aucella*. This is very abundant through the middle and lower portions of the formation.

The Toro formation is the local representative of the Knoxville group, but it probably corresponds to a small part only of Knoxville time, the rest being represented by the unconformities above and below. It belongs to the lower Cretaceous or Shasta series.

Within the San Luis quadrangle the strata are confined to the region along the Santa Lucia axis. They constitute the brush-covered valleys and mountains through the central portion of the range, from Cuesta Pass northwestward to the edge of the quadrangle. Southeast of the pass the formation is buried under the Monterey shale, except a narrow strip outcropping along the sides of the range for several miles.

Although the Toro formation is much disturbed and broken, the structure, particularly of that part northwest of Cuesta Pass, is in a broad way that of a syncline. The syncline is bordered by two lines of great igneous masses intruded along its edges. These, on account of their superior hardness, now form the double crest of this portion of the range. The rock has been designated the Cuesta diabase. Its intrusive character is shown by the fact that wherever it comes in contact with the shale the latter has been baked to a hard, gritty rock which often rings when struck. The cliffs that rise so picturesquely near Cuesta Pass are composed of sandstone of the Toro formation metamorphosed by the diabase. The sharply projecting points of the range northwest of the great serpentine area are formed of the baked shale also. There are several localities, notably on the Eagle ranch, where the shale has been hardened, but not sufficiently eroded to reveal the diabase which must lie below in laccolithic form. At some time after the intrusion of the diabase, but previous to the deposition of the Atascadero formation, the Toro formation was intruded by peridotite, which is now represented by the serpentine. This intrusion metamorphosed the shale but slightly.

The relation existing between the Toro and San Luis formations was clearly made out at a number of points. Two miles above the mouth of Reservoir Canyon there is a patch of Toro shale which has been but little disturbed, the strata being nearly horizontal. On the southern edge of this area specimens of *Aucella* were found at the very base of the formation. Just below, on the slope of the hill, the San Luis formation with its dikes of basic igneous rocks was observed to pass directly under the *Aucella*-bearing shale and through the hill, coming out on the opposite side.

At the mouth of Reservoir Canyon, on a hill north of the road, is a small patch of basal conglomerate of the Toro formation. To the east this extends under the shale of that formation, but on all the other sides the San Luis formation appears from beneath. The conglomerate has a thickness of about 30 feet and is made of small pebbles. One of the intrusives in the older formation was traced from one side of the hill to the other, passing beneath but not into the conglomerate.

Isolated patches of this basal conglomerate, which in some places contain specimens of *Aucella*, appear near the road crossing the Santa Lucia Range from Morro Creek to Graves Creek. These patches of conglomerate are mere remnants of a once much more extensive formation. They are strung along from this point for several miles in a southeasterly direction. Wherever exposed this conglomerate shows a marked unconformity with the San Luis formation.

Atascadero formation.—This formation, the local representative of the Chico group, consists mainly of certain soft sandstones of a grayish-yellow color. The formation derives its name from Atascadero Creek. A few poorly preserved fossils were found in it at several points along the northern slope of the Santa Lucia Range. Within this quadrangle it is confined to two areas. The more important one stretches as a long band, 1 to 2 miles wide, along the northern slope of the Santa Lucia Range, reaching entirely across the quadrangle. The other area is located on the opposite side of the Santa Lucia Range and farther west. It also has the form of a rather narrow strip and reaches along the coast from a point 5 miles west of Cayucos to and beyond the edge of the quadrangle. No fossils were found in this southern belt, but there is every other reason for believing that the beds are of upper Cretaceous age. Not only are they lithologically similar to those on the northern side of the mountains, but there is no other period to which they might be assigned except the Eocene. There is, moreover, no evidence to indicate that rocks of the latter age were ever present in this portion of the Coast Ranges.

Near the coast the Atascadero formation occurs above the San Luis formation, but northeast of the Santa Lucia Range it rests on the Toro. In the latter region the Atascadero terminates downward in a conglomerate which is in places 100 feet thick and contains large granite bowlders. The striking contrast in general lithologic character between the Atascadero and Toro formations is indicative of a marked change in conditions of deposition. The hypothesis that there is a hiatus in the Cretaceous sediments is well founded. It is based, on the one hand, on the fact that the Atascadero sediments extend over the Toro across both strike and dip, indicating that the Toro had been upturned and planed off before the Atascadero began to be deposited (as may be seen at many points, particularly on the divide between Atascadero and Santa Margarita creeks), and, on the other hand, on the fact that the Atascadero in the same locality rests indiscriminately upon the Toro and San Luis formations.

Another interesting fact should be mentioned in connection with the discussion of an unconformity: The serpentine here, as in other portions of the Coast Ranges, wherever it comes in contact with the lower Cretaceous is intrusive, while it has nowhere been observed to penetrate the Atascadero formation. There were at least two epochs of igneous activity during the Cretaceous, and three if the formation of the San Luis buttes be included; this supports the view that marked movements occurred during Cretaceous time.

NEOCENE SYSTEM.

No strata of Eocene age were discovered within the San Luis quadrangle, although to the southeast, in Santa Barbara and Ventura counties, strata of that age are extensively developed. The absence of the formation makes it probable that during Eocene time this portion of the Coast Ranges was dry land. Eocene strata occur along the western edge of San Joaquin Valley on the borders of the Coast Ranges, and extend across Ventura County toward the ocean until finally buried under more recent deposits. This seems to indicate that during the Eocene the Great Valley did not open to the west but formed a long, narrow arm of the ocean, with the outlet at the southern end. With the opening of the Neocene the geography of the Coast Ranges again changed. Strata of Miocene age are so widely distributed throughout the Coast Ranges as to have led the earlier geologists to think that the first land in this region dated from the upheaval which terminated that period of sedimentation.

The Neocene of the San Luis quadrangle is divided into three distinct divisions by unconformities which mark two epochs of uplift and erosion. This period was also marked by numerous volcanic outbreaks and the intrusion of much igneous material.

With the beginning of the Neocene a subsidence commenced to affect the land. This continued through a part of Miocene time, until nearly the whole of the central and southern Coast Range region was submerged. The movement was not uniform, but was marked by at least one stop of considerable importance. Within the San Luis quadrangle land continued to exist for a long time along the axis of the San Jose Range, but even this was probably buried before the close of the period of sedimentation.

The lowest division of the Neocene is made up of Vaquero sandstone and Monterey shale. That group of strata which is now distinguished as the Pismo and Santa Margarita formations overlies these beds unconformably, but by the earlier geologists the whole was considered a continuous series of sediments and termed the Miocene. It is now known that the sequence was not continuous, though paleontologists have not decided whether the Pismo and Santa Margarita are late Miocene or early Pliocene. Erosion has removed much of the Monterey shale, but, from the similarity in the succession of the strata in the different areas, it is clear that this formation once formed a continuous sheet over the whole quadrangle. The Pismo and Santa Margarita formations are also much less extensive than formerly, although in all probability they did not cover the whole quadrangle. The stratigraphic break between the Monterey and these overlying formations is a profound one.

The latest Neocene formation within the quadrangle is termed the Paso Robles. It is of fresh-water origin and occupies a large part of the Salinas drainage area. Marine Pliocene has not been certainly recognized. Some beds which may belong under that head have been mapped with the fresh-water Pliocene because of the absence of definite evidence of their marine origin.

Vaquero sandstone.—Below the heavy shale which makes up the Monterey are certain sandstone and conglomerate beds to which the name Vaquero is applied, because of their extensive occurrence on Los Vaqueros Creek, a tributary of Salinas River in Monterey County. This formation is developed to a remarkable degree along the southern side of the granite area. Only a small portion of it falls within the quadrangle. It dips from 15° to 30° to the south and southeast, and beyond the quadrangle is exposed for a distance of nearly 5 miles across the strike. This would give it a total thickness of 5000 to 6000 feet. It seems probable that these sandstones and conglomerates were in origin, partly at least, contemporaneous with the bituminous Monterey shale, the former representing the shore deposits, and the latter representing deposits formed at a considerable distance from the land. This view can not be demonstrated because faulting along the southern side of the granite area has thrown down the sandstones on the northeast, so that they can not be traced continuously to the shales in the Santa Lucia Range. In any case the region of the San Jose Mountains must have formed a rugged coast facing the open ocean in order to permit the formation of such a thickness of coarse fragmental material. The character of the conglomerate at the base of the formation is shown best in the canyon of Salinas River.

The Vaquero sandstone is thin over most of its area in the quadrangle, and is usually fossiliferous. The land during Eocene time must have been reduced to a condition of low relief, and with the coming in of the Neocene must have been shortly submerged to a depth too great for the accumulation of much near-shore detritus.

Monterey shale.—Above the Vaquero sandstone and conformable with it is a great thickness of shale with some rhyolitic tuffs and volcanic ash and limestone, which was called by Whitney the Bituminous shale series, and to which Blake applied the name Monterey.

In the San Luis quadrangle clay shale forms the base and comes next above the Vaquero sandstone. The beds have a considerable thickness in some places, but in others are absent. Farther to the southeast in the Coast Ranges the clay shale at this horizon attains great thickness and is highly gypsiferous and alkaline. These varying conditions at the same horizon would appear to indicate an archipelago with exposed shores and deep, protected bays.

The shale is followed in ascending order by the volcanic beds. The latter are widely distributed over the quadrangle, occurring everywhere at the same horizon. Volcanic activity in this region during the early Neocene lasted a long time. It was of exceptional character, as its product is represented mainly by beds of volcanic ash and pumice. The areal distribution of the volcanic beds through the Coast Ranges has not yet been fully determined, but in the region under discussion they have been observed at points 60 miles apart. At several places within the quadrangle the beds are several hundred feet thick, though divided into several distinct groups of strata by beds of clay shale which may reach a thickness of 100 or more feet. This condition is well illustrated on the coast near Pismo. The eruptions probably took place beneath the sea, and the pumice, blown out with explosive violence and widely distributed over the ocean, settled to the bottom and formed regularly stratified beds.

There were many centers of volcanic activity, all of which were probably not in eruption at the same time. Some of these have been exposed by erosion. One was located about 5 miles south of the town of San Luis Obispo, east of the point at which the creek enters the San Luis Range. The bold bluffs facing the valley are about 700 feet high and consist almost wholly of fragmental volcanic material, chiefly pumice with occasionally a stratum of shale. At the base of the formation there are large subangular pebbles of obsidian in a cement made up of the same material.

Three miles west of Pismo, on the coast, large fragments of shale are buried in the pumice. In the ash exposed at this point were found well-preserved molluscan remains, indicating clearly that the volcanic material was deposited beneath the ocean.

Near the northern edge of the quadrangle, between the forks of Old Creek, the tuffs outcrop again in great thickness and extend for a number of miles along the southern slope of the Santa Lucia Range. Here they are associated with a thin flow of banded rhyolite.

The ash forms a continuous horizon along the southern slope of the San Luis Range from near Point Buchon to the eastern edge of the quadrangle, although in some places it is covered by more recent deposits. It is also traceable along much of the northern side of this range. Similar volcanic beds occur near the base of the Monterey formation in the Santa Lucia Range, through the central portion of the quadrangle, but not generally in thick beds, except toward the west, on Old Creek.

Much of this pumice appears to have undergone secondary alteration. This is particularly the case along lines of disturbance, as on the southern slope of the Santa Lucia and San Luis ranges. From Lion Rock, near Point Buchon, southeastward to and beyond Picacho Peak it has been impregnated with iron pyrites and so changed that its original character was not understood for some time. As a result of the mineralization and subsequent oxidation the mass has become hardened and very resistant to disintegration. It is this rock which forms the picturesque features of the coast at Lion Rock and between Port Harford and Pismo. The ash has preserved more perfectly than any other formation the record of the ocean terraces.

The limestone beds of the Monterey have a somewhat irregular thickness. They are confined chiefly to the horizon between the volcanic ash and the siliceous shale, which is still higher in the formation. Nodular-like layers and concretionary masses of limestone occur sparingly in portions of the siliceous shale. The limestone attains a thickness of about 300 feet along the southern slope of the Santa Lucia Range east of the town of San Luis Obispo. Generally, however, it is much thinner, and in places scarcely appears at all. It is not massive, but, like the shale, occurs in rather thin layers separated by seams of more earthy material. In color it is yellowish to whitish, and freshly broken pieces give out a strongly fetid odor, due to organic remains.

A microscopic study of the limestone shows it to consist in large measure of nearly obliterated skeletons of calcareous organisms, chiefly Foraminifera. The limestone contains no distinguishable detrital material of shore origin, and only in rare instances have molluscan remains been found in it. The beds were evidently formed in waters free from shore material.

Within the San Luis quadrangle the siliceous shale, or Bituminous shale, as it has been called by the older geologists, constitutes the greater part of the Monterey. These beds underlie the younger formations of Salinas Valley. East of Cuesta Pass they form all of the higher portion of the Santa Lucia Range. The central and southern portion of the San Luis Range is also made up of the shale, but east of San Luis Obispo Creek the beds pass underneath the Pismo formation, although still outcropping as a narrow fringe on either side of the range. At Arroyo Grande Creek they appear again, and southeast of that point they form the predominant rock over a large extent of country. In general the shale is regularly and evenly banded. (See fig. 3.) The bands, which are separated by thin layers of softer material, range in thickness from an inch or less up to 6 inches. In a fresh and unaltered condition the shale is dark yellowish brown, and is often strongly impregnated with bituminous matter. On weathered surfaces it bleaches to a light yellow. Over large areas it has undergone silicification, which has so changed its appearance that, were it not for numerous transitional phases, the origin of the silicified beds would often be difficult to recognize. The different degrees of change can be traced from the dark bituminous shale through the light porcelain-like varieties to the flinty forms. Some of the flints are opaline, while others have a waxy appearance and still others are jet-black. The metamorphism has affected the rock so irregularly that often considerable variation can be seen in the same hand specimen.

Analyses show that the unaltered shale generally contains 80 to 90 per cent of silica, and the flints as high as 98 per cent. In those areas of shale which have undergone the most metamorphism the bands are generally sharply folded and contorted and are filled with a network of veinlets of chalcedonic quartz. The change which the shale has undergone is not so much the introduction of new silica as the transformation of that which it already contained. The nonpolarizing amorphous silica of the unaltered shale has given place to the polarizing chalcedonic variety. The unaltered shale often shows its origin to the unaided eye, for it appears to be made up almost wholly of minute circular forms which under the microscope are seen to be of organic origin. Some are clearly distinguished as Foraminifera, while others are diatoms or Radiolaria. In most cases the structure of these little tests has disappeared on account of the transformation which the rock material has undergone.

At one or more horizons there are beds of a white, chalky rock which under the microscope is seen to be composed of diatoms in a good state of preservation. One of these horizons is immediately above the volcanic ash beds, and at the contact there is a layer, in places 20 feet thick, in which the diatoms are mixed with fine particles of volcanic glass. It is not known why in these cases the beds of diatoms have been preserved with so little change, but the cause is probably to be looked for in the conditions of deposition. Some portions of the diatomaceous beds have experienced a transformation, and hand specimens were obtained in which the flinty alteration product appeared sharply marked off from the unaltered portion by lines running directly across the bedding.

The amount of material referable to volcanic origin scattered through the great bulk of the siliceous shale is certainly small. In the absence of distinguishable detrital material of shore origin we are led to the conclusion that the shale is in great part of organic origin. In addition to the microscopic organisms, the shale contains innumerable fish scales, and in rare instances complete skeletons have been found. Bones of whale and seal and of other sea mammals are also scattered through the shale. Molluscan remains are not plentiful.

Pismo and Santa Margarita formations.—Overlying the Monterey shale unconformably is a series of soft white sandstones, conglomerates, diatomaceous beds, and flinty shales which represents the San Pablo group. The names Pismo and Santa Margarita have been given to two formations in this area which appear to be closely related in stratigraphic position, but are not known to have been connected. The names are derived from the towns of Pismo and Santa Margarita. The abundant fossils in the formations show them to be of middle Neocene age, but whether they should be placed in the Miocene or the Pliocene has not been determined. The original extent of these sediments has been greatly reduced through erosion. The areas in which these formations are exposed on opposite sides of the Santa Lucia Range may once have been connected. There is a change in the character of the sediments from conglomerates and sandstones on the old shore line of the Santa Margarita area northeast of Salinas River to organic deposits of the Pismo formation in the ocean on the southern side of the San Luis Range. Sandstone, however, predominates, showing that the sea in which it was being deposited was comparatively shallow. The sandstone has evidently been derived from the disintegration of granite, and deposited under conditions which would remove the mica scales, for it consists largely of angular quartz grains and kaolinic material resulting from the decay of the feldspar fragments. Rock of this character is particularly well exemplified in the hills of soft, crumbling sand below Santa Margarita.

The Pismo beds form the greater portion of the San Luis Range east of San Luis Obispo Creek. The Santa Margarita beds lie along the central and western portion of Salinas Valley, extending many miles to the northwest of the boundary of the quadrangle. While the greater portion of the formation here consists of conglomerates and coarse sandstone, typical of shore deposits, there is at one horizon a bed of white and chalky diatomaceous earth over 50 feet thick. Associated with the diatomaceous beds are several thin ones—the greatest not more than a foot thick—of fine white volcanic ash or pumice. *Ostrea titan* is perhaps the most prominent fossil in these beds in Salinas Valley. At one point the shells of this great oyster form a bed almost free from other material and more than 30 feet thick. The conglomerates include pebbles of many kinds, but in places rounded fragments of Monterey shale are perhaps the most abundant. They are often penetrated by mollusk borings. The diatomaceous beds and volcanic ash are well exposed in the railroad cuts below Atascadero station, and at the point where the railroad crosses Santa Margarita Creek below the town of that name.

Two lines of disturbance are traceable on the borders of Salinas Valley—one on the west, near the base of the Santa Lucia Range, the other along the southwest edge of the granite. In each the Santa Margarita formation has been folded, and in places overturned; but throughout the central portion of the valley the formation is nearly flat. The greatest exposed thickness is below the town of Santa Margarita, where it is estimated to be approximately 1500 feet.

The sandstones of the Pismo formation are unusually porous, and in many places have been impregnated with bitumen, which has seeped up through them from the Monterey formation beneath.

Along the southern edge of San Luis Valley the basal strata of the Pismo formation lap over the edges of the more steeply inclined Monterey strata, and in one place rest upon the San Luis formation. It is evident from this fact that the periods of deposition of the two formations must have been separated by a long interval of time, sufficient for the elevation and erosion of several thousand feet of the Monterey shales. The chemical alteration which has so widely affected the shale of the Monterey formation must have taken place in great measure prior to the San Pablo epoch, for fragments of the flinty shales occur abundantly in the sandstone at the base of the Santa Margarita.

The Monterey formation was strongly folded before the deposition of the formations of the San Pablo epoch, and folding occurred again at the close of the latter period of sedimentation. Between San Luis Obispo and Arroyo Grande creeks the structure of the Pismo beds is that of an open syncline. The thickness of the formation is here about 3000 feet. To the west of San Luis Obispo Creek the portion of the Pismo formation adjoining the San Luis Range has been forced into a vertical position and in some places slightly overturned. A small body of the bituminized sand of this formation is exposed in the ocean cliffs between Pismo and Mallagh Landing. Locally it has been overturned and folded under the Monterey shale. The upturned strata, forming overhanging sea cliffs, are shown in fig. 10 on the illustration sheet. The unconformity between the two formations is also finely shown at this point.

Along the southern side of the Pismo syncline in the San Luis Range the sandstone is replaced by an organic shale which in places is flinty and closely resembles the slightly altered phase of the Monterey shale. Beds of this character are particularly well shown in a bluff facing San Luis Obispo Creek just above Sycamore Springs. One notes then, in passing across the Pismo and Santa Margarita formations from northeast to southwest, a change from conglomerate to sandstone and siliceous shale corresponding to the change in the character of material deposited as the water became deeper and quieter. There does not seem, however, to be any evidence that the shale furnished any of the bituminous products so abundant in the region.

Paso Robles formation.—The later Neocene deposits, in the portion of the Coast Ranges under discussion, consist of an extensive series of beds which are probably of fresh-water origin. These beds fill a large part of the middle Salinas drainage area. They are well exposed about the town of Paso Robles, from which this formation is named. They extend up Salinas Valley as far as Atascadero where, half a mile below the station, they form a high bluff. The strata here, consisting of but slightly coherent gravels and conglomerates, lie at an angle of about 30° upon the sharply folded San Pablo formation. They have without doubt undergone some disturbance.

From the town of Paso Robles the formation extends westward some distance, but it is found over large areas farther north and northeast, extending down the river as far as Metz station, and up Estrella Creek nearly or quite to the low divide separating this stream from San Joaquin Valley. The formation consists of generally incoherent conglomerate and sandy and marly clays. The conglomerate is more extensively developed at the base of the formation. It consists almost wholly of pebbles of the Monterey shale. These pebbles have in places been cemented by siliceous waters, giving rise to a massive and ornamental rock. The beds of fine conglomerate, sands, and clays which make up the bulk of the formation are almost everywhere impregnated with lime. The waters have been so richly charged with carbonate of lime that in many places a layer of that material of considerable thickness has been left over the surface.

No reliable estimate can be given of the thickness of the formation, but it is certainly much more than 1000 feet. Bluffs of the basal conglomerate 300 feet high are exposed in the canyon of Salinas River below Bradley station and also in places upon San Benito River. The strata as a rule lie nearly horizontal, although they have locally undergone considerable tilting. Upon the edge of Salinas River below Paso Robles the beds are somewhat faulted.

The position of the Paso Robles formation in Salinas Valley, its peculiar character, the total absence of remains of marine organisms, or in fact, organisms of any kind so far as observed, make it appear probable that it is of fresh-water origin. In the canyon of Salinas River below Bradley there is a thin layer of dark, carbonaceous material intercalated between layers of gravel, a fact which adds probability to the hypothesis advanced as to the fresh-water origin of the beds. What relation this fresh-water Pliocene bears to the marine Pliocene upon the coast, both north and south of the quadrangle, it is difficult to say. It is possible that it is contemporaneous with the Merced beds, near San Francisco.

Only a small area of the Paso Robles formation of Salinas Valley occurs within the quadrangle. East of Atascadero it rests upon the granite as well as upon the Monterey formation and Vaquero sandstone. It has been truncated to the same base-level which is so clearly outlined by the crests of the granite ridges east of Salinas River.

Beds occupying stratigraphically the same position as those just described appear upon the coast side of the Santa Lucia Range, filling the southeastern portion of San Luis Valley and a considerable area about the town of Arroyo Grande. The low range of hills forming the eastern portion of the San Luis Range separates the two localities at the present time, but they were probably once connected. The greatest thickness shown by these beds, about 200 feet, was observed a little south of Arroyo Grande. About Arroyo Grande the beds show no disturbance, for the strata dip no more than is usual for shore deposits. The formation is made up largely of fragments of the Monterey shale, which are often considerably cemented. In addition there are some sandy and clayey strata. In an asphalt quarry on the hill above the town of Arroyo Grande a good contact is shown between these beds and the diatomaceous strata of the Pismo formation. The upper portion of the latter has been honeycombed to a depth of 6 inches by *Pholas* borings, and afterwards filled with the sand of the Paso Robles formation which was laid down upon the old surface. The sand has been impregnated with the dark bitumen, so that the relations existing are brought into strong relief.

Beds similar to those about Arroyo Grande are exposed at numerous points through the eastern portion of San Luis Valley. They appear in the road at Edna and in the bed of the creek near by. At the bridge on the edge of the town the stratification is horizontal. A little farther down the creek the beds dip 10° to 15° SW. This point is close under the edge of the hills limiting San Luis Valley on the south, and if this valley had existed at the time of the deposition of the beds they would naturally dip in the opposite direction—that is, away from the shore line which the hills would have formed. The facts shown here strongly support the view that faulting has taken place since the deposition of the Paso Robles formation. In this case San Luis Valley must be considered in part a structural depression, the valley floor having been at one time open at the southern end across the low hills which now separate it from Arroyo Grande.

There is no direct evidence that the strata south of the Santa Lucia to which the term Paso Robles has been applied are of the same age as those in Salinas Valley. From their position with reference to the ocean it would be most reasonable to suppose that these beds are of marine origin, for, particularly in the case of the exposures at Arroyo Grande, there is at present no barrier between them and the ocean. The presence of the *Pholas* borings in the underlying rock might also be thought to furnish evidence of the marine origin of the beds under discussion. There are, however, no signs of marine life in them, not even fragments of Monterey shale with *Pholas* borings, which are so common at the base of the Pismo and Santa Margarita formations.

PLEISTOCENE DEPOSITS.

Under this head are included stream and ocean terrace formations, stream gravels, alluvial bottom lands, and blown sands. These deposits represent a complicated history, although confined to the most recent geologic period.

Terrace deposits.—The terrace formations are among the oldest of these deposits. River-terrace deposits are not very prominent within the quadrangle. Terraces may be observed, however, along the lower courses of Chorro Creek, on San Luis Obispo Creek above the canyon, and on Salinas River, particularly to the north of the quadrangle.

Nearly all portions of the coast are more or less distinctly terraced, the clearness with which the terraces are shown being dependent in large measure upon the resistance of the rocks to wave action as well as to subaerial disintegration and erosion. The terraces are least distinct upon the San Luis formation and most clearly preserved where cut in the Monterey shale (see fig. 1, illustration sheet) and volcanic ash. Their obliteration even in favored localities has been accomplished partly by erosion and partly by burial underneath waste slopes from the hills behind.

South of Arroyo Grande Valley, extending to the Santa Maria Valley and forming all the extreme southern portion of the quadrangle, is a deposit of sand and stratified sandy clays. Good sections are exposed along the Southern Pacific Railway, and in the bluffs bordering Santa Maria Valley. In the former exposures the stratification is distinct, but much of the surficial portion shows no stratification and appears to have been transported by the wind. Large dunes of drifting sand border the coastal portion of this Pleistocene deposit. These beds form a gently inclined mesa the upper edge of which reaches an elevation of 460 feet. They rest upon the conglomerate beds of the Paso Robles formation.

Wave-cut terraces appear from elevations of about 10 feet above the present ocean level up to a height of 750 feet. The upper terraces are preserved in distinct form only upon the seaward slope of the San Luis Range. Lower terraces are better marked, and are especially distinct in the ash cliffs at Lion Rock and Mallagh Landing. (See fig. 11.)

As the land rose from the depressed attitude recorded by the terraces it reached an elevation greater than at present, for all the larger valleys near the ocean are filled with alluvium, the streams thus flowing over built-up channels. The former higher altitude is shown by submerged stream channels at the western end of the San Luis Range. The eastern portion of San Luis Valley is filled to a depth of about 100 feet in places, the deposit thinning out toward the edges, with unconsolidated clays, fairly well stratified, indicating the presence here of a body of water during some portion of Pleistocene time. The streams meandered at a later period over these deposits, as is shown in the railroad cut north of Steele station, where is exposed an old channel eroded in them and filled with gravel.

The Laguna is a body of water occupying the west arm of San Luis Valley. It appears to have been formed through the filling of a portion of the old valley floor by débris brought down through stream action from the San Luis Range on the south. The recent depression caused San Luis Obispo Creek to build up its channel, which may have affected it as far back as the outlet of this western arm of the valley.

Alluvium, stream gravels, and sand dunes.—The Pleistocene alluvium in the bottoms of many of the valleys is of no great depth, and much of the material mapped as alluvium might with almost as much reason have been disregarded and the underlying rocks represented instead.

The winds sweep up Los Osos Valley very strongly from the ocean. To the south of Morro Bay is a large expanse of ancient dunes now covered with bushes. Upon the slopes of the San Luis Range the sand has been found to a height of 900 feet. It may have reached this elevation during the period of a submergence, but probably is wind-drifted material. About the borders of the lower portion of Los Osos Valley are Pleistocene deposits, which are the equivalent of those south of Arroyo Grande Valley.

The strip of sand which has been thrown by the waves and wind across Morro Bay is fully one-fourth of a mile wide near its southern end. The wind has built dunes upon the inner edge which are 50 feet high and which are gradually encroaching upon the waters of the bay. This, in connection with the work of Chorro Creek, will shortly transform the bay into tidal flats.

IGNEOUS ROCKS.

The igneous masses within the San Luis quadrangle exhibit great difference in the conditions under which they cooled, as well as great range in chemical and mineralogical composition. Thus there are variations from glassy lavas cooled at the surface to rocks having the granular structure of once deep-seated granite masses, and a chemical range from highly siliceous rhyolite to basic peridotite.

The study of these igneous masses, especially the older ones, is made doubly difficult on account of the great alterations which they have undergone, yet many of the oldest rocks are less changed than those of more recent formation. The degree of change which a rock undergoes in a given time is largely dependent upon its mineralogical composition.

The different igneous masses will be taken up in order of age, as nearly as this can be determined, beginning with the oldest.

PRE-JURATRIAS IGNEOUS ROCKS.

Granite.—The term granite is applied to the oldest rock exposed within the San Luis quadrangle. This rock occurs in the low, brush-covered mountains northeast of Salinas River, forming the western extension of the San Jose Range. It is deeply weathered, and only in the canyons can fresh specimens be obtained. Disintegration over most of the surface is proceeding faster than erosion.

The great mass of the granite in eastern San Luis Obispo County, of which that within this quadrangle forms but a small portion, is of fairly uniform composition and appearance. It may generally be considered a typical granite, although in places it contains too large a proportion of plagioclase feldspar to be so classed. A typical facies contains alkali feldspar, plagioclase, quartz, biotite, scattered grains of yellow titanite, and a little magnetite. The rock is medium to coarse grained and in places porphyritic with large phenocrysts of orthoclase feldspar.

Both varieties of feldspar are usually glassy in appearance, so that in the hand specimen they are often somewhat difficult to distinguish from the quartz. The orthoclase phenocrysts contain inclusions of plagioclase feldspar and biotite.

The quartz is usually abundant and may form at times nearly half of the mass of the rock. The proportion of alkali and plagioclase feldspar varies considerably, and although the former is as a rule in excess yet there are some portions of the area where the reverse is the case, and the rock is more correctly termed quartz-monzonite.

Biotite occurs in small, irregular grains disseminated uniformly through the rock.

The main body of the granite is intersected by dikes of a finer-grained granite having the character of aplite, for it contains little or no mica. They vary in width from a few inches to hundreds of feet and in some places are very numerous. The material of these dikes presents a strong contrast with the normal granite through the lack of mica and the flesh tint of the alkali feldspar. In some cases small garnets are scattered sparingly through the dikes.

The only other distinct variation of the granite noted was a broad dike containing hornblende in the place of mica. It occurs upon the northern slope of the mountains. The dike appears to be more nearly related to the aplite dikes than to the main body of the granite.

As has already been intimated, the age of the granite can not be determined by means of any relations which it exhibits within the quadrangle, the oldest sediments exposed in contact with it being the Vaquero sandstone of the lower Miocene. There is, however, no reason for doubting the continuity of this area of granite with that of Monterey County, to the northwest, which appears in contact with the oldest unaltered sedimentary strata of the Coast Ranges, strata believed to be of Jurassic age.

The granites of California are known to be of different ages, and while those of the Gold Belt of the Sierra Nevada have been shown to be post-Juratrias there is reason for believing that those of the Coast Ranges are much older.

Both southeast and northwest of the San Luis quadrangle the granites are associated with mica-schists, quartzites, and marbles which are certainly as old as the Paleozoic and possibly much older. Whatever the age of this granite there can be no doubt of the existence of a long erosion interval between the period of its formation and the deposition of the Jurassic beds of the Franciscan group, an interval sufficient for the removal through the whole region of the Coast Ranges of any unaltered facies of the sedimentary formations into which the granite magma forced its way, and for the exposure over large areas of nearly uniform granitic rocks.

JURATRIAS (?) IGNEOUS ROCKS.

INTRUSIVE BASALT, DIABASE, PYROXENITE, PERIDOTITE.

The San Luis formation was repeatedly intruded by igneous masses previous to the deposition over its upturned and eroded strata of the next younger formation, the Toro. It is filled with innumerable dikes of a basic character, the larger number of which, judging from the field relations, are of pre-Cretaceous age. In the following paragraphs the important types of these rocks will be briefly discussed. The general statement might be made that, so far as studied, they show no exceptional characters, and as a rule the finer-grained varieties are difficult of determination because of the amount of alteration.

Basalt.—Owing to the distortion which the formation as a whole has suffered it is not easy to decide in many cases whether the basalt associated with the San Luis formation is intrusive or should be considered as surface flows. It is clear, however, that there are some surface flows, and these will be discussed later. There can be no doubt that the basalt is older than the Toro, for it is absent from areas occupied by that formation. It occurs very widely distributed through the San Luis and at points where the latter is overlain by the Toro formation, but nowhere does it penetrate the latter.

This old basalt in the San Luis formation is not in many cases easily to be distinguished from diabase, either in the hand specimen or under the microscope. It includes rocks of intrusive origin which are dark and heavy and usually fine grained. In many places it is amygdaloidal. The rock contained originally a calcic feldspar, pyroxene, iron oxide, and in many cases olivine, but now it is so altered that the constituents are with difficulty recognized. They all seem very similar in character and possess little petrographic interest.

In a number of occurrences this basalt is important. It presents the form of long, irregular dikes, which as a rule conform fairly well to the dip and strike of the inclosing rocks.

The intrusive nature of the basalt is clearly indicated by the metamorphism of the wall rocks. While this is not apparent at all points, yet the masses of hornblendic and other schists which occur at the contact, and only there, constitute sufficient evidence. Interbedded flows of contemporaneous origin have been supposed to exist in certain portions of the San Luis formation, but within this quadrangle no evidence supporting this view was obtained.

Within some of the larger basaltic intrusions there are considerable areas of a porphyritic facies, containing as the prominent constituent large phenocrysts of plagioclase feldspar. A spheroidal structure is very often exhibited by the fine-grained basalt. In an excellent exposure of the porphyritic facies on the coast north of the mouth of Toro Creek the spheroidal structure also appears. The porphyritic facies is found at a number of points along the Santa Lucia Range near the northern end of the quadrangle. One of these ancient intrusive masses outcrops prominently in the bluffs at Port Harford. Here the dark basaltic facies is spheroidal, while the porphyritic one is massive.

Diabase.—Of the pre-Cretaceous eruptives the next in importance is the diabase. It can not be sharply distinguished petrographically in many cases from the intrusive basalt. It is as a rule, however, much coarser grained and has undergone less alteration.

The rocks to which the term diabase is applied have an ophitic structure and consist essentially of a calcic feldspar and augite with a varying quantity of iron oxide. Those occurrences most closely resembling basalt contain olivine in some cases and are much more altered. Large dikes of the diabase are particularly abundant along the northern slope of the San Luis Range. Some of them are coarse grained and approach gabbro in structure. The rock is very tough and heavy and where soil has gathered upon it the surface often shows hard, nodular masses.

Pyroxenite and peridotite.—Within the area of the San Luis formation there are several long, narrow dikes of pyroxenite and peridotite. With these, as with many of the basaltic dikes, the boundaries can not be distinctly traced owing to the covering of soil, and it was thought best not to attempt to map them separately.

There can be little question of the pre-Cretaceous age of these basic rocks. In one or two cases they appear to be intrusive in the Osos basalt, but owing to poor exposures and the extreme surface alteration of both rocks this could not be decided with certainty. The pyroxenite and peridotite are clearly to be distinguished from the other basic rocks intruded in the San Luis formation and undoubtedly mark a distinct period of igneous activity.

Most of these dikes might be termed pyroxenite, for the olivine in them is subordinate to the pyroxenes. In the hand specimen as well as under the microscope they can be easily distinguished from the pyroxenite and peridotite of Cretaceous age.

In the pyroxenite rhombic and monoclinic pyroxenes are the chief constituents. Olivine comes next in importance. The hypersthene is often the freshest mineral present, although both it and the olivine are more or less changed to serpentine and greenish alteration products. A small amount of feldspar is usually present. Some specimens might be termed fairly fresh in spite of their age.

BASALT FLOWS.

Osos basalt.—There are a number of areas of basalt which, from their relation to the San Luis formation, do not appear to be intrusive but to have cooled as surface flows. The basalt is named from its outcrops in Los Osos Valley. It is earlier than the Cretaceous peridotite and probably antedates the Toro formation, for, although there are a number of areas of this lava scattered over the quadrangle, none of them show either flows or dikes in the Toro.

The Osos basalt has the same physical and petrographic character wherever it appears. It is dark and fine grained and generally amygdaloidal. The surface is so deeply weathered that it is difficult to obtain specimens coherent enough for study. In the thin section examined under the microscope all the components appear to have undergone marked alteration. The body of the rock is made up of a network of fine feldspar laths completely clouded, green alteration products of a mineral probably augite, and grains of iron oxide.

The more important areas of the lava occur in the Los Osos Valley and along its borders. Other large exposures are found east and northeast of Morro in the foothills of the Santa Lucia Range. In addition there are other areas of a fine-grained basaltic rock which may belong with this basalt, but owing to the amount of faulting and distortion which the older rocks have undergone it can not be told with certainty whether they are dikes or flows upon the ancient erosion surface of the San Luis formation. There is no reason whatever to suppose that they are surface flows interbedded in the San Luis formation. On the map these areas are not discriminated from the intrusive basalts.

At the eastern end of the Los Osos Valley the relation of this lava to the San Luis complex is clearly shown. The basalt rests upon the nearly level floor of the older rocks, which, previous to the lava flow, had been upturned, intruded by the basic rocks which are almost everywhere so abundant in it, and then planed off by erosion. The dikes intruded in the San Luis formation can be traced up to the edge of the lava, under which they disappear. The line of contact of the lava with the older complex can be followed around the hill. It is marked by numerous springs, the water coming out at the level of the old rock floor.

Like the intrusive basalt, diabase, and pyroxenite already described, none of the surface basalt appears to have come up through the Toro, and for this reason all these rocks are judged to be older than that formation.

It would appear from the occurrence of widely scattered areas of the Osos basalt that it once must have been much more extensive, and that some of these areas were originally connected. The remarkable fact, however, is that any of this early surface basalt should have remained to the present day, through all the vicissitudes to which this region has been subjected. The preservation of the basalt must be due to the fact that it was protected by later formations, and only recently has been exposed.

To the reader who is not familiar with the geology of the Coast Ranges it may at first sight appear as if too many periods of eruption have been assigned to the interval between the late Juratrias to which the San Luis formation is believed to belong and the early Cretaceous represented by the Toro formation. It must be clearly evident, however, to anyone who has given extended study to the geology of this region that the hiatus marked by the San Luis–Toro unconformity is a very important one. In the earlier geologic work in California the unconformity was overlooked and even now its importance is not so generally recognized as it should be.

CRETACEOUS IGNEOUS ROCKS.

EARLY CRETACEOUS.

Under this head are included two types of igneous rock the age of which could not be definitely ascertained from any observations made within the quadrangle. These two types are dacite and andesite. Though petrographically distinct, they form a geological unit. They appear as products of the differentiation of one common magma, and are now represented by the line of buttes reaching from Morro Rock southeastward past the town of San Luis Obispo. These igneous masses are judged to be older than the Cretaceous serpentines because, where dikes of the latter extend near them, these dikes show no indication of having been pushed aside as they certainly would if they had been in existence at the time of the intrusion of the dacite and andesite. On the other hand, the strata of the San Luis formation with the included pre-Cretaceous intrusives bend about the large igneous masses under discussion, just as should be expected.

Dacite-granophyre.—The rocks of the San Luis quadrangle to which this name is applied possess a fine-granular groundmass, and are hence properly termed dacite-granophyre. They include the igneous masses which form the northwest portion of the line of buttes to which reference has been made. Morro Rock, Black Hill, Hollister Peak, and other intervening buttes are composed of this rock. There is in addition a somewhat distinct group of small intrusions extending farther eastward from Hollister Peak as far as Pennington Creek. These intrusive bodies are more strictly plugs than dikes, for most of them are either circular or elliptical in section. Some of the smaller, however, are long and narrow and exhibit the usual dike form.

Morro Rock is typical of the larger dacite buttes. The rock has a light-gray granular groundmass in which appear phenocrysts of a soda-lime feldspar (oligoclase), biotite, quartz (rather sparingly disseminated), occasionally hornblende prisms, much decayed, and small pseudomorphs of calcite after some mineral, possibly titanite. This pseudomorph is distinguished in the hand specimen by pale-yellow spots. The more important constituents of a specimen from Morro Rock are as follows:

Partial analysis of dacite from Morro Rock.

	Per cent.
SiO_2	66.64
CaO	3.26
K_2O	3.08
Na_2O	3.77

This analysis shows that the groundmass is rich in potash, feldspar, and quartz, and that the rock approaches latite in composition.

Some of the smaller intrusive masses contain no quartz phenocrysts, while others are porcelain like, with no dark silicates and only quartz phenocrysts. It might be thought that the numerous areas of this rock once formed a continuous sheet, but this is not the case, as the rocks in many of the outcrops have distinctive characters, and the older sedimentary rock inclosing the masses bends around them as if it had been pushed aside when they appeared.

The group of small intrusive plugs extending to Pennington Creek includes rocks much richer in quartz. These rocks are also lighter in color and contain no hornblende. The phenocrysts of oligoclase, quartz, and mica are small, and the rock presents in the hand specimen almost the appearance of a fine-grained granite. The structure of all these dacites is massive except some of the dike-like bodies near Pennington Creek, which exhibit distinct flow structure.

The dacite forming the larger buttes is deeply discolored by oxidation, but nevertheless is very resistant to erosion, and where not too much seamed presents bold topographic features. Large masses of the rock which are free from seams often exhibit in a marked degree the curved surfaces produced by exfoliation. This is shown exceptionally well on Black Hill.

Andesite-granophyre.—With the exception of one igneous body near Cerro Romauldo, the rocks of the other peaks or buttes in the line which has been mentioned, beginning with Romauldo and extending southeastward past San Luis Obispo, are less siliceous and are properly classed among the andesites. The most prominent and picturesque butte is known as Cerro San Luis Obispo. The constituents of the rock forming these peaks are greatly altered even in the best specimens obtainable. The rock weathers yellow upon the surface, but the deeper portions are dark greenish gray to black. The rock is marked by phenocrysts of feldspar, biotite, and a ferromagnesian silicate. The microscope shows a calcic feldspar (labradorite), biotite, and enstatite, the latter being particularly decomposed, in a much altered fine-granular groundmass. This rock may be designated andesite-granophyre. Its principal constituents are as follows:

Partial analysis of andesite-granophyre.

	Per cent.
SiO_2	63.92
CaO	3.83
K_2O	2.68
Na_2O	3.75

The groundmass of this rock must also carry some quartz and orthoclase.

As scenic features these buttes, stretching from Morro Bay to San Luis Obispo, are very interesting. They have no counterparts in the Coast Ranges. They are interesting to the student of petrography, also, as their rock characters are uncommon.

MIDDLE CRETACEOUS (EARLIER THAN THE CHICO).

At least two clearly defined epochs of igneous activity—and three if the dacite and andesite just described are included—are recognized as having characterized the Cretaceous period in this portion of the Coast Range. Igneous activity was confined to the earlier half of the period—that is, to the time previous to the deposition of the Chico group. Of the two epochs of eruption now to be described, that to which the Cuesta diabase belongs comes first, and that in which the peridotites and related rocks were intruded, second.

Cuesta diabase.—The term Cuesta diabase is applied to those geologically related intrusives appearing upon opposite sides of the long area of Toro shale which extends from near Cuesta Pass on the south to the northern edge of the quadrangle. This rock forms several distinct peaks on the northern side of the Santa Lucia Range, as well as much of the crest to the northwest of the great serpentine area.

With the exception of local feldspathic variations the rock has a grayish-brown color and a fairly uniform fine-grained texture. Upon the edges, however, where it comes in contact with the Toro shale, it is very dense and generally amygdaloidal. In some places there is a narrow band of a sort of friction breccia or tuffaceous facies.

The rock consists essentially of partially idiomorphic augite, plagioclase feldspar (labradorite), iron oxide, and in certain facies hornblende and quartz. The rock exhibits the greatest variation near Cuesta Pass. Irregular vein-like segregations which are coarser and richer in feldspar traverse the generally dark rock. These sometimes contain quartz and a feldspar apparently less calcic than labradorite. In other portions of the mass just north of the pass there are variations which are coarsely crystalline but which contain a feldspar that is more calcic, perhaps, than that of the normal rock. Some of these masses structurally are typical gabbros. The following partial analysis has been made of the normal dark rock:

Partial analysis of normal Cuesta diabase.

	Per cent.
SiO_2	47.55
CaO	9.86
K_2O	.72
Na_2O	5.26

Notwithstanding its many different facies the Cuesta diabase can usually be distinguished without trouble in the field. If it were not for its generally constant character it often would be difficult to determine the relationship of the many isolated areas of this rock. It appears probable that these masses all had a common origin, and may have spread out underneath the Toro shale from one common fissure. The synclinal structure of the shale may already have existed at the time of the intrusion of the diabase, or it may possibly have arisen when the overlying Monterey shales were folded. The form of the eruptive masses would appear to be laccolithic, very similar to that of the igneous sheets which appeared later underneath the Monterey formation.

Serpentine and associated basic rocks.—The rocks mapped under this head are all geologically related and are among the most widely distributed igneous masses within the Coast Ranges. All the evidence at hand favors the view that these rocks, at least through the central portion of the Coast Ranges, date from post-Knoxville time. Whenever they are in contact with Knoxville beds the relation is one of intrusion and they never have been known to penetrate the upper Cretaceous (Chico group). Similar rocks in the Sierra Nevada have been thought to be of earlier date.

The designation "peridotite" is applied to rocks which consist either wholly of olivine or of olivine and a subordinate amount of other ferromagnesian silicates. Those varieties rich in olivine are frequently found altered to serpentine, but when there is a greater proportion of pyroxene or hornblende the original character is more nearly retained.

Peridotites and pyroxenites are the less altered rocks of Cretaceous age comprised in this class. They occupy a comparatively insignificant area within the San Luis quadrangle, occurring as small bunch-like masses about the borders of the large body of altered peridotite (serpentine) which forms the summit of the Santa Lucia Range northwest of Cuesta Pass. In places there are small masses of almost pure monoclinic pyroxene, but usually in addition to one or more of the pyroxenes or hornblendes there is a varying proportion of olivine and some feldspar. Like the feldspathic rocks associated with the serpentines these rocks appear to be local differentiations of the basic magma. Some of these bodies have the form of small irregular dikes, while others seem to be mere bunches, segregated from the magma at some other point and borne to their present position during its upward movement.

Serpentine is the most abundant of the igneous rocks within the quadrangle, unless, perhaps, it be those of pre-Cretaceous age. The serpentine is a dark rock with a slightly greenish tinge. It is rather uniform over the whole area, consisting of serpentinized olivine and a monoclinic pyroxene. The pyroxene was originally augite but has been changed to diallage. In places the pyroxene is wholly absent. It is distinguished in the hand specimen by the shining cleavage faces. When the rock consists entirely of altered olivine it has a dark olive tint and a homogeneous appearance. Iron oxides and occasionally chromite are the other constituents of the rock.

Although dikes of serpentine are often continuous for several miles, they are far from regular in width. They expand and contract in lenticular shape as a rule, although some of the larger areas are mere bunches, having no particular form. Their direction corresponds to the strike of the San Luis formation.

The serpentine is intrusive in the lower Cretaceous rocks of the Coast Ranges, but does not appear in those of upper Cretaceous age. In several localities this serpentine is intrusive in the Osos basalt, as may be seen by a study of the map.

Serpentine is more resistant to disintegration and erosion than the strata of the San Luis formation, so that its outcrops generally form ridges and hills. Very little residual soil gathers upon the serpentine, erosion removing it almost as fast as it forms.

The basic rocks here called gabbro consist of a calcic feldspar and monoclinic pyroxene. Within the San Luis quadrangle gabbro is not present in any large amount, but together with other feldspathic facies of the peridotite magma, occurs along the edges of the great serpentine belt upon the Santa Lucia Range. There are many varieties of the gabbro, including facies which link it with the peridotite. With the replacement of the augite by hypersthene the rock becomes a norite. Olivine may occur in both varieties. With a decrease of pyroxene and increase of olivine there are transitions to troctolite, and with a decrease of feldspar, to some variety of periodotite or pyroxenite.

Diabase is the most abundant of the feldspathic rocks associated with the serpentine. In this region hornblende often replaces the pyroxene, wholly or in part, making a transition to diorite. These rocks are almost universally rather fine grained. They are very hard and resistant and occur as narrow dikes or bunches.

The large serpentine masses have in most places undergone extensive internal movement so that they are more or less sheared and broken. This character is particularly noticeable near fault planes. As a result of this differential movement the dikes of diabase that either penetrate the serpentine or lie along its edges are, as a rule, disrupted. When the dikes break at their narrower parts the fragments are separated, and when the fragments are exposed upon the surface by erosion they present very much the appearance of bowlders embedded in the crushed serpentine. The exceedingly irregular character of diabase dikes is well shown in the face of a bluff at the head of Chorro Creek.

In rare instances small bunchy dikes of this diabase occur in the San Luis formation several hundred feet from the nearest exposed serpentine mass. Such dikes can always be distinguished from the older diabase by certain petrographic characters and a fresher condition. The diabase, if a differentiation product of the peridotite magma, would naturally be expected to be closely associated with it, but, as shown by this occasional occurrence in detached masses, it must have had a certain independence.

For a fuller discussion of the interesting phenomena connected with the differentiation of these basic rocks the reader is referred to a paper by the author on "The Geology of Point Sal": Bull. Department of Geology, Univ. of California, vol. 2, No. 1.

NEOCENE IGNEOUS ROCKS.

The rocks included under this head are all intrusive in the Monterey shale, but represent a great range in time as well as in mineralogical composition. The more siliceous types appeared shortly after the beginning of the deposition of the lower Neocene sediments (Vaquero and Monterey formations), while the more calcic ones probably followed the initial folding of these formations. None of the eruptives are intrusive in the Pismo and Santa Margarita formations, and it is probable that they all antedate these formations, but the evidence is not conclusive.

Rhyolite.—The term rhyolite is applied to a rock which is chemically the equivalent of granite but has cooled on or near the surface, usually acquiring characteristic textures. The rock commonly has a glassy, spherulitic, or cryptocrystalline base which often exhibits a flow texture. In the base are usually embedded crystals of quartz and feldspar; more rarely mica and hornblende are present. Potash feldspar is most frequently the predominant one in rhyolite, but this may be replaced, wholly or in part, by a soda feldspar, as is the case in some of the rocks to be described.

Within the San Luis quadrangle there are two distinct types of rhyolite. Both of them occur in the basal portion of the Monterey shale and probably belong to the same period of volcanic activity. The ash and tuffs, with one local flow, were laid down early in the history of the formation, before the enormous thickness of siliceous shales had been deposited. They mark a period of eruption during the deposition of an apparently conformable series of sediments. One of these types also occurs at a later date and intrusive in the same formation.

The first eruptions were especially marked by explosive action, which resulted in throwing out large quantities of fragmental material. The flow of massive lava was very small. The wide distribution and often great thickness of the pumiceous deposits have already been described. The material was originally in most cases a light, frothy pumice, which, through the force of the explosions, was blown into fragments, often having a diameter of several inches, but commonly much finer and more dust-like. Upon the edge of San Luis Valley, and a little east of the canyon of San Luis Obispo Creek, the base of the ash deposit is made up of fragments, some of them bowlder-like and nearly a foot in diameter, of a beautiful massive, perlitic glass. Although no massive flow of lava could be discovered in this vicinity it is evident from the size of the bowlders that the orifice of the old volcano could not have been far away.

In certain portions of the ash deposit there is such an abundance of feldspar crystals of uniform size as to give the material the appearance of a massive crystalline rock. The crystals are all polysynthetically twined, the extinction angles indicating a soda feldspar. The ash deposits in which these plagioclase feldspars occur characterize the southern slope of the San Luis Range from Lion Rock eastward to Pismo, and the northern slope from near San Luis Obispo Creek eastward toward Arroyo Grande Creek. The ash beds near the northern border of the quadrangle belong to the more siliceous type of rhyolite shortly to be described.

Much of the ash deposit, particularly that portion along the southern slope of the San Luis Range, has been affected by mineralizing agents. Lines of weakness and faulting have developed along the borders of the synclinal folds of the Monterey shale, and the ash, which was penetrated by siliceous mineral waters, has been changed to a massive rock and impregnated with iron pyrites. In the progress of weathering the iron pyrites discolors the rock so that the surface outcrops much resemble the gossan of a mineral vein. During investigations made in the laboratory it was discovered that the mineralized ash contained another secondary mineral besides iron pyrites. A portion of the soft, oxidized ash was pulverized in a mortar and then in a pan, and the lighter material was washed away, leaving a mass of clear, sparkling grains. These, when mounted and examined under the microscope, appeared to be perfectly formed crystals, which by their optical and crystallographic properties were determined to be zircon.

The most siliceous and at the same time the most typical variety of rhyolite occurs as a thin flow of local extent interbedded with a considerable thickness of tuffs of the same material upon the mountains between the two forks of Old Creek, near the northern boundary of the quadrangle. The rock is reddish or grayish in color and finely banded with flowage lines. In a semi-glassy or stony base appear numerous small phenocrysts of quartz, and more rarely those of an alkali feldspar.

This rhyolite sheet terminates at one spot in flattened nodular bodies ranging from half an inch to 8 inches in diameter. Some of these are entirely free, others are more or less connected in the plane of flow. They exhibit the same banding as the rest of the rhyolite, and in many cases have shrunk away at the center. From this center radiating cracks spread out toward the surface and across the flowage lines. The centers of some of these nodules are hollow; those of others are filled with chalcedony. In general appearance many of them resemble concretions, but they are probably to be classed as spherulites, which are common in many siliceous volcanic rocks. They apparently differ from spherulites, however, in having no semblance of a radiating structure. A number of specimens were obtained which were covered with ribs, the position of the ribs corresponding to cracks upon the interior, and the hollows between the ribs to portions which had sunk in.

The other type of massive rhyolite, which is apparently petrographically related to the soda-rhyolite ash already described but is of very much later age, occurs as intruded sheets in the limestone and shale near the base of the Monterey shale on the southern slope of the Santa Lucia Range about 4 miles east of Edna. The largest sheet is about 1 mile long and 100 feet thick. All of the sheets follow very regularly the dip and strike of the inclosing rocks, which are inclined at an angle of about 45° and faulted downward from a horizon found higher up on the main portion of the range. Columnar structure is very well developed at several points, the columns lying perpendicular to the surface of the sheet.

This rhyolite occurs in two facies, the most common one being gray in color, varying to black, and either compact or scoriaceous. The other is compact and more glassy. The only constituent porphyritically developed in this rock is a soda feldspar. In thinnest sections the groundmass appears to be very dense, consisting in part of feldspar microlites and in part of glass. The following partial analysis shows that this rhyolite is rich in soda, which would be expected from the character of the feldspar:

Partial analysis of rhyolite.

	Per cent.
SiO_2	73.82
CaO	.74
K_2O	2.56
Na_2O	4.17

The feldspar crystals abundant in portions of the ash deposits already described have the same character as those in the rhyolite sheet, but this ash is certainly not related to any exposed masses of rhyolite. These rhyolite sheets or dikes show no indications of ever having been associated with a volcanic neck such as must have supplied the material for the ash deposits, and besides they are believed to be much later in origin. The age of this rhyolite with reference to the more basic intrusions at the base of the Monterey shale could not be determined.

Pyroxene-andesite.—Intrusive andesite of post-Monterey age occurs on a small scale at several points. One small body occurs at the extreme eastern edge of the quadrangle on Los Berros Creek. The rock has a fine-grained base in which are developed numerous phenocrysts of a lime-soda feldspar.

Another body of andesite has been intruded between the Toro shales and the Cuesta diabase near the summit of the Santa Lucia Range. The road through Cuesta Pass crosses the outcrop. This rock is usually amygdaloidal. It contains prominent phenocrysts of green augite, rather sparingly disseminated, and rhombic pyroxene, now entirely decomposed but determinable through its prismatic cross sections.

A sheet of andesite occupies a unique position near the summit of a mountain between the head of Atascadero and Tassajera creeks. The liquid magma appears to have been squeezed up through the upturned Toro shale and, upon reaching the Monterey shales which cap the hill, spread out under them in a saucer-shaped or laccolithic sheet. This sheet can be followed nearly around the mountain at the contact of the two formations. Much of the rock is fine grained and without noticeable phenocrysts. Upon the upper and under surfaces the sheet is amygdaloidal. It has reddened and baked the shales immediately adjoining. At some places the rock shows traces of olivine, but alteration has generally destroyed this mineral as well as the augite. Some portions of the rock contain scattered, large, somewhat lath-shaped phenocrysts, which are apparently less calcic than the feldspar in the groundmass.

Quartz-basalt.—The quartz-basalt found within the San Luis quadrangle has been intruded into the basal portion of the Monterey shale. The locality is on the southern slope of the Santa Lucia Range 5 miles east of Edna. There are two dikes, the larger of which outcrops nearly continuously for a distance of 2½ miles, following the strike of the inclosing rocks. The smaller dike extends parallel with the other but lies a little higher up the range. It has a length of half a mile.

The rock is uniformly dark and fine grained with a few scattered phenocrysts of labradorite feldspar. The most abundant and interesting phenocrysts, however, are of quartz, which is distributed in a fairly uniform manner through the greater portion of the rock. Under the microscope these quartz grains show the effects of corrasion in the presence of irregular boundaries and in an enveloping rim of augite microlites. The groundmass consists of lath-shaped crystals of calcic feldspar, augite, and magnetite. A partial analysis given shows that the rock contains a rather low percentage of lime, but there can be no doubt that its proper place is among the basalts.

Partial analysis of quartz-basalt.

	Per cent.
SiO_2	54.51
CaO	6.77
K_2O	2.05
Na_2O	3.36

Quartz-basalt is a rather uncommon rock in this region. The only other known locality in California at which it is found is near Lassen Peak, where the rock occurs as one of a series of recent lavas.

Olivine-diabase.—Olivine-diabase has an ophitic structure and consists of a calcic feldspar, augite, olivine, and iron oxides. The rock within the San Luis quadrangle to which this term is applied is exceptionally rich in olivine. This mineral often forms the most important constituent, so that some occurrences included here might with as much propriety be placed in the peridotite group and termed picrite. Owing to the large proportion of ferromagnesian silicates the rock is dark in color, and on account of the excess of olivine is generally much decomposed. Remains of fresh rock occur in the form of bowlder-like masses in the shelly decomposed material. The rocks at several of the smaller areas included under this head are poor in olivine and are really typical diabases.

The largest areas of olivine-diabase are found near the head of Old Creek, where a large sheet of the igneous mass has been exposed by the almost complete removal of the overlying Monterey shale. There are other important areas in the mountains near Cuesta station and along the summit of the Santa Lucia Range between Morro and Graves creeks. At the locality last named the crest of the range is occupied by a long, narrow, synclinal fold of Monterey strata at present of no great thickness, and through this the diabase has broken in the most irregular manner. At the time of the intrusion, however, what is now the surface must have been overlain by several thousand feet of sedimentary rocks.

The field relations make it clear that this calcic rock and the augite-teschenite about to be described are differentiations of one common magma. Both types occur characteristically in sheet form in the lower Monterey strata.

Augite-teschenite.—The term teschenite is applied to a rock having an ophitic structure, and consisting of calcic feldspar, augite, analcite, and iron oxide. The analcite is believed to have replaced some soda-rich mineral, although from recent studies of analcite-bearing rocks which are in a fresher condition than these under discussion it appears that analcite may be a primary constituent of igneous rocks. In the case of the augite-teschenite of the central Coast Ranges the rock is so altered that it is doubtful if this question ever can be definitely decided. Hydration of the components and surface disintegration have affected the rock so deeply that it is often a difficult matter to obtain material for study.

With decrease of the analcite and increase of the olivine there occur transitions to olivine-diabase. Variations of this kind are noticeable in one of the areas north of Old Creek. Microscopically the rock varies greatly. The olivine-rich varieties are dark, while those without olivine, which are more common, are light colored and dotted over with the glassy analcite or its alteration product, natrolite. In fact the alteration has proceeded so far in most localities that natrolite is much more abundant than analcite. In nearly all cases the analcite occurs in angular spaces whose outlines are determined by the faces of the other constituents. Therefore analcite, or the mineral from which it was derived, was the last product of the magma to crystallize.

So far as known this rock type has not been found in America outside of Santa Barbara and San Luis Obispo counties, California. It is typically shown in the San Luis quadrangle underlying the Monterey formation a little south of Serrano station. Another exposure is near Lion Rock, a short distance south of Point Buchon. Here the rock is distinctly seen to be intrusive in the Monterey shale, lifting it up, or breaking through and metamorphosing it. A well-formed columnar structure is also shown here. In a vertical dike exposed on the face of the cliffs the columns are piled one over the other as are sticks in a cord of wood, the columns lying perpendicular to the walls of the dike. (See fig. 9.)

An interesting petrographic feature is exhibited here. Upon the worn surface of these columns near high tide the analcite is arranged in regular bands about 4 inches apart and parallel with the walls of the dike. Under the influence of the waves the rock wears away faster along the lines in which the most of the analcite is segregated, so that it presents a ribbed surface.

STRUCTURE.

Nearly all the structural features of this portion of the Coast Ranges have a linear arrangement along northwest-southeast lines. Folding and faulting have determined primarily the direction of the alternating mountain ridges and valleys crossed as one goes from the Great Valley to the ocean; but erosion, taking advantage of the zones of broken rocks, has wrought out the valleys and mountains as we know them to-day.

At about the close of the Juratrias period the Coast Range region experienced a disturbance which, next to that recorded by the intrusion of the granite into the crystalline schists, was the most severe in its history. At this time the San Luis formation was closely folded, and subsequently it was planed off. Then the Toro formation was deposited upon this surface, and both formations were folded and subjected to erosion; and so down through the whole series of formations represented in this region—a period of elevation and folding terminated each one. So many times has this process been repeated that in the case of the older formations it is impossible to discriminate the effects of the different disturbances.

Whether faulting in addition to folding played an important part in the early geologic history of this region can not be decided with certainty. The earliest faulting detected dates from post-Monterey time. Along the fault line upon the northern edge of the Rinconada Valley the sandstones of the Vaquero formation have been thrown down upon one side, while on the other the San Luis formation appears. Upon the latter the Santa Margarita formation rests, the Monterey formation being absent. The relative positions of the strata here seem to demand an age for the fault line greater than that of the Santa Margarita formation.

With the close of the deposition of the Monterey shale pronounced disturbances affected this region in common with the rest of the Coast Ranges. The strata were thrown into a series of anticlinal and synclinal arches having a northwest-southeast direction. The axes of the present Santa Lucia and San Luis ranges occupy lines of downfold, or synclines, while the intervening region and the region to the south of the San Luis Range were developed on anticlines. In this process the shales were minutely folded and crumpled, as shown in fig. 3.

The Monterey shale, thousands of feet in thickness, was eroded from most of the areas of the anticlines, exposing the much softer rocks of the San Luis formation. After this long period of erosion, the region was again submerged and the Pismo and the Santa Margarita formations were deposited. Then movement of the same nature as that which had affected the Monterey formation again occurred, and the Pismo and Santa Margarita formations were folded.

As a result of the disturbances of Neocene time the San Luis quadrangle was divided, in a broad way, into five crustal blocks. One line of folding and faulting marks the Salinas Valley along the southern side of the granite area. Another line of branching faults marks the base and northern slope of the Santa Lucia Range. A third line of greater importance is traceable along the southern slope of this range, and a fourth marks the northern edge of the San Luis Range. These lines, then, are sufficiently distinct to permit a five-fold division of the region, as follows: (1) the granite range north of Salinas River; (2) the valley of the Salinas and its continuation to the southeast in Rinconada Valley; (3) the Santa Lucia Range; (4) the southern foothills of the Santa Lucia Range and San Luis and Los Osos valleys; (5) San Luis Valley. While faulting along the lines indicated probably occurred at different intervals through the Neocene, there is no evidence that it extended into the Pleistocene.

The position of remnants of the Monterey shale strung along the foothills on the south side of the Santa Lucia Range would indicate that in this region the formation was not much disturbed by the folding which affected it in the mountain ranges on either hand. From Serrano northwestward to and beyond Morro Creek the shales are nearly level and become tilted and otherwise disturbed only as they approach the fault line at the base of the main Santa Lucia Range. The center of the anticlinal arch between the Santa Lucia and San Luis ranges probably lay near the line of the San Luis buttes.

The fault zone extending along the southern base of the Santa Lucia Range is of considerable magnitude, but just when it was formed, or whether it has any relation to the present height of the range, is not known. The patches of Monterey shale at the base of the range, which have already been referred to, give some clue to the magnitude of the faulting. Southeast of Cuesta Pass the Monterey shale lies mostly above the fault zone, although narrow strips at the eastern end of San Luis Valley have been faulted down. The main portion of the range southeast of the pass is composed of a tightly compressed synclinal fold of the Monterey shale, although near the extreme eastern edge of the quadrangle a subordinate fold begins upon the southwest site of Lopez Canyon. Along Lopez Canyon the Monterey trough must be very deep, for the formation has a thickness of between 4000 and 5000 feet. Toward the northwest the trough rises. North of Cuesta Pass, where it is crossed by Tassajera Creek, the shale has been practically cut through. Still farther northwest the center of the trough is represented by a mere remnant of shale upon one of the high peaks between this creek and Atascadero Creek. In the same direction, along what must have been the center of the fold the Monterey strata have been entirely removed, and the Toro underneath them deeply eroded, until the extreme northern edge of the quadrangle is reached. Along the southern foot of the Santa Lucia Range, opposite places where the Monterey shale has been entirely removed from its summit, may be found, as already mentioned, remnants of that formation thrown down by a series of normal faults. Between the probable elevation of the bottom of the portion faulted down and the elevation of the present top of the range there is a difference of about 2000 feet. How much has been removed from the summit of the range after the erosion of the Monterey shale can not be determined. There is then a fault of probably considerably more than 2000 feet.

As this fault is traced along the foot of the range from Serrano to Toro Creek, where the displacement has been greatest, some interesting facts appear. For some distance the fault zone passes along the edge of or through some of the great serpentine dikes. Its position is indicated by the sheared and crushed rock and a line of large springs which supply the most of the water to the streams of this section. At many points the Monterey shale, nearly level or dipping into the range, can be observed terminating against the fault. In some places slides of serpentine have occurred, deeply burying portions of the faulted shale, the presence of which might not be suspected if it were not for the stream canyons. Upon a ridge at the foot of the main range, a little southeast of Toro Creek, the Monterey shale can be seen broken up by a series of step faults, the same horizon being repeated at three different points and each faulted portion dipping more or less steeply into the range. The same thing may be observed upon the ridge north of the creek. In a railroad cut a mile northwest of Serrano the Monterey shale shows the effects of an overthrust. The strata in the upper part of the cut have been pushed over the lower ones, and in the dragging they have been doubled back near the line of movement.

The fault zone upon the northern side of the Santa Lucia Range is less regular than that just described. The movements here seem to have been accompanied by a strong tangential thrust, for as we approach the fault line, the Monterey shale, which in the valley is nearly level, gradually becomes tilted more steeply downward and, adjoining the fault, stands vertical. This fault zone is traceable along the southwestern side of the Rinconada and Santa Margarita valleys. It becomes somewhat split up west of Paloma station, near the Eagle ranch house, but northwest of that point is distinctly marked again. As in the case of the zone on the opposite side of the Santa Lucia Range, there are frequently several fault lines near together. At the point on the range where the road crosses from Morro to Graves Creek the Monterey shale, Atascadero sandstone, and Toro shale are faulted down, in a series of parallel fractures, into the San Luis formation.

The line of faulting that separates Salinas Valley from the granite mountains in the northeast corner of the quadrangle lies a little south of the outcrops of the granite. It is followed by the river below the point where the stream emerges from the granite, but above that point it continues along the northeastern side of the system of valleys that extends up to Rinconada Valley. The displacement, particularly in the vicinity of Rinconada Valley, is believed to be considerable, for none of the sandstone so extensively developed to the north of it appears on the opposite side. At various cuts along the railroad near Paloma and Atascadero stations the disturbed strata appear. At Paloma the Monterey shale has been closely folded and forced against the Santa Margarita formation so that both are overturned.

The granite block appears to have acted as a unit, so far as movements are concerned, through all its history. It shows little signs of having been sheared, and contains no dikes of any of the intrusives so common in the other formations of the quadrangle.

Numerous small fault displacements were observed along the northeastern slope of the San Luis Range, particularly toward its western end. These faults seem to have played no part in the present elevation of the range, unless it be toward the eastern end, near Edna, where one is supposed to have taken place after the deposition of the Paso Robles formation. The northern portion of the San Luis Range between San Luis Obispo Creek and the ocean is formed of the San Luis formation and included igneous rocks. The Monterey shale overlaps this portion from the south, gradually thinning out. Small areas appear far down on the northern slope, owing their preservation to the fact that they have been faulted down into the older rocks.* These are normal faults with the hade to the southwest, the strata dipping to the northeast. The largest of the faults of this type extends across Los Osos Creek. The downthrow amounts to at least 500 feet. Two miles to the southeast there is a small fault with hade and throw in the opposite direction. The phenomena shown here seem most easily explainable upon the supposition that the faulting antedated the last folding in this region, which may have been that at the close of the San Pablo epoch, for the throw of the faults is in the opposite direction, in most cases, to that which one would expect to see manifested with the uplift of the range.

The southern slope of the San Luis Range facing the ocean is rugged and abrupt, but here no distinct fault lines have been detected.

From the relation of the Monterey shale to the San Luis formation which forms the promontory at Port Harford and probably outcrops beneath the sea both to the southeast and northwest it would appear that erosion of the softer rocks of the latter formation and the gradual cutting back by the sea waves against the resistant Monterey shale would account for much of the steep face of the range.

A section measured across the San Luis Range near the highest point shows that it is essentially a closely folded syncline, with a narrow subordinate fold near the middle. However, both northwest and southeast of the center of the range at its highest point the main fold is found to be replaced by several subordinate folds, none of which is of sufficient magnitude to expose the basal portion of the Monterey formation. These subordinate folds come to an end on the coast between Point Buchon and the mouth of Islay Creek. Their nose-like terminations are finely shown in the ocean cliffs.

To the southeast, toward the canyon of San Luis Obispo Creek, the range decreases in height but becomes more complex in structure. Two subordinate folds appear with nose-like terminations. At the point where they pass beneath the sandstones of the Pismo formation they have been thrust against the latter, almost overturning them. The main body of the Pismo formation forms an open fold beneath which the Monterey shale with its sharper plications passes, to appear again at Arroyo Grande Creek.

One of the most interesting and striking structural features of the district is exhibited by large sandstone dikes in the Monterey shale. Great bodies of sand which are now bituminized were formed in the centers of the anticlines just referred to and were forced into cavities in the shale. This must have happened during the disturbance terminating the deposition of the Pismo formation. These sand pockets or bosses occur about three-fourths of a mile north of Sycamore Springs. One is on the eastern side of See Canyon near its mouth; the other is in a small canyon a little to the west of See Canyon. The bodies of sand are located in the anticlines near their nose-like terminations. The larger body to the west of See Canyon is 500 to 600 feet across, elongated somewhat in the direction of the anticlinal fold, and with narrow radiating veins of sand cutting across the hard siliceous shale. Some of the veins are but a few inches wide, though continuous for long distances. The smaller body of sand in See Canyon is about 200 feet across, but has connecting pockets and dikes extending out over a diameter of 700 feet. The sand is structureless, but lithologically resembles very closely that forming the soft sandstone of the Pismo formation near by. It was undoubtedly forced into open fissures produced in the folding of the shale. The sand is generally bituminized, although now dried out at the surface. It must have been impregnated by the oil or tar after being forced into the fissures. There is a maltha or "tar" spring, now running slightly, in See Canyon but a short distance away.

Sandstone dikes have been described from the Toro formation at different points in California, but none are so large or show so intimate a relation to structure as these just described. The western portion of the San Luis Range must have undergone a much greater amount of uplift at the close of the San Pablo deposition than the eastern part, judging from the sharply folded strata of the Pismo formation at their present termination near the sand pockets.

The structural relationships of some of the intrusive rocks are very remarkable. This is particularly true of those which have entered the Monterey shale. Masses of the olivine-diabase and augite-teschenite magmas have come up underneath the Monterey shale, but have rarely, if ever, broken completely through the formation. Having penetrated upward to the limestone or bituminous shale horizon the eruptives have spread out between the strata and are now exposed in many places as sheets along the eroded edges of the Monterey synclines. Two interesting cases of this kind occur between the town of San Luis Obispo and Serrano station. Here are two hills, one a half mile the other nearly a mile in diameter, rising abruptly from the rolling country about and capped by a thin layer of Monterey shale and limestones. Each hill has the form of an amphitheater, the strata dipping in toward the center from all sides but one, and on this side the drainage from the center has eroded a gulch. The peculiar topography and saucer-like structure is due to a sheet of augite-teschenite which outcrops just below the shales around the steep, brush-covered sides of each of these hills. The igneous rock metamorphosed the overlying shale and limestone so that they were less easily eroded. The igneous mass being deeper down in the center and on one side, the amphitheater-like depression was formed.

The long narrow syncline formed of the basal portion of the Monterey shale which caps the Santa Lucia Range near the northern edge of the quadrangle has been invaded along its center for more than 3 miles by numerous irregular bodies of olivine-diabase. In places they break through in dike form, in others they lift up and partly inclose large masses of the shale.

At the north edge of the quadrangle, north of Old Creek, there are two large areas of olivine-diabase. One outcrops around the edges of a long, high hill of Monterey shale. Only a portion of this eruptive body appears within the quadrangle. If the shale were removed from its upper surface it would undoubtedly appear much as does the other area of olivine-diabase which lies a short distance southwest. This latter area is more than a mile across. But few patches of the shale and ash appear scattered over the surface of the eruptive sheets. These sheets are real laccoliths, with possibly the distinction that instead of coming up and arching the strata convexly over them they have encountered strata of Monterey shale which were already folded in synclinal troughs and have followed up the dip on either side. The generally concave upper surface of these sheets is in direct contrast to the typically convex upper surface of those igneous masses originally described under the term laccolith.

In some cases the synclines are very broad and open, as in those last described, but in others the igneous masses have followed the strata upward at angles of 25° to 35°. In no case is there evidence at hand to show that these eruptives ever broke completely through the shale. Some of the sheet-like dikes occurring at the base of the Monterey shale have appeared not along the centers of the synclines but upon their outer edges, where, in the close folding to which the rocks have been subjected, the steeply inclined strata may have been ruptured and incipient faulting induced. The fault zone on the southern slope of the Santa Lucia Range may have originated in this way. It is characterized by many igneous masses of post-Monterey time.

The Cuesta diabase seems to bear much the same relation to the Toro shales as the olivine-diabase and teschenite bear to the Monterey shale, only that the Toro shale did not offer so resistant a covering as the Monterey. It is most reasonable to suppose that the different masses of Cuesta diabase strung along the Santa Lucia Range had a common source underneath the Toro shale, which in places was broken through. There are local areas of the shale evidently metamorphosed by underlying igneous masses which have not yet been exposed by erosion.

The structural relations of the older intrusives are apparently more simple, as they follow in general the dip and strike of the San Luis rocks. The heavy-bedded sandstone is comparatively free from intrusions, while that part of the formation in which the jasper occurs, offering less resistance, is filled with the igneous masses. On the coast west of Cayucos may be seen a dike separating masses from the jasper.

The serpentine dikes have the same position in the older rocks as the older eruptives. In most cases the serpentine dikes are in contact with the older basic dikes, and, like the latter, are more abundant in certain portions of the formation. The alteration of the rocks adjacent to the serpentines is generally very slight, less even than that produced by the Cuesta diabase.

GEOLOGIC HISTORY.

PRE-JURATRIAS TIME.

The earliest geologic event of which we have any clear record in the central and southern Coast Ranges of California is the invasion of the crust by great masses of molten granite, which caught up and highly metamorphosed the existing sediments, changing them to marbles and schists. Not only is the date of this disturbance unknown, but the age of the metamorphosed sediments is likewise doubtful. In the coarsely crystalline marble, with its secondary minerals—such as graphite, pyroxene, mica, garnet, etc.—the original fossils, if any existed, must have been totally obliterated. Within the San Luis quadrangle erosion has completely removed the metamorphosed sedimentary terranes which appear farther northwest in the Santa Lucia Range, and there remains a fairly uniform granite body exposed over many square miles of country.

JURATRIAS PERIOD.

The time required for the complete removal of these early sedimentary beds must have been very considerable. It undoubtedly embraced the early Mesozoic and may have begun in the Paleozoic. There is really no known reason why the schists, gneisses, and marbles may not belong to the Algonkian. The fact of greatest interest, however, is that in very early geologic times land existed in the present Pacific border region. The western boundary of the continent in this latitude could not have been very different from its present configuration. Notwithstanding all the oscillations of level and the great mountain-making movements which have taken place it would seem that the fold in the crust marking the edge of the continental plateau is of very ancient date. The absence of all sedimentary formations in the central Coast Ranges between the basement complex of granites, schists, and marbles and the various members of the Franciscan group is fair evidence that an extensive land area existed in the region during the time indicated by that hiatus.

Toward the close of Jurassic time the sea encroached upon this land, and the Franciscan sediments began to be deposited over the deeply eroded surface of the crystalline complex. Wherever the base of the Franciscan group is exposed by erosion it is seen resting on these rocks with a thick basal conglomerate. Pebbles of the granite and gneisses are abundant in the conglomerate. At Slate Springs, on the coast of Monterey County, the basal conglomerates and sandstone are fully 1000 feet thick. The conglomerate is so thoroughly cemented that the siliceous matrix is as resistant to erosion as are the granitic pebbles themselves.

This subsidence was marked by oscillatory movements with accompanying changes in ocean currents and in the character of sediments deposited. Although so widely distributed through the Coast Range region, the beds of this group mark a near-shore or shallow-water condition, for they consist largely of sandstone. In addition there are in certain horizons considerable bodies of shale or slate, and lenticular strata of radiolarian jasper. Molluscan life was not plentiful in this ancient ocean, if we can judge from the remains so far discovered, for within the quadrangle marine fossils have been found at only one point. During an interval of the deposition of clays in a body of quiet water the bottom was thickly populated with a small *Pecten*. These, with some fossils from the slate at Slate Springs, on the coast of Monterey County, are among the best preserved forms yet discovered.

The conditions under which the beds of radiolarian jasper were deposited are rather difficult to understand. These lenticular beds occur at several horizons in the San Luis and are petrographically sharply distinguished from the shale and sandstone.

With the beginning of deposition of each of these beds of jasper a marked change must have occurred in the character of the ocean currents, for those laden with detritus from the land gave place to others free from this detritus but filled with a multitude of microscopic organisms. Within the San Luis quadrangle the deposits indicate that the organisms were largely radiolaria with siliceous tests, but farther north in the Santa Cruz Mountains there occur in the same formation thick beds of foraminiferal limestone in addition to the jasper.

The total thickness of sediments in the San Luis formation could not be ascertained. It is probably considerably more than 10,000 feet. No indications of contemporaneous igneous action were observed, and it appears probable that the innumerable dikes which the formation contains are all of later age, being intruded subsequent to the period or at the time of its initial folding.

Judging from a wide survey of Coast Range geology, and especially from the known relation of the Franciscan group to the lower Cretaceous, it seems highly probable that the first disturbance and upheaval of the Franciscan was contemporaneous with the post-Jurassic revolution in the Sierra Nevada and Klamath Mountains, which involved the youngest portion of the Auriferous slates. It seems most reasonable to believe that the marked unconformity between the Knoxville and the Franciscan groups which characterizes the whole of the Coast Range region is found in the Klamath Mountains, into which the Coast Ranges merge, and in which the Knoxville rests unconformably upon the Jurassic. If this be true for the Klamath Mountains it is without question true for the Sierra Nevada. In the Sierra Nevada the Mariposa slate of the "bed-rock series" reaches up into the upper Jurassic, and, as in the Coast Ranges, these upturned and closely folded strata are intruded by numberless dikes of igneous rocks. There can be no doubt that the granite in the Coast Ranges is very much older than that intruded at the time of the post-Jurassic revolution in the Sierras.

After the intrusion of the first igneous rocks in the Franciscan group erosion planed off the folded strata. Then igneous action was renewed and basaltic lavas were poured over the surface. There is little clue to the character of the surface, for it has undergone much distortion since, but there are reasons for believing that it was an old one without strong relief. This is illustrated by several of the outcrops of the Osos basalt where the contact with the underlying rocks appear. The scattered remnants of the basalt which have escaped the long periods of erosion indicate that it was originally rather extensive.

CRETACEOUS PERIOD.

The igneous masses (dacite and andesite) constituting the San Luis buttes were intruded at some time between the middle of the Cretaceous and the period of intrusion of the basaltic dikes in the San Luis formation. On Pine Mountain, some miles northwest of the quadrangle, a large mass of dacite occupies such a position with reference to an area of Toro shale as to lead to the view that it has been intruded through them. Within the quadrangle the bodies of dacite and andesite have pushed aside the dikes of basalt but have not so disturbed the serpentines, which date from middle Cretaceous time, and the picturesque peaks which the dacite and andesite form are not the result of mountain-making forces, but of the differential work of erosion.

With the beginning of the Cretaceous much of the Coast Range region again became submerged. Just how extensive this submergence was it is difficult to say, but the presence of the widely scattered remnants of deposits of the Knoxville group from Santa Barbara County northward through the Coast Ranges makes it appear probable that the region was very generally under the ocean and that sedimentation was taking place. The prevalence of clay shale indicates conditions very different from those of Franciscan or Chico time, when sandstone predominated.

The largest remaining area of Knoxville rocks in this portion of the Coast Ranges is that extending across the quadrangle in the line of the Santa Lucia axis. A downfold was probably formed along this axis shortly after the Toro was deposited, thus preserving it from erosion. No traces of this shale are found along the similar syncline forming the San Luis Range, so that previous to the middle Neocene the formation was removed by erosion from all other portions of the quadrangle.

With but slight oscillations of level, submergence continued through the lower Cretaceous until within the San Luis quadrangle 3000 to 4000 feet of Toro shale and sandstone were deposited. The lower portion of this formation is almost entirely shale, but toward the top sandstone is much more abundant. The lower Cretaceous was terminated by renewed disturbances and igneous action. Three different liquid magmas were erupted at probably as many different times between the initiation of the upheaval and the beginning of the Atascadero sedimentation: the Cuesta diabase, the peridotite, and the dacite-andesite magmas. The time relation of the dacite-andesite to the others is not known, but of the others the Cuesta diabase is the older. Dikes of serpentine appear in the diabase, and along the southern slope of the Santa Lucia the great peridotite masses have broken apart the originally connected bodies of diabase.

The fact is of interest that these igneous intrusions were not confined to this locality. The peridotite magma with its feldspathic facies has been intruded into rocks older than the Chico all through the Coast Ranges. In addition to those areas of Cuesta diabase within the quadrangle another is known at Point Sal, 30 miles to the south. This one has also a laccolithic character. The dacite-andesite occurs at intervals from Pine Mountain south to San Luis Obispo, a distance of 50 miles. The altered peridotites (serpentine) are especially remarkable for their extent, covering an area of several thousand square miles in the Coast Ranges and representing a once enormous mass of molten rock. The metamorphic action which these bodies had upon the adjoining rocks is surprisingly small. There are a number of large masses of glaucophane-schist which at first sight would seem to have been formed at the contact of the serpentine with the Franciscan group, but a closer examination shows that in every case the metamorphism can be traced to one of the earlier basaltic intrusions.

After a period of considerable length, during which the Coast Ranges must have been dry land, the region sank, and upon the folded and eroded Knoxville group the upper Cretaceous (Chico group) was deposited. This was a time of shallow waters and strong currents, for the formations of that group consist very largely of sandstone and a considerable proportion of conglomerate. It is difficult to estimate the original extent of the Atascadero formation. It was certainly much more extensive than now. The long, narrow arm along the Santa Lucia axis may have been preserved in a manner similar to the Toro because it occupied an axis of downfolding. The ancient shore line must have lain near the San Jose Range, for the proportion of conglomerates increases in that direction. To the southeast of the quadrangle in Santa Barbara County the conglomerates are very abundant and contain large bowlders.

No igneous activity seems to have marked the upper Cretaceous or the Eocene in this portion of the Coast Ranges. This was perhaps the longest interval of comparative quiet since the upheaval terminating the Franciscan sedimentation.

EOCENE PERIOD.

With the close of the Cretaceous and the advent of the Tertiary a marked change took place. The region of the Coast Ranges began to rise and the ocean was excluded from the greater portion of it. The water continued, however, to occupy Sacramento and San Joaquin valleys, maintaining an outlet to the south across Ventura and eastern Santa Barbara counties. This view is based upon the fact that within the San Luis quadrangle, as well as northwestward through the heart of the Coast Ranges, the Eocene, or Tejon formation, is entirely absent, while on the borders of the Great Valley and southward across the Coast Ranges the formation is extensively developed. The Eocene, then, in the region under discussion was an epoch of erosion, and it was during this time that large portions of the earlier formations were removed. The region was probably reduced to one of low relief, and the waste material was deposited beyond the present shore line.

NEOCENE PERIOD.

Early Neocene sedimentation and volcanic activity.—After this prolonged interval of elevation the region of the Coast Ranges began to sink, and continued to do so until nearly or quite all of the central and southern portions were buried beneath the Pacific. So far-reaching and profound was this downward movement that it was formerly thought that the Coast Ranges first originated with the subsequent uplift.

This interval of slow sinking of the land was not one of entire quiet, for but a small fraction of the Monterey sediments had been deposited when volcanoes broke out over the ocean floor, giving rise to some of the most interesting phenomena of the quadrangle.

Sandstone and conglomerate mark the Vaquero formation (early Neocene). Their greatest thickness is a little to the east of the quadrangle, where a rugged shore must have existed through a great part of the epoch. Most of the region over which the Monterey sediments were spread was of low relief, a fact indicated by the continuous character of well-marked strata near the base of the formation. The volcanic disturbances which were inaugurated after but a few hundred feet of the formation had been deposited were altogether different from any others which had occurred in the region. The massive flows were local in extent, but the fragmental material blown out from explosive vents spread far and wide over the ocean, and, settling down, gave rise to a nearly continuous stratum (in some places more than one) of volcanic ash and pumice. The eruptions were intermittent and extended over a long period of time, for in many places thick beds of shale separate the strata of ash. Many vents existed, giving rise to local accumulations hundreds of feet in thickness. Away from these vents the thickness of the beds decreases so that we can approximate the positions of some of them. Diatoms as well as mollusks inhabited the water in the vicinity of the eruptions, and their skeletons remain buried in the ash. Southeast of Edna a bed of fine, dust-like pumice blends upward into a deposit fully 20 feet thick, one-third of which consists of diatoms.

The eruptions once more ceased, and for long periods sedimentation quietly continued. The deposits, instead of being of the usual detrital character, were composed almost wholly of the calcareous and siliceous tests of microscopic organisms. For a time after the eruptions ceased calcareous organisms abounded, as is indicated by the limestones. The strongly fetid odor of the limestone strata shows their organic origin.

After the deposition of the limestone, organisms with siliceous skeletons largely replaced those with calcareous. This condition lasted through an interval sufficient for the formation of fully 4000 feet of siliceous shales. All the study thus far devoted to these shales tends to show that they are composed of material mostly of organic origin. Diatoms, radiolaria, and to a lesser degree foraminifera and fish remains make up the bulk of these rocks. The general absence of distinguishable detrital material of shore origin from this great thickness of shales, shows that either the region must have lain some distance offshore, or that the waters were quiet and not reached by currents laden with sand and mud. The time required for the deposition of 4000 feet of such material, which so far as we know accumulates at an exceedingly slow rate, must have been enormous. These siliceous shales are of wide extent through the Coast Ranges of California. In portions of the old sea bottom which were nearer shore the shales are replaced by sandstones, and in others which must have been partly separated from the open ocean, clays, rich in alkali and gypsum, take their place.

Middle Neocene deformation and erosion.—Again disturbing forces began to affect this region. Elevation occurred and the Monterey shale was folded, and in local areas sharply contorted. Igneous action was renewed. This was probably in part contemporaneous with the folding and in part of later date. A great variety of eruptive masses were forced upward along the lines of weakness manifested by the folded rocks. These lines appear to have been in many cases the axes of synclines, in others the fault zone along the southern slope of the Santa Lucia Range. Augite-teschenite, olivine-diabase, quartz-basalt, and rhyolite constituted the igneous masses. All are intrusive in the Monterey shale, but none appear in the later formations of the San Pablo epoch. The teschenite and olivine-diabase are the most extensive and are generally laccolithic. They were undoubtedly not all formed at once, but must be regarded as representing a long and complicated series of disturbances whose individual records we can not discriminate.

A period of prolonged erosion intervened after the elevation of the Monterey shale before subsidence again overtook the region and the middle Neocene (Pismo and Santa Margarita formations) began to be formed. It is probable that during at least a portion of the period the coast was considerably more elevated than now, for the planed-off Monterey shale passes beneath the sea with the Pismo and Santa Margarita sandstones resting upon it.

The period of elevation and erosion was long enough to permit of the removal of a thickness of thousands of feet of Monterey shale over the region between the Santa Lucia and the San Luis ranges, as well as that south of the latter range, much of which is now occupied by the ocean. This is shown by the fact that when the region sank and the San Pablo deposition began, the basal beds of this group lapped across the eroded edges of the Monterey shale and, in the region back of Port Harford, as well as in the lower edge of San Luis Valley, rested directly upon the San Luis formation. It thus appears that with the post-Monterey deformation the position of the present mountain ranges and valleys was in large part determined through the fact that the Monterey shale, which is very resistant to the forces of disintegration and erosion, occupied synclines, after having been eroded from the anticlines.

Previous to the deposition of the San Pablo group chemical action had changed the character of much of the Monterey shale. The original colloidal silica of the shales had become chalcedonic, through the influence of heat and circulating waters. Although this change has probably continued to a certain degree down to the present, as is shown by the numerous mineral springs, both hot and cold, nevertheless the fragments of shale in the conglomerates at the base of the San Pablo group had undergone complete alteration to a flinty and chalcedonic condition when this formation began to be deposited.

Middle Neocene deposition and renewed volcanic activity.—It is difficult to estimate the original extent of the San Pablo group, for the beds are generally soft and eroded. It is very probable, however, that they covered a large part of the quadrangle, reaching eastward and northward from the San Luis Range across the Santa Lucia Range and through the upper Salinas Valley. The granitic mass in the northeast corner of the quadrangle must have formed a portion of the ancient shore line. The conglomerate in the Santa Margarita formation becomes more prominent in this direction, and the sandstone shows its granitic origin in the coarse granules of quartz and kaolinized feldspar. The portion of these beds now exposed near the ocean then lay farthest offshore, for they are formed to a considerable extent of siliceous organisms, showing a duplication, in a slight degree, of the conditions existing during the Monterey deposition.

Volcanic eruptions occurred at some point in this region during the deposition of the Santa Margarita formation, as is shown by the thin layers of pumice dust in the formation in Salinas Valley. At intervals throughout the valley there are outcrops of a bed of diatomaceous earth inclosed in sandstones, showing temporarily a marked change in conditions of sedimentation. The three or four strata of ash are associated with the diatomaceous earth and record as many recurrences of the explosive action of some volcano whose location is at present unknown.

Late Neocene elevation.—After the deposition of at least 3000 feet of sediments an elevation accompanied by folding terminated this epoch. The folding was not so intense as that terminating the Monterey epoch, but it appears in general to have followed the same lines. The Pismo strata in the eastern portion of the San Luis Range were folded in an open syncline, but west of San Luis Obispo Creek the disturbance, either at this time or at a later epoch, was so much greater that the formation has been completely removed except for a mere fringe around the mountains back of Port Harford. The lifting of the Santa Lucia axis exposed the beds there to greater erosion, so that in this section the formation now occurs in three separated areas. Two of these are within the quadrangle; the other is on the headwaters of Arroyo Grande Creek, east of the quadrangle.

The lines or zones of structural weakness which have given rise in part to the present topographic features were present certainly as early as the disturbance terminating the Monterey deposition. With the post-San Pablo movements they were accentuated and the later formations were involved. Thus along both edges of the block forming Salinas Valley the Santa Margarita beds were sharply folded and in places faulted.

The larger features in the relief of this region must date from this upheaval terminating the San Pablo epoch. Faulting has been an important factor in the elevation of the Santa Lucia Range, but not in recent times. It probably took place at intervals through the Neocene, for the Paso Robles beds have been faulted, but the general relations exhibited by the Santa Margarita formation indicate that the more important movements of this nature were probably not later than the disturbance which marked the uplift of that formation.

Late Neocene lakes.—In the later Neocene the conditions were very different from any that had prevailed in the Coast Ranges. Instead of again being submerged beneath the ocean the region was occupied by fresh-water lakes. Such a lake covered hundreds of square miles in the basin of the middle and upper Salinas Valley. In this lake a series of conglomerates and sandy and marly clays over 1000 feet in thickness was deposited. They form what has been termed the Paso Robles formation. In portions of the Coast Ranges volcanic activity continued through this lake period. The history of the later Neocene when fully known will undoubtedly be found to be very complicated. Mountain-making movements still continued to be felt, for the Paso Robles formation is faulted and locally steeply tilted.

Late Neocene beds similar to those in Salinas Valley also occupy the eastern portion of San Luis Valley and a limited area about Arroyo Grande. Because of the absence of fossil remains it has been impossible to decide definitely whether they originated in fresh or salt water. The position of the Paso Robles beds at Edna, dipping down toward the older rocks of the San Luis Range, is very suggestive of faulting on a considerable scale at the close of the Neocene. No such movements seem to have occurred in this region during the Pleistocene.

Whatever may have been the specific time, an upward movement was eventually inaugurated, and the late Neocene lakes disappeared. While it is possible that they were drained by simple headwater cutting, it is far more likely that their disappearance was a result of orographic movements.

PLEISTOCENE PERIOD.

There is reason for believing that the early Pleistocene elevation, following the disturbances at the close of the Neocene, carried the land to a much greater height than that which it has at present. This is not so clearly shown within the San Luis quadrangle, in the topography of either the land or the adjoining submarine shelf, as along other portions of the coast. Such an elevation would have exposed the submarine continental plateau which borders much of the coast of California and its postulation most readily explains the presence of Pleistocene mammalian remains upon the Santa Barbara Islands, as well as the deep, narrow valleys which cross the plateau from the present shore to the deep water outside.

The lower portion of the Santa Maria Valley, which touches the extreme southern end of the quadrangle, has at some comparatively recent time been excavated much deeper than it is at present, for it is filled to a depth of at least several hundred feet by sands and gravel. The bottom of this channel has not been reached by any of the wells of the valley. These deposits extend up the valley for a distance of 20 miles, far beyond any effects which the recent subsidence could have produced. The lower portion of Salinas Valley is also filled to a great depth with similar material, which appears to be of Pleistocene age.

After what was probably a comparatively short period of elevation the Coast Ranges sank until the shore-line level was 1000 to 1500 feet lower than at present. The amount of depression within the San Luis quadrangle is not precisely known. It was probably at least 1000 feet, although the highest distinct wave-cut terrace has an elevation of but 750 feet. In the gradual recovery from this depression the movement was intermittent, as is shown by the numerous terraces ranging from the one at 750 feet down to one 10 feet above mean tide level.

No thorough attempt has yet been made to correlate the terraces along the California coast in order to determine just how much the warping or dfferential movement has been. There can not be much doubt, however, that the older terraces have been deformed to a considerable degree.

The land gradually rose until it attained an elevation considerably greater than the present. Just how much greater this elevation was is not known with certainty, but it probably amounted to 300 to 400 feet. A more detailed survey of the submarine topography will be needed to settle this question.

All the larger streams which enter the ocean within the quadrangle have tidal lagoons at their mouths, and their valleys, often for several miles, are filled with alluvium. San Luis Obispo Creek illustrates well the conditions consequent upon the submergence of the mouth of a stream.

Islay and Coon creeks, which flow westward from the San Luis Range, enter the ocean about one mile apart. Both clearly show evidence of recent subsidence. The old channels of these streams can be traced oceanward for some distance by means of soundings. They are also brought out distinctly during stormy weather when the channels are marked by the absence of breakers which appear at either side. The channel at the mouth of Islay Creek is made use of by such occasional boats as come in to load grain or hay.

The fact that the subsidence is of recent date is shown also at Morro Bay, which occupies the submerged portion of Los Osos Valley. Judging from the rate at which the bay is filling, the subsidence could not have been a very remote event. The rapidity with which the waves are tearing away the cliffs along portions of the coast of this region suggests that possibly a subsidence is now in progress.

TOPOGRAPHIC DEVELOPMENT.

GENERAL STATEMENT.

Two groups of agents are perpetually at work modifying the earth's surface; one tends to build up, the other to tear down. The constructive agents work from within the earth, giving rise to folds in the crust, to fault fissures with resulting mountain blocks, lava fields, and volcanic peaks. The agents of destruction work mainly from without. Under the influence of heat and cold and chemical and physical forces the rocky crust is being disintegrated. Through the agency of running water the waste material is constantly being transported from a higher to a lower level, from the highlands to the sea. Although perceptible changes in topography generally take long periods for their accomplishment, the earth is old enough for the highest mountains of the present day to have been worn down many times. Great mountains with rugged outlines exist to-day because of the recent preponderance of constructive over destructive forces. In most regions of low relief the agents of destruction have worked long without serious interruption.

The cycle of erosion, as that period is termed which includes the time from the elevation of a mountain region to its complete removal by erosion, seldom runs its course without interruption such as would be brought about by depression or renewed elevation of a region. Consequently we generally find that topographic features show the effects of the interaction of these two forces. Plains of incomplete erosion, or peneplains, as they are termed, are found reaching back to mountains not yet worn down; while the streams which traverse these plains may flow in channels flooded by submergence, or they may cut narrow V-shaped canyons through recently elevated coastal reaches. These phenomena sometimes all appear in one region, indicating that the destructional forces have at various times been interrupted by orographic or epeirogenic movements.

That portion of California embraced within the Coast Ranges is a good example of such a region. Long epochs of quiet with the production of partial peneplains have alternated with those of upward and downward movements. These facts are clearly revealed in the topography. In addition the features of the region have been influenced in their development by structural conditions and the nature of the underlying rocks. Folds and faults along northwest-southeast lines determined the direction of the mountains and valleys of the Coast Ranges, while marked differences in the hardness of the various rock strata have determined, in part, the position and character of these features.

How far back the action of these causes which have produced the topographic features of the San Luis quadrangle can be traced is difficult to say. It is impossible to determine when certain lines or zones of weakness were developed, as, for instance, those bounding the Santa Lucia Range, which were affected by each renewed strain upon the crust.

EARLY PERIODS OF DEFORMATION.

Sometime during the Cretaceous the region now forming the Santa Lucia Range probably experienced a downfolding, to which condition we must attribute the preservation of the Toro and Atascadero formations. With the upheaval which terminated the deposition of the Monterey shale renewed synclinal folding took place along the Santa Lucia axis. Another synclinal fold was formed along the present San Luis Range. To the presence of these two synclines with the lines of faulting along their borders is believed to be due the existence of the chief mountains within the San Luis quadrangle.

If this be true these two mountain ranges then formed structural valleys with ridges on each side of them. In time erosion removed from the anticlines the Monterey shales and most of the other overlying beds and exposed the San Luis formation, not only in the region between the present mountain ranges but in Salinas Valley and in that area south of the San Luis Range now covered by the waters of the ocean.

The Osos basalt rests upon an ancient floor formed of the San Luis formation with its earlier intrusives. We know that the floor is very old because the Osos basalt antedates the intrusion of the large bodies of peridotite now so generally altered to serpentine. We may conclude then with reasonable certainty that the floor of San Luis Valley together with a part of that of the Los Osos is very old, and that it has been preserved partly by the sediments deposited upon it and partly by the Osos basalt. Deformation subsequently raised that portion of the San Luis Range lying west of San Luis Obispo Creek, and also the Santa

Lucia Range. It is probable that east of San Luis Valley no barrier existed separating this valley from the Salinas until after the San Pablo folding and uplift.

From the fact that the Pismo formation laps over the eroded edge of the Monterey and rests upon the San Luis at the southern edge of the San Luis Valley, we must conclude that the Monterey anticline, in this section, was eroded through before the deposition of the Pismo formation. The San Luis Range was not in existence at this time, but was probably raised during the movements at the close of the San Pablo epoch.

DEVELOPMENT OF THE SANTA LUCIA PENEPLAIN.

With the upheaval at the close of the middle Neocene the more important features of the present topography were outlined. The Santa Lucia Range probably originated at this time, for during the following period of sedimentation (Paso Robles) a barrier existed between Salinas Valley and the ocean. While the boundaries of the fresh-water deposits of the late Neocene can be determined with some accuracy in the San Luis quadrangle, there is little evidence as to the position and character of the seacoast, owing to the lack of deposits which can definitely be recognized as of marine origin. Marine Pliocene deposits appear at many points along the California coast, indicating that the land was very considerably lower than at present, but such deposits have not been detected in this quadrangle, with the exception of the beds in the vicinity of Arroyo Grande mapped as Paso Robles.

The slight developments of the Pliocene along the coastal portion of the quadrangle may mean that during much of that epoch the land was more elevated than at present, or, what is more probable, that owing to the absence of large streams the accumulation of sediments was not great and subsequent erosion has nearly if not quite removed them.

The occurrence of marine Pliocene beds at so many points along the whole coast of California, and of fresh-water Pliocene lake deposits in the interior, leads to the belief that practically the whole region stood much lower than now, and that before those movements commenced which have generally been believed to have terminated the Neocene a large part of the land surface had been reduced to the condition of a peneplain. This is the earliest peneplain of which there is any remnant in the central Coast Ranges. It will be termed the Santa Lucia peneplain because it is best preserved along the crest of the Santa Lucia Range. At an earlier epoch, when the Vaquero sandstone and Monterey shale were being deposited, this region had also been reduced to the condition of a plain, although to the east and north there must have been mountainous land masses, as shown by the great increase in thickness of sandstone and conglomerates in these directions. A partial planation of the surface took place during the San Pablo epoch, but it is difficult to determinate the extent of these beds over the Coast Ranges because of the degree to which they have been eroded. That the Santa Lucia peneplain does not antedate the deposition of the Santa Margarita and Pismo beds is shown by the manner in which the latter beds have been folded in with the Monterey shale in the San Luis Range.

Just what event marks the termination of the Pliocene and the beginning of the Pleistocene is a question upon which California geologists are not agreed, but in the present discussion it will be assumed to be coincident with the last important mountain-making movement. The line thus drawn corresponds more nearly with the paleontologic evidence than any other, and marks an important event which it is believed can clearly be distinguished along the whole coast. Deposits of Pliocene age are almost everywhere more or less faulted and folded. Beds of undoubted Pleistocene age are as a rule undisturbed, having been merely lifted or depressed with the epeirogenic movements of the coast.

That portion of the Santa Lucia peneplain lying within the San Luis quadrangle is seen to best advantage from the summit of the range south of Cuesta Pass. The range here is made up of a great thickness of flinty Monterey shale eroded into rather sharp ridges and deep V-shaped canyons. The ridges have a fairly uniform height of 2600 to 2800 feet and present the appearance of having been eroded out of a plain. This plain widens from about 2 miles a little south of Cuesta Pass, and appears to extend many miles in a southeasterly direction. It includes a large portion of the mountains of the Santa Maria-Sisquoc basin in northern Santa Barbara County, being terminated finally at the farthest point of vision by the San Rafael Mountains of the northeastern portion of the county. The granite mountains to the east of the quadrangle known as the San Jose Range rise but little above the level of this peneplain, which sweeps around the head of the Salinas basin to meet them.

Northwest of Cuesta Pass the peneplain character has been largely obliterated because of the presence of the soft Cretaceous shale. As the Santa Lucia Range is followed northwestward from this quadrangle into Monterey County the plain which has been described appears to be developed to a much greater extent. West of Nacimiento Creek in this region the range presents a remarkably flat top, as seen in profile from the higher ridges to the north. The plateau-like summit, though deeply dissected by canyons, has a width of about 10 miles.

The flat-topped granite range north of Salinas River, extending into the extreme northeastern portion of the quadrangle, has an elevation of about 1900 feet. It now forms the southern extension of the Pleistocene peneplain of Salinas Valley, and is separated from the Santa Lucia Range by the Rinconada and Santa Margarita valleys. This was probably, when somewhat less worn down than at present, a portion of the late Neocene peneplain. Toward the close of the Pliocene the Paso Robles formation was undoubtedly extended over much if not all of this lower portion of the Santa Lucia peneplain.

The Santa Lucia peneplain extended south of this range across the region of the San Luis buttes and over the northern portion of the San Luis Range. The southwestern portion of the quadrangle was occupied by either the ocean or a body of fresh water.

PASO ROBLES DEPOSITION.

During the planation which resulted in the Santa Lucia peneplain the Paso Robles formation accumulated in Salinas Valley and upon the present seaward slope of the southern portion of the quadrangle. Between the time of upheaval which terminated the San Pablo epoch of the middle Neocene and the post-Pliocene disturbance which resulted in partially breaking up the Santa Lucia peneplain there appears to be no record of important events. In other portions of the Coast Ranges not only is the Pliocene history more complicated, but the disturbances at its close were greater.

The Paso Robles formation within the quadrangle does not, as a whole, show the effects of much disturbance. It is, however, locally tilted and faulted. Very probably at this time (the close of the Pliocene) renewed faulting along the Santa Lucia Range aided in breaking up the peneplain which has been described. Along the southern face of the range faulting was particularly marked.

The total displacement along this face of the range has already been stated to be not less than 2000 feet. The five highest of the San Luis buttes extending from the town northwestward to Morro Bay have a height of 1250 to 1500 feet. The greater portion of the San Luis Range has about the same elevation, but the Santa Lucia Range opposite the buttes has an altitude of 2600 to 2800 feet. It seems most reasonable to believe that a large part of this difference in elevation, perhaps 1000 feet, marks the amount of displacement of the Santa Lucia peneplain.

The thickness of the Paso Robles formation at Edna is not shown, but the hills at the south rise 300 feet higher than the surface of the beds, and, as the latter were possibly once continuous with those in the neighborhood of Arroyo Grande, the throw of the fault, if such the phenomenon indicates, must be more than 300 feet. There is, however, no positive evidence that these two remnants of Pliocene strata belong to the same formation, and there is a possibility that the beds at Edna were formed later in an eroded valley.

EARLY PLEISTOCENE ELEVATION.

A general elevation of the Pacific coast region is believed to have accompanied the disturbances which closed the Neocene. While there are some portions of the Coast Ranges where differential movements seem to have been slight, as in the plain-like valley of the upper Salinas River which adjoins the quadrangle, yet in general the amount of faulting and folding which the Pliocene beds exhibit and the present great elevation of some of them above the ocean indicate plainly the magnitude of the disturbances. There seems to be little doubt that the mountain-making movements at the close of the Neocene elevated the land to considerably more than its present height, crowding the shore line westward toward the borders of the continental plateau; although the view has also been held that no great elevation of the coast has taken place since the close of the middle Neocene and that the post-Pliocene disturbances were followed by a depression, in the recovery from which the coastal and river terraces were formed.

It is evident that not all of the Pleistocene history of the San Luis quadrangle can be traced without bringing in evidence from other portions of the coast. No large streams enter the ocean within its limits and the submarine topography here gives less aid to a study of the oscillations of the land than it does both to the north and the south.

There are, however, a number of facts which are difficult of explanation if a general elevation of the coast in early Pleistocene time is not admitted. Among the most important of these are the presence of Pleistocene deposits on the island of Santa Rosa, containing the bones of the mammoth, submarine valleys extending unbroken across the continental plateau and up close to the present shore line, and thick Pleistocene deposits in the valleys near the mouths of the larger streams. The recent slight subsidence of the coast has added to the difficulty of discriminating the movements of Pleistocene time.

The coast of California is bordered by a submerged continental plateau varying in width from 10 to 150 miles. From the surface of this plateau rise the coast islands, while from its outer edge the descent is very rapid to the depths of Pacific Ocean. A number of deep, narrow valleys cross the plateau, and in several instances at least are most easily explained by supposing them to be the drowned portions of valleys once occupied by streams which now enter the ocean at or near their landward termination. The submarine valley of Monterey Bay commences very close to the shores at the mouth of the broad Salinas Valley and extending across the plateau attains a depth of over 3000 feet at its outer edge.

The soundings which have been made opposite the San Luis quadrangle have not been numerous enough to indicate clearly the nature of sea floor there. The bottom appears to be an extensive gently sloping plain with no submarine valleys. At the mouth of the Santa Maria, a stream which enters the ocean just south of the quadrangle, an elevation of 1000 feet would extend the land 15 miles. A similar elevation opposite Morro Bay would remove the shore line 10 miles.

The present ocean floor deepens very gradually to about 350 feet, and then becomes much steeper. There are no records of soundings along this portion of the outer edge of the plateau. The streams of the quadrangle are small and the absence of defined channels upon the more gently sloping portions of the submarine plateau is not to be wondered at. Near Point Buchon there are two small submerged channels due to the last subsidence of the coast. These will be described later. At many points both north and south of the quadrangle the submarine contours follow those of the shore line to a depth of 2000 feet, a fact strongly favoring the view that there was a great elevation in very recent geological times.

That the Santa Barbara Islands were connected with the mainland in early Pleistocene time is indisputably shown by the presence of remains of the mammoth. At its deepest point the submerged ridge connecting the islands with the mainland is 750 feet below the surface of the ocean. To have enabled land animals to have free communication with the islands the elevation must have been more than that amount.

It may be said with some reason that, as the Santa Barbara Islands lie nearly 100 miles south of the San Luis quadrangle, movements of the land in the former region would not necessarily be experienced in the latter. No evidence has yet come to light, however, to show that since the time of disturbance which is here considered as closing the Pliocene, differential movements have taken place of sufficient intensity to depress the region of the Santa Barbara Islands 1000 feet or more without profoundly affecting the adjoining regions.

The early Pleistocene elevation was probably of brief duration, so that the streams had no more than enough time to cut canyon-like valleys across the continental plateau. The evidences of this elevation, except in the cases of the larger streams, it might naturally be supposed would be obliterated by subsequent subsidence and valley filling.

Salinas River, the headwaters of which lie partly within the quadrangle, empties into the ocean about as far north of the area as the Santa Barbara Islands are south. A well bored at the town of Salinas near the ocean in the broad lower portion of the present valley reached a depth of nearly 800 feet. The material passed through consisted of strata of sand, clay, gravel, and bowlders, indicating rapidly changing conditions of deposition, and is without doubt of Pleistocene age. If we deduct the filling due to the recent subsidence of the coast, which can not be much more than 300 feet, there remains a thickness of at least 500 feet of material which collected in the valley during the subsidence of middle Pleistocene time.

During the early Pleistocene elevation the leading features of the present drainage were evolved. While there appear to be some obscure problems concerned in the development of the San Luis-Los Osos valley, it seems most reasonable to suppose that it was not in existence prior to the uplift referred to above. San Luis Obispo and Corral de Piedra creeks established their channels over a surface having a continuous slope from Santa Lucia Range southwestward to the ocean, the San Luis and Los Osos valleys being filled with soft sediments belonging to the Pismo and Paso Robles formations. An examination of the topographic map reveals the fact that the branches of Corral de Piedra Creek unite within the San Luis Range after flowing across the open valley to the north. The same thing is shown in the case of San Luis Obispo Creek. These facts make it evident that San Luis Valley did not exist at the time of the origination of the present drainage. If it were not that a normal relation exists between the different tributaries and the trunk portions of the two streams just mentioned, it might be easily supposed that San Luis Valley originally drained northwestward through Los Osos Valley to Estero Bay. San Luis Obispo and Corral de Piedra creeks exhibit about the same degree of development as the Arroyo Grande where they traverse similar rock formations.

The development of San Luis Valley is due, then, to the work of two groups of tributary streams upon an area underlain by soft rocks. The difference in the rapidity of erosion upon soft and hard rocks is particularly well illustrated in the case of San Luis Obispo Creek. On each side of the San Luis Range where the creek crosses it there is a rim of Monterey shale and the stream channel is narrow, while in the center of the range, where the soft sandstones of the Pismo formation were encountered, a broad valley has been developed.

While San Luis Valley was being formed the valleys of the other streams were being excavated, and the San Luis buttes began to stand out in bold outlines much as they do at the present time. The topography, however, of the coastal slope lacked in general very much of its present maturity. Still less mature were the features of that portion of the Salinas Basin lying within the quadrangle, for with longer course to the ocean and more gentle grade erosion here became slower.

EARLY PLEISTOCENE SUBMERGENCE.

In time the land began to sink, and continued to do so until it had reached a position far below the present one. There are no phenomena in the neighborhood of the San Luis quadrangle to indicate whether the movement was continuous or by stages. There can be no doubt that the entire California coast was included in this downward movement, and that the terraces so plainly shown at many points were formed during the uplift succeeding this submergence. The highest terrace upon the mainland and islands of southern California has an elevation of about 1500 feet.

Near the mouth of Russian River, north of San Francisco, there is a well-marked terrace at 1520 feet. A terrace has been described as present along the coast of northwestern California at an elevation of 1500 feet. There is little reason to doubt that these terraces mark the limit of the downward movement of the land during the middle Pleistocene.

The portion of the coast lying within or adjacent to the San Luis quadrangle has not afforded any definite evidence, in the line of wave-cut terraces, of submergence as compared with the amount shown by the coasts of northern and southern California. There are, however, in the region under discussion some suggestions of a similar degree of subsidence. The Point Sal ridge, a few miles south of the quadrangle, has been planed off at an elevation of 1500 feet, while along the southern face of the Santa Lucia Range there are remnants of a gently sloping surface cut against the steep mountain slopes at about the same elevation. The conditions of slope, rock structure, and resistance to subaerial decay and erosion vary so greatly along the California coast that the absence of definite terraces at a given elevation should not be construed as necessarily indicating that terraces never existed.

The numerous terraces which characterize the California coast from 1500 feet down to sea level show that the movement took place by stages alternating with periods of comparative rest. Some of the terraces have been preserved in one place, some in another. Where the slopes are very steep or the rocks are unfavorable for their preservation all the terraces have been destroyed by erosion.

A well-marked terrace occurs at an elevation between 900 and 1000 feet at many different points on the coast. It is distinguished at Point Sal by a beach deposit and shells. At a corresponding elevation upon the seaward face of the Santa Lucia Range 60 miles north of the quadrangle is a broad shoulder with steep slopes above and below.

The coast of the northern portion of the quadrangle is bordered by a narrow strip of lowland back of which the hills rise abruptly to between 400 and 500 feet. Viewed from a point a little west of Cayucos the tops of the hills appear to form a slightly undulating plain which gradually rises back toward the Santa Lucia Range, the steep slopes of which it intersects 6 to 8 miles from the coast. The upper edge of this old surface of erosion has an elevation of about 1000 feet. East of Morro at a greater distance from the coast the former plain appears less distinct but seems to be related to shoulder-like remnants at the base of the steep mountain slopes of 1200 to 1500 feet elevation.

It is very probable that the larger part of this surface is in great measure the work of the waves, although subaerial erosion may have been concerned in the production of the higher portion.

The highest wave-cut shelf showing pebbles which was discovered is on the northern slope of Valencia Peak at the seaward end of the San Luis Range. It has an elevation of 750 feet. Coon Creek enters the ocean a little to the south of this peak. Its canyon shows a series of well-marked shoulders along its southern side corresponding in height to a stream valley eroded at the time the 750-foot terrace was being cut. Coon Creek, although having a very limited drainage, had at that time excavated a valley half a mile wide. Now the creek flows in a narrow canyon in the bottom of the former valley.

If, as seems likely, this portion of the coast was submerged more than 750 feet below the present level, the effects of wave and subaerial erosion are not to be distinguished above that height. Southeast of the San Luis quadrangle there was an extensive plain-like surface developed during this depression, and owing to its gentle slope it does not exhibit the work of subaerial and wave erosion any more plainly than the area just described. Each must have played an important part in its production. The plain extends over all that portion of the Santa Ynez Range lying west of Gaviota Pass. The crests of all the present ridges when viewed from the proper position appear to fall into a gently sloping surface which toward the east attains an elevation of 1000 feet. This same plain extended over a large section of the country embraced by the Santa Ynez Valley and the region lying between it and the Santa Maria Valley. It was limited upon the northeast by the hard Monterey shale of the San Rafael Range. Zaca Lake, in the canyon of the same name, occupies a portion of a graded valley extending back into the San Rafael Range. The lake owes its existence to-day to the fact that the stream now cutting its channel 500 feet deeper has not yet reached in this process the portion of the old canyon in which the lake lies.

Morro Rock has an elevation of but 576 feet, indicating that during the period of depression it was submerged. As the land rose its summit was for a time a portion of the shore, for there still remain a few waterworn pebbles upon it. The base is now deeply buried in sand as a result of the last sinking of the coast.

During the period of submergence, when the terraces were being formed, Los Osos Valley was occupied by an arm of the ocean. Deposits of sand, possibly of wind origin, remain upon its northern slope. The western portion of the San Luis Range rose above the water, forming an island with a bold face to the south and west.

On the southern side of the San Luis Range, west of Port Harford, the Monterey shale is replaced by the softer rocks of the San Luis formation. A broad, gently sloping plateau-like ridge forms a projection into the ocean at Port Harford having an elevation of about 700 feet.

But little if any of the range east of San Luis Obispo Creek stood above the water while the land was submerged to about the 900-foot contour. When the shore line stood at the 750-foot contour the soft Pismo sandstone had been reduced to a gently sloping plain. Its character is finely brought out if viewed from a point southeast of Arroyo Grande. A plateau-like plain is seen to sweep around the ridge of resistant Monterey shale rising north of Pismo, and to extend over all that portion of the the range lying east and north up to the crest overlooking San Luis Valley. South of Arroyo Grande Creek there is a terrace-like shoulder corresponding in height to the plain just described. The Pleistocene mesa, the materials of which were accumulated during this depression, extends over all the region between the lower Arroyo Grande Creek and the Santa Maria. The eastern edge of this mesa attains an elevation of 450 feet. The Pleistocene deposits have been removed by erosion from the Nipomo Valley, the surface of which appears to be an older wave-cut plain. The streams which entered the ocean here must have been loaded with detritus to permit of the accumulation of such a thickness of Pleistocene material.

The gently undulating surface of the San Luis Valley north of Edna is underlain by stratified clay and gravel which appear to be of Pleistocene age and to have accumulated in a body of water. The best evidence at hand seems to indicate that this valley was an arm of the ocean, although as the land rose the ocean water may have been replaced by a lagoon or fresh-water lake. If we are correct in assuming that the valley was eroded during the elevation in early Pleistocene time, it must have been flooded in the depression which followed. The Pleistocene beds are best exposed in a railroad cut 2 miles north of Edna. They have a maximum thickness of about 100 feet. As one looks northwest from Edna the old surface of deposition appears to have been preserved in a flat ridge extending out into the valley toward Steele station. This ridge has a height of a little over 300 feet, corresponding very closely to a prominent terrace upon the southern side of the Los Osos-San Luis valley.

DEVELOPMENT OF THE SALINAS PENEPLAIN.

Salinas River drains a larger area than any other stream in the Coast Ranges, and in the basin of this stream are found the most far-reaching effects of peneplanation during that period of coastal submergence which has been under discussion. A large portion of the Salinas basin was reduced to an almost perfect plain. This was accomplished the more readily because of the low relief, and the wide distribution of easily eroded rock strata.

The lower portion of Salinas Valley opening on Monterey Bay is 10 miles wide and is underlain by Pleistocene deposits. The valley narrows up the river and is soon shut in by high mountains, the range on the west rising very steeply 3000 feet. A little below Kings City soft Neocene deposits are encountered, and from this point upward the mountains recede and the Pleistocene peneplain begins. Viewed from some point on the bluffs overlooking the river the plain appears deeply trenched by the modern streams, but its evenness as a whole is remarkable. Southward the plain expands in the direction of the Santa Lucia watershed, and opposite Paso Robles does not appear to be clearly differentiated from the older peneplain upon that range.

The Salinas peneplain, as the plain under discussion may be termed, is the largest in this portion of the Coast Ranges, having a length of fully 100 miles and an extreme width of 40 miles. Except at the very head of the river the scenery was monotonous and the divides were low. Salinas River flowed sluggishly over a broad bed, meandering here and there.

As a result of a later uplift the peneplain has been largely removed in the region about the Estrella, the chief tributary of the Salinas from the north. As the Estrella is ascended the Salinas peneplain is found to exhibit more nearly its primitive condition. The plain continues to rise to the southeast, and passing over an almost imperceptible divide, blends with the Carriso Plain, which stretches away for 60 miles farther. This plain is without an outlet at the present time, although having an elevation of nearly 2000 feet. The rainfall in this region is very light, and since the uplift of the coast the rejuvenated streams, tributaries of the Estrella, have not yet extended their drainage back to the plain.

Farther up Salinas River, above the junction of the Estrella, the peneplain is found to have been extended over a considerable area in the northeastern corner of the quadrangle, including formations of very diverse character, such as granite, Monterey shale, and the soft middle and late Neocene deposits. The San Jose Range, formed of granite, rises with abrupt slopes between the Salinas and the Estrella arms of the peneplain. Seen in profile the deeply dissected mountain slopes make a sharp angle with the peneplain instead of blending into it. The Salinas peneplain, although largely destroyed in places, may usually be distinguished from the older Santa Lucia peneplain, from which it is separated by slopes.

The granitic portion of the peneplain presents a most remarkably even sky line as viewed from different points south of Salinas River. As before remarked, its even surface must have been largely produced during the formation of the Santa Lucia peneplain, but the finishing touches were given at the time of the extension of the Salinas peneplain.

RECENT UPLIFT OF THE COAST.

After the long period of comparative quiet during which the extensive erosion plains just described were developed, the coast began to rise with comparative rapidity. The uplift was, however, marked by many periods of rest, during which terraces were cut by the waves. Near the mouth of Coon Creek and on the slope of Valencia Peak terraces were noted at heights of 40, 60, 80, 100, 200, 350, 570, 700, and 750 feet. These measurements were taken with an aneroid barometer and are given in round numbers. At Lion Rock, a little south of Point Buchon, terraces appear in the volcanic ash at elevations of 40, 80, and 110 feet. Terraces upon the San Luis formation at Port Harford are not so well preserved. They were noted, however, at about 100, 150, 200, 350 feet or a little more, an apparent terrace at 500, and one at 700 feet.

Near Mallagh Landing terraces were noted at heights of 10, 60, 110, 140, and 200 feet. These terraces are cut in the volcanic ash at the base of the Monterey shale and are very distinct. The volcanic ash is but slightly affected by atmospheric agencies so that its decay is slow and it preserves the old wave lines remarkably well. Caves appear in the ash 10 feet above the water a little north of Mallagh Landing, while at present other caves are being worn out directly beneath them. (See fig. 12.)

In addition to the terraces described one covered by the water at high tide was observed at a number of points. As the present wave erosion progresses the surficial layer of Pleistocene material is at first removed, exposing the old wave-cut terrace, and this in turn is attacked by the waves in their formation of a new surface.

The coastal plain along the northern portion of the quadrangle appears to be limited very generally in its landward extension at an elevation in the neighborhood of 100 feet. Along the present shore line this plain terminates in cliffs that vary in height owing to unequal rate of recession.

As the coast slowly rose the existing drainage lines were pushed seaward and those streams which had become graded began deepening their channels. If San Luis Valley was occupied by the ocean during the depression, as the phenomena seem to indicate, then the drainage of this valley across the San Luis Range by means of the Corral de Piedra and San Luis Obispo creeks must have been kept open during the uplift, or it would have been diverted through Los Osos Valley to Morro Bay.

The lower portion of the northern slope of San Luis Peak is remarkably regular and smooth. The surface is not one of erosion, but is due to a bed of slightly cemented gravel and bowlders which probably accumulated under water. On the northwest slope there is a terrace-like shoulder at an elevation of 400 feet.

Along the northeastern slope of the San Luis Range facing the San Luis and Los Osos valleys there are three terraces having elevations of 260, 325, and 425 feet. The absence of pebbles on these terraces is rather peculiar, unless the adjoining body of water was generally quiet owing to its protection from the open ocean. At one point on the upper terrace just south of Sycamore Canyon are waterworn bowlders of andesite which must have been derived from the buttes on the opposite side of the valley. They probably were transported to their present position when the valley was filled with Neocene deposits, for their accumulation would be impossible under present topographic conditions.

On the west side of San Luis Valley near the entrance to the canyon leading down to Port Harford there is a terrace which has a mean elevation of about 225 feet, sloping with the gentle grade of the valley toward the canyon. This is clearly a stream terrace and probably marks the level of the valley floor at the time the ocean waters were drained from the valley and streams began to traverse its surface. The bottom of the valley below the terrace has now an elevation of only 100 feet. The present divide between the San Luis and Los Osos valleys has a height of but 180 feet, showing that it must have been lowered considerably since the formation of the terrace, otherwise the streams would have flowed northwestward into Morro Bay.

The result of the elevation of the land was manifested sooner in the renewal of stream erosion on the coastal slope of the Santa Lucia Range than in the Salinas basin, for in the former region the slopes were shorter and steeper. As the upward movement continued Salinas River began to deepen its channel, and as this renewal of stream life finally spread to the tributaries the destruction of the Salinas peneplain was begun.

The intermittent character of the upward movement resulted in terraces along Salinas River as it did on the coast. These terraces are not prominent within the quadrangle, but 15 miles below San Miguel, where the river is bordered on the southwest by the Monterey shale, six distinct benches have been cut in the resistant rock, ranging in height above the present stream from 40 to 200 feet.

Salinas River now crosses the northeastern corner of the quadrangle in a granite canyon 500 to 700 feet deep, but upon the southwest the leading tributaries, Rinconada, Trout, and Santa Margarita creeks, have eroded broad valleys in the soft sandstones of the Santa Margarita formation. The position of Salinas River, confined as it is in the more resistant granite, is remarkable. If we survey the country from some elevated point, the real valley of the Salinas appears to lie to the southwest, where the above-mentioned tributary valleys, practically coalescing, constitute a long valley parallel with the Santa Lucia Range, but transverse to the courses of the streams which have produced it. Rinconada Creek issues from the Santa Lucia Range through a narrow canyon, and then, flowing through the broad and fertile valley, joins the Salinas in the granite. Trout Creek probably once entered the Salinas about 2 miles northeast of Santa Margarita, but now turns northwestward along the belt of soft rocks and enters the Salinas at the point where the latter leaves the granite. Northeast of Santa Margarita an elevation of only 50 feet now separates these two streams, but the Salinas, instead of taking advantage of the low gap, turns back again into the granite, passing through a canyon 500 feet deep and finally emerges 3 miles farther down the main valley.

The anomalous position of Salinas River is due to the fact that it was superimposed upon the granite at the time when the topography was very different. The Neocene formations once reached much farther over this old granite ridge and probably underlay the river at the time of the fullest development of the Salinas peneplain, the surface then sloping from the broad valley of the sluggish river gradually upward on the one hand toward the Santa Lucia Range to the southwest and on the other to the low granite ridges toward the northeast. When the uplift came and the current of the river was increased it began to cut down into the soft underlying sediments, soon encountering the buried granite. Its channel was, however, so completely established that it was compelled to go on cutting down where it had begun, notwithstanding the fact that the smaller streams to the southwest, encountering no hard rocks, soon formed a series of broad valleys though which one without a knowledge of the history of the region naturally would expect to find the trunk stream flowing.

Salinas River, except for a short distance where it flows over the conglomerates of the Vaquero sandstone, has graded its channel from source to mouth. The broad sandy bed completely absorbs the water for stretches of many miles during the hot summer months, and the work now done by the river is confined to short periods each year following exceptionally heavy storms.

Very much of the surface of the Salinas peneplain has been removed, producing large valleys in the process of formation of a new plain at a lower level. This is apparent in the region of the Rinconada and Santa Margarita valleys, and on a more extended scale down the river near the mouth of the Estrella.

DEFORMATION OF THE SALINAS PENEPLAIN.

As has already been stated, there are no indications within the San Luis quadrangle of any marked Pleistocene deformation. North of the quadrangle, however, near the junction of Estrella and Salinas rivers, the Salinas peneplain appears to have undergone considerable differential movement. Opposite the town of San Miguel the top of the peneplain has an elevation of 800 feet above the river and is tilted slightly to the northeast instead of southwest as it would be under normal conditions. Along this bluff facing the river an axis of disturbance is clearly apparent. It is evidently of the nature of a fold and can be traced down the river some miles and far up the Estrella to the southeast. The strata probably belong to the Paso Robles formation. Opposite the mouth of the Estrella and 200 feet above it is a shelf from which the surface slopes gently down to this stream, which occupies a channel about a mile from the shelf and is cutting into its southern bank. The phenomena strongly indicate that the stream has been gradually displaced from its original position at the foot of the main bluff by an upward folding of the earth. The original peneplain on the opposite side of Salinas River has been destroyed at this point and the amount of distortion could not be accurately measured, but it must be several hundred feet.

RECENT COASTAL DEPRESSION.

The upward movement of the coast continued until the land stood several hundred feet higher than at present. It has been estimated that at San Francisco Bay the recent subsidence amounts to between 300 to 400 feet. About the same amount of subsidence has taken place along the coast of southern California. There is no reason to believe that this estimate is far from the truth for that portion of the coast embraced by the San Luis quadrangle. In this region the contours of the ocean floor out to a depth of about 300 feet are approximately parallel to the present shore. An elevation of 300 feet would move the shore line out 10 miles at the mouth of Arroyo Grande Creek, while off Estero Bay the shore would be about 7 miles out. The slope of this land now submerged is so gentle that it is not likely that channels of much depth were made by the streams, except perhaps in the case of those flowing from the steeper portions of the San Luis Range. Islay and Coon creeks formed shallow but distinctly marked channels. These have not yet been entirely obliterated and can be readily traced outward from the present mouths of these streams by the absence of breakers during stormy weather.

All the larger streams exhibit characteristics of a sunken coast. They have tidal lagoons at their mouths and flow for some distance over alluvial bottoms or flood plains built up in previously eroded valleys. San Luis Obispo Creek illustrates these features most excellently. The broad, fertile bottom lands of Morro and Arroyo Grande creeks have also been formed by the silting up of earlier valleys of erosion.

The Laguna in the western arm of San Luis Valley appears to have been formed by the débris cone of a stream issuing from the San Luis Range and damming an old channel. As a result of the last depression San Luis Obispo Creek became silted up and unable to remove the large amount of waste brought down by the more steeply graded stream.

TOPOGRAPHIC FEATURES OF THE COAST LINE.

The low, sandy portions of the California coast are marked more or less prominently by sand dunes. Wind-blown sand, reaching nearly to its summit, has modified the seaward slope of Black Hill. In the same manner the northern slope of the San Luis Range opposite Morro Bay has been covered with sand to a height of about 700 feet. This sand has caused a deflection of Los Osos Creek where it emerges from the mountains.

The surface of the Pleistocene mesa south of Arroyo Grande is made up of wind-blown sand, being marked by low, irregular ridges and hollows without outlet. The most of this area is now covered with a growth of low shrubs, but near the coast dunes are forming and moving inland, until each in turn becomes covered with vegetation.

Morro Bay is protected by an interesting barrier beach. The irregularities of the shore line are for a distance of 8 miles buried behind a smoothly-sweeping crescent of sand. Toward the western extremity there are some dunes upon the inner edge of the beach which are over 50 feet high. The sand, carried by the wind, is rapidly encroaching upon the waters of the bay. During exceptionally heavy storms the waves sometimes break over the barrier beach, although at the eastern end of the bay a broad opening is always maintained.

The character of the ocean cliffs is intimately related to the nature of the rocks forming them. The San Luis formation with its strata of jasper and many igneous intrusions forms an irregular and picturesque coast. Five miles north of Port Harford a series of jasper lenses extends across the coastal plain and into the ocean. (See fig. 6.) The jasper, being so much more resistant, forms sharp rock stacks, one rising nearly 100 feet as a precipitous monolith.

Whether slopes facing the ocean are precipitous or gently inclined depends upon the structure of the rock and its resistance to subaerial decay. About 7 miles north of Port Harford a large mass of diabase presents a sloping front to the waves, owing to its great susceptibility to the attack of the atmospheric agencies. The Monterey shale, on the contrary, is very little affected by the atmosphere, so that under the attack of the waves the cliffs become vertical or even overhanging. This is well shown in the vicinity of Point Buchon, where the waves are undermining the shales, forming recesses and caves. Blocks of the shale finally become separated from the shore and form islands. Such a block of contorted shale is shown in fig. 3. A little distance west of Pismo the Monterey shale dips away from the shore at a steep angle, with the result that overhanging cliffs have been formed, the inclination of the cliff corresponding to the dip of the shale.

The volcanic ash is also very slowly attacked by atmospheric agencies, and wherever it is exposed at the coast very bold and striking features result. This is to be observed in the vicinity of Lion Rock, a little distance south of Point Buchon. Prominent rock stacks carved from the ash appear upon the coastal plain, while others have been isolated by the waves and form picturesque islands.

At Mallagh Landing the cliffs of volcanic ash exhibit interesting features. Several of the old shore lines are well preserved in the form of terraces and two of them exhibit caves. The caves of the 10-foot terraces are especially interesting. Several extend back 10 to 15 feet into the ash and have cemented beach pebbles at their inner extremities. Directly under this series of caves are those now being excavated by the waves. They can be entered only at low tide, and show by their extent that the sea has been at work at the present level for some time.

ECONOMIC GEOLOGY.

BITUMINOUS ROCK.

By the term bituminous rock is meant a porous rock, generally sandstone, which has been impregnated by thick, dark petroleum residue—maltha or "tar." The term asphaltum is applied to the solid form of bitumen in a more or less pure state. Bituminous rock is almost black in color, and when moderately cool fractures easily, yet under the influence of the sun's rays it melts down to a tough, viscid mass.

The important deposits of bituminous rock in the quadrangle are confined chiefly to those portions of the Pismo formation which rest on the bituminous Monterey shale. The characteristic feature of the Pismo formation is its soft, porous sandstone, which is easily permeated by oil and bitumen.

While springs of tar and oil occur in all the divisions of the Tertiary in California, the most important source of these materials appears to be in the bituminous shales of Miocene age (Monterey shale). These shales extend through the Coast Ranges from near San Francisco on the north to and beyond Los Angeles on the south. It seems clear from investigations which have been made that the source of the oil, as well as of the thicker product known as tar or asphaltum, does not lie below these bituminous shales, except in one instance, in Ventura County, where there is a body of oil-producing shale in the Eocene.

All the oil-shale beds are largely of organic origin. Those in the Monterey formation are chiefly siliceous with a subordinate portion possessing a calcareous nature, while in the Eocene the shale is entirely calcareous. There is good reason for believing that these shales, through a long-continued process of distillation, have given rise to the organic products described. That this process is still going on may be inferred from the springs of tar and oil, and especially from the hot mineral springs, which afford evidence of chemical action far below. At points where the tar or oil springs issue directly at the surface from the hard, compact Monterey shale the conditions are not favorable for the preservation of the bituminous matter. For the material to collect in large quantity a porous reservoir is needed. Wherever the Pismo formation occurs such a reservoir is afforded by the thick beds of slightly cemented sand. The slowly seeping bitumen passes upward from the shale into the sand and converts it into a black, sticky mass. Weathering dissipates the volatile portions of the bitumen and the mass assumes a brownish color. The sandstone thus impregnated is more resistant to erosion than when not affected, and wherever there is a large body of bitumen, prominent topographic features may result, such as the picturesque cliffs below Edna.

Nearly the whole of the eastern portion of the San Luis Range is made up of Pismo sandstone. In many places, particularly near Edna, it has been richly impregnated with the tarry oil, forming the bituminous rock of commerce. Many quarries have been opened here and the material is shown to be inexhaustible.

In See Canyon north of the Pismo formation an oil spring issues from the Monterey shale, but no deposit has been formed, owing to the lack of a reservoir. That the oil comes from the Monterey shale is shown by the fact that near Port Harford, where the Pismo sandstone passes off from the Monterey shale and rests upon the San Luis formation, its bituminous content disappears. Along the coast between Mallagh Landing and Pismo the relation of the bituminized sandstone to the Monterey shale is distinctly shown. A body of this black and strong-smelling material rests unconformably on the shale, which is here less altered than usual and is itself richly impregnated by bitumen.

The western portion of the San Luis Range is free from any bituminous deposits with the exception of a small one in the northerly branch of Los Osos Canyon. The shale in this portion of the range is identical with that farther east, where the tar springs occur, and it may be that a greater degree of metamorphism has driven off the most of the organic matter.

At various points between San Luis Obispo Creek and Arroyo Grande springs of oil are still impregnating the sandstone. In a small hill north of the town of Arroyo Grande the oil has passed up into the Paso Robles formation, which consists of sand and conglomerates. In the bed of Arroyo Grande Creek near the town oil issues from the Monterey shales. In some places the shale is sufficiently porous to retain a large percentage of bitumen, but seldom enough to pay for quarrying the rock.

On Tar Spring Creek about 10 miles above the town of Arroyo Grande there are exceptionally large springs of thick petroleum or tar which have formed a great deposit in the middle of the valley. Much of this material has been dug up, purified, and taken away, but the supply is still abundant and is constantly receiving additions. Many animals are caught and held in this tarry mass until they perish, as is shown by the bones which have been taken from it. The springs here issue from sandstones, and it would appear that the location is favorable for the boring of wells.

But little bituminous matter now remains in the shale through Salinas Valley as well as in that forming the Santa Lucia Range east of Cuesta Pass. The barrenness of the shale in these localities is difficult to explain, unless it is a result of the siliceous metamorphism to which the rock has been subjected. It may be, too, that where the shale is more deeply buried the bituminous matter has not escaped so much, for as we follow the synclinal fold shown by the shale in the Santa Lucia toward the southeast, in which direction it dips, we begin to encounter signs of bitumen in the presence of small oil springs.

Prospect wells have been drilled in several places, but either the locality has been poorly chosen or the drilling has been abandoned before great depth was reached. The drill hole which gave rise to Sycamore Springs penetrated shale all the way to a depth of 900 feet. In a drill hole in the valley of Pismo Creek 3 miles below Edna a small quantity of oil is reported to have been found, but this hole was not deep enough to make the experiment of any great value. Since the field work for this folio was completed prospecting for oil has been renewed in this portion of the Coast Ranges, and oil in paying quantities is reported to have been found in the valley of the Huasna.

The structure of the San Luis Range where the bituminous rock occurs is that of an open syncline. The same structure is exhibited where the great springs of tar occur on Tar Spring Creek. In the former syncline the deposits of bituminous rock are richer and more continuous along the outer edge of the fold, the seepage of tar having a tendency to follow up the dip of the beds.

Although it is generally considered that the summit of an anticline is the most favorable locality for oil deposits, and while this may be accepted as true on general principles, yet in California, where the strata are so irregularly folded and broken, deposits of oil do not seem necessarily to be confined to anticlinal structures. In many portions of the oil districts of the Coast Ranges petroleum is encountered in monoclinal folds. In certain localities it occurs on one side of an anticlinal knob or fold, but rarely, if ever, in quantity at the summit of an anticline.

The character of the petroleum varies greatly in different portions of the Coast Ranges. In some places it has but a small percentage of nonvolatile matter, but in others, as in the San Luis Obispo region, it is almost always thick and tar-like.

BUILDING STONE.

Within the San Luis quadrangle there is a large variety and abundance of useful building stones. They are described under the following heads.

Granite.—The canyons which intersect the granite along Salinas River and north of it give numerous exposures of this rock suitable for building purposes. The granite is perhaps the most easily accessible in Rocky Canyon, which has cut deeply into the fresh rock. Over the greater portion of this granite area disintegration has gone on more rapidly than erosion, so that it is rare that the solid rock is exposed except in the deeper canyons. The granite is of medium-light color with a slightly porphyritic aspect and an inclination toward a flesh tint in some of the feldspars. Quarries could be opened within 2 miles from the railroad.

Dacite and andesite.—The buttes extending from San Luis Obispo northwestward to Morro Rock furnish excellent and durable stone for building purposes. A quarry has been opened on Morro Rock for the purpose of supplying material for the Port Harford breakwater, and blocks of any size can be obtained. It is to be hoped, however, that the grandeur and symmetrical proportions of this mass will not be marred, as equally good material can be obtained from the other buttes. Southeast of Morro as far as Hollister Peak the dacite forms rugged elevations. From its manner of weathering it is evident that large massive blocks of this rock could be obtained at many places. The rock contains free quartz throughout and is light grayish or bluish on fresh surfaces, but it weathers rapidly to yellow, which is its permanent color. On Pennington Creek are several small knobs of dacite which have a more granitic appearance. This rock is lighter in color and retains its fresh surface with but little change.

The remainder of the buttes lying between Hollister Peak and San Luis Obispo exhibit a darker and more basic rock, but the color rapidly changes to a grayish yellow after quarrying. This rock is also excellent for building purposes, but care is necessary in selecting locations for quarries, as the rock is much seamed in places. A quarry has been opened on Bishop Peak, from which rock is taken by rail to the breakwater at Port Harford. The most of this rock which has been used in the buildings about San Luis Obispo and in the railroad culverts was taken from loose bowlders with which the lower slopes of the buttes are strewn.

Sandstone.—The Atascadero formation contains an inexhaustible supply of sandstone suitable for building purposes. It is easily accessible, but with the exception of the stone used in the railway culverts near Santa Margarita, none has been quarried. This sandstone outcrops for many miles along the northern slope of the Santa Lucia Range, and also upon the coast between Cayucos and Cambria. In the latter locality the stone is especially fine in quality. It is well exposed near the mouth of Villa Creek, whence it can easily be shipped by water.

A fair quality of calcareous sandstone occurs in the Pismo formation below Edna, and it has been used by the railway in building culverts.

Near the town of Arroyo Grande the volcanic ash at the base of the Monterey shale has been used to a considerable extent. It is easily quarried and is adaptable for small buildings. The oxidation of the iron pyrites with which the ash is impregnated hardens it and leaves it of a yellow color.

The San Luis formation, though consisting largely of sandstone, has been so extensively sheared and fractured that it is only rarely that building stone in blocks of useful size can be obtained from it.

ROAD MATERIAL.

That part of San Luis Obispo County lying west of the Santa Lucia Range is well supplied with excellent road material, and owing to the clayey nature of much of the soil in this section, it should be in demand. The material referred to is the radiolarian jasper, or, as it is familiarly known, "red rock." A decomposed eruptive rock is sometimes used but it is neither so lasting nor does it make so hard a roadbed as the jasper. The latter rock can easily be distinguished by its hard, flinty character and banded structure. The jasper is so widely distributed and easily quarried that it should be extensively used.

CHROMIC IRON.

As a mining county San Luis Obispo is most widely known for its production of chromic iron. In years past many mines were worked here, but, owing to the low prices obtained in recent years, nothing is now being done. Chromic iron occurs, however, in large quantities, and, under favorable conditions, will again be mined. It is invariably found in the serpentine, to which it is genetically related.

One important group of mines is located on the mountains southwest of San Luis Valley. The work done here has been almost entirely on the surface and consisted in following up the irregular stringers and bunches of the ore. Most of the mines are along the southern slope of the Santa Lucia Range in the vicinity of the fault zone. The excellent exposures in some of the old workings show clearly the manner of formation of the ore. It occurs in irregular and more or less disconnected veins and bunches along fissured zones in the serpentine through which mineral-bearing waters have percolated. All stages of replacement of the serpentine by the chromite are exhibited, from that in which the ore appears in granules scattered through the porous serpentine to that in which it forms massive bunches many tons in weight. In the Pick and Shovel mine one mass weighing a thousand tons is reported to have been discovered. In the vicinity of some of the mines much float ore is scattered over the surface and some attempt has been made at concentrating it. The workings have so far been superficial and the deposits not much more than touched. The great difficulty in chrome-iron mining is the fact that the bodies of ore are so disconnected.

HEMATITE.

A deposit of hematite occurs in the mountains south of Los Osos Valley. It appears as a well-defined bed crossing a small canyon locally known as Profumo Canyon. It can easily be traced for fully a mile. The beds stand vertical, being inclosed in the shale and sandstone of the San Luis formation. It has a width of about 10 feet and is beautifully and regularly banded. The iron blends into the shale along parts of the deposit, and judging from this fact, as well as from the regular banding, which accords perfectly with that of the shale, it may be of contemporaneous formation.

MANGANESE.

Small deposits of manganese ore occur at several points, viz, on the north side of Clark Canyon; on the ridge southeast of Profumo Canyon, and near the Cambria road 8 miles west of Cayucos. The deposits are associated with jasper as the coating of seams and as nearly pure masses replacing the jasper. From all the evidence obtained these deposits probably bear some genetic relation to the jasper, although in its present form the manganese ore is certainly secondary. The jasper beds offer special opportunities for the passage of mineral-bearing solutions because of the easy parting along the bands. The deposits are probably not large enough to be of much commercial value.

PUMICE.

Extensive beds of pure pumice occur at various points associated with the volcanic ash near the base of the Monterey shale. The pumice is particularly prominent in the hills back of Pismo and east of Edna along the southern edge of San Luis Valley. A pure-white pumice, perhaps more finely pulverized, occurs in the form of thin beds in the Santa Margarita formation below Atascadero. This pumice possesses an important value as an abrasive material.

INFUSORIAL EARTH.

Beds of infusorial earth are associated with the Monterey, Pismo, and Santa Margarita formations. They are found on the mountains back of Pismo, very extensively about Arroyo Grande, and along the hills bordering the southern side of San Luis Valley. Another bed of considerable thickness occurs on the slope of the San Luis Range south of Morro Bay. Similar deposits appear at various points along Salinas Valley, extending as far up as Rinconada Valley. These diatomaceous beds are white and chalky in character. They are mostly made up of the siliceous skeletons of diatoms. This material is used in the manufacture of filters and as an abrasive.

LIMESTONE.

The important beds of limestone occur toward the base of the Monterey formation along the southern slope of the Santa Lucia Range. More or less limestone, however, is found at this horizon over the whole quadrangle wherever the Monterey formation occurs. The rock is fine grained and of a yellowish-white color, and gives out a strongly fetid odor when freshly broken. It has been used but little as a source of lime.

A vein of white crystalline dolomite occurs in Little Falls Canyon, a tributary of the upper Lopez Canyon.

SAND.

Extensive beds of quartz sand and kaolin are found in the Pismo formation both north of Arroyo Grande and in the Santa Margarita Valley. In the latter locality it is particularly clean and free from iron. The material is but slightly coherent and the sand and kaolin could easily be separated. The sand is valuable for the manufacture of glass, and the kaolin might be useful for pottery.

MINERAL SPRINGS.

Numerous sulphur springs, both warm and cold, issue from the Monterey shale along Islay Canyon in the western part of the San Luis Range. The springs are used chiefly for bathing purposes.

Sulphur springs are also found in Lopez Canyon. In Trout Creek Canyon there is a small alum spring.

A large iron spring issues near the edge of the granite in the valley of Middle Branch of Huerhuero Creek. Smaller iron springs occur in the lower portion of Rocky Canyon and at Port Harford.

The best known and most frequented springs are the Sycamore warm sulphur springs, where the water issues from a bore hole put down 900 feet for oil, and Newsom's warm sulphur springs 2½ miles east of the town of Arroyo Grande. The sulphur springs in the Monterey formation all appear to be the product of chemical activity within the bituminous shale. Water of this nature almost always appears with springs of tar and oil.

SOILS.

The soils of the San Luis quadrangle are much diversified, as might be inferred from the great variety of rocks present. The disintegration of the strata of the San Luis formation and its included igneous rocks, which form so much of the foothill region and open valleys south of the Santa Lucia Range, has resulted in a very rich soil. Not only are the valleys rich but even the steep hillsides also, which in their natural state support a heavy growth of wild oats and grasses.

The eruptive rocks are mostly rich in iron and soda and poor in silica and have produced the heavier dark and reddish soils. The serpentine alone of all the igneous rocks produces a very poor soil. The decomposition of the sandstone has given rise to a lighter soil than that derived from most of the igneous rocks, yet such soil might still be termed heavy, for it contains little quartz.

The Monterey shale disintegrates slowly, and as it consists chiefly of silica, produces the poorest of the soils. This is particularly the case where the rainfall is light. Along the coastal slopes of the San Luis Range and in its deep canyons, where the rainfall is heaviest, the residual soil on the Monterey shale appears to be very fertile.

The soils resulting from the disintegration of the sandstone of the Pismo formation are surprisingly productive, as is shown in the cultivated tracts north and northwest of Arroyo Grande. Springs are abundant, owing to the absorptive properties of the sandstone.

The granite region, or that part of it which is included within the quadrangle, contains almost no cultivable valleys, for the canyons are narrow and water is scarce. Much of the granite is disintegrated to a considerable depth, and only here and there do rocky points project above the sandy soil. The valley of Huerhuero Creek, draining the northern slope of the granite, has a deep, fertile soil below the point at which it leaves the granite. The hills bordering the lower portion of this valley consist of the Paso Robles formation, which is made up chiefly of sandy and marly clays. The hill lands on this formation are also fertile, but the scarcity of rainfall in this region makes the raising of cereal crops, except on the bottom lands, rather uncertain.

Between Salinas River and the Santa Lucia Range the rainfall is greater, but the most of this region has until recently been used solely as cattle range. The Rinconada, Santa Margarita, and other valleys farther down the river contain much fertile land.

September, 1903.

U.S. GEOLOGICAL SURVEY
CHARLES D. WALCOTT
DIRECTOR

TOPOGRAPHY

CALIFORNIA
(SAN LUIS OBISPO CO.)
SAN LUIS QUADRANGLE

Henry Gannett, Chief Topographer.
R.U. Goode, Geographer in charge.
Triangulation by U.S. Coast and Geodetic Survey.
Topography by L.C. Fletcher and U.S. Coast and Geodetic Survey.
Surveyed in 1895.

APPROXIMATE MEAN DECLINATION 1902.

Scale $\frac{1}{125000}$

Contour interval 100 feet.
Datum is mean sea level.

Edition of June 1903.

LEGEND

RELIEF
(printed in brown)

Figures *(showing heights above mean sea level instrumentally determined)*
Contours *(showing height above sea, horizontal form, and steepness of slope of the surface)*
Depression contours
Beach sand
Stream wash

DRAINAGE
(printed in blue)

Streams
Intermittent streams
Lakes and ponds
Intermittent lakes
Salt marshes
Fresh marshes

CULTURE
(printed in black)

Roads and buildings
Private and secondary roads
Trails
Railroads
Tunnels
Bridges
U.S. township and section lines
Land grant lines
City lines
Triangulation stations
Lighthouses

U. S. GEOLOGICAL SURVEY
CHARLES D. WALCOTT
DIRECTOR

AREAL GEOLOGY

CALIFORNIA
(SAN LUIS OBISPO CO.)
SAN LUIS QUADRANGLE

LEGEND

SURFICIAL ROCKS

(Areas of Surficial rocks are shown by patterns of dots and circles)

PLEISTOCENE

Recent

- Pal — Alluvium and stream gravel
- Pt — Terrace deposits and dune sand

SEDIMENTARY ROCKS

(Areas of Sedimentary rocks are shown by patterns of parallel lines)

NEOCENE

Pliocene

- Npr — Paso Robles formation (conglomerate and sandy and marly clays of fresh-water origin)

UNCONFORMITY

Miocene ? (San Pablo)

- Np — Pismo formation (sandstone and cherty diatomaceous shale)
- Nsm — Santa Margarita formation (soft sandstone and conglomerate, with beds of diatomaceous earth and volcanic ash)

UNCONFORMITY

Miocene

- Nm — Monterey shale (clay shale, limestone, and siliceous and bituminous, diatomaceous shales)
- Nv — Vaquero sandstone (sandstone and conglomerate)

UNCONFORMITY

CRETACEOUS

Chico

- Kat — Atascadero formation (sandstone with some conglomerate and shale)

UNCONFORMITY

Knoxville

- Kt — Toro formation (dark shale and thin-bedded sandstones)

UNCONFORMITY

JURATRIAS ?

Jurassic ? (Franciscan)

- Jsl — San Luis formation (sandstone, conglomerate, shale, and contact-metamorphic amphibole-schist)
- Jasper lentils in San Luis formation (variegated jasper and chert, composed largely of radiolarian remains)

IGNEOUS ROCKS

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

NEOCENE

Miocene (Pre-San Pablo)

- Nt — Augite-teschenite (intrusive sheets and dikes)
- Nd — Olivine-diabase (dikes and sheets)
- Nr, Nqb — Quartz-basalt and rhyolite (dikes and sheets)
- Nrt — Rhyolite tuff (interstratified with the Monterey shale)
- Npa — Pyroxene-andesite (dikes)

CRETACEOUS

Pre-Chico

- Ks — Serpentine and associated basic rocks (intrusive masses and dikes of serpentine, peridotite, pyroxenite, norite, and gabbro)
- Kc — Cuesta diabase (intrusive masses and sheets)
- Ka — Andesite-granophyre (volcanic necks and intrusive masses)
- Kd — Dacite-granophyre (volcanic necks, intrusive masses, and dikes)

Legend is continued on the left margin.

LEGEND

IGNEOUS ROCKS

(continued)

JURATRIAS ?

Jurassic ? (Post-Franciscan)

- Jo — Osos basalt (surface flows)
- Jd — Diabase and other basic rocks (intrusive diabase, olivine-diabase, basalt, pyroxenite, and peridotite)

PRE-JURATRIAS

- gr — Granite (plutonic basement rocks)

Faults are not clearly defined in the field and therefore are not shown on the map.

Sections

Henry Gannett, Chief Topographer.
R. U. Goode, Geographer in charge.
Triangulation by U. S. Coast and Geodetic Survey.
Topography by L. C. Fletcher and U. S. Coast and Geodetic Survey.
Surveyed in 1895.

TRUE NORTH — MAGNETIC NORTH — APPROXIMATE MEAN DECLINATION 1902.

Scale $\frac{1}{125000}$

Miles — Kilometers

Contour interval 100 feet.
Datum is mean sea level.
Edition of Aug. 1903.

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

Geology by Harold W. Fairbanks.
Surveyed in 1897, 98, and 99.

U.S. GEOLOGICAL SURVEY
CHARLES D. WALCOTT
DIRECTOR

ECONOMIC GEOLOGY

CALIFORNIA
(SAN LUIS OBISPO CO.)
SAN LUIS QUADRANGLE

LEGEND

IGNEOUS ROCKS
(continued)

Jurassic? (Post-Franciscan) — JURATRIAS?

- Jo — Osos basalt *(surface flows)*
- Jd — Diabase and other basic rocks *(intrusive diabase, olivine-diabase, basalt, pyroxenite, and peridotite)*

PRE-JURATRIAS

- gr — Granite *(plutonic basement rocks)*

Faults are not clearly defined in the field and therefore are not shown on the map.

⚒ Mines and quarries *(bituminous rock, chrome iron, and building stone)*

○MS Mineral springs

Sections

A B C D E F

Known productive formations

- *Bituminous rock* *(soft porous sandstone of the Pismo and Santa Margarita formations are impregnated with bitumen from the underlying Monterey shale)*
- *Chrome-iron* *(serpentine contains scattered deposits of chrome-iron ore)*
- *Hematite* *(bed of iron ore in San Luis formation)*
- *Pumice deposits* *(beds in rhyolite tuff and Santa Margarita formation)*
- *Infusorial earth* *(deposits in Monterey, Pismo, and Santa Margarita formations)*
- *Building stone* *(sandstone, dacite, granite, and andesite, suitable for building purposes)*
- *Road material* *(jasper)*

LEGEND

SURFICIAL ROCKS
(Areas of Surficial rocks are shown by patterns of dots and circles)

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Miocene? (San Pablo)
- Np — Pismo formation *(sandstone and cherty diatomaceous shale)*
- Nsm — Santa Margarita formation *(soft sandstone and conglomerate, with beds of diatomaceous earth and volcanic ash)*

UNCONFORMITY

Miocene
- Nm — Monterey shale *(clay shale, limestone, and siliceous and bituminous, diatomaceous shales)*
- Nv — Vaquero sandstone *(sandstone and conglomerate)*

UNCONFORMITY

CRETACEOUS

Chico
- Kat — Atascadero formation *(sandstone with some conglomerate and shale)*

UNCONFORMITY

Knoxville
- Kt — Toro formation *(dark shale and thin-bedded sandstones)*

UNCONFORMITY

JURATRIAS?

Jurassic? (Franciscan)
- Jsl — San Luis formation *(sandstone, conglomerate, shale, and contact-metamorphic amphibole-schist)*
- Jasper lentils in San Luis formation *(variegated jasper and chert, composed largely of radiolarian remains)*

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

NEOCENE

Miocene (Pre-San Pablo)
- Nt — Augite-teschenite *(intrusive sheets and dikes)*
- Nd — Olivine-diabase *(dikes and sheets)*
- Nr, Nqb — Quartz-basalt and rhyolite *(dikes and sheets)*
- Nrt — Rhyolite tuff *(interstratified with the Monterey shale)*
- Npa — Pyroxene-andesite *(dikes)*

CRETACEOUS

Pre-Chico
- Ks — Serpentine and associated basic rocks *(intrusive masses and dikes of serpentine, peridotite, pyroxenite, norite, and gabbro)*
- Kc — Cuesta diabase *(intrusive masses and sheets)*
- Ka — Andesite-granophyre *(volcanic necks and intrusive masses)*
- Kd — Dacite-granophyre *(volcanic necks, intrusive masses, and dikes)*

Legend is continued on the left margin.

Henry Gannett, Chief Topographer.
R.U. Goode, Geographer in charge.
Triangulation by U.S. Coast and Geodetic Survey.
Topography by L.C. Fletcher and U.S. Coast and Geodetic Survey.
Surveyed in 1895.

TRUE NORTH — MAGNETIC NORTH — 15½°
APPROXIMATE MEAN DECLINATION 1902.

Scale $\frac{1}{125000}$

1 ½ 0 1 2 3 4 5 Miles

1 ½ 0 1 2 3 4 5 Kilometers

Contour interval 100 feet.
Datum is mean sea level.
Edition of Aug. 1903.

DIAGRAM OF TOWNSHIP

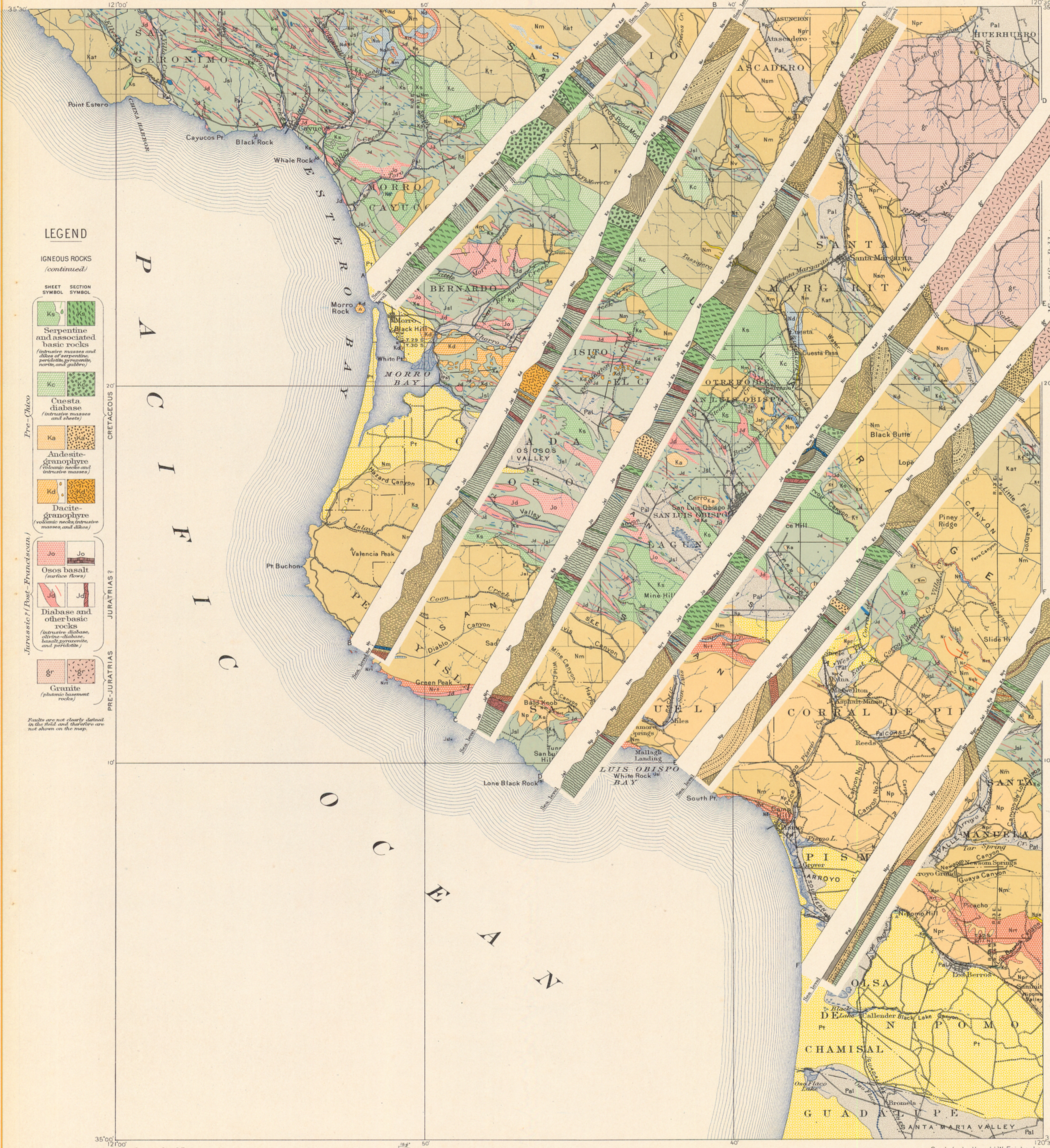
6	5	4	3	2	1
7	8	9	10	11	12
18	17	16	15	14	13
19	20	21	22	23	24
30	29	28	27	26	25
31	32	33	34	35	36

Geology by Harold W. Fairbanks.
Surveyed in 1897, 98, and 99.

U.S. GEOLOGICAL SURVEY
CHARLES D. WALCOTT
DIRECTOR

STRUCTURE SECTIONS

CALIFORNIA
(SAN LUIS OBISPO CO.)
SAN LUIS QUADRANGLE



LEGEND

SURFICIAL ROCKS

SHEET SYMBOL / SECTION SYMBOL

Recent — PLEISTOCENE

- Pal — Alluvium and stream gravel
- Pt — Terrace deposits and dune sand

SEDIMENTARY ROCKS

Pliocene

- Npr — Paso Robles formation (conglomerate and sandy and marly clays of fresh-water origin)

UNCONFORMITY

Miocene? (San Pablo)

- Np — Pismo formation (sandstone and cherty diatomaceous shale)
- Nsm — Santa Margarita formation (soft sandstone and conglomerate, with beds of diatomaceous earth and volcanic ash)

UNCONFORMITY

Miocene — NEOCENE

- Nm — Monterey shale (clay shale, limestone, and siliceous and bituminous diatomaceous shales)
- Nv — Vaquero sandstone (sandstone and conglomerate)

UNCONFORMITY

Chico — CRETACEOUS

- Kat — Atascadero formation (sandstone with some conglomerate and shale)

UNCONFORMITY

Knoxville

- Kt — Toro formation (dark shale and thin-bedded sandstone)

UNCONFORMITY

Jurassic? (Franciscan) — JURATRIAS?

- Jsl — San Luis formation (sandstone, conglomerate, shale, and contact-metamorphic quartzose schist)
- Jasper lentils in San Luis formation (variegated jasper and chert composed largely of radiolarian remains)

IGNEOUS ROCKS

SHEET SYMBOL / SECTION SYMBOL

Miocene (Pre-San Pablo) — NEOCENE

- Nt — Augite-teschenite (intrusive sheets and dikes)
- Nd — Olivine-diabase (dikes and sheets)
- Nqb, Nr — Quartz-basalt and rhyolite (dikes and sheets)
- Nrt — Rhyolite tuff (interstratified with the Monterey shale)
- Npa — Pyroxene andesite dikes

Legend is continued on the left margin.

Henry Gannett, Chief Topographer.
R.U. Goode, Geographer in charge.
Triangulation by U.S. Coast and Geodetic Survey.
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Surveyed in 1895.

APPROXIMATE MEAN DECLINATION 1902.

Scale $\frac{1}{125000}$

Miles / Kilometers

Edition of Jan. 1904.

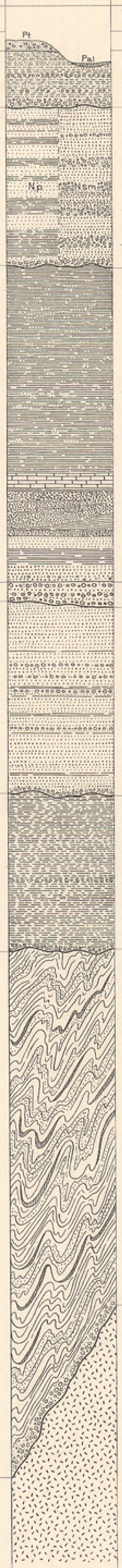
DIAGRAM OF TOWNSHIP

Geology by Harold W. Fairbanks.
Surveyed in 1897, 98, and 99.

COLUMNAR SECTION

COLUMNAR SECTION OF THE SEDIMENTARY ROCKS OF THE SAN LUIS QUADRANGLE.

SCALE: 1 INCH = 2000 FEET.



Period.		Formation Name.	Symbol.	Thickness in Feet.	Character of Rocks.
PLEISTOCENE		Alluvium and stream gravel.	Pal	1-100	Clay and gravel.
		Terrace deposits and dune sand.	Pt	10-400±	Sand and gravel.
NEOCENE	PLIOCENE?	Paso Robles formation.	Npr	1000+	Sandy and marly clay, with pebbly conglomerates; thick conglomerate at the bottom, formed of fragments of Monterey shale.
		UNCONFORMITY.			
	MIOCENE? (SAN PABLO)	Pismo formation (in the southern portion).	Np	3000±	Sandstone and conglomerate at the bottom, followed above by siliceous shale, diatomaceous earth, and thick beds of soft sandstone.
		Santa Margarita formation (in the northern portion).	Nsm	1500±	Alternations of conglomerates with soft sandstone, containing several strata of diatomaceous earth and pumice.
		UNCONFORMITY.			
	MIOCENE	Monterey shale.	Nm	5000-7000	Thinly stratified bituminous shale, largely siliceous, with diatomaceous earth in places. The shales are the source of the oil and asphaltum; sulphur springs also issue from them. Thin-bedded limestone. Volcanic ash of varying thickness, in places separated into thin beds by layers of shale. Sandstone at the bottom.
		Vaquero sandstone.	Nv	0-500	Sandstone and conglomerate.
		UNCONFORMITY.			
CRETACEOUS	CHICO	Atascadero formation.	Kat	3000-4000	Thick- and thin-bedded sandstone, with small amount of conglomerate and shale.
		UNCONFORMITY.			
	KNOXVILLE	Toro formation.	Kt	3000±	Dark, thin-bedded clay shale, with thin irregular layers of conglomerate at the bottom and near the middle.
		UNCONFORMITY.			
JURATRIAS?	JURASSIC? (FRANCISCAN)	San Luis formation.	Jsl	1000±	Usually an earthy sandstone, but in places there is a considerable thickness of dark shale, very similar to the Toro formation. Contains numerous radiolarian jasper lentils and some contact-metamorphic schist.
PRE-JURATRIAS		Granite.	gr		Biotite-granite with some quartz-monzonite, cut by dikes of aplite.

HAROLD W. FAIRBANKS,
Geologist.

FIG. 1.—QUATERNARY TERRACE DEPOSITS RESTING UNCONFORMABLY ON ERODED EDGES OF MONTEREY SHALE, ON THE COAST BETWEEN PISMO AND PORT HARFORD.

The contact is a wave-cut plain. Rain sculpture is well shown in the soft terrace gravels.

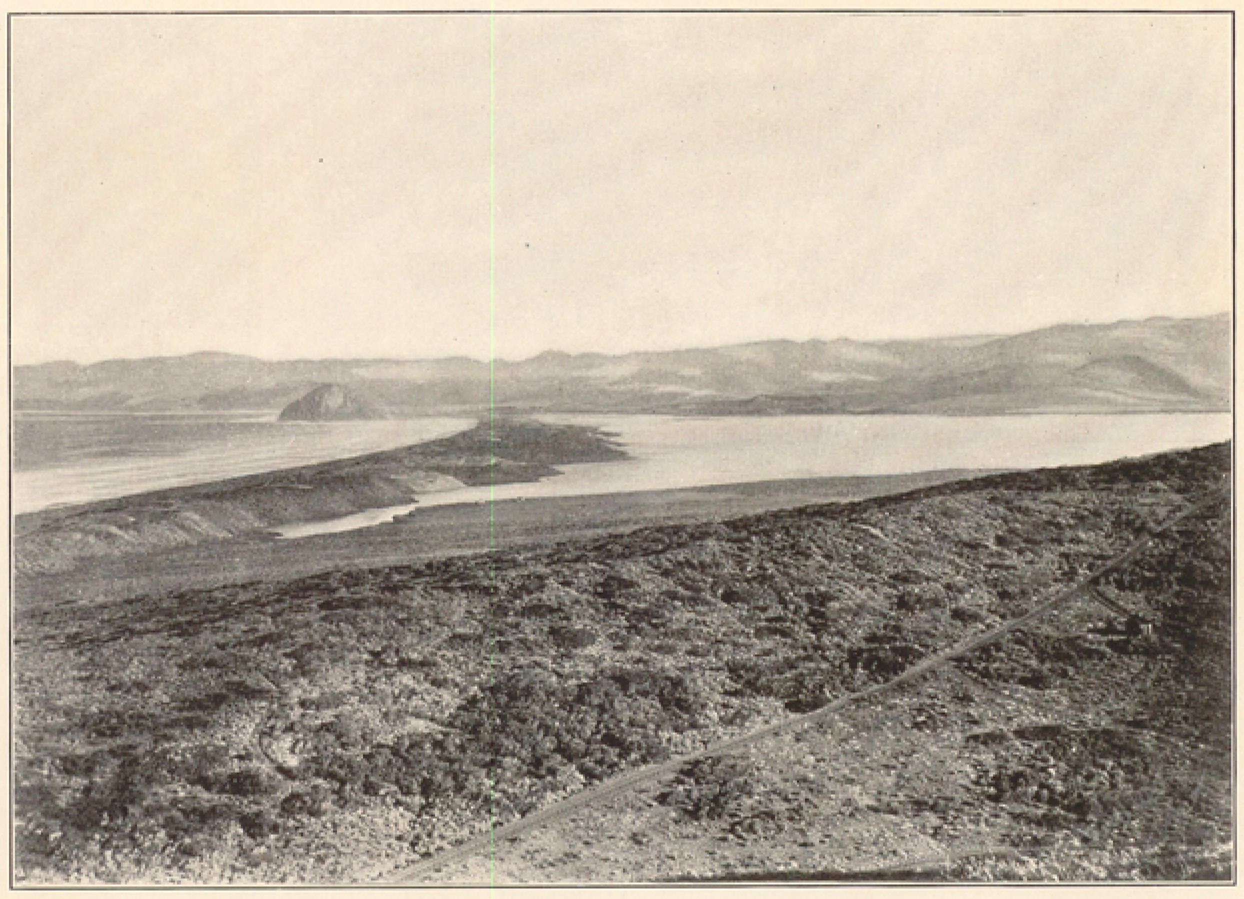


FIG. 2.—MORRO BAY FROM THE SOUTH.

The barrier beach between the bay and the ocean was formed during the last sinking of the land, and it has been made higher and broader by the formation of sand dunes. Morro Rock is shown beyond the northern end of the barrier.

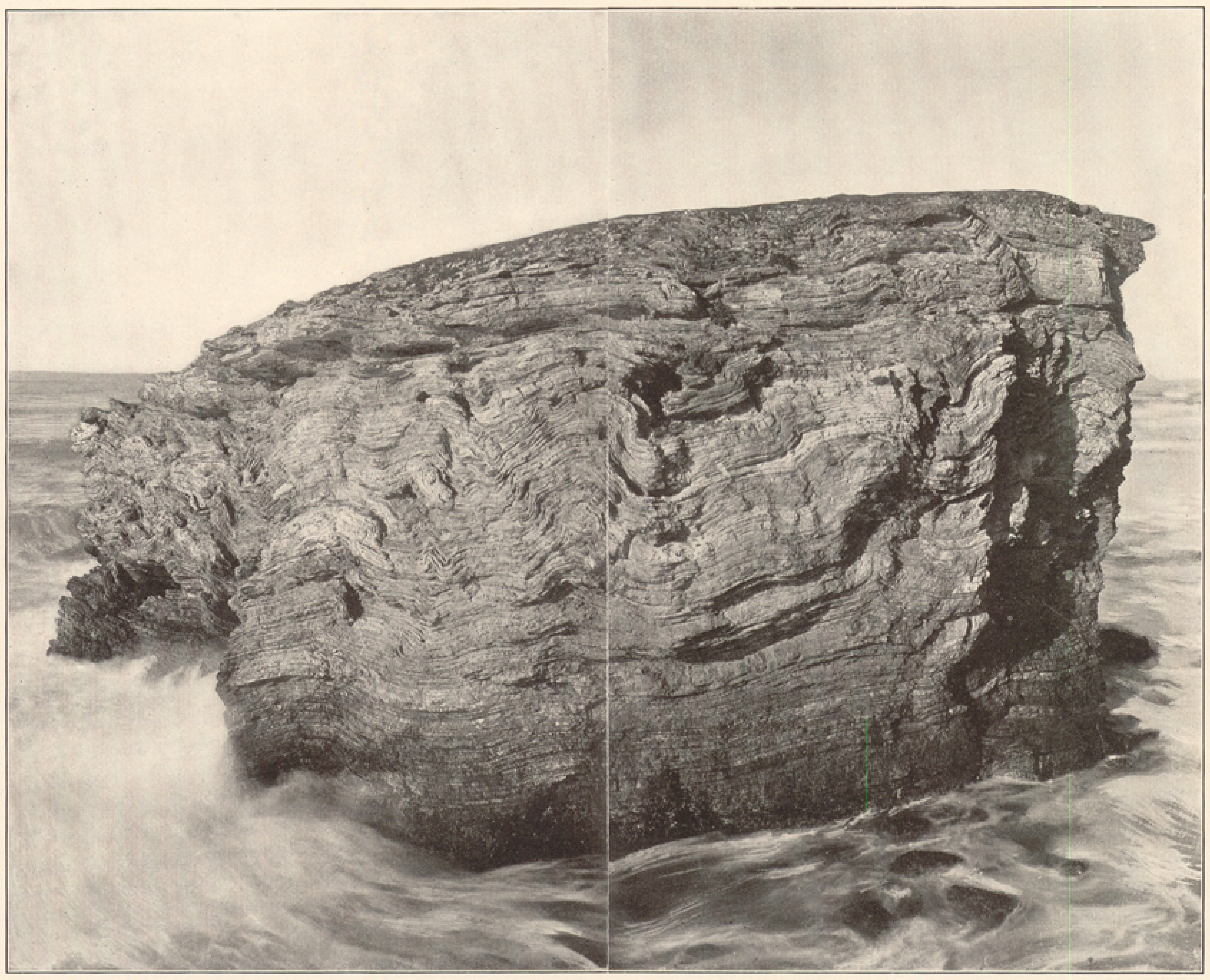


FIG. 3.—CONTORTED MONTEREY SHALE NEAR POINT BUCHON.

This isolated rock shows the characteristic crumpling to which the shale has been subjected in many places. The thin layers of hard shale are separated by partings of softer material, which has favored crumpling rather than crushing under pressure.

FIG. 4.—PROMINENT BUTTES NORTHWEST OF SAN LUIS OBISPO.

These are the southernmost of the chain of lofty buttes extending from San Luis Obispo to Morro Bay

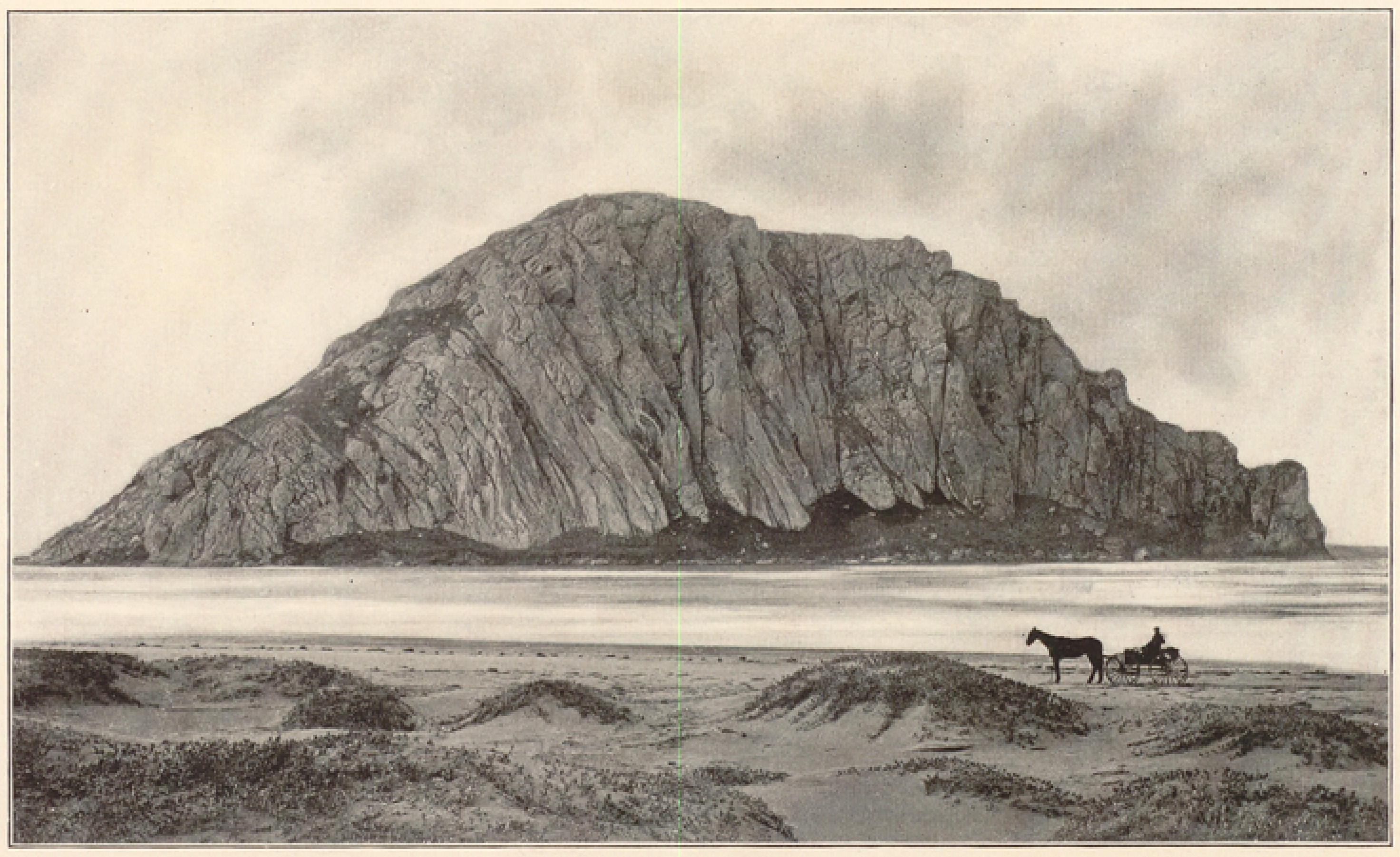


FIG. 5.—MORRO ROCK FROM THE EAST.

This is the northernmost of the chain of buttes extending to San Luis Obispo. The steep, rugged slopes are due to the resistant nature of the igneous rock of which the butte is composed.

Fig. 6.—OUTCROP OF A LENTICULAR BED OF JASPER ON THE COAST NORTH OF PORT HARFORD.

The iasper masses stand vertical and weather out in jagged points that rise above the flat surface of the Quaternary terrace gravels which partly bury them.

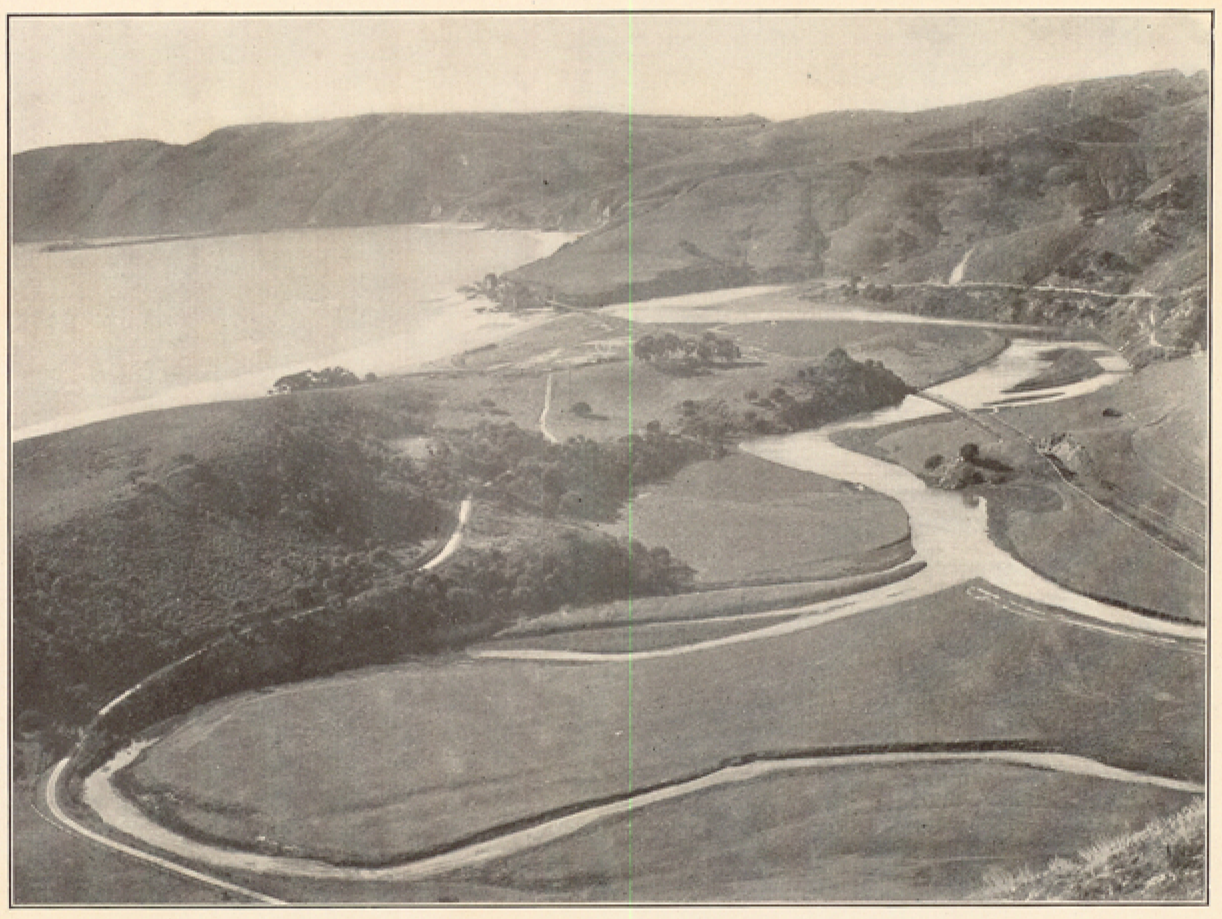


Fig. 7.—TIDAL LAGOON FORMED BY SAND SPIT AT MOUTH OF SAN LUIS OBISPO CREEK.

In the foreground is an ox-bow cut-off, and in the distance, beyond the wharf at Port Harford, is San Luis Hill, leveled off at a height of 700 feet by marine planation during the last great submergence of the coast.

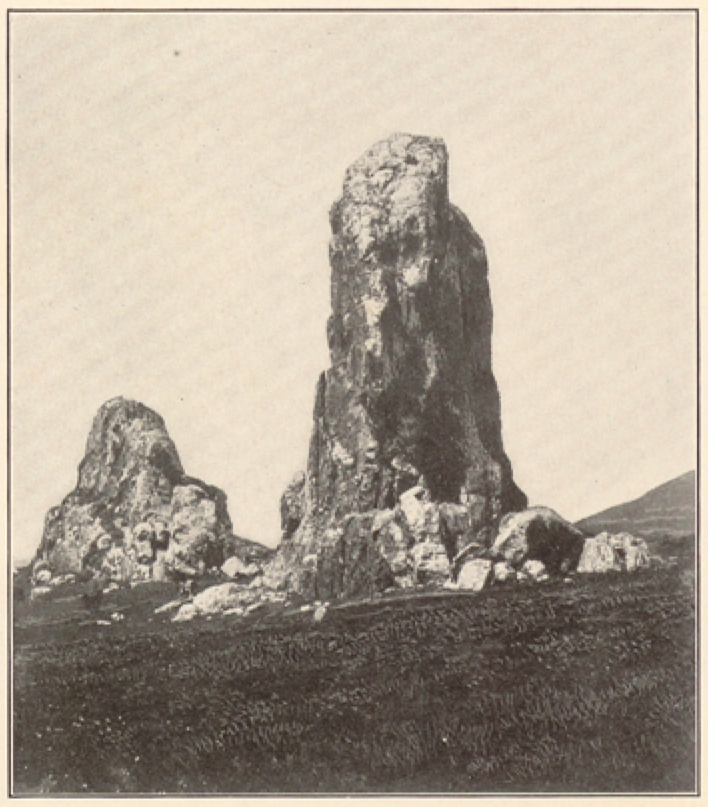


Fig. 8.—NEAR VIEW OF ONE OF THE LENTICULAR MASSES OF JASPER SHOWN IN FIG. 6.

Looking approximately along the strike.

Fig. 9.—NEAR VIEW OF A PORTION OF A TESCHENITE DIKE IN MONTEREY SHALE SOUTH OF POINT BUCHON.

The dike is vertical and shows columnar structure. The columns lie horizontal and are perpendicular to the walls of the dike. The altered analcite is arranged in bands parallel to the dike wall and weathers easily, causing the surface to appear ribbed at right angles to the columns.

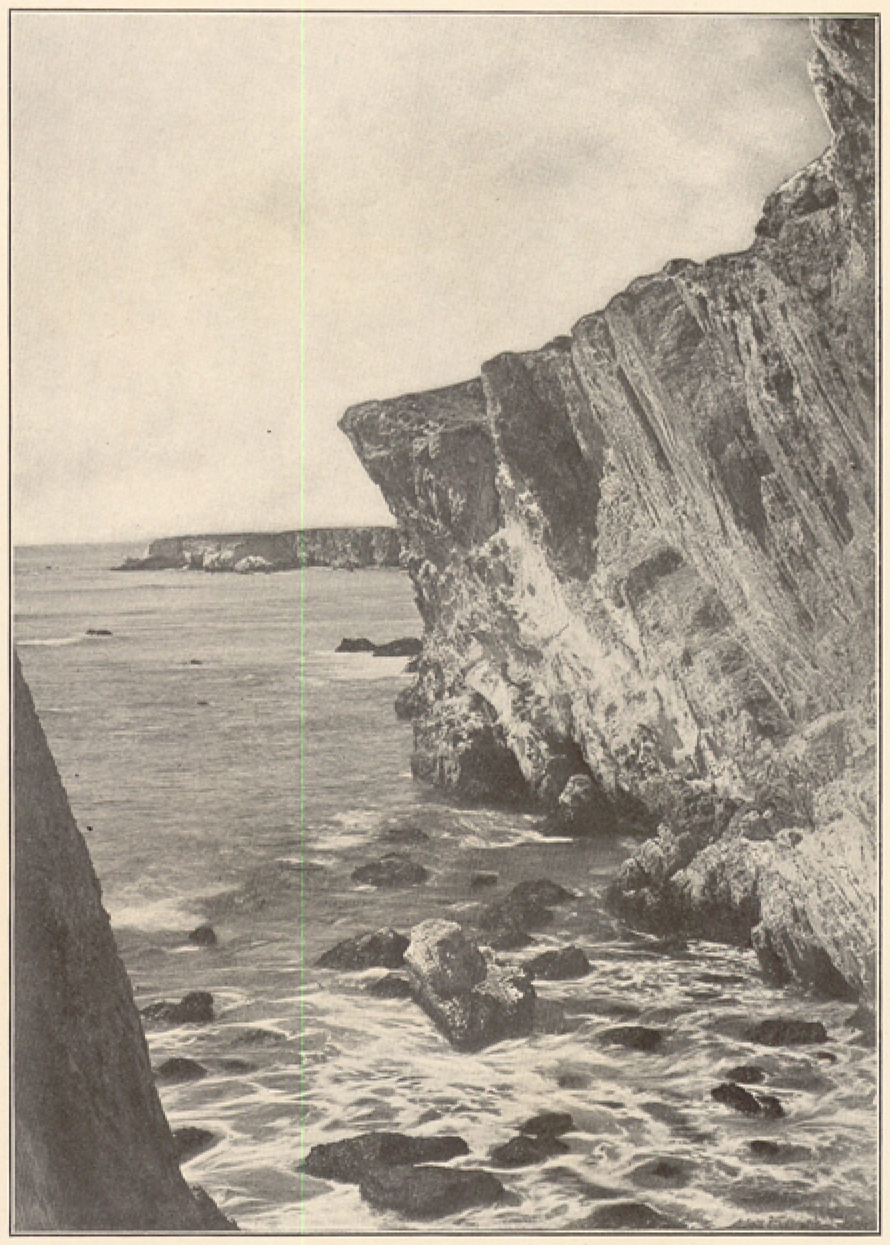


Fig. 10.—OVERHANGING CLIFFS ON THE COAST NEAR PISMO.

The character of the cliff is due to the attitude of the bedding. The rocks are the basal portion of the Monterey shale.

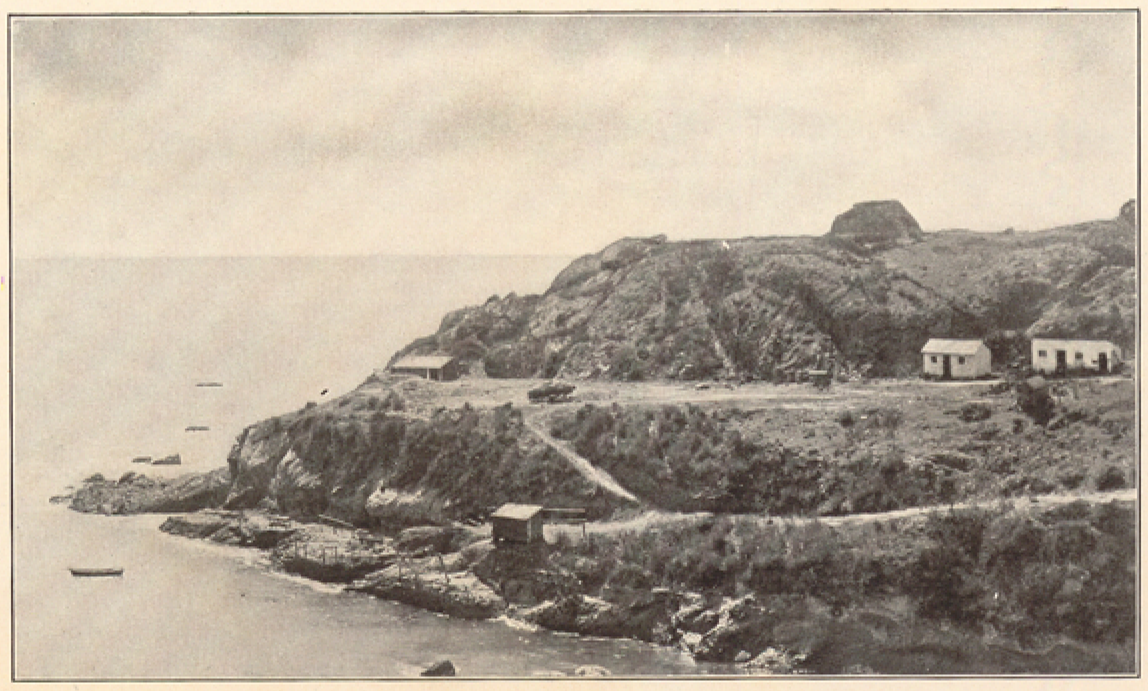


Fig. 11.—WAVE-CUT TERRACES AT MALLAGH LANDING.

The terraces are cut in the volcanic ash at the base of the Monterey shale. The upper bench is 100 feet above sea level; the middle one, 60 feet; and the lower one, 10 feet.

Fig. 12.—SEA CAVES NORTH OF MALLAGH LANDING.

The upper cave was cut out by the waves when the land stood 10 feet lower, with reference to sea level. The volcanic ash, in which it has been cut, is only slightly affected by atmospheric agencies, so that the waves undermine it. The lower cave is being formed by present wave action.

redeposited as beds or trains of sand and clay, thus forming another gradation into sedimentary deposits. Some of this glacial wash was deposited in tunnels and channels in the ice, and forms characteristic ridges and mounds of sand and gravel, known as osars, or eskers, and kames. The material deposited by the ice is called glacial drift; that washed from the ice onto the adjacent land is called modified drift. It is usual also to class as surficial rocks the deposits of the sea and of lakes and rivers that were made at the same time as the ice deposit.

AGES OF ROCKS.

Rocks are further distinguished according to their relative ages, for they were not formed all at one time, but from age to age in the earth's history. Classification by age is independent of origin; igneous, sedimentary, and surficial rocks may be of the same age.

When the predominant material of a rock mass is essentially the same, and it is bounded by rocks of different materials, it is convenient to call the mass throughout its extent a *formation*, and such a formation is the unit of geologic mapping.

Several formations considered together are designated a *system*. The time taken for the deposition of a formation is called an *epoch*, and the time taken for that of a system, or some larger fraction of a system, a *period*. The rocks are mapped by formations, and the formations are classified into systems. The rocks composing a system and the time taken for its deposition are given the same name, as, for instance, Cambrian system, Cambrian period.

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

Strata often contain the remains of plants and animals which lived in the sea or were washed from the land into lakes or seas or were buried in surficial deposits on the land. Rocks that contain the remains of life are called fossiliferous. By studying these remains, or fossils, it has been found that the species of each period of the earth's history have to a great extent differed from those 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 formations are remote one from the 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 rocks of different areas, provinces, and continents afford the most important means for combining local histories into a general earth history.

Colors and patterns.—To show the relative ages of strata, the history of the sedimentary rocks is divided into periods. The names of the periods in proper order (from new to old), with the colors and symbol assigned to each, are given in the table in the next column. The names of certain subdivisions and groups of the periods, frequently used in geologic writings, are bracketed against the appropriate period names.

To distinguish the sedimentary formations of any one period from those of another the patterns for the formations of each period are printed in the appropriate period-color, with the exception of the one at the top of the column (Pleistocene) and the one at the bottom (Archean). The sedimentary formations of any one period, excepting the Pleistocene and the Archean, are distinguished from one another by different patterns, made of parallel straight lines. Two tints of the period-color are used: a pale tint is printed evenly over the whole surface representing the period; a dark tint brings out the different patterns representing formations. Each formation is furthermore given

Period.			Symbol.	Color.
Cenozoic	Pleistocene		P	Any colors
	Neocene	Pliocene / Miocene	N	Buffs.
	Eocene, including Oligocene		E	Olive-browns.
Mesozoic	Cretaceous		K	Olive-greens.
	Juratrias	Jurassic / Triassic	J	Blue-greens.
Paleozoic	Carboniferous, including Permian		Ç	Blues.
	Devonian		D	Blue-purples.
	Silurian, including Ordovician		S	Red-purples.
	Cambrian		€	Pinks.
	Algonkian		A	Orange-browns.
	Archean		Æ	Any colors.

a letter-symbol composed of the period letter combined with small letters standing for the formation name. In the case of a sedimentary formation of uncertain age the pattern is printed on white ground in the color of the period to which the formation is supposed to belong, the letter-symbol of the period being omitted.

The number and extent of surficial formations, chiefly Pleistocene, render them so important that, to distinguish them from those of other periods and from the igneous rocks, patterns of dots and circles, printed in any colors, are used.

The origin of the Archean rocks is not fully settled. Many of them are certainly igneous. Whether sedimentary rocks are also included is not determined. The Archean rocks, and all metamorphic rocks of unknown origin, of whatever age, are represented on the maps by patterns consisting of short dashes irregularly placed. These are printed in any color, and may be darker or lighter than the background. If the rock is a schist the dashes or hachures may be arranged in wavy parallel lines. If the metamorphic rock is known to be of sedimentary origin the hachure patterns may be combined with the parallel-line patterns of sedimentary formations. If the rock is recognized as having been originally igneous, the hachures may be combined with the igneous pattern.

Known igneous formations are represented by patterns of triangles or rhombs printed in any brilliant color. If the formation is of known age the letter-symbol of the formation is preceded by the capital letter-symbol of the proper period. If the age of the formation is unknown the letter-symbol consists of small letters which suggest the name of the rocks.

THE VARIOUS GEOLOGIC SHEETS.

Areal geology sheet.—This sheet 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 particular colored pattern and its letter-symbol on the map 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 symbols and names are arranged, in columnar form, according to the origin of the formations—surficial, sedimentary, and igneous—and within each group they are placed in the order of age, so far as known, the youngest at the top.

Economic geology sheet.—This sheet represents the distribution of useful minerals, the occurrence of artesian water, or other facts of economic interest, showing their relations to the features of topography and to the geologic formations. All the formations which appear on the historical geology sheet are shown on this sheet 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 symbol for mines is introduced at each occurrence, accompanied by the name of the principal mineral mined or of the stone quarried.

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 name 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 the formation of rocks, and having traced out the relations among beds on the surface, he can infer their relative positions after they pass beneath the surface, draw sections which represent the structure of the earth to a considerable depth, and construct a diagram exhibiting 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:

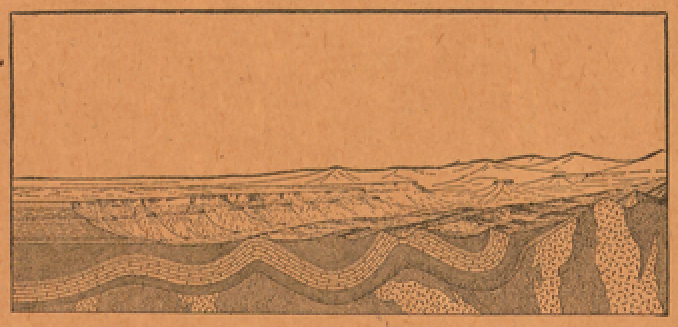


Fig. 2.—Sketch showing a vertical section in the front of the picture, with a landscape beyond.

The figure represents a landscape which is cut off sharply in the foreground by a vertical plane, so as to show the underground relations of the rocks.

The kinds of rock are indicated in the section 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:

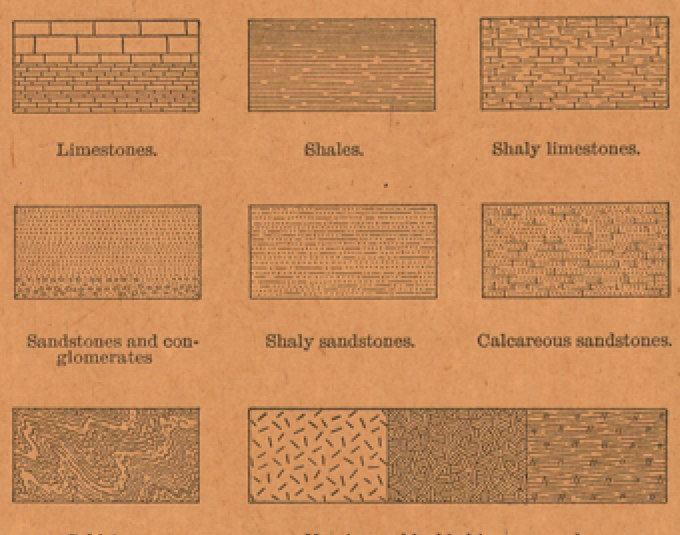


Fig. 3.—Symbols used to represent different kinds of rock.

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 beds of sandstone that rise to the surface. The upturned edges of these beds form the ridges, and the intermediate valleys follow the outcrops of limestone and calcareous shales.

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*.

When strata which are thus inclined are traced underground in mining, or by inference, it is frequently observed that they form troughs or arches, such as the section shows. 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 regarded as proof that forces exist which 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 slipped past one another. Such breaks are termed *faults*.

On the right of the sketch 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.

In fig. 2 there are three sets of formations, distinguished by their underground relations. The first of these, seen at the left of the section, is the 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 swelled upward 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 horizonal 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 strata thus rest upon an eroded surface of older strata 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 this pressure and intrusion of igneous rocks have not affected the overlying strata of the second set. Thus it is evident that an interval of considerable duration 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, marking a time interval between two periods of rock formation, is another unconformity.

The section and landscape in fig. 2 are ideal, but they illustrate relations which actually occur. The sections in the structure-section sheet are related to the maps as the section in the figure is related to the landscape. The profiles of the surface in the section correspond 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 rock formations which occur in the quadrangle. It presents a summary of the facts relating to the character of the rocks, the thicknesses of the formations, and the order of accumulation of successive deposits.

The rocks are described under the corresponding heading, and their characters are indicated in the columnar diagrams by appropriate symbols. The thicknesses of formations are given in figures which state the least and greatest measurements. The average thickness of each formation 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 is placed at the bottom of the column, the youngest at the top, and igneous rocks or surficial deposits, when present, are indicated in their proper relations.

The formations are combined into systems which correspond with the periods of geologic history. Thus the ages of the rocks are shown, and also the total thickness of each system.

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

CHARLES D. WALCOTT,
Director.

Revised January, 1902.

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41	Sonora	California	25
42	Nueces	Texas	25
43	Bidwell Bar	California	25
44	Tazewell	Virginia-West Virginia	25
45	Boise	Idaho	25
46	Richmond	Kentucky	25
47	London	Kentucky	25
48	Tenmile District Special	Colorado	25
49	Roseburg	Oregon	25
50	Holyoke	Mass.-Conn.	50
51	Big Trees	California	25
52	Absaroka	Wyoming	25
53	Standingstone	Tennessee	25

No.*	Name of folio.	State.	Price.†
			Cents.
54	Tacoma	Washington	25
55	Fort Benton	Montana	25
56	Little Belt Mountains	Montana	25
57	Telluride	Colorado	25
58	Elmoro	Colorado	25
59	Bristol	Virginia-Tennessee	25
60	La Plata	Colorado	25
61	Monterey	Virginia-West Virginia	25
62	Menominee Special	Michigan	25
63	Mother Lode District	California	50
64	Uvalde	Texas	25
65	Tintic Special	Utah	25
66	Colfax	California	25
67	Danville	Illinois-Indiana	25
68	Walsenburg	Colorado	25
69	Huntington	West Virginia-Ohio	25
70	Washington	D. C.-Va.-Md.	50
71	Spanish Peaks	Colorado	25
72	Charleston	West Virginia	25
73	Coos Bay	Oregon	25
74	Coalgate	Indian Territory	25
75	Maynardville	Tennessee	25
76	Austin	Texas	25
77	Raleigh	West Virginia	25
78	Rome	Georgia-Alabama	25
79	Atoka	Indian Territory	25
80	Norfolk	Virginia-North Carolina	25
81	Chicago	Illinois-Indiana	50
82	Masontown-Uniontown	Pennsylvania	25
83	New York City	New York-New Jersey	50
84	Ditney	Indiana	25
85	Oelrichs	South Dakota-Nebraska	25
86	Ellensburg	Washington	25
87	Camp Clarke	Nebraska	25
88	Scotts Bluff	Nebraska	25
89	Port Orford	Oregon	25
90	Cranberry	North Carolina-Tennessee	25
91	Hartville	Wyoming	25
92	Gaines	Pennsylvania-New York	25
93	Elkland-Tioga	Pennsylvania	25
94	Brownsville-Connellsville	Pennsylvania	25
95	Columbia	Tennessee	25
96	Olivet	South Dakota	25
97	Parker	South Dakota	25
98	Tishomingo	Indian Territory	25
99	Mitchell	South Dakota	25
100	Alexandria	South Dakota	25
101	San Luis	California	25
102	Indiana	Pennsylvania	25
103	Nampa	Idaho-Oregon	25
104	Silver City	Idaho	25
105	Patoka	Indiana-Illinois	25

* Order by number.
† Payment must be made by money order or in cash.
‡ These folios are out of stock.

Circulars showing the location of the area covered by any of the above folios, as well as information concerning topographic maps and other publications of the Geological Survey, may be had on application to the Director, United States Geological Survey, Washington, D. C.