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LOGIC ATLAS

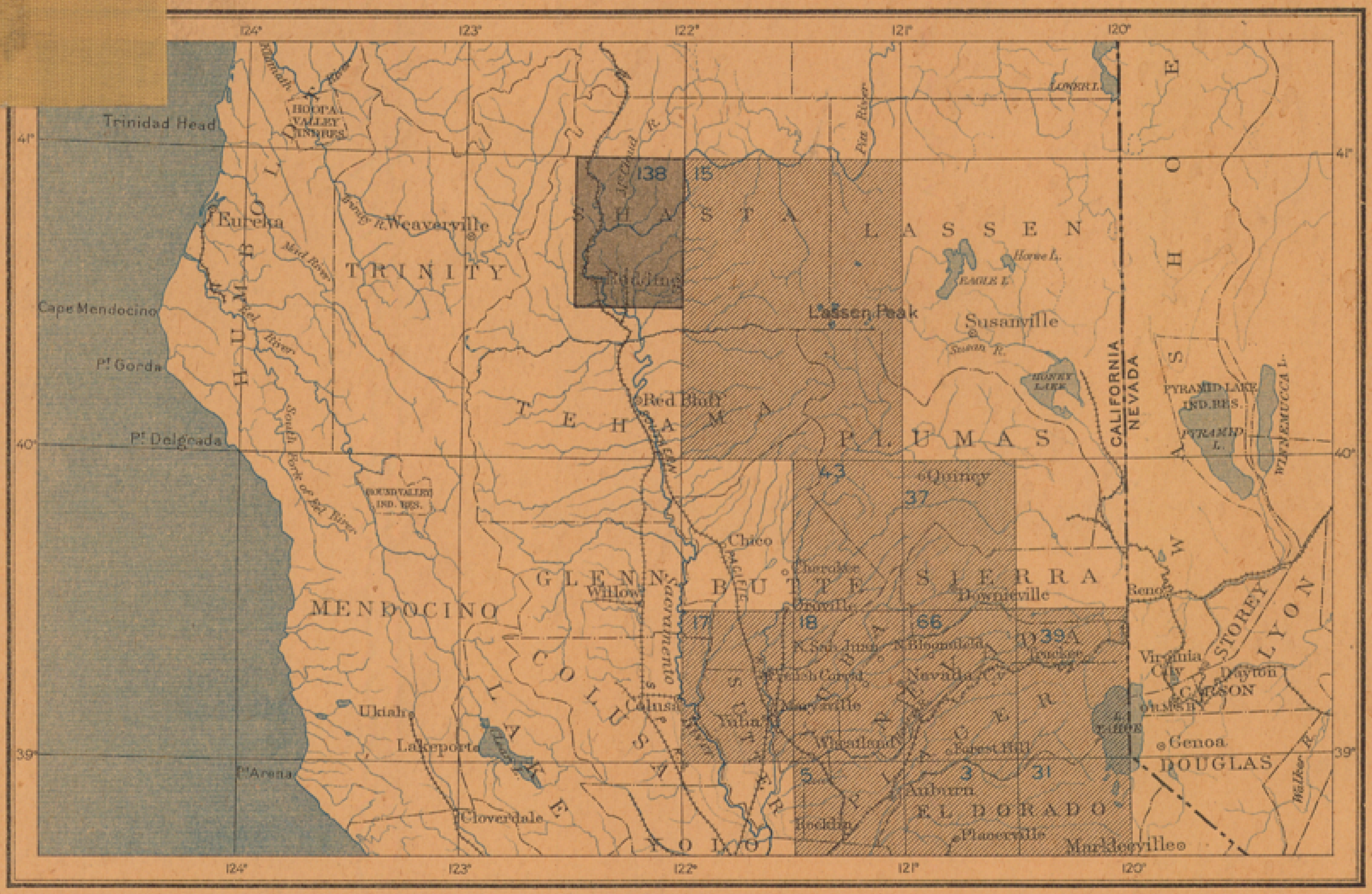
OF THE

UNITED STATES

REDDING FOLIO

CALIFORNIA

INDEX MAP



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DOCUMENTS

CONTENTS

DESCRIPTIVE TEXT
TOPOGRAPHIC MAP
COLUMNAR SECTION SHEET
AREAL GEOLOGY MAP
STRUCTURE-SECTION SHEET

WASHINGTON, D. C.

ENGRAVED AND PRINTED BY THE U. S. GEOLOGICAL SURVEY

GEORGE W. STOSE, EDITOR OF GEOLOGIC MAPS   S. J. KUBEL, CHIEF ENGRAVER

1906

GEOLOGIC AND TOPOGRAPHIC ATLAS OF UNITED STATES.

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

THE TOPOGRAPHIC MAP.

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

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

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

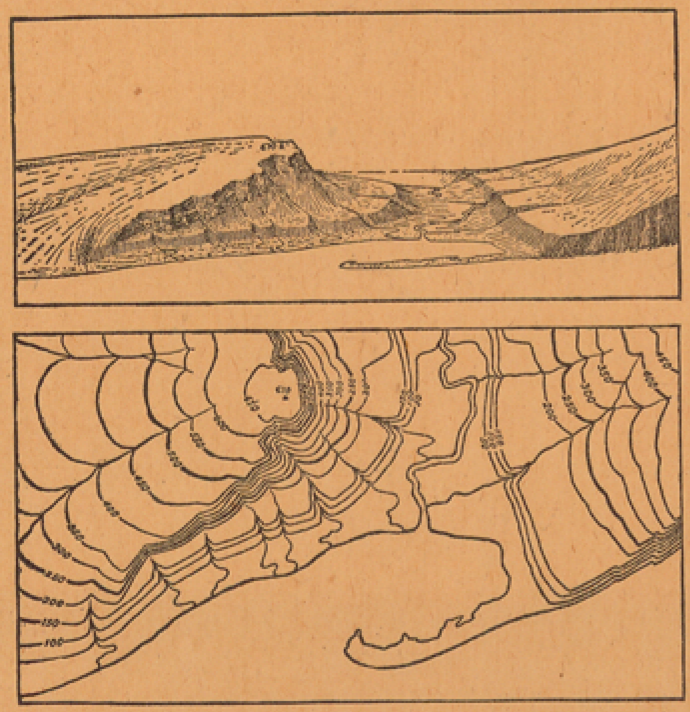


FIG. 1.—Ideal view and corresponding contour map.

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

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

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

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

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

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

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

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

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

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

The atlas sheets, being only parts of one map of the United States, disregard political boundary lines, such as those of States, counties, and townships. To each sheet, and to the quadrangle it represents, is given the name of some well-known town or natural feature within its limits, and at the sides and corners of each sheet the names of adjacent sheets, if published, are printed.

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

THE GEOLOGIC MAPS.

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

KINDS OF ROCKS.

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

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

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

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

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

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

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

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

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

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

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

FORMATIONS.

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

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

AGES OF ROCKS.

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

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

(Continued on third page of cover.)

DESCRIPTION OF THE REDDING QUADRANGLE.

By J. S. Diller.

INTRODUCTION.

Location and area.—The Redding quadrangle lies in the northern part of California and is bounded by meridians 122° and 122° 30′ west longitude and parallels 40° 30′ and 41° north latitude. It measures a little over 34 miles from north to south and nearly 27 miles from east to west, and contains about 905 square miles, a little less than one-fourth the area of Shasta County. It comprises the central portion of the county, embracing the north end of the Sacramento Valley, and Redding is its chief town.

Outline of the geography and geology of the region.—The broad mountain belt of the Pacific coast of the United States, approximately 150 miles in width, extending through northern California and Oregon, is naturally divided into three mountain ranges, the Coast, Cascade, and Sierra Nevada, and two valleys, the Sacramento Valley of California and the Sound or Willamette Valley of Oregon.

In California the Sacramento Valley separates the Coast Range from the Sierras. In northern Oregon the Willamette Valley separates the Coast and Cascade ranges, but in the northwestern part of California and the southwestern part of Oregon is an irregular group of mountains, the Klamath Mountains, in which all the ranges meet and form an irregular upland 200 miles in length between the heads of Sacramento and Willamette valleys. Each of these great topographic features may be regarded as outlining a geologic province. The Redding quadrangle embraces parts of three of these provinces—the north end of the Sacramento Valley, part of the Cascade Range, and part of the Klamath Mountains—and contains records more or less complete of the geologic history of all three provinces. The course of events in the development of each province is in strong contrast with that in the others. These events are briefly as follows:

The Sacramento Valley is a depression between the Sierra Nevada, Coast Range, and Klamath Mountains and has long been receiving the material washed down from the mountains. During the Cretaceous period it was still covered by the sea, and also in part during the Tertiary; but since that time it has been above sea level and drained by Sacramento River, whose floods have made the deposits which form the present surface of the valley.

The Cascade Range, which is represented in the Redding quadrangle by the western edge of the Lassen Peak volcanic ridge, is purely volcanic, consisting of intermingled lavas and tuffs piled up around the craters from which they were erupted. So many volcanic vents were active in the same belt that the volcanic cones which were built up about them coalesced and formed a prominent range, with a long, gentle slope coming down to the Sacramento Valley.

The Klamath Mountains are not the direct result of upbuilding, like the other two provinces, but are mainly the product of upheaval which raised above the sea a long succession of sedimentary and igneous rocks.

The Klamath Mountains contain the oldest rocks of the region, and in this respect are like the Sierra Nevada farther southeast. Large masses of limestone and other sedimentary rocks of Devonian and Carboniferous age occur, as well as some older crystalline schists. There is a small proportion of Triassic and Jurassic rocks, and the whole is covered here and there by remnants of a once continuous sheet of Cretaceous sandstones, shales, and conglomerates. At times while these rocks were forming, especially before the middle Devonian and during the latter part of the Carboniferous and the greater portion of the Mesozoic, volcanoes were active in the Klamath Mountain region, giving rise to extensive sheets of contemporaneous lava and tuff intermingled with the sedimentary rocks and covering them in many places. The whole body of sediments and lavas is penetrated by many dikes and masses of coarse granular plutonic rocks, such as granodiorite, gabbro, and serpentine. This complex of sedimentary and igneous rocks was uplifted, forming the Klamath Mountains, at the close of the Jurassic. Erosion and subsidence during the Cretaceous brought the Klamath Mountains down to sea level, but at the close of the Cretaceous they were again uplifted and with various later oscillations and consequent erosion have been carved to their present form.

Climate.—Separated from the Pacific by a prominent mountain range, the Redding quadrangle partakes somewhat of the arid climate of the interior, which, however, is partly ameliorated by mountains in the north and east. The climate of the quadrangle differs considerably in different parts. The range in temperature and rainfall in the Klamath Mountains is probably quite unlike that of the northern part of the Sacramento Valley, where the only available observations were made by the Weather Bureau. The mean annual temperature for twenty-two years previous to 1899 is 62.4°, ranging from an average of 45.2° in January to 81.9° in July. The highest temperature recorded was 114° and the lowest 18°. The average annual precipitation for the same time is 25.56 inches, almost the whole falling between October 1 and May 30. June to September inclusive are dry months, with only occasional small showers in the valleys, though they are more common in the mountains. According to observations at Red Bluff, the general movement of the air is from the mountains on the north and east into the valley. During the summer months, however, there is a well-marked northerly movement of the air, which is in part due to a strong westerly indraft through the Golden Gate and its subsequent deflection northward through the valley. Killing frost rarely occurs as late in the spring as March 30 or as early in the fall as November 7.

Vegetation.—Although the greater part of the Redding quadrangle is forested, most of it is but sparsely covered with small trees and scrub, and other portions, particularly large tracts of the gravel plains in the Sacramento Valley and the dry, stony plain of the Piedmont, are treeless but afford fine pasturage for much of the year. In the lowlands and the foothills of the Klamath Mountains several varieties of oak (chiefly *Quercus douglasii*) and the digger pine (*Pinus sabiniana*) are most common, with manzanita and live oak generally prevailing in the underbrush. About the higher summits pines increase and timber becomes more valuable, but none of it is lumbered except in the northwest corner of the quadrangle, at Lamoine, where there is a box factory.

Population and industries.—The Redding quadrangle, though covering less than one-fourth of Shasta County, includes its most populous portion. The county had a population in 1900 of 17,318; of this number 2946 lived in Redding, and it is probable that the whole quadrangle contains scarcely less than 12,000 inhabitants.

The principal industry is mining, and Redding is the outfitting and business center. Shasta County has long been noted for its gold, and lately copper and silver have become important. Agriculture, including fruit raising, is of much less importance, though with irrigation its relative value might be greatly increased. The fine pasturage afforded by the Sacramento Valley during the rainy season favors stock raising and wool growing, for the animals may be kept in the mountains during the summer; but this resource is limited. Wheat, which is raised chiefly for hay, stands first among the farm products, with barley next, and small amounts of corn, oats, and rye. The orchards yield prunes and peaches for shipment, with grapes, pears, almonds, figs, and a few apples for home consumption. The generation of electricity for light and power is a thriving industry. Fishing deserves mention, and the propagation of fish is of great importance. McCloud River, on account of its large supply of cool water, the temperature rarely rising as high as 60° even during the summer, has an abundance of salmon and trout. Of the latter there are two varieties, the rainbow and the Dolly Varden. The former has been hatched and distributed to many parts of the world. A station for hatching salmon was established at Baird, on the McCloud, in 1872 and has been in operation more or less actively ever since. The output of the station, amounting in some years to many millions of partially developed eggs, is largely distributed to other hatching stations of the State for final development. The run of salmon in the McCloud in 1903–4 was said to be the greatest ever known up to that time. Over 32,000,000 eggs were taken at the McCloud station in 1903 and more the year following.

TOPOGRAPHY.

RELIEF.

Attention has already been called to the fact that the Redding quadrangle embraces parts of three great topographic provinces, namely, the Sacramento Valley, the foothills of the Lassen Peak volcanic ridge (Cascade Range), and part of the Klamath Mountains.

SACRAMENTO VALLEY.

The north end of the Sacramento Valley, lying between the foothills of the Klamath Mountains on the west and north and those of the Lassen Peak volcanic ridge from Millville to Bellavista on the east, is characterized by a broad plain of gravel and sand, across which the river and its tributaries have cut valleys rarely as much as 100 feet in depth and ranging from one-fourth mile to 4 miles in width. The floors of these valleys are generally flat, being the flood plains of the adjacent streams, and are covered with fine alluvial soil which, when well watered, is excellent for agricultural purposes. The sand and gravel plain is well illustrated by the Stillwater and Millville plains, at an altitude of about 500 feet, gradually rising to the north. The alluvial valleys are represented along Cow Creek, Stillwater Creek, and the Sacramento below Redding. This sand and gravel plain, rising nearly 100 feet above the alluvial valleys, represents the ancient flood plains of the streams during the Redding epoch, before the streams had cut their present valleys. It is interesting to note that the plain, especially around the north end of the valley from Buckeye by Lilienthal to Calkins, extends beyond the limit of the sand and gravel that fill the Sacramento Valley, and that this extended border is cut into the hard rocks.

PIEDMONT PLAIN.

In the southeastern part of the quadrangle, drained by Cow Creek and its tributaries, is a series of low, flat ridges running northeast from the vicinity of Bellavista and Millville toward Crater and Magee peaks, which, like Lassen Peak, were once active volcanoes and belong to the Cascade Range. The broad, even crests of these ridges, separated by relatively narrow canyons in which the present streams flow, are evidently parts of a once continuous plain which gradually rises northeastward from an elevation of 500 feet on the gravel plain of the Sacramento Valley to nearly 5000 feet as it approaches the volcanic peaks of the range. As this plain belongs to the foothills of the mountains, it may be designated the Piedmont Plain to conveniently distinguish it from the plain of the Sacramento Valley proper. The Piedmont Plain is for the most part dry, sterile, and usually strewn with numerous lava fragments, making the roads across it extremely rough, in strong contrast with the sand and gravel plain of the Sacramento Valley. This arises from the fact that the Piedmont Plain is generally underlain by volcanic material in the form of lava flows or agglomerate tuff, and it is evident that in origin the Piedmont Plain is intimately related to the upbuilding of the Lassen Peak volcanic ridge. Backbone Ridge, north of Furnaceville, marks the northern limit of the Piedmont Plain, where it reaches the canyon of Pit River, but northwest of Sugarloaf it crosses the canyon and appears on the divide between Pit River and Squaw Creek. In this portion of its course Pit River marks approximately the boundary between the Piedmont Plain and the Klamath Mountains.

KLAMATH MOUNTAINS.

The divides.—The portion of the Klamath Mountains which lies within the Redding quadrangle occupies its northern two-thirds and embraces all the country not included in the Sacramento Valley proper and the Piedmont Plain. The hills and mountains are arranged chiefly in four ridges, running approximately north and south and forming the divides between the principal streams. Named from the east, these are the Brock Mountain divide, between the Great Bend of Pit River and Squaw Creek; Town Mountain divide, between Squaw Creek and the McCloud; Hirz Mountain divide, between the McCloud and the Little Sacramento; and the Clear Creek divide, lying west of the Little Sacramento.

The Brock Mountain divide is most regular in the southern part, where the ridge, attaining a height of 3000 feet, is formed of limestone. In a small way the limestone is extremely rough and jagged, owing to the peculiar fluting which results from weathering. Farther north igneous rocks become more abundant and in Bagley Mountain rise to a height of 4437 feet.

The Town Mountain divide is the most rugged mountain ridge of the quadrangle, having a succession of five prominent peaks over 4000 feet high within a distance of 12 miles. The high peaks are all composed of igneous rocks, arranged in sheets dipping eastward and presenting steeper slopes with a succession of small cliffs to the northwest. West of Town and Horse mountains is a lower but very prominent ridge of gray limestone, which farther south, beyond Pit River, appears in Gray Rocks. Bear Mountain, a short distance to the southeast, is capped by igneous material.

The Hirz Mountain divide widens and increases in height northward to 5355 feet in High Mountain, also called Nawtawakit Mountain, the highest point in the quadrangle, near the middle of its northern boundary. The divide is very irregular, but its crest keeps close to the McCloud, where the limestone and igneous rocks, though near the larger stream, resist erosion more effectively than the thin sandstones and shales on the side toward the Little Sacramento.

The top of the Clear Creek divide, which attains an altitude of over 5000 feet, lies just outside the Redding quadrangle, but the greater portion of its eastern slope, with several points rising to over 4000 feet near Sacramento and Little Sacramento rivers, is included within the boundaries.

Klamath peneplain.—About the level of the highest summits the slopes become gentler and the crests flattish, approximating a general plain. This suggests that before the deep valleys were carved by the present streams they were connected in a landscape of gentle relief, in which the hills were low and rounded and the valleys broad and shallow. In the Redding quadrangle this high plain of gentle relief is scarcely perceptible, owing to the later destructive erosion by the large streams; but in some other portions of the Klamath Mountains the plain is well developed and gives to the uplands of the region in which it occurs the character of a plateau. To facilitate reference to this feature it has been designated the Klamath peneplain (Bull. U. S. Geol. Survey No. 196, 1902, p. 15).

Earlier river valleys.—The Klamath Mountain valleys of the Redding quadrangle are in general narrow and canyon-like in their lower parts, with steep slopes, while the upper parts, involving the crests of the ridges, are much wider and are characterized by gentle slopes. These wide upper parts have been called for convenience the earlier valleys, to distinguish them from the canyon-like portion below, designated the later valleys.

One of the best preserved of the earlier valleys is that of Pit River. The flat divide south of this river and east of Sherman is the border of the Piedmont Plain. The lavas of the Lassen Peak volcanic ridge forced the Pit to the western border of the partially developed peneplain, and beyond Jones Valley the river cuts across a portion of the Klamath Mountains directly to the Sacramento. It is in this portion that the early valley, at an elevation of about 1500 feet, is well preserved and may be well seen looking westward through the valley from Sugarloaf, 2 miles northwest of Furnaceville. The level of the broad, shallow old valley of the Pit is scarcely 500 feet below the flat Backbone Ridge which divides it from Little Cow Creek, and is in very strong contrast with the narrow, deep, canyon-like valley containing the present river.

Traces of earlier valleys may be followed in the uplands along the McCloud and Little Sacramento, but for various reasons they are not so well marked as that of the Pit. This earlier-valley epoch is given great interest by the discovery of Potter Creek cave at the level of the earlier valley. The cave contained bones of forty species of animals, of which at least seventeen, including the mastodon, elephant, and tapir, are extinct. The character of the fauna in good part indicates low relief, and, as pointed out by Mr. Sinclair (Science, new ser., vol. 17, 1903, pp. 708–712), is quite out of harmony with the present topography of the region.

Later river valleys.—Later valleys in the Klamath Mountains occur along all the present streams, but their most striking development is found along the larger rivers, especially the Pit, McCloud, Little Sacramento, and Sacramento, where the canyon-like valleys are narrow and deep, with steep slopes to the water's edge, leaving little or no space for roads or cultivation.

In these later valleys, especially along the Sacramento, there are terraces which appear to mark intervals of stability, permitting the streams under favoring local conditions to widen the valley slightly. Their best development is in the vicinity of Keswick, where the terraces are capped by patches of gravel like that of the Sacramento Valley and represent an epoch when Sacramento River flowed at a level about 200 feet above its present bed, in a somewhat wider valley. Following the river farther north, we find remnants of the old valleys on the spurs from the east in the very sharp bends near the mouth of Sugarloaf Creek, and beyond this the terraces are capped by a sheet of lava which came from Mount Shasta. At Delta gravel of the old river bed is preserved beneath the lava.

In comparing the stream valleys of the Klamath Mountains with those of the Piedmont Plain and the Sacramento Valley it appears that in the Piedmont Plain only the later valleys are found, while in the Sacramento Valley proper only the very latest occur, corresponding to that below the Keswick terrace.

DRAINAGE.

The Little Sacramento rises in the lower mountains at the western base of Mount Shasta. About 30 miles from its source it enters the Redding quadrangle and with many meanders follows a direct general course across the western part of the quadrangle, receiving with the Pit and the McCloud the drainage of the entire area. Below the mouth of the Pit it is known as the Sacramento. It has no falls, but is full of rocky rapids until the Sacramento Valley is reached, a few miles above Redding. The following table shows the height of the water level of the river in July, 1900, at a number of points in the quadrangle, named from north to south, and gives an idea of its water power:

Elevation of water level of Sacramento and Little Sacramento rivers, July, 1900.

Locality.	Date.	Elevation.	Distance between stations.	Fall per mile.
		Feet.	*Mi.*	*Feet.*
Railroad bridge one-half mile south of Portuguese Flat	July 28	1277	......	......
Railroad bridge 1 mile south of Portuguese Flat	July 28	1263	½	28
Mouth of Slate Creek, near Slatonis	....	1222	1½	27+
Mouth of Little Dog Creek, one-half mile below Delta	....	1086	4	34
Railroad bridge 1 mile below Delta	July 27	1049	¾	49
Railroad bridge 2 miles below Delta	July 26	1033	1	16
Gregory (Baird Spur)	July 25	938	4	24
Railroad bridge 4 miles below Gregory	July 24	839	4	20
Railroad bridge near Elmore	July 24	737	5	24
Mouth of Pit River	July 20	639	5	20
Kennett bridge	July 20	624	2	8
Keswick bridge	July 20	511	12	9
Mouth of Middle Creek	July 20	495	2	8
Redding free bridge	July 4	456	6	6.5

The greatest fall, 49 feet per mile, is near Delta. The average fall per mile for 25¾ miles north of the mouth of Pit River is nearly 25 feet, and the average fall for 16 miles between the mouths of Pit River and Middle Creek is 9 feet. Below Middle Creek the rapids continue for a mile to the long stretches of still water which characterize the meandering stream in the Sacramento Valley, where the fall to tide water averages scarcely 2 feet to the mile.

Sacramento River is not navigable in the Redding quadrangle. It is comparatively shallow, with occasional riffles of gravel.

Pit River joins the Little Sacramento near the middle of the quadrangle, and just above the junction carries more than fifteen times as much water as does the Little Sacramento. Like the latter, it is without falls, but contains a succession of rapids from the Great Bend to its mouth, a distance of about 30 miles. Its water level in September, 1900, near the mouth of the McCloud was 688 feet, and at Bully Hill Bridge, 7 miles farther up, was 760 feet, giving the river an average fall of 11 feet to the mile for the last 11 miles of its course. Pit River rises in the vicinity of Goose Lake, nearly 100 miles east of the Redding quadrangle, but does not receive its most important tributaries until it reaches Fall River and Hat Creek, which are strong and regular streams from the perpetual snows of Mount Shasta and Lassen Peak, and which increase its flow to more than ten times its volume above the mouth of Fall River. The comparatively constant water supply during the summer makes Pit River an excellent logging stream, and it has been used for that purpose to transport wood and lumber for the mines and smelters at Bully Hill and Keswick.

McCloud River is the chief tributary of the Pit within the quadrangle. It rises at the southeastern base of Mount Shasta and has a length of over 40 miles, nearly half of which is in the Redding quadrangle. From the lavas at the base of Mount Shasta great springs coming from the snows about the summit gush forth in the McCloud Canyon, and give to the river a large and regular supply of water, with a surface temperature, as already stated, rarely as high as 60°, even in midsummer. The cool canyon of the McCloud, well supplied with fish and game, is a delightful summer resort, and much of the land has already been bought by San Francisco people for that purpose. Stream measurements (September 23, 1902) have shown that the river at Johns Camp and at the United States fishery contains 1272 and 1275 second-feet respectively, with a fall of about 21 feet to the mile. The McCloud is usually lowest in September, just before the rains begin. Mr. Livingston Stone, of the McCloud fishery, reports 9 feet of rain and a rise of the river to 26 feet above low-water mark February 2, 1881, when the fishery was washed away. Rises of 15, 16, and 20 feet are not uncommon. The height of the river varies from day to day, even in the dry season. The oscillations are related to the rate of melting of the Mud Creek Glacier on Mount Shasta, for within twelve to twenty hours after a particularly warm interval the McCloud rises at the fishery and is clouded with light-colored sediment like that coming from glaciers. McCloud River is a narrow, rushing stream between steep, wooded, rocky slopes and affords an especially attractive water power. Within the quadrangle the river falls nearly 450 feet in 21 miles, or at the average rate of 21 feet to the mile. The fall is not quite as great as that of the Little Sacramento, but as its volume is over four times as large, and regular, it is much more efficient. Recognizing the McCloud as an important water power, several companies are now preparing to utilize it in an electric plant.

DESCRIPTIVE GEOLOGY.

SEDIMENTARY ROCKS.

In the Redding quadrangle, besides a large number of igneous rocks, fifteen sedimentary formations have been recognized and outlined upon the areal geology map. Collectively they contain a more complete record of the geologic history of northern California than has yet been found in any other quadrangle.

DEVONIAN SYSTEM.

KENNETT FORMATION.

Lithologic character.—The Kennett formation (Jour. Geol., vol. 2, p. 591) is made up chiefly of black shales, often cherty, with some thin-bedded sandstones, inclosing in many places lenticular masses of gray, highly fossiliferous limestone. The thin gray sandstones occasionally contain a large amount of material derived from volcanic rocks.

One of the best sections of these rocks, though it certainly does not include the whole of the Kennett formation, may be seen on the left slope of Backbone Creek 3½ miles north of Kennett, where 865 feet of sediments are fully exposed in the following order, beginning at the top:

Partial section of Kennett formation on Backbone Creek north of Kennett.

	Feet.
1. Shales, mostly dark, with thin sandy beds	140
2. Massive, light-colored limestone with little chert, but full of corals	100
3. Thin-bedded sandstone and shales which are cherty and gray below. Near the middle part is a limestone lens 10 to 15 feet thick	300
4. Thin-bedded limestone, crowded with massive branching and cup corals. Cherty nodules and bands in bluish limestone, becoming whitish and without chert below	250
5. Siliceous shales, 10 feet of banded chert at top, succeeded by sandy shales, black shale, and fine shaly sandstone, very thin bedded	75

The sandstones of this section were not examined microscopically, but farther down Backbone Creek, where they are well exposed, the basal beds contain many grains and occasional small pebbles of microporphyritic igneous rocks, apparently identical with portions of the Copley metaandesite and Balaklala rhyolite. The cherts, wherever examined microscopically, were found to contain traces of radiolaria.

The limestone, which forms a much larger portion of the Kennett formation in this section than elsewhere, resists erosion much more effectively than the shales and thin sandstones about it, so that it forms prominent ledges which may be seen for miles; but as the lenses are of small extent they do not determine important topographic features.

Distribution.—The Kennett formation occurs in the western and southwestern parts of the quadrangle, where its distribution is in marked contrast with that of the other formations, being in isolated patches scattered sparsely over an irregular area 20 miles in length and 10 miles in greatest breadth.

The two divides to the southwest of Backbone Creek, on both sides of Little Backbone Creek, expose parts of essentially the same section as that given for the slope northeast of Backbone Creek. Above the Golinsky mine on Quarry Ridge the black shales beneath the limestone have a thickness of about 50 feet. They are somewhat siliceous and full of radiolarian remains, which produce minute spots visible with a hand lens. The shales are conformable with the limestone, the whole series generally striking about N. 60° E. and dipping 30° SE.

A large body of limestone occurs also in the divide between Little Backbone and Squaw creeks, along the trail from Kennett to the Mammoth mine, and several small masses partly or completely surrounded by metarhyolite crop out near the crest at an elevation of from 3800 to 4400 feet, in secs. 13, 18, and 19, nearly 6 miles northwest of Kennett. These isolated masses, as shown by their abundant fossils, were once directly connected not only with one another but with the larger masses of limestone and shale already referred to. The separation in most cases is clearly due to erosion, which has removed the intervening material, as will be shown later, to form the Bragdon.

The northernmost locality of the Kennett formation exposed in the Redding quadrangle is in the SE. ¼ sec. 33, T. 35 N., R. 5 W., on the slope north of Little Sugarloaf Creek. The area is small and the rocks are chiefly dark shales, in some places decidedly cherty, with radiolarian spots, and ferruginous sandstone rich in corals.

The Kennett formation of the Backbone region crosses the river a short distance above Morley, where near the water's edge the shales are rich in fossils. To the northeast they disappear for some distance, being covered up by the Bragdon formation, but reappear west of Baird; at this point the limestone ledges are few and smaller, and sandy shales and sandstones largely predominate. Considerable limestone occurs in sec. 16, near the head of Bailey Creek, on the east slope of O'Brien Mountain. Small masses crop out also in secs. 9 and 21. Farther south and southwest a mass of shales, containing a ledge of fossiliferous limestone, outcrops in the SE. ¼ sec. 17, near the Buckeye road. Similar ledges rich in fossils occur, surrounded by igneous rocks, in the southeastern part of sec. 25, about 3 miles west of Lilienthal. Slates with some limestone, formerly burned for lime, occur in sec. 6, east of Newtown, also west of Newtown on the road to Old Diggings. A larger belt of slaty shales stretches more or less continuously from near Waugh to Clear Creek, a mile below Horsetown, where several lenses of limestone occur.

The separate areas of Devonian sediments noted above, about a dozen in number, are all characterized by essentially the same fossils and are doubtless only remnants of a continuous sheet which once covered the whole area, but which has since been much deformed and reduced by erosion to its present fragmentary state.

Thickness.—Only the lower part of the Kennett formation is usually exposed. Its maximum preserved thickness is about 865 feet. To judge from the amount of Bragdon sediment derived from the Kennett, the latter may have lost much of its original thickness by erosion, but in some places its upper part is covered unconformably by the Bragdon.

Paleontologic character.—Fossils have been found in nearly all the areas of the Kennett formation, but they are most abundant and varied in the region north and west of Kennett, from which place they can be easily reached.

The fossils collected in the Kennett formation were referred to Prof. Charles Schuchert for study, and he has furnished the following report:

The section of the Backbone locality given by Mr. Diller has one general fauna indicative of the middle Devonian. The general age has been known for some years, but the collections of 1902 have given us a definite section and also species that are known to occur in other American localities. This is especially true of the fossils of the lower shale zone, which repeats the fauna of the Eureka and White Pine districts of Nevada and the middle Devonian of Iowa. The species that are common to at least two of these regions are *Schizophoria striatula*, *Stropheodonta canace*, *Gypidula lotis*, *Pugnax altus*, *Atrypa missouriensis*, and *Cyrtina missouriensis ?*.

Taking these species in connection with the corals of the limestones, as *Heliolites porosa*, *Endophyllum* or *Spongophyllum*, and *Phillipsastræa*, one sees plainly that the California middle Devonian belongs to the "Euro-Asiatic province." This province extends east in North America as far as central Missouri, eastern Iowa, Milwaukee, Wis., and Petoskey, Mich. East of these places occur the middle Devonian faunas of the "North American type."

Relation to volcanic rocks.—Everywhere within the Redding quadrangle the exposed Kennett formation is limited below by a mass of ancient volcanic rocks. This relation is most evident a few miles north and northwest of Kennett, where the Kennett formation lies on the crests of the divides, exposing the ancient lavas and tuffs beneath. These ancient volcanics, especially the tuffaceous ones, are arranged in more or less distinct sheets, and the Devonian sediments overlie them in places with approximate conformity. As the sediments are soft and fine the contact is not well exposed. Locally traces of shale breccia were found near the contact, suggesting faults. The presence of igneous material associated with chert in the Backbone Creek Devonian sandstones confirms the view that the volcanics are older than the Devonian sediments resting upon them. Generally, however, the sediments of the Kennett formation are so fine that they do not contain a conspicuous record of their source.

The Kennett formation is limited above by the unconformably overlapping Bragdon formation, whose sediments were derived chiefly from the erosion of the Kennett. In many places the Kennett was completely washed away and the Bragdon overlaps upon the older volcanics. These relations are well exposed along the border of the Bragdon, from the upper part of Backbone Creek across the Sacramento and around the northern shoulder of O'Brien Mountain to Bailey Creek, west of Baird.

CARBONIFEROUS SYSTEM.

MISSISSIPPIAN SERIES.

BRAGDON FORMATION.

Lithologic character.—The Bragdon formation, named by Mr. O. H. Hershey (Am. Geol., vol. 27, p. 238), is composed chiefly of thin-bedded, interstratified shale, sandstone, and conglomerate. The shale is dark, often black, in beds ranging from a few inches to 60 feet in thickness. The sandstone is generally less than 2 feet in thickness and rarely over 10 feet. It is for the most part gray and normal in composition, though sometimes dark, hard, and flinty, like some forms of quartzite, and in places decidedly tuffaceous.

The conglomerate constitutes the most characteristic portion of the formation. It is generally composed in large part of black and gray pebbles of cherty quartz with others of sandstone, shale, and limestone derived from the Kennett formation. The limestone pebbles disappear by weathering, leaving holes on the surface, which give to the conglomerate a peculiar porous aspect. The beds of conglomerate are usually less than 10 feet in thickness, but sometimes attain a maximum of nearly 50 feet. Quartz and chert pebbles prevail in the smaller and finer beds, and sometimes also in the larger beds, where the pebbles are not over an inch in diameter. As the beds become coarser pebbles of sandstone become most abundant, while those of limestone also generally increase in number and size. Conglomerate extends throughout the area of the Bragdon formation, but appears most abundantly along the Little Sacramento. Much of it along the river is fine, but some is coarse—with one exception much coarser than that found elsewhere. A short distance above Elmore, on the left bank of the river, some of the smooth, round cobbles of sandstone in a bed of conglomerate attain a maximum of 2 feet in diameter, though they are generally not over 6 inches.

Igneous material is rare or entirely wanting in many of the conglomerates, but in others it is abundant and appears to have been derived chiefly from the Copley metaandesite. Some of the sandstone beds are dark and closely resemble igneous rocks (Bass Mountain diabase), with which they are frequently associated in the field. These sandstones were observed at one point west of Little Sacramento River. They are most abundant east of the river and northeast of Delta, in the upper part of the Bragdon. They are composed of the same minerals, though in angular fragments, as the Bass Mountain diabase—chiefly plagioclase and augite. These sandstones in part possibly represent contemporaneous volcanic activity during the latter portion of the Bragdon.

Distribution.—The large area of Bragdon in the northwestern portion of the Redding quadrangle is part of a still larger, irregularly pear-shaped mass which extends from Trinity River northeast to the McCloud. Except the stem, the smaller end of the pear-shaped area lies within the Redding quadrangle and is trenched by the Little Sacramento from Portuguese Flat to Morley.

As compared with the Kennett formation in distribution, the Bragdon is remarkable for its continuity. It is interrupted at only two points—on Dog Creek by an area of volcanic rocks and on Little Sugarloaf Creek by a small mass of Devonian shales. There are several small outliers; one is a mile southeast of Bayha, and the other half a mile east of Morley.

Thickness.—Within the Redding quadrangle the broad area of the Bragdon formation is so affected by small folds that its thickness is difficult to determine, but farther north, on Hazel Creek, where the Bragdon occupies a definite belt between the Kennett and the Baird, it has been estimated at about 2900 feet, after making due allowance for folds and faults. It is possible, however, that the maximum thickness in the Redding quadrangle may be as much as 6000 feet.

Fossils and age.—Fossils have been found in the limestone pebbles of the Bragdon conglomerate and also in the sandstones and shales interstratified with the conglomerate; those in the pebbles are older than the Bragdon formation and belong to the formation from which the pebbles were derived, while those of the sandstones and shales mark the age of the Bragdon. Since the age of this formation has been a matter of discussion, the evidence bearing on that subject requires fuller treatment than it would otherwise receive.

Fossils collected from pebbles in the conglomerate at a large number of localities throughout the Bragdon area were referred to Professor Schuchert and Dr. Girty, and all of them so far as determinable, with one possible but doubtful exception found on Bailey Creek, were reported as Devonian, like those already known in the Kennett region, and show clearly that the conglomerate is later than the middle Devonian.

In the sandstones and shales fossils were found at half a dozen localities. An important occurrence is upon the divide southwest of Nawtawakit or High Mountain, where the sandstones, conformably interbedded with characteristic Bragdon conglomerate, contain shells which Dr. Girty reports as "Paleozoic and without much doubt early Carboniferous, related to the Baird." The fossils, among which is a large "*Spirifer* of the *striatus* type," occur in several beds well exposed and are undoubtedly of the Bragdon horizon.

Perhaps the most important locality is beside the railroad 1½ miles northeast of Lamoine, where fossils were found in the sandstone adjoining the Bragdon conglomerate. From this locality Dr. Girty reports *Schizodus* sp., *Loxonema* sp., *Pleurotomaria ?* sp., and *Straparollus* aff. *S. luxus*. There is no room for doubt that these fossils belong to the Bragdon and are not derived from an older formation, and Dr. Girty remarks that if this be admitted "no other conclusion is possible than that the Bragdon is a Paleozoic formation. Indeed, it is fairly safe to say that the horizon is not later than Baird, for the local faunas have many points of resemblance with that of the Baird and none at all with those of the overlying Carboniferous formations."

This matter is more fully discussed in the American Journal of Science, vol. 19, 1905, p. 386.

Relation to adjacent formations.—The inference drawn from the fossils that the Bragdon is of Carboniferous age and lies between the Baird and the Kennett formations is confirmed by its stratigraphic position in the section from O'Brien Mountain to McCloud River. On the McCloud near the fishery the Baird is well exposed, and on the slope of O'Brien Mountain the Kennett limestone outcrops. Between them on Bailey Creek is the Bragdon, dipping eastward beneath the Baird. From this point the two adjoining formations can be traced northward for many miles in essentially the same relation. They are conformable and represent continuous sedimentation. The boundary between them is marked by the upper limit of the characteristic Bragdon conglomerate.

The Bragdon rests upon the Kennett formation and is made up largely of sediments derived from the Kennett. It is evident that the two formations are unconformable and that the Kennett had been greatly eroded before the Bragdon was deposited upon it. In fact, the erosion was so great that the Devonian sediments were in some places completely washed away, allowing the Bragdon sediments to be deposited directly upon the pre-Kennett (probably pre-Devonian) volcanic rocks. The residual character of the Devonian areas between the ancient volcanics and the Bragdon is well illustrated along the border of the latter from Bailey Creek to the head of Backbone Creek.

BAIRD FORMATION.

Lithologic character.—The formation next succeeding the Bragdon is of great thickness and consists chiefly of tuffaceous rocks, above which there are siliceous and calcareous shales and sandstones, more or less tuffaceous and usually rich in fossils. The Baird, as originally named by Prof. J. P. Smith, included only the fossiliferous upper portion. It is here extended downward to include the tuffaceous rocks and the adjoining sandstones and shales which overlie the topmost Bragdon conglomerate.

Tuffs.—In the Baird formation, beneath the highly fossiliferous portion at the top, is a mass of tuff ranging from a few score to 500 feet in thickness and usually of strong colors, red or yellow to white, in contrast with their associated fragmental rocks. Northwest of Baird, on the road from the fishery toward Radcliffe's, tuffs are well exposed for about three-fourths of a mile. They are soft and friable, and locally they are bedded and distinctly fragmental. A few smooth, round pebbles, one of banded chert, and another larger one of rhyolite, were found inclosed in the fine tuff. With these exceptions the coarsest material seen here is sandstone thickly peppered with small white grains of kaolin, among which stand out grains of quartz and reddish andesite.

The exceptional aspect of these rocks suggests at once that they are tuffs, and there can be no doubt that they are composed chiefly if not wholly of volcanic material. Many of the fragments are lapilli, and the others are broken crystals of feldspar and quartz, with a trace of deep-brown hornblende and flecks of chlorite representing some decomposed ferromagnesian silicate; but definite traces of pumiceous or glassy fragments could not be found.

A mile farther northeast, on a prominent spur running from the limestone to the left bank of McCloud River, rhyolitic and andesitic sandstones contain Baird fossils, and along the river nearly opposite the mouth of Greens Creek beds rich in fossils contain also distinct particles of volcanic material, chiefly of andesitic types.

One of the best examples of fine tuffaceous conglomerates in the Baird formation outcrops near the McCloud on the unfinished road to Middle Salt Creek. It is made up wholly of volcanic material, some of it andesitic and crowded with feldspar microlites, but most of it rhyolitic. Some fragments are devitrified, showing traces of the original perlitic cracks; others contain anhedral quartz embedded in a mosaic of quartz and feldspar. It lies not far beneath the McCloud limestone and is permeated by carbonate of lime.

The prominent horizon of tuffs of wide extent in the Baird indicates contemporaneous volcanic activity, though no definite flows of lava were found associated with the tuff.

Fossiliferous sediments above the tuffs.—The siliceous and calcareous shales and sandstones at the top of the formation, to which the term Baird was first applied, are largely tuffaceous also. They are well exposed on the right bank of McCloud River a short distance above the Baird fishery, and farther north at least as far as Campbell's. Locally the limy and cherty shales and hard sandstones are nearly free from igneous matter, but generally it prevails even where fossils are abundant, so that there is no striking contrast between the upper and lower portions of the Baird as here defined, and no paleontologic break, for Baird forms go down into the Bragdon.

Distribution.—From the fishery the Baird formation extends northward in a narrow belt up McCloud River for a dozen miles and then passes into the high hills west of the river. On the east it is limited generally by augite-diorite, which sends many dikes through the Baird into the Bragdon, which limits the Baird on the west.

Southward from the fishery the distribution of the Baird is less regular. In the vicinity of Pit River the metaandesite, augite-diorite, and granodiorite cut it off, but it appears again south of Gray Rocks and as a narrow belt extends along the western border of the McCloud limestone to the Sacramento Valley.

Thickness.—The total thickness of the Baird formation is not easily determined, on account of the irregular limits of the exposures, due to intrusives, but it is certainly 650 feet and possibly much more. The tuffs at the base are approximately 500 feet thick, and the overlying fossiliferous beds about 150 feet.

Fauna and age.—The fauna of the formation was listed in 1894 by Prof. J. P. Smith (Jour. Geol., vol. 2, pp. 595-597), who calls it the Baird, and remarks: "In a paleontological sense the Baird shales are homotaxial with the Waverly, while stratigraphically they probably are not, but would agree more nearly in position with the higher divisions of the Lower Carboniferous of the Mississippi Valley." It is "equivalent to the Lower Carboniferous of the Eureka district, Nevada."

Relation to adjacent formations.—The Baird is conformable with the Bragdon below, as well as with the McCloud limestone above. The line between Baird and Bragdon, as already explained, is determined by the topmost horizon of the peculiar Bragdon conglomerate, and there was continuous sedimentation from one to the other, with but slight change in the character of the sediment.

South of the Black Diamond mine the Baird is well exposed, lying in conformable contact beneath the McCloud limestone; but from the same mine northward the Baird is separated from the McCloud limestone by an irregular belt of augite-diorite intruded between them and breaking them into many pieces.

PENNSYLVANIAN SERIES.

M'CLOUD LIMESTONE.

History.—The McCloud limestone lies stratigraphically next above the Baird formation, though generally separated from it by intruded augite-diorite. It was early noted by Trask (Rept. on Geology of Coast Mountains, 1855), who collected fossils near Bass's ranch, Stillwater, and first determined its age. The Geological Survey of California (Geol. of California, vol. 1, pp. 326-327), under Prof. J. D. Whitney, visited the same locality and added much new information, but more notable data as to its distribution and fauna have been contributed in later years by Messrs. H. W. Fairbanks (Ann. Rept. Cal. State Mining Bureau, vol. 11, p. 35 and map of Shasta County; Am. Geol., vol. 14, p. 28) and J. P. Smith (Jour. Geol., vol. 2, p. 599).

Lithologic character.—The limestone is dark gray and massive below and lighter colored and somewhat thinner bedded above, with many nodules and sheets of gray chert, often containing silicified fossils.

The largest and most accessible exposures of the McCloud limestone are at Gray Rocks, near Bayha, the old Bass's ranch locality, and farther north on McCloud River opposite the United States fishery. The two localities are separated by quartz-augite-diorite, which cuts the limestone.

Topography.—The McCloud limestone generally resists weathering more effectively than the associated quartz-augite-diorites, so that it usually gives rise to bold outcrops and, where large, becomes one of the principal factors in the topography, forming prominent ridges and peaks.

Caves.—The massiveness of the McCloud limestone and its purity under certain conditions of internal drainage have afforded the opportunity for the development of large caverns. One of these near Potter Creek, a mile southeast of the fishery, and another opposite Johns Camp, 7 miles farther up the McCloud, have been found by Dr. J. C. Merriam and his assistants to contain deposits inclosing numerous bones of Pleistocene animals; these will be noticed more fully in connection with the origin of the earlier river valleys.

Distribution.—The limestone can be traced more or less continuously for 25 miles from the north end of the Sacramento Valley near Lilienthal northward to Nawtawakit Mountain, where it passes beyond the quadrangle boundary. Near Lilienthal it begins with a series of small limestone lenses, apparently included in Dekkas andesite and worn down to the level of the valley plain. Although much metamorphosed and in some places wholly crystalline, they contain distinct traces of fossils definitely fixing their age. Farther north they rise above the plain and form hills increasing in prominence to Gray Rocks. For 10 miles beyond Pit River the escarpment of McCloud limestone forms one of the principal topographic features, but it is very much cut up by quartz-augite-diorite into irregular patches of limestone separated from one another by distances varying from a few feet to over 2 miles. How much of this irregularity may be due to the original lenticular character of the limestone is not known, but there can be no doubt that it is mostly due to the dissecting igneous rock. The largest mass is that opposite the fishery. Two other large masses occur in the Hirz Mountain region, but farther north, in the western portion of Nawtawakit Mountain, there is a considerable decrease in size.

Thickness.—In thickness the McCloud limestone varies from 200 feet or less near the south end, where it appears in small lenses, to approximately 2000 feet in the prominent rugged mountain formed by it a short distance northeast of the fishery.

Age.—The fossil fauna of the McCloud limestone was long ago made known by Mr. F. B. Meek in vol. 1 of the Paleontology of California, and in reviewing it Prof. J. P. Smith, who collected extensively in the field, says that the McCloud limestone is "in part equivalent to the Coal Measures."

Relation to adjacent formations.—Throughout the greater part of its extent in the Redding quadrangle the McCloud limestone is bounded both east and west by quartz-augite-diorite, but for over 2 miles south of the Black Diamond mine it lies conformably between the Baird and the Nosoni formations.

NOSONI FORMATION.

Lithologic character.—Next above the McCloud limestone is a formation composed very largely of andesite or basalt tuffs and tuffaceous conglomerate and a few flows of lava, but locally interstratified with these volcanic products are shales and sandstones, in part calcareous, and often rich in fossils. The formation is well exposed on Nosoni Creek, hence the name Nosoni formation. It includes the "McCloud shales" of Smith and Fairbanks, as well as the pyroclastic rocks with which these shales are so intimately associated.

Pyroclastic rocks.—The greater portion of the Nosoni is made up of fragmental volcanic rocks, but it includes also a small number of contemporaneous flows. All belong to essentially the same type of lava, near the dividing line between the augite-andesites and the basalts, but on account of the prevalence of intersertal structure and the occurrence of olivine the lavas are regarded as mainly basalts.

The rocks are dark and compact, with uneven fracture. In most cases they are holocrystalline, decidedly microporphyritic, and made up chiefly of plagioclase, with much augite, less magnetite, and occasional olivine or iddingsite. The tabular phenocrysts of labradorite are inclosed in a groundmass having intersertal structure modified by fluidal movement, giving the lath-shaped crystals of labradorite a parallel or stream-like arrangement, with the granular augite and oxides of iron between them. Augite occurs sparingly among the phenocrysts, but olivine or iddingsite is more common, though neither appears in the groundmass and both are sometimes entirely absent.

Where hypocrystalline the feldspars are less developed in a general matrix of unindividualized material, deeply stained by oxide of iron. It is rarely amygdaloidal, with amygdules of chlorite and calcite. Most of the lava is altered and chlorite with calcite becomes abundant.

The fragmental material is in rare cases coarsely agglomeratic. Conglomerate tuffs with pebbles a few inches in diameter are common, but the most abundant form has lapilli not over half an inch in greatest dimension. The fragments are rarely holocrystalline. Some are hyalopilitic, looking more like lapilli from andesitic than from basaltic eruptions. They become more abundant to the south. Fine tuffs are rare. None were found containing remnants or pseudomorphs after pumice or glass particles. Near the base of the Nosoni opposite Horse Mountain, adjoining the McCloud limestone, are gray calcareous shales and thin sandstones containing many of the characteristic long, slender *Fusulina*. Overlying these shales is a bed of tuff succeeded by a greater thickness of small-bedded, somewhat tuffaceous sandstone, which is capped by a lens of limestone about 30 feet in thickness. Farther up the ridge are purplish shales and tuffs with characteristic fossils, and the whole assemblage of Nosoni strata is overlain by the mass of andesites forming the summit of Horse Mountain.

Distribution.—The Nosoni forms a north and south belt lying next east of the McCloud limestone and extends from the northern border of the Sacramento Valley to beyond the boundary of the quadrangle. The belt widens to the north. In the vicinity of Pit River the Nosoni formation is cut off by the intruded quartz-augite-diorite, but beyond that point it begins again with a considerable amount of andesitic or basaltic tuff.

Northwest of Town Mountain the Nosoni is again cut off by the quartz-augite-diorite, which includes masses of the McCloud limestone, but the formation reappears beyond Dekkas Creek, where andesitic tuffs and conglomerates begin to form its greater portion and continue to increase in bulk rapidly in that direction. In the northern portion of the field the tuffaceous beds lie for the most part below the fossiliferous shales and sandstones, though small masses of such strata are occasionally found interbedded with the tuffs. A good example of this kind occurs on the southeastern slope of Nawtawakit Mountain at an elevation of about 2000 feet.

Thickness.—Opposite the fishery, on the western slope of Horse Mountain, the Nosoni formation is well exposed, with a total thickness of over 500 feet from the McCloud limestone below to the andesites of Horse Mountain above. Farther north, however, there are greater accumulations of volcanic material, and the thickness increases to a maximum of about 1200 feet on the eastern slope of Nawtawakit Mountain.

Fossils and age.—Fossils are common and sometimes abundant in the shales and more or less tuffaceous sandstones, and among them one of the most useful in the field for recognizing the horizon is a long, slender *Fusulina*. *Productus*, too, is occasionally abundant.

This fossiliferous horizon was discovered by Mr. H. W. Fairbanks and first described by Prof. J. P. Smith (Jour. Geol., vol. 2, p. 602), whose conclusion was that the strata here called Nosoni "are the probable equivalents of the Robinson beds of the Taylorsville region and of the Little Grizzly Creek beds of Plumas County, which seem to form the top of the Carboniferous formation."

Relation to adjacent formations.—The Nosoni conformably overlies the McCloud limestone opposite Horse Mountain and farther south, but to the north the accumulation of so great a mass of pyroclastic rocks beneath the main horizon of fossils suggests an unconformity. However, the occurrence near the bottom of the pyroclastics of small lenses of shale bearing essentially the same fossils as those above and the close affinity of the fauna with that of the McCloud limestone strengthen the evidence in favor of conformity.

The general dip of the Nosoni formation is to the east, and there is no doubt that it is overlain, most likely with unconformity, by the great mass of andesitic rocks forming Horse, Town, Minnesota, and Salt Creek mountains. The volcanic rocks are nearly or quite alike, and the only guide in drawing the line has been the occurrence of fossils characteristic of the Nosoni formation. No characteristic fossils have been found in this great body of volcanic rocks next above the Nosoni, but in the strata overlying the volcanics characteristic Triassic forms occur, and they are so different as to suggest a decided break somewhere between the Nosoni and the Pit formations.

TRIASSIC SYSTEM.

PIT FORMATION.

Lithologic character.—The Pit formation (the Pit shales of J. P. Smith: Jour. Geol., vol. 2, p. 502) is composed largely of dark and gray shales, thin-bedded sandstones, and many layers of tuffs. It lies beneath the Hosselkus limestone on the east and upon the andesites and rhyolites of the volcanic belt on the west. The shales are black to gray, and weather whitish. Under the microscope they usually show many round spots, which occasionally contain distinct remains of minute marine organisms, probably in most cases radiolaria. In some places the shales are highly siliceous, well bedded, and of a greenish gray color.

Tuffs.—The tuffs are usually of fine angular sand ejected from active volcanoes and in the field closely resemble interbedded sheets of altered andesitic or rhyolitic lava. Occasionally they are coarse, more distinctly fragmental, and locally silicified.

One of the best sections for studying the interbedded shales and tuffs of the Pit formation is on the spur from Brock Mountain to Squaw Creek, along the line between Tps. 34 and 35 N. There are within about a mile, from the limestone crest to the creek, at least a dozen beds of tuff, ranging from 5 to 20 or more feet in thickness, between the more abundant dark shales. Some of the tuff beds can be traced along the strike north and south for a mile or more and dip to the east conformably with the shales. The tuffs are generally dark gray, with occasional quartz grains, and closely resemble some forms of rhyolite-porphyry; but a thin section shows that the whole is made up of angular fragments of quartz, altered feldspar, some ferromagnesian minerals, magnetite, and lapilli. An occasional curved form like splinters of glass is found altered to quartz. These beds sometimes contain lapilli which are distinct to the naked eye, but frequently they do not appear in the field to be fragmental rocks. The sharp, angular character of the grains of igneous minerals, with the associated volcanic particles, shows that the material is practically a volcanic sand.

On the new road from Squaw Creek to the limestone quarry at the south end of Brock Mountain the tuffs are large and vary more in the size of the particles, but the bulk is of fine material. Higher up Squaw Creek and on the slopes of Winnibulli Mountain they are somewhat coarser. They represent contemporaneous volcanic activity, but flows of rhyolite have not generally been found associated with them. Their source appears to be to the southeast, where rhyolitic rocks of the same age occur.

Physiographic expression.—The physiographic expression of the Pit formation is complex. In general its shales and thin sandstones are much softer than the adjacent formations east and west, and they have determined the course of Squaw Creek and its valley; but the valley is hilly and irregular owing to the local occurrence of hard beds of tuff or intruded sheets or dikes of rhyolite which resist erosion much more effectively than the surrounding shales, and some of the hills, as for example Winnibulli, approach in size those on the sides of the valley.

Distribution.—The Pit formation enters the northern part of the quadrangle from the northeast in Mewittipom Mountain, at the head of North Fork of Squaw Creek, where the upper part of the formation is well exposed. Seventy-five feet of gray shaly slates, in part calcareous, immediately underlie the Hosselkus limestone, and beneath the shale there is much imperfectly bedded tuff, including small patches of gray, greenish, or brownish, rarely banded radiolarian chert. The shales, like the limestone, strike N. 80° E. and dip 56° SE., but just beyond the northern border of the quadrangle the strike is turned much more to the east by the Grizzly arch, whose axis runs in that direction. In the western portion of Mewittipom Mountain, at the head of Chatterdowen Creek, the tuff and sandstone dip southwest beneath a syncline in which the Pit formation turns southward across the Redding quadrangle. On the steep slopes of Mewittipom a great thickness of the reddish Pit shales and tuffs is well exposed. The lower half of the formation was examined on the divide between the forks of Chatterdowen Creek, where greenish siliceous sandstone with conchoidal fracture is underlain by black and reddish fossiliferous shales of great thickness that rest upon the andesites and tuffs of the Town Mountain belt of volcanics.

Extending southward the belt of the Pit formation spreads out, at first slowly, but near Pit River more rapidly, until along that stream it has a width of at least 12 miles. This widening of the belt is due to folding, which brings down the Pit formation in Jones Valley and causes it to extend westward beyond Bear Mountain. To the south it disappears beneath the Cretaceous of the Sacramento Valley.

Thickness.—The total thickness of the Pit formation has not been accurately measured, but careful estimates in the field indicate that it is probably somewhat over 2000 feet.

Fossils and age.—Fossils are uncommon in the greater part of the formation, and yet traces may be found at many places. They are usually ammonites, but rarely so preserved that even their generic determination is possible. At the top of the formation, however, there are several hundred feet of shales and tuffs in which fossils are more abundant and have been referred by Prof. J. P. Smith to the upper Triassic, though it is possible that the less fossiliferous and larger portion below may belong to the middle Triassic.

Relation to adjacent formations.—The relation of the Pit formation to those which are next earlier and later is in the one case complex, but in the other sharp and definite. Everywhere the Pit formation rests upon volcanic rocks, either andesites or rhyolites, or upon their associated tuffs, and it is evident that these volcanic rocks, which form the prominent hills from Horse Mountain to Salt Creek Mountain inclusive, are older than the Pit formation and lie conformably beneath it; but the volcanic activity which gave rise to this great mass of lavas continued at intervals throughout the deposition of the Pit formation, giving rise within it to interbedded flows, intruded sheets, and dikes, as well as to numerous beds of tuff. For this reason the relation of the Pit formation to the associated igneous rocks appears complex. On the other hand, the Pit formation at many points may be seen to lie conformably beneath the Hosselkus limestone.

HOSSELKUS LIMESTONE.

Lithologic character.—The Hosselkus limestone, named from a locality in Genesee Valley, Plumas County, Cal., where a limestone of the same fauna occurs (Bull. Geol. Soc. America, vol. 3, pp. 369–412), conformably overlies the Pit formation. It is best exposed in Brock Mountain, of which it forms the entire summit.

Prof. J. P. Smith (Jour. Geol., vol. 2, p. 606) has thoroughly studied this limestone in the Brock Mountain region, and considers it in three divisions, each characterized by numerous fossils and lithologic features. The lowest division, the Trachyceras beds, about 50 feet in thickness, consists of rather hard, pure limestone, thin bedded, dark bluish, and with abundant fossils. Next above come the Atractites beds, about 100 feet in thickness. They are hard and siliceous, and while fossils are very numerous it is almost impossible to get out good specimens. Finally, the Spiriferina beds include the upper 50 feet of hard, siliceous, somewhat more massive limestone, in which *Spiriferina* is the most common fossil. These subdivisions are not sharply marked. In general the limestone is much thinner bedded and darker than the McCloud limestone, with which it might otherwise be confused. Small ammonites are the most noticeable fossils of the Hosselkus limestone, while cup corals characterize the McCloud limestone.

Distribution.—As already indicated, the main mass of the Hosselkus limestone is exposed in Brock Mountain, where by a gentle fold its outcrop belt is widened to 2 miles. Along the strike the outcrop is continuous for 7 miles. To the north, beyond Brock Mountain, a small lens of Hosselkus limestone appears on North Fork of Squaw Creek, and a mile beyond it a larger mass in which deformation has widened the belt. Another small lens appears in sec. 19, T. 36 N., R. 2 W., and still another beyond the limits of the quadrangle, in sec. 1, T. 36 N., R. 3 W., where it forms a narrow syncline, rising to the northwest and marking the point where the strata are turned eastward by the Grizzly arch. On the southern slope of Mewittipom Mountain the Hosselkus limestone appears again in several exposures with sharp curves. At the point where it crosses the northern border of the quadrangle the lower portion has abundant small ammonites, while the upper part is very irregularly cherty and siliceous, with many brecciated patches. Southeast of Brock

Mountain, a short distance beyond Pit River, the limestone disappears, except for one or two small lenses, for 5 miles; it reappears on Cedar Creek in large masses, nearly 3 miles in length, which form occasional prominent cliffs by the stage road between Furnaceville and Round Mountain. An interesting feature here is that the limestone is, in part, at least, overturned and rests upon later formations. On the spur southwest of the mouth of Cedar Creek two limestones occur, one 60 feet and the other approximately 100 feet thick, separated by 150 feet of dark shales. The whole set of beds dips to the southwest and is evidently overturned. It is possible that the limestone has been repeated by faulting, but this seems improbable, for the two have largely different faunas. In the upper one, exposed at Eilers, corals are more abundant than in the lower.

The Brock Mountain belt of the Hosselkus limestone, which has just been traced across the northeast portion of the Redding quadrangle from Mewittipom Mountain through Brock Mountain to Cedar Creek, is remarkable for its eastward curvature at both ends—a feature of structural significance.

Twelve miles southwest of the Brock Mountain belt, about Bear Mountain, there are isolated outcrops of the Hosselkus limestone of so great importance structurally that they are considered by themselves. The principal exposure is on the northwestern slope of Bear Mountain, near the center of sec. 12, T. 33 N., R. 4 W., where a dark-gray fossiliferous limestone, locally 50 feet in thickness, occurs with a dip of 52° E. beneath the mountain. This limestone horizon lies between the shales and thin-bedded sandstones which form the base of the mountain and the tuffaceous sandstone and conglomerate which form its upper part, and can be traced at intervals all around the mountain, dipping into it in such a way as to indicate the existence of a shallow syncline with the axis of the fold nearly north and south. An outcropping mass of the limestone 50 feet thick occurs on the southwestern slope, and another of nearly the same thickness on the northwestern slope. It is overlain in part by a thin body of shales which are capped by conglomerates composed largely of igneous material. The limestone, especially on the southwestern slope, is much broken and looks like limestone conglomerate. The top is irregular and is covered by a thin shale. The basal portion of the overlying tuffaceous conglomerate contains numerous fragments of the fossiliferous limestone beneath. Around the north end of Bear Mountain, where ledges of limestone were not seen, its former presence is indicated by numerous limestone fragments in the conglomerate. The limestone is well characterized as Hosselkus by numerous fossils, among which are bones of large reptiles common to the limestone of Brock Mountain (Merriam, J. C., Bull. Geol. Dept. Univ. Cal., vol. 3, pp. 63–108).

Thickness and lenticular character.—The lenticular character of the Hosselkus limestone is evident from its areal distribution. The largest lentil, that of Brock Mountain, has a thickness of 200 feet. The next largest is that of Cedar Creek, which is about 160 feet thick. To the north and west the thickness decreases. On the east end of Mewittipom Mountain it is not over 75 feet, and the lentils about Bear Mountain scarcely reach 50 feet.

The lack of continuity in the outcrop of the Hosselkus limestone is certainly not due to intruded igneous rocks, for it is bordered on both sides by shales which apparently continue, more or less unbroken, between the outcrops of limestone. Nor does its lenticular character appear to be due to displacement by which the intervening portions were removed, for the remnants are really lenticular in shape, thinning to an edge regularly parallel to the bedding, as if due to limitations in the conditions of deposition.

Fossils, age, and relation to adjacent formations.—The Hosselkus limestone is especially remarkable for its fossil cephalopods and reptiles. The former are being investigated by Prof. J. P. Smith, of Stanford University, and the latter by Prof. J. C. Merriam, of the State University at Berkeley, Cal. The age of the former is upper Triassic, and it lies with apparent conformity between the Pit formation and the Brock shale.

BROCK SHALE.

Name and character.—The Brock shale conformably overlies the Hosselkus limestone in Brock Mountain, whence the name, and has a thickness of about 400 feet. In the lower 300 feet or more adjoining the limestone the shales are dark, somewhat calcareous, and frequently contain *Halobia*. Above these come sandy shales, gray and reddish in color and characterized locally by *Pseudomonotis subcircularis*.

Distribution.—The Brock shale is well exposed in Pit River, with *Pseudomonotis* rather common in the synclinal ridge running north into the limestone of Brock Mountain. The same shale can be traced as a narrow, probably continuous belt northwestward across the quadrangle. *Pseudomonotis* was not found at as many points as *Halobia*, but since it is rarely as abundant as *Halobia* this is not surprising. Near the northern limit of the quadrangle, on the slope of Mewittipom Mountain, the shale is well characterized by its fossils and has its full thickness overlain by tuffaceous conglomerate containing calcareous fragments. The Brock shale is also exposed on Cedar Creek, but owing to an overturn it here apparently underlies the Hosselkus limestone. A thin sheet of Brock shale may be present on Bear Mountain, but it was not identified by fossils.

Relations and age.—There is no doubt concerning the conformability of the Brock shale and the Hosselkus limestone, but the relation of the shale to the overlying Modin formation has not been definitely determined. It seems probable, however, that the two formations are unconformable.

The age of the Brock shale is certainly Triassic. Concerning the fossils from this shale Dr. Stanton reports as follows:

> The shales immediately overlying the Hosselkus limestone contain two fossiliferous horizons—a lower one, extending up 300 or 400 feet, which has yielded only a *Halobia*, very closely related to the one that occurs in the limestone and below it, and an *Atractites*, while the higher horizon is locally filled with *Pseudomonotis subcircularis* Gabb. Wherever the *Halobia* and the *Pseudomonotis* were found in the same section they were always found in separate beds, with the same stratigraphic relationship to each other and to the limestone.

JURASSIC SYSTEM.

MODIN FORMATION.

Lithologic character and name.—The Modin formation is an extensive succession of tuffaceous beds, overlain by a greater mass of compact, fine gray shaly sandstones and shales, with a few small lenses of limestone. It is named from Modin Creek, near the mouth of which, in the northeastern part of the quadrangle, the formation has yielded most of its fossils.

Tuffaceous bed.—At the base of the Modin formation is an extensive bed of volcanic conglomerate that possibly marks a definite horizon of volcanic activity, though no certain flows of lava were discovered at that level, unless it be in the north end of Bear Mountain. The source of the material was not found. The fragments in the tuff are mainly andesitic, with a dense groundmass of feldspar microlites. There are a few phenocrysts of augite and more of altered plagioclase. The degree of crystallization in the groundmass is generally lower than that of the earlier volcanic rocks. The fragments are generally angular to subangular, but some appear to be waterworn. They are rarely as large as a foot in diameter. Coarse and fine are intermingled without assortment, as if pyroclastic. The most remarkable feature of the conglomerate is found in the fragments or nodules of limestone which it contains.

One of the best exposures of this conglomerate is in Bear Mountain, where it overlies the Hosselkus limestone and crops out all around the mountain, of which it forms the entire tabular summit. The fossils in the fragments of limestone contained in the conglomerate are, at least in part, the same as those of the Hosselkus limestone, so that the source of the fragments in this case seems evident. The material with which they are associated is volcanic, and it appears as if the limestone fragments were dislodged by volcanic action, a view which would account for their irregular and unexpected distribution.

A much larger complete section of the Modin formation, affording excellent exposures of the tuffaceous conglomerate beds at the base, is found along Pit River between Flat Creek and Potem Creek. West of Flat Creek the Brock shale occurs, in the upper 100 feet or more of which occasional specimens of *Pseudomonotis* were found. The basal conglomerate, with prominent fragments of andesitic lavas and fossiliferous calcareous nodules, occurs just east of the mouth of Flat Creek, and similar conglomerates occur at several other points farther east, especially at the mouth of Lick Creek and in the northwestern part of sec. 7, T. 34 N., R. 1 W. Careful search has shown that some of the limestone nodules contain imperfect fossils.

The basal tuffaceous beds are well exposed on Squaw Creek, just above the mouth of North Fork, and contain scattered limestone fragments, generally a few inches in diameter. They are fossiliferous and, like those at Bear Mountain, throw definite light on the derivation of the limestone fragments from an older formation.

Sandstones and shales.—The most common rock of the Modin formation above the tuffaceous beds along Pit River is a very fine gray sandstone, usually thin bedded and associated with slaty shales. Interbedded with these were found limestone lenses 13 to 20 feet long and 12 to 18 inches in thickness. They resemble the nodules found in the tuffaceous conglomerate, but are far above them and contain no fossils.

Limestone lentils.—In a portion of the Modin formation south and southwest of Bagley Mountain, among the shales and thin-bedded sandstones, there are a number of small lenses of limestone, one of which, in the southern part of sec. 15, T. 36 N., R. 2 W., has a thickness of nearly 100 feet and a length from north to south of over a mile. It includes two layers of shale, has yielded a number of fossils, and may be traced in a series of small lenses for over 4 miles.

Distribution.—As shown on the areal geology map, the Modin occupies two distinct areas. The main belt-like area, 3 by 15 miles, extends northward from Cedar Creek across Pit River to the northern boundary of the quadrangle, where it turns eastward and finally disappears beneath the great field of Tertiary lavas. The smaller area, less than a square mile in extent, occupies the summit of Bear Mountain.

Thickness.—The outcrop of the Modin formation has a width of about 3 miles and an average dip, almost wholly in one direction, of over 50°. If there is no faulting it is well within reason to estimate its thickness at 3000 feet. This estimate includes the tuffaceous beds at the base, which in Bear Mountain reach their maximum thickness of about 400 feet.

Fossils and age.—Among the fossils in the limestone fragments of the basal tuff on Squaw Creek Dr. Stanton recognizes "*Pseudomonotis* sp. related to *Pseudomonotis subcircularis* Gabb," and remarks: "This lot seems to be derived from the upper Triassic, but the tuff in which the limestone fragments were found is more probably of Jurassic age."

Dr. Stanton has collected a large number of fossils, chiefly from the shales, sandstones, and limestones above the basal tuff of the Modin formation, and reports as follows:

> Between the *Pseudomonotis subcircularis* horizon [Brock shale] and the beds yielding a well-characterized Jurassic fauna [Potem formation] comparable with that found at Taylorsville there is a broad belt in which a great thickness of rocks is represented and from which fossils were collected at many localities. In the field these were considered Jurassic, and I still think that most if not all of them are of that period, but the paleontologic evidence is not so complete as is desirable. The fossils at most localities belonged to few species and were either poorly preserved or belonged to persistent types that would not aid in discriminating Jurassic from Triassic.

Overturn of the Modin formation on Pit River.—One of the features of the Pit River section of the Modin formation is its general dip to the west instead of to the east, as is the case with all the older formations of that region. Slaty cleavage is often well developed and generally dips eastward at a high angle. It seems evident that at this point the Modin formation, like the Brock shale and the Hosselkus limestone, has been overturned as a result of the sharp bend to the east along Cedar Creek.

Relation to adjacent formations.—The fragments of Triassic limestone contained in the basal tuffaceous conglomerate of the Modin tend to show that the Modin lies unconformably upon the Brock shale. The overlap, however, must be small, for the narrow belt of Brock shale continues for miles without conspicuous variation. The shale is absent in Bear Mountain, however.

The relation of the Modin formation to the overlying Potem formation appears to be one of conformity, though the Modin epoch closed at a time of vigorous volcanic activity, especially in the vicinity of Bagley Mountain.

POTEM FORMATION.

Lithologic character.—The Potem formation is composed of sandstones, shales, and tuffs. The thin-bedded sandstones and gray, sometimes slaty shales predominate in its lower part and make up the greater portion of the formation. They are more or less calcareous and contain a few small lentils of limestone. Tuffaceous conglomerates occur sparingly in the lower half of the formation, but in the upper part they are most abundant—in fact, nearly all the sediments of this part are of igneous material. Some of this material may have been furnished by contemporaneous volcanic activity, but most of it was derived by the ordinary processes of erosion from a wide expanse of volcanic rocks.

Distribution.—The Potem formation occurs in the Redding quadrangle in one area only, along the northeastern border, in the vicinity of the Great Bend of Pit River. Its fossiliferous shales and sandstones are well developed on Potem Creek, which may be taken as the type locality. In the Lassen Peak folio this formation was called the Bend formation, but as that name had prior use in Texas, Potem is here substituted.

Thickness.—The total thickness of the Potem formation can not be closely estimated, but a study of the section along Pit River on both sides of the mouth of Potem Creek leads to the conviction that it must be at least several thousand feet.

Fossils, age, and correlation.—Concerning the fossils of the Potem formation, of which he made large collections, Dr. Stanton remarks:

> Overlying the beds [Modin] just discussed and covering a considerable area near the eastern margin of the quadrangle is another formation characterized by a well-marked Jurassic fauna, including several species that occur in the Hardgrave sandstone near Taylorsville. Among the forms may be mentioned *Rhynchonella*, *Pecten acutiplicatus* Meek, *Pecten* (*Entolium*), *Pinna expansa* Hyatt, *Modiola*, *Gervillia*, *Lima*, *Trigonia* (several species), *Goniomya*, *Pholadomya*, and *Ammonites* of *Coroniceras* type, etc. It is probable that horizons somewhat higher than the Hardgrave sandstone are included in the formation, but some of the types that seem later, as indicated by their occurrence in the Taylorsville region, are immediately associated with the Hardgrave species. This fauna is very distinct from all those that precede it in this region.

So far as yet known the Potem formation is the equivalent of the "Hardgrave" sandstone of Taylorsville (Bull. Geol. Soc. America, vol. 3, pp. 369–412), and most likely also of the "Mormon" sandstone, for the small *Rhynchonella* occurs in the gray sandstone of both localities; but the still later faunas of the "Thompson" limestone, "Hinchman" tuff, and "Bicknell" sandstone of the Taylorsville region have not yet been found in the Great Bend region. It is possible that they are covered up by younger formations east of the Great Bend or that they may have been completely removed by erosion.

Overturn of a part of the Potem.—The shales and sandstones along Potem Creek and the slope west of it dip southwest, like the bulk of the Modin formation, with which they have been overturned, but farther east, between Potem Creek and Pit River, the general dip is more nearly normal, to the northeast. It is important to note, however, that the position of the strata in the Modin formation is decidedly variable, a condition due to the fact that it has been greatly compressed in all directions.

Relation to adjacent formations.—The relation of the Potem to the adjacent formations is not always clear, especially that to the Modin. Along a portion of their contact both have essentially the same strike and dip and appear conformable, though at that point both are overturned; but elsewhere they are separated by prominent masses of andesitic lavas and tuffs such as form Bagley Mountain and the point south of Pit River opposite the mouth of Potem Creek, indicating an epoch of vigorous volcanic activity and a probable unconformity between them, a view which is strengthened by the fact that the faunas of the two formations are unlike.

The next formation younger than the Potem is the Chico, which is Cretaceous. The two formations are found in contact near Round Mountain, just east of the Redding quadrangle, and are strikingly unconformable, indicating one of the most profound interruptions known in the sedimentation of that region.

CRETACEOUS SYSTEM.

CHICO FORMATION.

Lithologic character.—The Chico formation is composed chiefly of yellowish sandstone, often pebbly, passing toward the base into conglomerate and upward into gray shales. It is decidedly softer than any of the older formations.

Distribution.—It may be said in general of the distribution of the Chico formation that it extends throughout the Sacramento Valley, but is covered by later formations, except around the valley borders where the cover has been washed away. A great bulk of it lies southwest of the Redding quadrangle along the western border of the Sacramento Valley. To the northeast it extends through Lassen Strait, between the Klamath Mountains and the Sierra, and possibly connects with the Chico of northern California and Oregon. Within the quadrangle it is limited in its distribution to irregular patches along the borders of the Sacramento Valley.

The "Horsetown beds," which are here included in the Chico, appear only in two small areas near the southwest corner of the quadrangle, about a mile from Larkin. On the Sacramento above Redding the Chico is well exposed, and again at Sand Flat, east of Buckeye, where it has been fruitlessly bored for oil.

On Dry Creek shales appear overlying the sandstone and conglomerate at the base of the formation and dipping about 10° S. The basal conglomerate has a thickness of at least 15 feet and includes material from the Triassic shales and igneous rocks against which it rests.

Basin Hollow affords one of the largest exposures of the upper shales, which form adobe, but there are prominent ledges of sandstone and conglomerates also. One bed of the latter is nearly 20 feet in thickness and contains some pebbles at least 4 inches in diameter. From Basin Hollow the Chico extends eastward across the Copper City arch of older rocks, and outcrops in patches at Oak Run, Oak Flat, and Little Cow Creek, 3 miles east of Furnaceville, as well as at Round Mountain, 4 miles beyond the eastern limit of the Redding quadrangle. This is the easternmost exposure of the Chico in the region. It dips to the east and disappears beneath the later formations which underlie the lavas of the Lassen Peak district. How far it extends beneath the lavas is unknown, but it may connect by way of the Great Bend of Pit River and Mount Shasta with the Chico of Shasta Valley.

Thickness.—The greatest thickness of the Chico formation in the Redding quadrangle is at Basin Hollow, where it is about 500 feet. It thickens rapidly southwestward from Redding by the conformable addition beneath of older beds—first the Horsetown, then the Knoxville—until on Elder Creek, 50 miles from Redding, the Shasta-Chico series of beds attains an estimated thickness of 29,000 feet.

Fossils and age.—The Chico formation is highly fossiliferous and its fauna is well known. Its age is below the middle of the Upper Cretaceous, but the addition of the Horsetown and Knoxville beneath carries the succession of strata far into the Lower Cretaceous.

Relation to adjacent formations.—The Chico rests with marked unconformity on the older formations, from the Jurassic to the Devonian inclusive, around the north end of the Sacramento Valley. This unconformity is the most profound interruption among the sedimentary rocks of the Pacific coast and can be traced over a wide area. The relation of the Chico to the Ione will be considered later.

TERTIARY SYSTEM.

MIOCENE SERIES.

IONE FORMATION.

Composition and distribution.—Within the Redding quadrangle the Ione formation is composed of gravel, sand, and clay, with occasional beds of coaly material, and has a thickness not exceeding 50 feet. Sands, often micaceous, are by far the most abundant. The best exposures of the Ione formation are outside of the quadrangle, along the western border of the Sacramento Valley, as well as to the east on Little Cow Creek and about the Great Bend of Pit River to the head of Kosk Creek, where it is certainly over 1000 feet in thickness.

It crops out around the borders of the valleys and canyons of the Piedmont region in the Redding quadrangle, forming a narrow belt between the Chico below and the Tuscan tuff above. On the one hand, it is difficult to decide in some places whether the nonfossiliferous beds overlying those well characterized by Chico fossils are Cretaceous or Ione, and on the other, the tuffs of the Tuscan formation and gravels of the Ione appear to be interstratified, and therefore the upper boundary is not always evident. In general, however, where the Ione is best developed there is little difficulty in recognizing it.

Fossils and age.—The fossils of the Ione formation are chiefly leaves and occur most abundantly in the sandstones and shales on Little Cow Creek above Phillips's sawmill and near the head of Kosk Creek, where the following, determined by Dr. F. H. Knowlton, were collected:

Little Cow Creek.

Ficus asiminæfolia ? Lesq.
Populus Zaddachi ? Heer.
Platanus dissecta Lesq.
Laurus californica ? Lesq.
Salix n. sp.
Cinnamomum n. sp.
Zizyphus n. sp.

Near head of Kosk Creek.

Sabalites californicus Lesq.
Ulmus californica Lesq.
Ficus tiliæfolia Al. Br.
Populus Zaddachi Heer.
Quercus convexa Lesq.
Fagus Antipofii Abich.
Persea pseudo-carolinensis Lesq.
Laurus sp.
Magnolia californica Lesq.
Rhus mixta Lesq.

Concerning these Dr. Knowlton remarks that "all of the species (with one exception), whether correctly identified or not, come from what is known (in the Sierra Nevada) as the auriferous gravels. . . . There is nothing in the collection which suggests an age as old as the Eocene." The formation is accordingly considered to be of Miocene age.

A mussel (Unio) has been found with the leaves on Little Cow Creek and indicates that the water was fresh at that point, but farther south in the Sacramento Valley, about Marysville Buttes, as shown by Mr. Lindgren, the same formation contains marine fossils. During the Ione epoch the great bay which occupied the Sacramento Valley was receiving so large an influx of water by way of the "Lassen Strait" region as to keep its upper part comparatively fresh. The conditions were such, however, as to favor the accumulation of vegetation, from which small beds of coal were formed at a number of localities. At the same time the ancient streams were depositing auriferous gravels over the gentle slope of the Sierra Nevada.

Relation to adjacent formations.—On the western side of the Sacramento Valley the Ione formation rests upon the Chico with marked unconformity, but along Cow Creek and Little Cow Creek on the eastern side of the valley the unconformity, though appreciable, is much less distinct. The movement producing this discordance must have taken place about the close of the Cretaceous, and it is evident that the resulting deformation was much greater in the Klamath Mountain region than about the north end of the Sierra Nevada. Since that deformation and upheaval the Klamath Mountains have remained for the most part above the sea, and the same may be said of the "Lassen Strait" region, which during the Ione epoch was occupied by a body of fresh water connecting with the sea by way of the Sacramento Valley.

The rock next younger than the Ione is the Tuscan tuff, which rests unconformably upon its eroded surface; in some places, especially near Oak Run, the Ione had been completely removed by erosion before the deposition of the Tuscan tuff, which now rests directly upon the Cretaceous.

PLIOCENE SERIES.

TUSCAN TUFF.

Lithologic character.—The Tuscan tuff is almost wholly andesitic, ranging in texture from coarse agglomerates, in which there are unassorted angular fragments a yard in diameter mingled with fragments of all sizes, down to dust. Fine-textured gray tuff, often distinctly stratified, is by far the most abundant. It is composed of small fragments of andesite, sometimes pumiceous, with broken crystals of andesine and hornblende, embedded in a fine gray matrix composed of minute angular particles of volcanic glass, which constitute the major part of the rock. In the basal portion sands and gravels occasionally occur interstratified with the tuff. Along the eastern border of the quadrangle the upper part of the tuff locally contains fragments of dacite and basalt, but even where most abundant they form only a small portion of the tuff.

Distribution.—The Tuscan tuff was named from its occurrence about Tuscan Springs, in the Lassen Peak quadrangle. It extends throughout the northern part of the Sacramento Valley, but is generally covered by the Red Bluff formation except around the valley borders. It outcrops along the eastern side of the valley almost continuously from Chico Creek to Little Cow Creek and forms the broad stony plains of the Piedmont region, represented by the Swede Creek Plains and others in the southeastern part of the Redding quadrangle. The canyons cut across these plains and afford excellent exposures of the tuff, which is found to include occasional flows of lava. The plains are underlain by layers of unassorted material containing many angular fragments which weather out on the surface and make it exceedingly stony. Around the northern border of the valley from Little Cow Creek to Horsetown the lack of continuous exposure, as shown on the map, is due chiefly to a cover of Red Bluff gravel, though some of it has been removed by erosion.

There is a typical exposure $2\frac{1}{2}$ miles northeast of Buckeye, on Stillwater Creek, where the specimens were obtained for the educational series of rocks described in Bulletin 150, page 211.

Thickness.—In the stony plains region along the eastern border of the quadrangle the tuff is 400 feet thick and much of the material is coarse, but on the western border of the valley it is much finer and usually less than 25 feet in thickness.

Source of material.—The material of the Tuscan tuff is all derived from the volcanoes of the Lassen Peak region. This is clearly shown by the distribution of the material, not only as to size of fragments and thickness of mass, but also as to the kind of lava. The bulk of the finer material which appears on the western side of the Sacramento Valley contains a considerable amount of hornblende and most likely came from the greater volcano of Lassen Peak.

Relation to adjacent formations.—The Tuscan tuff in many places appears to rest conformably upon the Ione, but in others, as already stated, the two formations are evidently separated by an interval of erosion. A similar interval separates the Tuscan tuff from the Red Bluff.

Age.—During Miocene and Pliocene time the volcanoes of the Cascade Range were in vigorous activity. The border of the great volcanic field to which they belong extends into the southeastern part of the Redding quadrangle, where it is represented by the Tuscan tuff and some overlapping flows which have been mapped separately. As the mass of the Tuscan tuff lies unconformably between the Ione (Miocene) on the one hand and the Red Bluff (Quaternary) on the other, it is chiefly Pliocene.

QUATERNARY SYSTEM.

RED BLUFF FORMATION.

The Red Bluff formation consists chiefly of gravel and sands, with a small proportion of clay. It is well exposed on Sacramento River $1\frac{1}{2}$ miles east of Redding, in a prominent bluff nearly 100 feet in height. The exposure which gave name to the formation is at Red Bluff, nearly 40 miles south of Redding. In the Redding quadrangle gravel predominates largely over sand; the well-rounded pebbles rarely attain a diameter of 4 inches, although there are occasional rough bowlders having a diameter of over 5 feet. Farther south, at Red Bluff, the type locality, sand prevails associated with small beds of fine gravel.

The Red Bluff formation occupies the central portion of the Sacramento Valley west of the Piedmont region. It forms the gravel plains of the Redding region, laps up over the edge of the Piedmont Plain on the east, as well as over the edge of a peneplain cut in the older rocks around the northern and western borders of the Sacramento Valley, and connects directly with the terrace level which follows up the river by Keswick and Copley about 200 feet above the present level of the river. It rests unconformably upon all older rocks. Much of the Tuscan tuff, which is next to it in age, was removed by erosion before the Red Bluff was deposited.

It is evident that during the Red Bluff epoch Sacramento River and its tributaries were supplied with a large amount of gravel and sand, which they carried to the great valley for deposition. The presence of occasional bowlders suggests floating ice as an agent of transportation, and it is not improbable that glaciers in the higher mountains had a considerable share in furnishing both the sediments and the water for the streams of the Red Bluff epoch.

The older portion of the Red Bluff formation, which is covered up in the Sacramento Valley, possibly records events closely related to those chronicled by the interesting bones in the Potter Creek cave, on the McCloud, which show that elephants, mastodons, tapirs, camels, and many other forms now extinct enlivened the ancient landscape.

ALLUVIUM.

The alluvium is the fine silt, sand, and gravel of the flood plains near the level of the present streams. On the surface fine material generally prevails and affords by far the larger part of the agricultural soils of the region. It is well developed along Cow Creek and its tributaries and along Sacramento River, particularly from Redding to the southern margin of the quadrangle.

IGNEOUS ROCKS.

INTRODUCTION.

In the Redding quadrangle there is a long succession of igneous rocks, which began with the eruption of acidic and basic volcanics before the middle of the Devonian and continued at intervals in the Carboniferous, Triassic, and Jurassic nearly to the end of the Mesozoic, when a variety of dike rocks such as quartz-augite-diorite, augite-diorite-porphyry, dacite-porphyry, and amphibolite appeared, with larger masses of quartz-hornblende-diorite, quartz-mica-diorite, and serpentine. During the Tertiary followed the great eruptions of the Cascade Range from the vicinity of Lassen Peak and Mount Shasta, which flooded the northeastern part of California with lava and continued with decreasing energy to the late Quaternary.

PRE-KENNETT.

COPLEY METAANDESITE.

General description.—The Copley metaandesite was named from its occurrence in the vicinity of Copley, where the most important type is well exposed. It is generally pale green on weathered surface, but darker green and compact on fresh, somewhat shaly fracture. Distinct porphyritic structure is not common, but the rock is frequently more or less fragmental, a feature which shows most clearly on the weathered surface.

Occurrence.—The Copley metaandesite includes a great mass of lava made up of many separate volcanic flows of considerable variety and sheets of tuffs more or less distinctly bedded but generally so compressed as to develop slaty cleavage.

Cut by numerous joints in various directions and deeply eroded and intersected by many dikes of rhyolite and quartz-augite-diorite, the Copley metaandesite has an aspect of greater age than any other area of volcanics in the Redding quadrangle. This feature is emphasized also by the occurrence of auriferous quartz veins, especially in the southwestern portion, where some of them are mined. In the northern half of the area, on the slopes of Bass and O'Brien mountains, the metaandesites are less altered and the sheeted character and beds of tuff better preserved than farther south.

In the tuffs, especially from Bass Mountain northward, the lapilli are sometimes well preserved, with crystals of fresh augite and feldspar in a yellowish devitrified groundmass. Many of the lapilli and some of the flows are amygdaloidal, leaving no doubt as to the explosive character of the volcanic action by which they were produced, and though they are not common, their wide distribution shows that the whole mass with which they are connected is made up of surface eruptions.

Southwest of Redding the metaandesite is generally a breccia of green fragments in a light-greenish matrix. It is rarely coarse; the fragments where largest are generally less than 4 inches in diameter. Near the eastern border of the mass, about Olney Creek and Oregon Gulch, are some of the best exposures of breccia. Grains of quartz frequently appear on the weathered surface, so that it looks like quartz-porphyry, but on closer examination these grains are generally found to be secondary—in fact, to be amygdules filling ancient steam holes in the andesite. It is often difficult to decide in the field, where the rocks are as highly altered as those of Larkin and Old Diggings, whether the quartz is primary or secondary, and it is probable, on this account, that some quartz-porphyries may have been included in the areas marked metaandesite. Here and there the metaandesite is rotten and deeply stained by oxide of iron. At other places it has a decided cleavage, like slate, and has lost its general resemblance to lava, but in thin section under a microscope traces of its original igneous structure may still be seen.

Relation to adjacent rocks.—The oldest rocks with which the Copley metaandesite comes in contact are those of Devonian age. Their relation may be seen to greatest advantage in the Kennett region, where Devonian rocks clearly overlie the ancient rhyolites and andesites.

Masses of shale occur in the O'Brien Mountain and Larkin areas of the Copley metaandesite, and in places they contain beds of tuff. They are usually long, narrow belts, folded or faulted down into the volcanics upon which they rest. The shales are associated with fossiliferous limestones of Devonian age, and show that the Copley metaandesites are older than the middle Devonian. This relation is also emphasized by the fact, set forth more fully in the description of the Kennett formation, that the Devonian sediments are derived in part from the Copley metaandesite. The Bragdon, like the Kennett, rests upon the metaandesite and contains much sediment derived from it.

The Copley metaandesite is clearly cut by dikes of the adjoining Balaklala rhyolite, as well as of all the younger eruptives, the most abundant of which are quartz-augite-diorite and dacite-porphyry.

Distribution.—The principal area of the Copley metaandesite is that of O'Brien Mountain, extending south through Bass Mountain and the hills about the National mine to Copley and Old Diggings. Pit River crosses the northern portion and the Little Sacramento and Sacramento follow the general course of the northwestern border. The rocky banks of the latter afford particularly good exposures.

Another area of Copley metaandesite lies southwest of Redding and is in line with that of O'Brien and Bass mountains, though separated from it by a mass of rhyolite.

Two small areas of Copley metaandesite occur in the northwest corner of the Redding quadrangle, one on Dog Creek and the other at Portuguese Flat. These areas are completely surrounded by rocks of later age and it is probable that the volcanic rocks occupy a large area beneath the Bragdon.

Petrographic description.—The Copley metaandesite is well exposed along the river in the vicinity of Copley, where it is decidedly green and compact, though in places clearly fragmental. In thin section under a microscope it is found to be composed chiefly of plagioclase (apparently andesine) and chlorite with variable amounts of epidote, fibrous green hornblende, magnetite, and calcite, sometimes also quartz. The plagioclase is most abundant, generally much altered, but sometimes fresh, in well-defined elongated crystals, with irregular patches of chlorite apparently derived from augite filling the spaces between them. Epidote is generally present and often abundant and varies inversely with the amount of calcite present. Magnetite is less abundant, in some places rare. The regular intersertal structure is often modified by the parallel, stream-like arrangement of the feldspars. The rock, though generally holocrystalline, is often hypocrystalline and ranges in structure from pilotaxitic and intersertal to granular in which only the feldspar shows traces of crystallographic boundaries.

Originally the rock was some form of pyroxene-andesite, but in view of the degree of alteration it may be more appropriately designated metaandesite.

BALAKLALA RHYOLITE.

General description.—The Balaklala rhyolite was named from the fact that it forms the hills about the Balaklala mine. Where freshest the rock is gray, generally with distinct phenocrysts of quartz, and is often impregnated by pyrite. On the surface it is deeply stained with oxide of iron and is porous from the decomposition of the pyrite. Flow structure is rarely distinct. In many cases it is fragmental and most frequently it is brecciated.

Occurrence.—The Balaklala rhyolite is made up of a succession of irregular lava flows and tuffs which have been so compressed and folded as to render very obscure the original layered arrangement of the mass. Little Backbone Creek and Squaw Creek cut narrow valleys in it to a depth of 1000 feet. Their slopes are steep and rocky, in strong contrast with the gentle relief and small ledges of the main ridge about the heads of Cottonwood, Motion, and Spring creeks. The ledges in the rocky canyons are generally irregular and massive, rarely appearing as sheets or flows, and yet the occurrence of tuff among the masses of nonfragmental material clearly indicates that it is of volcanic origin. In the vicinity of the Uncle Sam mine it is usually lighter colored and is rich in larger grains of quartz, so that in the field it resembles granite-porphyry. Breccia is common and occasionally conspicuous. The best examples observed are on the slope north of Squaw Creek, where some of the fragments are over a foot in diameter. Finer breccia occurs on the railroad near the mouth of Squaw Creek and on the divide near the trail between the heads of Cottonwood and Motion creeks, as well as beneath the limestone on the Quarry road $1\frac{1}{4}$ miles northeast of Kennett. The fragments are generally rhyolitic, but in some cases decidedly andesitic, like the Copley metaandesite.

The Balaklala rhyolite is everywhere cut by numerous joints running in many directions, but those having a northeast-southwest trend appear to be most common and are sometimes accompanied by shearing. In some places, especially about Balaklala Hill, the shearing was so great as to render the rock fissile, like shale, but the grains of quartz are generally preserved.

Relation and age.—The Balaklala rhyolite, with its associated tuffs, clearly underlies the Kennett limestone and shale which form the crest of the ridges between Squaw Creek and Backbone Creek. The Devonian sandstones on Backbone Creek contain rhyolitic material like that of the Balaklala, and afford conclusive evidence that the Balaklala rhyolite is older than the middle Devonian.

The rhyolite penetrates and overlies the Copley metaandesite. The mass of the metaandesite was erupted before that of the rhyolite, but their eruptions appear to some extent to have alternated, and it has not been possible in all cases to separate them.

It is not certain that all the dikes of rhyolite west of the Sacramento are Balaklala and older than the middle Devonian. There were extensive eruptions of rhyolite early in the Triassic and it is possible that some of the dikes west of the Sacramento may have been formed at that time. The dike-like masses on the slope west of Copley are very fresh and may belong to this class. At several points also, but more particularly on the east slope of Backbone Creek, over 4 miles above Kennett, a peculiar breccia of shale fragments, apparently cemented by igneous material, was found along the contact of the rhyolite and the Devonian shale, indicating that the rhyolite is younger than the shale and presumably of Triassic age, but this is not separated on the map from the Balaklala rhyolite. Some of the tuffs underlying the limestones contain dark fragments of shale which is probably older than the Kennett.

Distribution.—The principal area is that of which Balaklala Hill is a part, extending from Backbone Creek southwestward across the western border of the Redding quadrangle to Iron Mountain, and forming the country rock of the copper deposits of that region.

An area of rhyolite lies along the eastern side of the Sacramento from Keswick to Waugh and has been cut down to the level of the plain about the north end of the Sacramento Valley. Another small area occurs on Dog Creek, 3 miles west of Delta; it is here partially surrounded by the Bragdon, from which, on the eastern side in McCall Gulch, it is separated by a fault.

Petrographic description.—Having been much affected by pressure, the Balaklala rhyolite has an uneven fracture. When fresh its color is light gray and the dark phenocrysts of quartz are distinct on the compact groundmass. Frequently, however, the rock has a granular appearance in the field and loses all trace of porphyritic structure, though in thin section under a microscope it is still distinct. The irregular phenocrysts of quartz are much embayed by the groundmass and broken, giving wavy extinction. The feldspar occurs in sharply defined crystals and also in fragments or groups of fragments. The crystals are tabular. Those of orthoclase are without twinning or simply Carlsbad twins. Those of plagioclase have multiple twinning. It is doubtful if the orthoclase is generally in excess of the plagioclase. It is possible that this rock is more closely related to dacite than to rhyolite.

The groundmass is generally finely cryptocrystalline and may contain few or many microlites of feldspar. Where altered, the feldspar of the groundmass yields sericite, and locally it becomes abundant.

CARBONIFEROUS.

BASS MOUNTAIN DIABASE.

General description.—The diabase of the southern slope of Bass Mountain is generally a dark, somewhat greenish, compact lava which is not porphyritic, but is occasionally vesicular and more frequently fragmental. Where fresh this lava has darker spots of augite embedded in a lighter colored groundmass.

Distribution.—There are two principal areas or groups of areas of the Bass Mountain diabase. One on the southern slope of Bass Mountain extends southward to the border of the newer rocks about Sacramento Valley as an irregular area over 6 miles in length and 4 miles in width, with several included tracts of Kennett and Chico; the other consists of four or more small parallel strips 1 to 3 miles in length extending northwest and southeast in the region of Middle Salt Creek.

Occurrence.—The best exposures are about the head of Rancheria Creek, on the lower slopes of Bass Mountain, where the ledges are made up of irregular masses of tuff and sheets of lava which are locally vesicular. Fragmental material is much the more abundant on the mountain slopes, but less so farther south, though in places clearly made up of small cellular lapilli such as commonly result from explosive eruptions in connection with the volcanic effusion of this type of lava. The rock is generally well jointed, but not slaty, and yields a deep-red soil.

Rocks of essentially the same character as the diabase of the southern slope of Bass Mountain occur within the Bragdon area in the vicinity of Middle Salt Creek and apparently throw light upon the general relations of the larger mass south of Bass Mountain. On Middle Salt Creek the diabase occurs as interbedded flows. The sheets are not only conformable between the layers of the Bragdon sediments, but are occasionally associated with beds of volcanic sand whose origin is connected with the eruption of the diabase. These tuffaceous sandstones are composed of the same minerals as the diabase and contain occasional fragments of the underlying shale. The whole association indicates contemporaneous volcanic activity at intervals in the later portion of the Bragdon epoch, and it is believed that the Bass Mountain diabase belongs to that horizon, though the evidence is not altogether satisfactory.

Relation to adjacent formations.—The relation of the diabase on Middle Salt Creek to the Bragdon is clearly that of contemporaneous interbedded flows. In the case of the masses south of Bass Mountain, which are supposed to be of the same age, the relations are different. The diabase appears to rest directly upon the eroded surface of the Copley metaandesite and of the Kennett formation. The absence of the Bragdon beneath is evidence that the eruption took place on land, but its presence above shows that after the eruptions from the several centers south of Bass Mountain the district subsided, was covered by the Bragdon sea, and received the upper beds of the Bragdon formation. The large patches of Kennett within the Bass Mountain diabase area may have been laid bare by recent erosion, but it is evident that the diabase cover is not very thick and that the Devonian was not completely covered by it, for the Bragdon at one point appears to rest directly on the Kennett.

Relation to the quartz-augite-diorite.—In the Middle Salt Creek region, to a limited extent, the Bragdon is cut by dikes and intruded sheets of quartz-augite-diorite, which frequently has an ophitic structure and is not clearly distinguishable petrographically from the Bass Mountain diabase. The two can be distinguished only when it is possible to discover their relation to the Bragdon. It is evident that since the same diorite cuts the Jurassic rocks it is much younger than the diabase. No dikes of the diorite were found in the diabase. In the Middle and North Salt Creek regions the bodies of igneous rocks of the Bragdon area are chiefly diabase, but farther southeast, on Salt Creek, the diorite prevails, though it is possible that considerable masses of quartz-augite-diorite are included in the areas marked Bass Mountain diabase.

Petrographic description.—Normally the Bass Mountain diabase is holocrystalline, generally with automorphic plagioclase and xenomorphic augite. The fabric is ophitic or ophitic granular. Rarely, when pyroxene is abundant, there are poikilitic patches. Some of the vesicular flows and the lapilli in the tuff contained originally considerable amorphous matter. In this case the automorphic plagioclase is long and narrow, but in the larger masses where the diabase is normal it becomes more coarsely crystalline, the plagioclase becomes partly xenomorphic, and the structure tends toward even granular.

The greatest variation of the rock is in its mineral composition. Ordinarily that on the middle southeastern slope of Bass Mountain is composed of plagioclase and augite, but at the base, near the road, graphic quartz intergrown with plagioclase becomes common and the rock is a quartz-diabase. Granitic quartz, but not generally graphic, is a common constituent of the diabase along the road to within a mile of Newtown, and yet there are places within this large area where it practically disappears.

Hornblende is another of the variable minerals. In many places there is no trace of it; in others there is a small amount of light-brown hornblende, increasing in quantity until it equals or exceeds that of the augite. Sometimes it is in parallel intergrowth with the augite, but generally it is independent, yet holds essentially the same relation as the augite to the rock fabric. The quartz and hornblende vary without reference to each other, and both occur at intervals in both areas—that is, among the interbedded sheets of the Bragdon formation along North Salt Creek, as well as in the area northeast of Newtown.

In many places the rock is highly altered, the feldspars are kaolinized, and the augite is completely replaced by chlorite and calcite. Green hornblende, which is secondary, generally after augite, is rarely abundant and less widely distributed than the brown hornblende.

QUARTZ-LATITE.

In the Nosoni formation are several small masses of somewhat rhyolitic rock, on the southwest spurs of Bollibokka and Horse mountains. At the latter locality only tuffs were seen interbedded with fossiliferous shales, but at the former, about $1\frac{1}{4}$ miles a little east of north from the mouth of Nosoni Creek, a well-defined sheet of lava of rhyolitic aspect occurs, but is not separately mapped. It is about 75 feet in thickness, and, like the tuffs below and the tuffs and fossiliferous shales above, strikes nearly north and south and dips eastward into Bollibokka Mountain. A prominent ledge of this reddish rock is locally banded and has cavities suggesting lithophysæ. The rock has a few long plagioclase twins with symmetric extinction angles up to 30°, indicating labradorite. They are inclosed in a microgranitic groundmass of quartz and feldspar, of which a few of the grains show lamellar twinning. Notwithstanding the rhyolitic aspect of the rock, the absence of orthoclase, with the prevalence of labradorite and the presence of free quartz, places it among the quartz-latites.

TRIASSIC.

DEKKAS ANDESITE.

General description.—The Dekkas andesite is generally a dark-gray lava that is more or less porphyritic, but not conspicuously so to the naked eye. It takes its name from Dekkas Creek, along which the rock is well exposed. It includes a great mass of lava made up of many separate overlapping volcanic flows and sheets of tuff more or less distinctly bedded, irregularly conformable, and dipping eastward.

Occurrence. — Its best exposures are on the western slope of the ridge from Horse Mountain to Bollibokka Mountain, where the hard layers of tuff and lava make a succession of bold bluffs and show better than elsewhere their general character and position. That the sheets of lava were flows upon the surface is shown by the vesicular character of the upper portion, which has since been converted into amygdaloid, and by their association with layers of volcanic ejecta.

On the western slope of Town Mountain the sheets of lava are more prominent than those of fragmental material. Near the summit, above the bulk of the altered andesites, are prominent cliffs formed by several sheets of a fine granular rock (quartz-augite-diorite) like that which so extensively cuts the McCloud limestone, while the summit of the mountain is made up chiefly of fine tuffs and shales locally containing red chert.

On the western slope of Minnesota and Salt Creek mountains fragmental volcanic rocks are most prominent, but, as elsewhere, the fragments are not coarse, being rarely over an inch in diameter and never much larger. This indicates a considerable distance from the volcano whence they issued, and yet the distance can not have been great, for layers composed wholly of very fine material, such as volcanic dust, are equally uncommon.

This belt is remarkable for the numerous layers of fossiliferous, more or less tuffaceous shale which it contains interbedded with the lavas and tuffs. As the shales inclose many microscopic fossils of marine origin similar to those of the Pit shales to the east, the volcanic products must have spread out upon the sea floor.

Relation.—The Town Mountain belt of Dekkas andesite from one end to the other is bounded on the west by the Carboniferous and on the east chiefly by the Triassic, and its sheets of lava and tuff, like the rocks of both adjoining systems, dip to the east between them so as to approximately fix the general horizon of the volcanic activity which it represents. Along the eastern border these flows of volcanic rocks are overlain conformably by, and to a small extent are interbedded with, the bottom part of the Pit shales. On the western side the relation to the Nosoni formation as outlined is equally clear. The outcrops of the Dekkas andesite and Nosoni formation are approximately parallel for over 20 miles, but the Nosoni belt narrows to the south, and on Campbell Creek, as well as near Lilienthal, it is unconformably overlapped by the andesitic flows, which extend westward a short distance beyond the McCloud limestone.

The stratigraphic position of the great body of volcanic rocks made up of the Dekkas andesite and the Bully Hill rhyolite, conformably under the Triassic and unconformably upon the upper Carboniferous, fixes the horizon of great volcanic activity at the beginning of the Mesozoic. Although the greatest volume of volcanic products occurs at this horizon, it must be remembered that there was vigorous volcanic activity in the same region during the later Carboniferous, and that it continued with decreasing energy into the Triassic.

Distribution.—The main area of Dekkas andesite is from 1 to 2½ miles in width, with a length of over 25 miles. It stretches from the end of the Sacramento Valley proper northward and slightly northeastward beyond the boundary of the quadrangle, forming an irregular ridge with prominent peaks, including Horse, Town, Minnesota, and Salt Creek mountains, and part of Bollibokka.

The total thickness of the mass is approximately 1000 feet, but it varies from place to place, not only in this respect but also in composition.

The Clikapudi area of andesite southeast of Copper City is scarcely 2 square miles in extent. This area is supposed to represent the Dekkas rock brought to the surface by an anticline and by the erosion of rocks from the crest. At the Pit River bridge it incloses a mass of shales and beyond the river appears to be overlain on the southeast by rhyolite related to that of Bully Hill. The greatest dimension of the exposure runs northwest and southeast, determined by an anticlinal fold with Pit shales on both sides.

Petrographic description.—The Dekkas andesite is generally a compact, light- to dark-gray rock which is decidedly microporphyritic, though scarcely porphyritic to the naked eye. Most of the phenocrysts appear to be labradorite, square to rectangular in cross section, attaining commonly 3 by 1.5 mm. in size, but a few are of augite almost completely changed to chlorite and epidote. The groundmass is generally much altered, but the great preponderance of feldspar microlites and grains, commingled with chlorite, epidote, some black oxides, and other less definite secondary products, suggests original pilotaxitic and intersertal structures such as are common to many augite-andesites. In many of the flows the groundmass is more plainly crystalline. The multitude of striated plagioclase crystals in the mass are generally about 0.15 to 0.3 mm. in length and appear to be andesine. Where holocrystalline these minute feldspars lie in all directions and with ophitic structure clamp angular patches of chlorite and clouded grains of epidote between them. Oxides of iron are common, but rarely abundant. Some of the dark basaltic-looking flows are holocrystalline, with a decided tendency to ophitic, sometimes subgranular structure, but no trace of olivine or iddingsite was found, as in the similar lavas of the Nosoni formation. This basic form associated with the Dekkas andesite is in the field much like the augite-diorite which forms definite dikes cutting the Dekkas andesite, and it is most likely that the irregular sheets are intruded. They were not mapped separately. The chlorite appears to come wholly from the alteration of augite. No distinct traces of original hornblende or mica, such as occur in the augite-diorite, could be found, though in several cases small amounts of secondary hornblende were present.

BULLY HILL RHYOLITE.

General description.—This rhyolite takes its name from Bully Hill, famous for its mines, where, though much altered, the rhyolite is well exposed. On a fresh fracture it is gray, containing distinct phenocrysts of quartz in a compact groundmass. On the surface it is usually porous and deeply stained reddish from the oxidation of pyrite.

Occurrence and relations.—In the Bully Hill region the rhyolite is arranged in flows alternating with tuffs dipping southeastward beneath the Pit shales, but in places, as for example on Baxter Creek near Copper City, it cuts the lower portion of the Pit shales and envelops its fragments. The long, narrow belts running from Bully Hill toward the Afterthought district are for the most part along the crest of an arch running from the Klamath Mountains southeast toward the Sierra Nevada. It is flanked on both sides by the Pit shales, with anticlinal dips, but part of the area, not readily separable, is occupied by a somewhat later rhyolite, which, on Cedar Creek and in a number of small occurrences north of Pit River, cuts through the Pit shales to the Hosselkus limestone. For convenience, all the rhyolites erupted in the Redding quadrangle during the deposition of the Pit shales are included under the term Bully Hill rhyolite, though they represent a considerable range of time. Bedded tuffs, composed largely of crystal fragments of quartz and feldspar, with a smaller proportion of glass and pumice particles replaced by quartz, are common among the Pit shales and are locally associated with sheets of rhyolite.

Distribution.—The area is extremely irregular and roughly T-shaped, with Bully Hill at the radial center. The top part lies along the southeastern base of the prominent ridge formed by Horse and Town mountains, and extends from Pit River northeastward, forming many prominent ledges, to the slopes of Didallas Creek. From Bully Hill the stem part of the area extends southeastward to the Afterthought region along Cow Creek, where it spreads and disappears beneath the cover of lavas from Lassen Peak.

Petrographic description.—The freshest exposures of the Bully Hill rhyolite are on Horse Creek and on Town Creek near the power house of the Bully Hill mine, where the rock is light gray, mottled with darker cloudings, and in places has a well-marked conchoidal fracture. Phenocrysts of quartz are common, but small. These phenocrysts, with a few of orthoclase and plagioclase, are sometimes idiomorphic, but more frequently they are broken to many fragments and scattered by fluidal motion of the lava.

The groundmass of this rhyolite is usually compact and cryptocrystalline. Originally it may have been composed largely of amorphous matter, but no glass nor definite evidence of spherulitic or perlitic structure was observed. Some portions, especially the knotty ones, have been greatly silicified. In the portions of the mass affected by the sheared zones in which the ores have accumulated, the rock is greatly altered and locally converted into a sericite-schist. On the surface at Bully Hill the rhyolite is brecciated and much decomposed, leaving a kaolinized siliceous mass deeply stained by oxide of iron. Beneath the surface it is gray and locally full of siliceous knots, which characterize it generally in the vicinity of the mines. The same sort of knotty rhyolite occurs in the hill above the Copper City mines, but was not seen well developed anywhere else in the region.

The rhyolitic dikes which penetrate the Bass Mountain diabase and the Dekkas andesite in Minnesota Mountain are considered to be Bully Hill rhyolite, though in general the groundmass is more crystalline and perhaps locally holocrystalline.

JURASSIC.

BAGLEY ANDESITE.

General character.—The Bagley andesite includes the lavas and pyroclastics of a succession of volcanic eruptions of similar general character. It is commonly filled with an abundance of small phenocrysts of plagioclase, and rarely also with dark grains in a greenish groundmass.

Distribution.—There are two areas, one including Bagley Mountain, from which the rock takes its name, near the northeast corner of the Redding quadrangle, and the other along Pit River near the eastern border.

Occurrence.—Both masses are composed chiefly of andesitic tuff, sometimes coarse, almost agglomeratic, but generally fine and stratified, with occasional traces of marine fossils.

More than three-fourths of the Bagley Mountain area is occupied by tuff. The lavas are most abundant near the summit and the whole mass has a thickness of about 1000 feet. Much pyroclastic material occurs in the Pit River area, but lava flows are almost equally abundant. Pit River cuts a deep canyon across the area, exposing in the steep slope opposite the mouth of Potem Creek great sheets of lava and tuff dipping to the northeast. In some places these rocks have a distinct cleavage, but its production has not been accompanied by any considerable degree of metamorphism nor even by deformation of fossils.

Relation.—Both areas of the Bagley andesite lie practically on the border between the Potem and Modin formations, but do not necessarily indicate an unconformity. These areas represent centers of greater accumulation of volcanic material near points of eruption during the beginning of the Potem epoch. Between the two points the contemporaneous sediments contain some detritus from both centers, but apparently the greater portion comes from a different source. For this reason the intermediate sediments were included in the Potem.

Petrographic description.—The prevailing type of Bagley andesite in the deep canyon of Potem Creek near its mouth is darker and generally fresher than elsewhere, but not so porphyritic. In thin section the numerous irregular phenocrysts of plagioclase lie in a fine granular, apparently holocrystalline groundmass of well-defined plagioclase crystals and grains of augite. Along Pit River it is less microporphyritic and there is considerable dark-brown glass present in place of the augite. The glass is for the most part altered, yielding much carbonate of lime.

In the Bagley Mountain area a small portion of the lava contains phenocrysts of hypersthene, possibly also of hornblende and rarely of augite, with those of plagioclase. The hypersthene is replaced by oxide of iron or by a dark-green pleochroic, chloritic mineral, but the augite is fresh. The groundmass in this type is less crystalline than in the other and is full of feldspar microlites, with much yellowish-green chlorite.

LATE JURASSIC OR EARLY CRETACEOUS.

QUARTZ-HORNBLENDE-DIORITE.

General description.—At several points in the quadrangle there are areas of holocrystalline, even-granular rock, like granite in appearance, composed essentially of quartz, plagioclase, and hornblende. These form stocks and cut rocks as young as the Triassic rhyolites.

Occurrence.—In the Redding region generally this rock is covered by residual material, except in the rocky canyons of vigorous streams like Spring Creek, where it is well exposed. The light-gray color is varied by dark blotches and angular patches which look like inclusions, but are really secretions ranging in size from half an inch to 2 feet in diameter. Toward the north in the canyons the rock is medium grained, but on the borders, especially toward the south end, it is finer grained and cuts the adjacent volcanics, as may be seen on Rock Creek near the stage road bridge half a mile southeast of Keswick. The same general relations are found about all the bodies of quartz-hornblende-diorite, and they may be regarded as stocks. The rock is cut by many joints and locally by quartz veins, some of which are auriferous.

Distribution.—The principal area of quartz-hornblende-diorite is that about Shasta, on the western border of the quadrangle, extending northward beyond Minnesota, a station on the mine railroad between Keswick and Iron Mountain, and westward beyond the quadrangle boundary toward Clear Creek.

A smaller area extends from Bayha northward to Pit and McCloud rivers, where the quartz-hornblende-diorite is lighter colored and coarser grained than that of the Shasta area. It varies little in color and there are but few dark portions, possibly early secretions. On the borders it is finer grained, and especially also in the long tongue running northeast near the mouth of the McCloud, where it is in places decidedly porphyritic.

Small areas occur at the crossroads schoolhouse 3 miles south of Bayha, at the falls of Clover Creek, and near Larkin. From the latter a decidedly porphyritic dike extends to the southeast.

Petrographic description.—There are two types or phases of the quartz-hornblende-diorite, the even granular and the porphyritic, of which the former is by far the more abundant. In the even-granular type the feldspar is usually a little more abundant than the quartz, and the hornblende is for the most part scarcely a third the amount of the feldspar, but these proportions vary greatly. In the lightest colored and coarsely crystalline rock there is little hornblende, but in the dark portions, especially the early segregations, it is about as abundant as the quartz and feldspar.

The feldspar is deeply kaolinized, but in polarized light much of it shows the lamellar twinning of plagioclase. Their absence in a few cases may possibly indicate the presence of orthoclase. Grains of epidote are common among the products of alteration in some grains, while scales of sericite prevail in others. The hornblende occurs in small grains and shreds. It is in most cases light brown, but often green and occasionally changed to chlorite A small amount of magnetite is present, and occasionally also, as at the falls of Clover Creek, leucoxene and traces of pyroxene.

Near the boundaries of the areas the rock becomes finer grained, but generally has an even granitic structure. In other places, especially east of Larkin, it is porphyritic. The feldspar in part and rarely the quartz appear as phenocrysts in a granitic groundmass, and the dike-like extension from this mass resembles the dacite-porphyries in texture.

Relation and age.—The age of the quartz-hornblende-diorite can not be closely determined in the Redding quadrangle. The youngest rock it cuts in that region is the Bully Hill rhyolite of early Triassic age. On the other hand, it is older than the dikes of quartz-augite-diorite and hornblendite, which are younger than the Potem and were erupted about the close of the Jurassic. While it is certain that the quartz-hornblende-diorite is of Mesozoic age, its eruption most likely occurred late in the Jurassic.

QUARTZ-MICA-DIORITE.

General description.—The quartz-mica-diorite found in this quadrangle is a gray rock of granitic habit, composed essentially of quartz, plagioclase feldspar (generally andesine), and a black mica (biotite). It frequently contains a small amount of orthoclase, showing its close relation to granodiorite.

Distribution.—There is only one small area of quartz-mica-diorite in the Redding quadrangle, in the southwest corner, a mile from Larkin. This occurrence is a small stock, but there are larger masses, possibly batholiths, farther west. The rock is bright and fresh, forming prominent ledges close to the edge of the plain, where it is quarried to a small extent for curbing and tombstones.

Petrographic description.—The medium-grained holocrystalline aggregate contains quartz and plagioclase in about equal proportions, with irregular scales of brown biotite forming about one-tenth of the mass. The feldspar is generally unaltered and xenomorphic, and zonal structure is common. A few grains of magnetite are present and minute crystals of zircon are rarely included in the quartz and feldspar. A small trace of calcite is present, probably from incipient alteration of feldspar, and a small quantity of the biotite has changed to chlorite.

Age.—The rock, though exposed under the same condition as the quartz-hornblende-diorite, is much less altered and on this account may be regarded as younger, but was certainly erupted before the beginning of the Chico epoch of the Cretaceous.

QUARTZ-AUGITE-DIORITE.

General description.—The augite-diorite of the Redding quadrangle is a dark, fine-grained, basaltic-looking rock which is composed mainly of plagioclase feldspar and augite, with a considerable amount of quartz.

Occurrence and relations.—The principal mass of quartz-augite-diorite in the quadrangle is a long, irregular belt, apparently a great dike, extending from Gray Rocks along the course of the McCloud limestone northeastward and northward almost continuously for over 20 miles to the limits of the quadrangle and to an unknown distance beyond, sending out many branch dikes into the adjoining formations, especially into the Baird and Bragdon, cutting the McCloud limestone into many pieces and enveloping some of them with variable, sometimes conspicuous, contact phenomena. The belt varies in width up to nearly a mile and is fine granular throughout. In shape it is most irregular on the western or concave side, where it adjoins the Baird formation. Although it penetrates both the Baird and McCloud formations, it rises chiefly between them and separates them along their strike for over 15 miles from Pit River to the southern slope of Nawtawakit Mountain. The large masses of limestone are cut across in all directions by many small dikes. Fragmental material resembling tuff was observed at several points, but it appeared in each case to be of local origin in connection with the intrusion and not of surface volcanic origin.

Dikes of quartz-augite-diorite occur in the pre-Cretaceous rocks throughout the Redding quadrangle, but are somewhat more abundant west of the main belt, where it cuts the Copley meta-andesite in the neighborhood of Pit River. A number of them, for the most part highly altered, occur on Squaw Creek, where the hornblendic phase is seen on the road a mile southeast of the Uncle Sam mine. Prominent dikes of comparatively fresh quartz-augite-diorite occur east of the main area, on the slopes of Minnesota and Bollibokka mountains, and also on the southern slope of Bagley Mountain, where it cuts rocks of Jurassic age.

Petrographic description.—Although this rock is often aphanitic, it is holocrystalline. The feldspars, for the most part andesine with some oligoclase, are in part automorphic, but generally the outline is somewhat modified by interferent crystallization. The augite is wholly xenomorphic, and the general structure of the rock is even granular, with a strong inclination to ophitic, characteristic of diabase. The quartz also is xenomorphic and occasionally graphic, as in quartz-diabase.

Augite is by far the most widely distributed ferromagnesian silicate, and quartz is almost always present, so that the most abundant phase of the rock is a quartz-augite-diorite, but other dark minerals occur locally and modify the rock considerably. The most important of these is hornblende, which, though generally absent or present in a mere trace, sometimes becomes abundant and produces a phase which will be considered presently under its appropriate heading.

Biotite also occurs sporadically, but never becomes so abundant as to modify the rock perceptibly. It is in irregular scales and occurs most commonly in a dike which crosses Bailey Creek and the wagon road three-fourths of a mile northwest of Baird.

Hornblendic phase.—The most general variation of the quartz-augite-diorite consists in the presence of pale-brown hornblende, ranging from a mere trace associated with much augite to a predominant amount with only a little augite. The extreme variation in this direction is represented by several dikes in the vicinity of Sherman and 2 miles south, near the forks of Dry Creek. This rock is porphyritic, with phenocrysts of light-brown hornblende from 1 to 9 mm. long and some grains of augite in a groundmass made up of hornblende and plagioclase with a small amount of quartz. The hornblende and plagioclase are present in nearly equal amounts, but the hornblende, being mostly automorphic in slender crystals like those in camptonite, is the more prominent. Part of the feldspar is automorphic, but most of it is xenomorphic, and there may be some orthoclase with the striated plagioclase and the clear granular quartz. There are traces of magnetite and pyrite and other secondary and accessory minerals.

One of the best examples of this hornblendic phase, but without prominent hornblende phenocrysts, occurs along the main road about 1½ miles northeast of Newtown, where it forms a large area which was not outlined against the Bass Mountain diabase on account of the close resemblance of the two in the field.

DACITE-PORPHYRY.

General description.—On Salt Creek and at other points there is a gray to reddish rock which is conspicuously porphyritic, with prominent phenocrysts of quartz and plagioclase embedded in a compact groundmass. The rock is properly a dacite-porphyry, though known to the miners of the region as bird's-eye porphyry.

Distribution.—This rock occurs generally in distinct dikes, but is not abundant. On Salt Creek 4 miles southeast of Gregory it forms an irregular area from which dikes appear to radiate. The greatest length of the mass is only about a mile, extending up and down Salt Creek from the wagon road, and it is scarcely 200 yards in width. The rock has prominent phenocrysts of quartz, but disintegrates easily, leaving much quartz among the residual material. From near the east end it sends off to the southeast a dike which soon runs out, but reappears in sec. 34 with a more easterly course. Another dike just south of the Salt Creek area has the same trend. A short dike extends to the northwest, and two interrupted lines of dikes extend to the southwest, one a little south of west and the other a few degrees west of south. The former appears at two points along Sacramento River in the first mile above Elmore, and reappears on Backbone Creek. At Smiths Gulch, on Clear Creek, in the same direction and beyond the quadrangle boundary, the most typical and conspicuously porphyritic dacite-porphyry of the region occurs. It is No. 90 of the "educational series of rocks," and has been described by Professor Iddings in Bull. U. S. Geol. Survey No. 150, page 233. The other line of dikes extends a little west of south. Crossing O'Brien Creek, it appears on the western slope of O'Brien Mountain and also on the railroad about half a mile below Morley, where the dike has a width of nearly 100 feet and the phenocrysts of quartz and feldspar in a partially granular groundmass are inconspicuous. The only other dikes of this material seen in the Redding quadrangle are on the hill along the road 1½ miles south of the Old Spanish mine, possibly also near by on Sugarloaf, as well as on Stillwater Creek near Lilienthal and in the Black Diamond mine near Bayha.

Petrographic description.—The dike-like projection to the southeast from the quartz-hornblende-diorite near Larkin is quite like the dacite-porphyry, and it is probable that they are

closely related genetically. Although distinctly porphyritic, the dikes are not all equally so. Biotite is rarely present and hornblende is not generally prominent. The dacite-porphyry on Salt Creek is most conspicuously porphyritic and approaches the type material of Smiths Gulch. In its residual sand there are sharp tabular crystals of feldspar over half an inch in length and anhedrons of quartz round like peas. The large feldspar crystals were not affected, but the quartz crystals were partially resorbed by the magma, the crystallographic outlines being removed, and the great majority of the original quartz crystals being left entirely anhedral, of various sizes from that of a small marble down to that of a pin's head; in fact, some may have been entirely resorbed.

The large phenocrysts of plagioclase are made up of many twinning lamellæ of low symmetrical extinction, indicating oligoclase. Small scales of biotite or hornblende are present, but for the most part not in sharply defined crystals; they are included in a microcrystalline groundmass composed of quartz and plagioclase. There are present also small amounts of augite and of magnetite; sphene, zircon, and apatite are included in the other minerals.

Age.—The dacite-porphyry cuts the early Triassic volcanics west of Lilienthal, but does not cut the Cretaceous. Like the quartz-hornblende-diorite, to which it is closely related, its eruption was certainly Mesozoic and probably took place late in the Jurassic.

HORNBLENDITE.

General description and occurrence.—There are two small areas of a panxenomorphic rock composed exclusively or nearly so of hornblende—a typical hornblendite—in the Redding quadrangle. The rock forms a 12-foot dike which outcrops on the railroad three-fourths of a mile north of Keswick and again on Flat Creek, 1½ miles to the northwest, where it may be traced for a short distance by a line of bowlders. A small fragment was found on the mountain slope a mile northwest of Copley, but it was not seen in situ at that place.

Petrographic description.—The rock is coarsely crystalline, with grains from 1 to 9 mm. in diameter. In transmitted light the hornblende is pale brown and pleochroic, with characteristic cleavage. Much of it is bleached, becoming pale green or colorless, with fibrous structure, but both forms in optical continuity appear in the same grain. For the most part the rock is composed almost exclusively of hornblende, with a few grains of magnetite. On Flat Creek, however, the hornblendite appears indistinctly porphyritic. The large anhedrons of black hornblende are so abundant as to overshadow the small quantity of greenish groundmass. The greenish portion is made up chiefly of green hornblende, with much chlorite, magnetite, and calcite, and fine granular quartz, and its original composition could not be determined.

Relations.—The dike of hornblendite cuts the Copley metaandesite and the quartz-hornblende-diorite and possibly may be related genetically to the hornblendic phase of the quartz-augite-diorite found in the same region, though the differences in composition and fabric are considerable and no transition forms were observed.

ANDESITE-PORPHYRY.

A few conspicuously porphyritic dikes with aphanitic hypocrystalline groundmass, composed when fresh of plagioclase, chiefly andesine and augite, are included under andesite-porphyry. The principal area is on Potem Creek, where the irregular dike cuts the Potem formation, but lies for the most part between the strata. The dike has a length of over 4 miles and in places a width of several hundred feet. On the weathered surface the kaolinized tabular phenocrysts of andesine are much more conspicuous than in the fresh rock, where the groundmass is decidedly aphanitic.

On Squaw Creek below East Fork is a dike whose general trend is east of north. It is over a hundred feet in thickness, and the long, narrow phenocrysts, which are locally abundant, are in some places completely absent. The greenish groundmass contains spots of chlorite from the decomposition of augite, and in thin section it is seen that spots rich in augite are poikilitic.

A small mass of andesite-porphyry occurs 1½ miles southwest of Copper City, and several others more or less decidedly porphyritic on the eastern slope of Bear Mountain and the border of Jones Valley. About 5 miles west of Kennett, near the Uncle Sam mine, is a 25-foot dike which is in part decidedly porphyritic, like the andesite-porphyries, but in its microcrystalline groundmass the minerals are xenomorphic and among them there is considerable granitic quartz. Both of these features tend to show the close relationship of these rocks to the quartz-augite-diorite.

SERPENTINE.

The serpentine which occurs in the northwest corner of the Redding quadrangle is part of a large area lying beyond the boundary, about the heads of Slate and Shotgun creeks, where it is so intermingled with gabbro as to suggest their genetic relation. The serpentine is in places vaguely porphyritic, and the pale-green color on fresh fracture contrasts with the reddish yellow of the weathered surface. The serpentinization is almost complete, but in a few thin sections traces of olivine and diallage still remain to show the composition of the original rock from which the serpentine was derived by alteration. From the relative prominence of the mesh structure in the serpentine, it is probable that the original peridotite contained about twice as much olivine as diallage, besides magnetite and chromite and perhaps other accessory minerals. A short distance beyond the quadrangle boundary the serpentine contains large bodies of chromite, which has been successfully mined.

The serpentine penetrates all the adjoining rocks of the Redding quadrangle, showing that it is at least younger than the early Carboniferous. It is supposed to be of late Mesozoic eruption, in connection with many other similar masses in the Coast Range.

TERTIARY.

BASALT.

General description and occurrence.—Basalt is represented in the southeastern part of the Redding quadrangle by a number of distinct flows from different volcanic vents on the slopes of the Lassen Peak volcanic ridge. The rock is closely related to diabase in chemical and mineralogical composition. Since these flows spread over that part of the country the creeks on their way to the Sacramento have cut canyons through them, exposing the underlying Tuscan tuff, Ione, and Cretaceous. The basalt sheets cap the usually flat-topped divides between the streams. The best examples are those along the south side of Bear Creek and between South Cow and Old Cow creeks.

The basalts about Bear Creek are generally gray in color and, though sometimes vesicular from the expansion of steam bubbles, have a porosity corresponding to the miarolitic structure of granite, due to the contraction consequent on crystallization. North of Bear Creek the lavas are often aphanitic and closely resemble andesite. This is especially the case on the divide between Cow Creek and Clover Creek, as well as on Bullskin Ridge, but in the neighborhood of Oak Run stage station the basalt is of the type first mentioned.

Petrographic description.—In thin section the microscope shows the Bear Creek basalt to be perfectly fresh. Where not vesicular it is holocrystalline, with ophitic structure. The round grains of olivine and angular ones of augite, with some magnetite, fill the spaces between the sharp crystals of labradorite. The rock has no trace of porphyritic structure in the field, but in thin section one finds in rare cases a phenocryst of plagioclase full of inclusions and occasionally also a crystal of olivine.

The andesitic type, which is most abundant north of Bear Creek, is hypocrystalline and decidedly microporphyritic. The phenocrysts are chiefly tabular plagioclase, with a small amount of augite and olivine and some rhombic pyroxene, embedded in a more or less felty groundmass full of feldspar microlites, with grains of pyroxene, magnetite, and considerable amorphous base. In this type olivine is never abundant and is sometimes entirely lacking, so that the rock belongs rather to the pyroxene-andesites than to the basalts. In the field, however, it was not separated from the normal basalts.

QUATERNARY.

PYROXENE ANDESITE.

General description and occurrence.—In the canyon of Little Sacramento River from Portuguese Flat southward to the mouth of Sugarloaf Creek there are, at many places, terrace-like benches about 150 feet above the level of the river. These benches are capped by remnants of a sheet of lava which was once continuous from Mount Shasta to the mouth of Sugarloaf Creek, a distance of about 50 miles. The lava escaped from a volcanic vent surmounted by a cinder cone on the southern slope of Mount Shasta and, getting into the narrow valley of the river, followed it until the flowing ceased and the lava congealed. It covered the old river bed completely to a depth of from 50 to 100 feet. Since then the river has cut a new canyon down through the lava sheet into the underlying shales and sandstones, as at Delta, where the gravel of the old river bed is exposed beneath the lava about 35 feet above the railroad and 70 feet above the river.

Petrographic description.—The upper surface of this long flow of pyroxene-andesite is generally somewhat vesicular and in many places decidedly porphyritic, with numerous small crystals of plagioclase, chiefly andesine, embedded in a dark-gray groundmass which the microscope discovers to be made up chiefly of small crystals of plagioclase and grains of pyroxene, with a few of olivine and considerable globulitic base. This andesite is decidedly basaltic.

There are a few small square sections of unstriated feldspar, probably orthoclase. The pyroxene is partly automorphic. Its parallel extinction and faint pleochroism indicate that it is probably bronzite.

Age.—Although this lava flow of the Sacramento is of late Quaternary age and the youngest in the Redding quadrangle, there has been over 50 feet of canyon cutting by the river since its eruption. Locally on the borders of Mount Shasta and Lassen Peak there are other flows of later eruption, coming down to within the last two hundred years.

STRUCTURE.

The Redding quadrangle embraces parts of three topographic provinces and it has structural features allied to each province. The principal of these are the Klamath Mountain uplift, the Copper City arch, the Sacramento Valley syncline, and the syncline of the Great Bend of Pit River. These features are all more or less fully represented on the sections of the structure sheet.

Klamath Mountain uplift.—If all the formations of post-Jurassic age were removed from northern California the consequent topographic changes would be striking, and one of the emphatic features would be the isolation of the Klamath Mountains. The bulk of the Coast Range of California and Oregon, as well as the Cascade Range, all bordering the Klamath Mountains, would have disappeared, but the mass of the Klamath Mountains would remain. Made up of rocks in general like those of the Sierra Nevada, the Klamath Mountains were affected chiefly along parallel lines of deformation running northwest and southeast, but also along others nearly at right angles. In the Mesozoic and Paleozoic rocks of the Redding quadrangle there is evidence of movements along both directions, but, with many small variations, the general dip of the formations, as shown in sections A–A and B–B, is to the southeast and east, away from the Klamath Mountains, in the western part of the quadrangle. This great uplift of the Klamath Mountains began possibly as early as the close of the Paleozoic, certainly as early as the close of the Jurassic, but has been affected since by many movements which have crushed the rocks of the Coast Range, while those of the Sierra Nevada have been much less affected.

Copper City arch.—From the vicinity of Copper City an arch in the Pit formation extends to the southeast toward the Sierra Nevada, bringing to the surface a stretch of Dekkas andesite and Bully Hill rhyolite flanked by the Pit formation, as shown in section D–D, and running under the lavas of the Lassen Peak portion of the Cascade Range. There was an upward movement of this arch after the deposition of the Chico, and again after the Ione was laid down, but the movements were small. The principal movement was pre-Cretaceous.

Sacramento Valley syncline.—The Cretaceous and Tertiary strata along the eastern border of the northern portion of the Sacramento Valley dip gently westward beneath the valley, but rise again to the surface along the western border and mark that portion of the valley as a broad, shallow syncline filled with deposits of a later geologic epoch. This feature is represented in section E–E. The same formations swing around the north end of the valley, connecting the sides, and it is evident that the syncline is rising to the north. Its extension in that direction may be represented by the syncline of Bear Mountain (section D–D), which lies southwest of the Copper City arch and is deep enough to catch the Hosselkus limestone and the tuffaceous conglomerate of the Modin formation in the upper part of Bear Mountain. Both arch and syncline are gentle, but the involved beds are locally much crumpled in a small way.

Syncline of the Great Bend of Pit River.—The broad, somewhat irregular curve of the outcrop of the Hosselkus limestone horizon, from Cedar Creek to beyond the northern boundary of the quadrangle, marks part of the border of a syncline filled by the Modin and Potem formations, of Jurassic age. This syncline is bounded on the north by the Grizzly arch, running east and west just beyond the northeastern limit of the Redding quadrangle, and is composed largely of Carboniferous strata. The eastern extremity of this arch passes beneath the Ione formation and the lavas of the Cascade Range, and both of these terranes have been uplifted, showing that there has been movement along the arch possibly as late as the Pleistocene.

Near the head of Chatterdowen Creek, where the Hosselkus limestone and Brock shale are turned eastward by the Grizzly arch, a narrow syncline extends northwest beyond the quadrangle boundary to the upper portion of Claiborne Creek, where the structure is well exposed.

The syncline of the Great Bend of Pit River and that of the Sacramento Valley lie close together, end to end, and are separated, if at all, only by the low arch running southeastward from Copper City. They represent the great depression in the pre-Cretaceous rocks between the Klamath Mountains and the north end of the Sierra Nevada, a depression which has been filled with the Chico and Ione formations, the Tuscan tuff, and the great lava mass of the Lassen Peak region, thus forming mountains out of later material, so that the Klamath Mountains appear to be continuous with the Sierra Nevada. During at least a portion of later Cretaceous time the Lassen depression was occupied by an arm of the sea, but during the Miocene the water was fresh.

AREAL DISTRIBUTION.

The structural features determine the areal distribution of the formations. The uplifts bring the older rocks to the surface and the depressions or synclines are filled with the newer formations. In the Redding quadrangle the Klamath uplift more than any other feature is expressed in the areal distribution. The general strike of the formations is north and south and the dip toward the east. The older formations outcrop in the western portion of the quadrangle, and the rocks are successively newer toward the east up through the Paleozoic and Mesozoic to the Tertiary and Quaternary.

The most ancient rocks of the quadrangle are volcanic, including the Copley metaandesite and the Balaklala rhyolite, which form a large area and several smaller ones near the western border of the quadrangle. Upon these rests the Kennett formation, which once formed a continuous cover, but by erosion and the eruption of later igneous rocks it has been reduced to a number of isolated patches; in the northwestern part of the quadrangle these are covered by the large area of Bragdon, but the Kennett reappears just beyond the northern border of the quadrangle. Next above the Bragdon is the Baird, whose outcrop, like that of the McCloud, the Nosoni, and the Pit formations, as well as the included volcanic horizons of the Dekkas andesite and the Bully Hill rhyolite, forms more definite north-south belts. The exposure of the Pit formation is widened by the Copper City arch and the syncline to the west, which catches the Hosselkus limestone and part of the Modin formation in the Bear Mountain syncline. In the northeast corner of the quadrangle the distribution of the Hosselkus limestone, Brock shale, and Modin and Potem formations is determined by the synclinal corner of the Great Bend of Pit River. The later formations, Cretaceous to Quaternary inclusive, are limited in their distribution to the Sacramento Valley and the great depression filled mainly by the lavas of the Lassen Peak region which appear in the southeast corner of the quadrangle.

HISTORICAL GEOLOGY.

SEDIMENTARY AND IGNEOUS RECORD.

PRE-DEVONIAN.

The geologic history recorded in the terranes of the Redding quadrangle should be prefaced by a statement concerning earlier events recorded in other portions of the Klamath Mountains, where there is exposed a series of schists, for the most part mica-schists, derived by regional metamorphism from sedimentary rocks. No fossils have been found in them and it seems probable that the schists are older than the Silurian, which is well preserved at one point in the north end of the Sierra Nevada. They are certainly older than the Devonian and give evidence not only of extensive sedimentation, but also of an epoch of metamorphism which antedates the earliest records in the Redding quadrangle.

The first events chronicled in the rocks of the quadrangle consist of extensive, vigorous, and long-continued volcanic activity, beginning with the effusion of a great mass of andesitic lavas (Copley metaandesite) and closing with the Balaklala rhyolite. The eruptions, as far as concerns the Redding quadrangle, appear to have taken place on land, for no marine beds have been found among the lavas, though some of the tuffs are stratified.

DEVONIAN.

Over the whole of the Klamath Mountain region during middle Devonian time deep-sea conditions prevailed, and fine sediments, chiefly shales, often siliceous and full of microscopic shells, were deposited, with occasional lenses of limestone in which corals and some other forms of marine life are especially abundant. The few sandstones found are made up of sediment derived from the earlier volcanics.

The middle Devonian epoch of deposition was closed by an uplift that exposed the consolidated beds of sandstone, shale, and limestone to vigorous erosion, which completely swept away large tracts of the Devonian sediments, exposing the underlying volcanics and paving the way, as it were, for the unconformity between the Devonian and Carboniferous.

CARBONIFEROUS.

Subsidence in the Redding quadrangle initiated the early part of the Carboniferous and the deposition of the Bragdon, with marked erosional discordance, upon the Devonian and earlier volcanics. The uplift and subsidence about the close of the Devonian were not accompanied in this quadrangle by any rock folding, for the bedding in the Bragdon and Kennett formations at their contact is apparently parallel. The fossils show that marine conditions prevailed during the Bragdon, and that the water was shallow is indicated by the fact that conglomerates are common in which the pebbles were derived largely from Devonian sediments, with some from the older lavas. Toward the close of the Bragdon epoch there were eruptions of diabase, and beds of volcanic sand, associated with contemporaneous flows, occur at various places. In the Bass Mountain region, however, the eruptions appear to have been on land and not directly associated with marine deposits.

Between the Bragdon and Baird epochs, both of which are early Carboniferous, there was continuous sedimentation without definite interruption. Volcanic activity became more general. The lavas came from different centers and were more andesitic. Toward the close of Baird time, however, volcanic activity ceased, and the long quiet succeeded during which the 2000 feet of McCloud limestone of the middle Carboniferous was deposited.

Oscillations began and the McCloud limestone was succeeded during the Nosoni epoch, of late Carboniferous age, by shales and sandstones, with an increasing amount of tuff. Pyroclastic rocks, with occasional sheets of basalt or basaltic andesite and rarely also fossiliferous shales, accumulated to a greater and greater thickness northward, indicating that the volcanic source was in that direction beyond Nawtawakit Mountain.

About the close of the Carboniferous and before the deposition of the Triassic there was extensive movement, resulting in mountain uplifts by which portions of the Sierra Nevada and of the Klamath Mountain region appeared above the sea, restricting the area over which the marine sediments of the succeeding period were laid down. So far as yet known the strata of Jurassic and Triassic age are limited to the southeastern portion of the Klamath Mountains, east of Sacramento River. While it is possible that these strata once covered the Klamath region and have been wholly or partially removed by subsequent erosion, the evidence is not yet conclusive and the determination of this point must await further investigation; but there is evidence in the unequal distribution already known that an uplift of the region occurred about the close of the Carboniferous and that it was accompanied by extensive volcanic activity, the igneous masses penetrating and overflowing the sediments of greater age.

TRIASSIC.

The vigorous volcanic activity begun in the late Carboniferous was accompanied, as already indicated, in part of the Klamath Mountains, at the close of the Paleozoic, by a short interval of upheaval and erosion and was then followed by extensive and long-continued volcanic eruptions of the Dekkas andesite and the Bully Hill rhyolite of early Triassic time. It was one of the most extensive and prolific volcanic epochs in the geologic history of northern California and stands nearly midway between the other great volcanic epochs, one in the early Paleozoic and the other in the Tertiary.

During the entire period of volcanic activity embracing the close of the Paleozoic and the beginning of the Mesozoic the eruptions of the Redding quadrangle were submarine, burying layers of characteristic fossiliferous shale. As the eruptions decreased at the close of the volcanic epoch, shales and sandstones began to predominate, with an occasional layer of lava and tuff in the Pit formation. Another epoch of quiescence followed, during which the Hosselkus limestone and the overlying Brock shale were formed.

JURASSIC.

The quiet of the closing Triassic was broken and the Jurassic initiated by volcanism which is represented in the extensive tuffaceous conglomerate at the base of the Modin, a conglomerate which contains, besides volcanic material, fragments of fossiliferous Triassic limestone. The slight unconformity of the Modin conglomerate on the Brock shale is due to changes of elevation in connection with the volcanic activity, but unaccompanied by rock folding. The source of the volcanic material was not discovered. It was of short duration and the succeeding strata were formed of finer sediments locally rich in fossils.

At the beginning of the Potem epoch there were andesitic eruptions of importance, chiefly at two places, Bagley Mountain and a point about 10 miles to the south. They were submarine and furnished much tuffaceous material for the Potem formation.

Between the Potem and the Chico is a conspicuous unconformity which represents a long interval, in part Jurassic but chiefly Cretaceous, and during that interval the geologic changes were more profound than at any other time. The Jurassic part of the interval is represented elsewhere in California by the Mariposa beds on the eastern side of the Sacramento Valley, while the Cretaceous part is represented by the Knoxville beds on the western side of the same valley. They are supposed to be unconformable, but they have not yet been found together in California.

At the close of the Jurassic period came one of the great mountain-building epochs of the Pacific coast of the United States. The rocks were greatly folded, faulted, and crushed, and uplifted, giving to the Sierra Nevada and the Klamath Mountains much greater altitude and extent than they had before. They probably extended northwestward beyond the present coast line so as to occupy a portion of what is now the Pacific Ocean. In connection with the intense dynamic action which formed the mountains, there was vigorous igneous intrusion, for all the beds older than the Cretaceous are intersected by batholiths or dikes of granitic, porphyritic, and aphanitic rocks, whose eruption must have taken place before the deposition of the Cretaceous in that region.

CRETACEOUS.

The epoch of mountain building and igneous activity closed with the Pacific coast of northern California farther west than it is now. The land began to subside more or less continuously and the sea to advance, with interruptions, upon the land, until toward the close of the Cretaceous the waves of the ocean beat against the western base of the Sierra Nevada in California and of the Blue Mountains in Oregon. The Klamath Mountains were chiefly, if not completely, covered by the advancing Cretaceous sea. This is indicated by the fact that not only are the Klamath Mountains practically surrounded by Cretaceous sediments, but isolated patches of Cretaceous strata occur at a number of points in these mountains, so that the evidence is conclusive that a large part if not the whole of this region was beneath the sea at the close of the epoch of Cretaceous subsidence. The same is true also of the foundations of the Cascade Range, and the fineness of the later Cretaceous sediments in the Sacramento Valley indicates that the Sierra Nevada region was reduced by long-continued erosion to one of low relief.

The Cretaceous subsidence of the land and advance of the sea were not without interruption, for at some time during the Cretaceous, probably near its close, there were intrusions of peridotite, which by alteration have given rise to great masses of serpentine. Some gabbros were intruded about this time, and there were such oscillations of the land as to change the succession of strata at many points from what it would have been had the subsidence been regular and continuous.

At the close of the Cretaceous period the Klamath Mountains were again uplifted and the Cretaceous strata in places were greatly crushed, but not so within the Redding quadrangle.

TERTIARY AND QUATERNARY.

The Tertiary period opened with the Klamath Mountains above the sea, and they have remained above ever since. During the Tertiary and the Pleistocene there were many oscillations of the land, alternating with long or short epochs when it was comparatively stable. These movements are registered for the most part in the topographic forms sculptured by erosion and may be most conveniently considered under the heading "physiographic record."

PHYSIOGRAPHIC RECORD.

Topographic provinces.—The three topographic provinces represented in the Redding quadrangle differ widely in origin. The plain of the Sacramento Valley is purely constructional, being due to valley filling leveled by the floods of the Sacramento. The Piedmont Plain bordering the Cascade province is also constructional, being due to volcanic floods from local vents or from larger volcanoes in the main ridge streaming and spreading in a plain toward the Sacramento Valley. The Klamath Mountains, on the other hand, are not built up like the other two, but are lifted up, and the special surface features are degradational, the result of erosion, chiefly stream carving, and will be considered chronologically in connection with the contemporary sedimentary and igneous record.

EOCENE, OLIGOCENE, AND MIOCENE.

During Eocene time California north of the fortieth parallel was wholly above sea level and received no marine deposits, though such extend north in the Sacramento Valley to Marysville Buttes and south along the coast of Oregon to Rogue River.

The Eocene was closed by a disturbance which folded the strata before the deposition of the Miocene, producing slight changes in the form and size of the land areas. An arm of the sea filled the Sacramento Valley, but at its north end the water was comparatively fresh. It extended northeast through the Lassen depression and received the thick deposit of fine sediments that make up the Ione formation.

Klamath peneplain.—The long-continued erosion of the Eocene, Oligocene, and Miocene reduced the Klamath Mountains and the Sierra Nevada region to a peneplain, which in the region first named is known as the Klamath peneplain. The low relief is indicated not only by the fine character of the sediment in the Ione, but also by the character of its fossil flora, which is that of a flat coastal region whose climatic conditions were similar to those of Florida.

PLIOCENE.

The volcanic eruptions which contributed to the Tuscan tuff took place chiefly in the Pliocene and were subsequent to an upheaval which led to the erosion of the Ione in the Redding quadrangle before the Tuscan tuff was deposited. The great volume of volcanics completely filled the Lassen depression, covering the Ione formation and many of the ancient streams of auriferous gravel on the western slope of the Sierra Nevada and, north of the fortieth parallel, forming the Piedmont Plain toward the Sacramento.

QUATERNARY.

Differential uplift began near the close of the Miocene and continued at intervals, with long halts and occasional subsidences, through the Pliocene and Quaternary, until some parts of the Klamath peneplain reached an elevation of nearly 7000 feet above the sea. This peneplain is also bordered by other similar but later plains of erosion whose relations have not yet been fully traced out. The uplift, which was slow but intermittent, greatly invigorated erosion, and the streams carved out their valleys wider or narrower in response to the grade imposed by the differential changes of level. One of the early stages recorded in the Redding region produced the wide elevated valleys illustrated by the earlier valley of Pit River. This is closely related in level to the Potter Creek cave, concerning whose fauna Mr. Sinclair remarks: "Associated with mountain and forest types like *Haplocerus* and the deer are plains species—the horse, camel, bison, and elephant," a combination which accords with the gentle relief with which it is associated on the border of a great river valley. According to Mr. Sinclair, "the types present, as well as the proportion of living and extinct species, indicate that we are dealing with an assemblage of forms of later Quaternary age."

The earlier-valley interval was closed by an uplift which changed the grade of the streams, causing them to wear away their beds and cut the narrow, canyon-like valleys which have been designated the later valleys. The uplift was long continued, with intervals of stability which permitted the streams under favoring conditions to widen their valleys slightly, as at Keswick and around the northern border of the Sacramento Valley, where the Redding quadrangle laps over upon a bordering peneplain. The final valley filling or aggrading of the north end of the Sacramento Valley with the Red Bluff formation was completed at this time, though the deposition of the older portion of the Red Bluff on the valley bottom began long before, at the time when the later-valley cutting was initiated. Another uplift at the close of the Red Bluff epoch increased the bottom cutting once more, and the streams carved out the narrow valleys in which we now find them. The uplift was circumferential about the northern part of the Sacramento Valley, but greatest on the east, less on the north, and least on the west, as evidenced by the various canyons and alluvial plains developed.

ECONOMIC GEOLOGY.

MINERAL RESOURCES.

Metalliferous Deposits.

Shasta County has long been celebrated for its mineral products, and for five years was the banner county of the State. Gold, silver, and copper are its principal products, and to copper it owes its preeminence. The value of its products rose from a total in 1897 of $2,224,706 to $6,737,571 in 1901, but owing to a decline in the price of copper and the occurrence of miners' strikes the total output was reduced in 1902 to $3,730,049 and in 1903 to $3,201,680, but in 1904 it rose again to $3,402,517. Although Shasta County embraces almost four times the area of the included Redding quadrangle, the greater part of the mineral values of the county now comes from within the quadrangle or from very close to its borders. The following table, compiled chiefly from data secured by Mr. Charles G. Yale, of the United States Geological Survey, gives a summary of the mineral production of Shasta County for 1904:

Mineral production of Shasta County in 1904.

Gold:		
From placers	$21,082	
From siliceous ores	641,272	
From copper ores	369,813	
		$1,032,167
Silver		399,686
Copper		3,402,517
Lime		10,800
Limestone		5,400
Chromite		2,250
Pyrite		5,500
Macadam		1,500
Brick		17,500

The silver is obtained chiefly from copper ores.

GOLD.

The gold obtained in the Redding quadrangle may be conveniently considered, according to its source, in three parts: (1) Placer gold, (2) gold from quartz veins, and (3) gold from copper mines.

Placer mining.—Placer gold was discovered in California by James W. Marshall in 1848, and the wave of prospectors early reached the Shasta region. At first mining was confined to the beds and bars of present streams, and until 1854 nearly all the gold produced in California came from this source. The maximum production of gold in California was nearly $68,000,000 in 1853, but as the shallow placers were worked out the higher gravels of the ancient streams were attacked by the more expensive hydraulic methods, and the yield of placer gold was kept up for many years, though on a reduced scale. The restrictions placed on hydraulic mining within the Sacramento drainage, which includes the Redding quadrangle, have materially reduced the annual yield in that region. Of the thirteen placer mines reported by the State mining bureau in March, 1902, in Shasta County, twelve are in the Redding quadrangle, one each near Slatonis, Copley, Redding, and Delamar, three near Delta, on Dog Creek, and five near Copper City, but their combined yield is not over a few thousand dollars. They are chiefly on low stream terraces and are worked during the rainy winter and spring, but in some cases on present stream beds the mines are worked at low water during the summer.

In the Redding quadrangle there were three localities in the early days where placer mining was especially active and productive—in the vicinity of Shasta, about Buckeye, and between these two localities at Old Diggings, near Sacramento River.

The Buckeye district embraced only shallow gravels and residual material of that portion of the peneplain about the head of Buckeye Creek and its tributaries, and could be worked only in the wet season. In 1881 $14,000 was reported from this district, but in late years the output has been very small. The gold is evidently derived from the auriferous quartz veins which intersect the ancient igneous rocks of the region. The long period of degradation incident to the development of the peneplain about Buckeye has greatly favored the concentration of placer gold in the vicinity.

The group of placer mines near Shasta was most active in the early days and, according to the census reports, yielded $25,920 in 1881. This, of course, is small compared with their original annual production, and they are now practically exhausted. Interest at present centers in rock mining, from which the bulk of the precious metals is obtained.

During the summers from 1902 to 1905 a suction dredger was used in Sacramento River near Middle Creek, above Redding. This work has been carried on in a small way more or less irregularly for a number of years, with varying results.

On Clear Creek below Horsetown, near the southwest corner of the quadrangle, a chain-bucket dredger was installed in 1903 on ground which, judged from the early yield of that region, should be rich. Difficulties were encountered and the dredger was burned, but it has been rebuilt and operations continued.

Vein mining.—With the decline of placer mining the source of the placer gold was sought farther up the same streams, and many claims were filed on quartz veins containing free gold and sulphides. Some of these veins have been worked with limited success, but on the whole they have been of too low grade for even moderate results unless worked under the most auspicious circumstances. Such a favorable opportunity occurred in supplying the demand of the Keswick smelter for siliceous ores to flux the copper and iron sulphides, and for several years a number of the mines in that vicinity, especially near Old Diggings, have been worked for this purpose, but with a total shipment, in large part of carefully selected and graded ores, amounting to not over 500 tons per month during the summer of 1903. This amount must have been greatly increased during the last two years to meet the demands of two new smelters.

The country rock of the auriferous quartz veins throughout, with the exception of the Shasta region, is essentially the same as that of the copper-ore bodies and consists of an ancient series of igneous rocks, andesites and rhyolites, so altered by pressure in many cases as to closely resemble slate. Although most of the mines are shallow, some of them, especially at Old Diggings and farther northwest on Squaw Creek, have reached a depth of 500 feet and indicate a considerable degree of continuity.

Most of the mines about Old Diggings, especially the Central, Evening Star, Mammoth, and Spanish, are working to a greater or less extent. All are on rather irregular but nearly parallel quartz veins, whose general course is a few degrees east of north (dip about 85° SE.), and have been worked in that direction as far as the National mine. The veins range in thickness from a few inches to 18 feet and carry disseminated pyrite and chalcopyrite. The Central mine is at present the largest producer of the Old Diggings vicinity and furnishes the bucket tramway over which the other mines ship their ore across Sacramento River to the Southern Pacific Railroad.

A group of veins about Quartz Hill have been worked and have furnished some ore for the Keswick smelter. The largest vein of the hill is not less than 40 feet in thickness, with a strike of N. 45° E. and a dip of 65° SE., but only the central portion has been removed. The northeastern extension of the veins of this region has furnished the gold for the early rich placers of the Buckeye region and may yet be the scene of greater activity.

A short distance southeast of the Old Spanish mine, about 3 miles west of Redding, the Crown Deep and Bracket mines were active in the summer of 1903, and were shipping ore to Keswick. The veins of these mines are less regular than those of the other regions and generally strike N. 12°–40° W., though at the Old Spanish mine the strike is usually N. 12°–35° E. At the Bracket and Crown Deep mines the veins are crushed in places and the intermingled vein material appears to be of several ages.

The auriferous quartz veins of the Old Spanish mine and Shasta region are in granodiorite, though they too belong to the same system as those already referred to; but thus far none of those in the granite have proved more durable than those in the other igneous rocks.

The quartz mines of Squaw Creek west of Kennett are of interest as being among the oldest and most extensively worked of the region. The Uncle Sam ran ten or more stamps for about a dozen years with a chlorination plant, and drifted on the vein for 1500 feet at a level about 500 feet beneath the cropping. An incline was sunk on the vein from the main level to 1040 feet beneath the surface. Two veins which combine strike nearly northwest and southeast and dip northeast, with a thickness ranging over 4 feet for much of their extent. The quartz contains locally disseminated pyrite, chalcopyrite, and occasional traces of free gold. The greater values were found in the upper part of the eastern portion of the mine, about a dike of andesite-porphyry which probably effected the enrichment of the vein. The mine was recently bonded and thoroughly prospected by the Trinity Copper Company.

The group of quartz veins about the Uncle Sam, extending from the Riley and Bliss to beyond the Clipper, are at an elevation of 2000 feet or more on North Fork of Squaw Creek, and are conveniently located to furnish siliceous ores which may be needed at the Mammoth smelter in treating the large bodies of copper ores of the same region. These veins generally strike about N. 50° W., but there are exceptional cases where they strike nearly east and west.

On Dog Creek, about 4 miles southwest of Delta, a mass of rhyolitic rock occurs, locally impregnated with sulphides and traversed occasionally by quartz veins. Half a dozen groups of claims have been located at this place in the Redding quadrangle, but none are now working. The only mine in the region now shipping ore is the Inca. A tunnel follows the small decomposed quartz vein N. 65° W., and only the carefully assorted ore is shipped in bags.

Gold associated with copper.—In the table already given it will be seen that a large part of the gold product of the Redding quadrangle comes from the copper mines. The leaching of the pyritiferous copper ores near the surface to form the gossan which characterizes such bodies removes the copper, but leaves most of the iron in the form of limonite, and with it the bulk of the gold and silver, so that in the early days the mines were opened and worked for gold and silver only, and it was not recognized until later that large bodies of copper ore were lying below. The presence of a small amount of the precious metals makes it possible to mine a comparatively low-grade copper ore at a profit.

SILVER.

With the mining of copper in the Redding region in 1897 the associated silver product of Shasta County greatly increased, and since then Shasta County has yielded more silver annually than any other county of the State. The product within the quadrangle is now derived wholly from the copper mines.

COPPER.

Within a decade California has come into prominence as a copper-producing State and at present is fifth in rank. This advance has brought Shasta County to first rank in the State as a source of mineral wealth, the greater part of which comes from the Redding quadrangle or from very close to its borders. The total copper product of California for 1904 was valued at $3,786,022, of which Shasta County yielded $3,402,517, an increase for the county of $1,231,020 over the product of 1903.

Although mines now operated for copper were located as early as 1862 near Copper City for gold and silver and their copper contents were noted, the real exploitation for copper in the Redding region began in 1895, at Iron Mountain, when that property came into the possession of a London syndicate.

COPPER DISTRICTS.

The copper region of Shasta County, about 30 miles in length and scarcely half as wide, extends nearly east and west across the middle of the Redding quadrangle and embraces two actively producing districts, Iron Mountain and Bully Hill, which are separated by a dozen miles of country where as yet no large bodies of copper ore have been found.

The Iron Mountain district is the largest and by far the most important of the region. Iron Mountain lies just outside of the border of the Redding quadrangle, northwest of Keswick, and from this locality the district extends nearly northeast for 25 miles, to beyond the Mammoth mine, and has a width of scarcely 2 miles. It comprises the holdings of the Mountain Copper Company, Balaklala, Trinity Copper Company, Mammoth, Summit, and a number of other companies.

The Bully Hill district, an area scarcely 3 miles north and south by 2 miles east and west, includes the Bully Hill and Copper City tracts, besides a number of prospected claims on the slope south and southwest of Horse Mountain.

The Afterthought, at the east end of the copper region, has recently become a producer. The Black Diamond, though not a producer, deserves consideration on account of the exceptional mode of occurrence of its deposits.

The country rock of the copper deposits is essentially the same throughout, though not all of the same age. It is chiefly rhyolite, with a smaller proportion of metaandesite and tuff and here and there a trace of included sediments. The copper-ore deposits are limited to lines or zones of disturbance in which the country rock is crushed and sheared, thus preparing the way for circulating waters and greatly enhancing the possibilities of mineral solution and deposition.

FISSURE SYSTEMS.

The rocks of the copper region have experienced disturbances at many periods extending over a wide range of time. These have doubtless varied greatly in intensity from time to time, but each is recorded in corresponding flexures and fractures of its own, producing a very complex aggregate, in which it is not only difficult but practically impossible to assign with certainty every effect to its period. The matter may be rendered clearer by considering the fissures in three groups—(1) earlier fissures filled, at least in part, by igneous rocks of pre-Cretaceous eruption, (2) fissures bearing ore deposits, and (3) fissures of late Cretaceous or post-Cretaceous age.

Earliest fissures.—These fissures, including a very large group through which from the earth's interior the numerous igneous rocks of the Redding quadrangle at various times reached the surface, are of earlier date than those which contain the ore deposits under consideration, for the ores are found in the igneous rocks which fill the earlier fissures. It is possible that there were ore deposits of importance antedating the Town Mountain series of igneous rocks or those of later Jurassic age and that they were modified or completely removed by subsequent erosion, but of such deposits distinct evidence has not been found.

Ore-bearing fissures.—The fissures which gave access to mineral-bearing solutions and thus permitted the formation of deposits of copper and auriferous quartz originated chiefly during the epoch of rock crushing and mountain making about the close of the Jurassic. This is indicated by the fact that the fissures bearing ore have been found in Jurassic rocks, but not in the Cretaceous.

All the important ore-bearing fissures in any district have been generally supposed to be approximately parallel, while those of different districts are more or less oblique. This is true of the smaller districts only, and the discordance is apparent only when we compare the general direction of the whole region with that of the separate districts. The greatest extension of the copper region is in a direction about N. 80° E., while that of the several districts ranges from N. 50° W. to N. 32° E.

The general trend of the Iron Mountain district is N. 32° E., but the strike of its ore-bearing fissures rarely conforms to this general direction. Perhaps the closest approach is in the southwestern part of the district, where the general course of the bodies is nearly northeast. In the middle portion of the field, about the head of Motion and Spring creeks, the strike of the ore-bearing fissures varies, but the principal ones usually run about N. 70° W., while in the north slope of Balaklala Mountain and beyond Squaw Creek their general course is more nearly N. 70° E., though locally diverted. The rocks are much sheared, and in all parts of the district the fissures containing the ore deposits are usually those that show the greatest shearing.

In the Bully Hill district the principal ore-bearing fissures course about N. 10° E., parallel with the greatest extent of the producing district, though there are local variations of minor importance.

In the Afterthought district the principal fissures range from N. 50°–60° W., parallel to the greatest extension of the district and also to the axis of an arch in the rocks, which stretches from the Klamath Mountains toward the Sierra Nevada.

The wide range in the direction of the ore-bearing fissures of the copper region is due to the fact that, as the region lies near the borders of the irregular Klamath Mountains, next to the Sierra Nevada, it has experienced earth strains of an especially wide range in direction.

In dip the ore-bearing fissures are usually vertical or at a high angle, but several prominent variations from this general rule occur in the northern portion of the Iron Mountain district, at the Shasta King and Mammoth mines, where the dip westward flattens and locally may be even reversed.

Fissures of late Cretaceous or post-Cretaceous age.—The ore bodies are traversed by occasional fissures which must be of later origin than the ore itself. Movements have occurred along these fissures, faulting the ore. Rarely the ore body is sheared and schistose like the adjacent country rock, and occasionally the shearing involves the bornite as well as the pyrite. Generally, however, the ore body is contrasted with the country rock by the absence of fissuring.

By far the greater part of the fissuring and movement affecting the ore bodies has probably taken place along their borders, which are sometimes polished (as in the Hornet mine), while the country rock is sheared and altered to a whitish gouge or selvage consisting generally of a mixture of clay and sericite. The fissures of later origin within or near the ore bodies sometimes contain secondary ores such as chalcocite, malachite, azurite, native copper, or quartz. While it is certain that some of the irregularity of form and distribution of the ore bodies is due to recent faulting, a large part is attributable to lack of regularity in the original deposits.

DISTRIBUTION OF ORES.

So far as yet known ore bodies of economic value have been found only in the Balaklala and Bully Hill rhyolites. At a number of points they occur near the contact with sedimentary rocks, but not within them. However, it is not improbable that such may yet be found, for similar deposits are known at Rio Tinto, Spain, in slates.

The Balaklala and Bully Hill eruptives, made up chiefly of ancient rhyolites, with andesites and tuffs and small masses of included sediments, the whole intersected by various dikes, afford a wide range in the chemical composition and physical condition of the country rock. The copper-ore bodies are usually found in the rhyolitic rocks, but occur also in the more basic forms or on the contact between the two. The limited general examinations of the mines made thus far do not disclose marked variation in deposit values due to variation in the country rock, and yet there are suggestions in the Bully Hill and Iron Mountain districts that such may be the case in the neighborhood of dikes.

The ore bodies are found in irregular fissures along which there has been much shearing, so that a narrow zone of the adjacent rock is often rendered fissile. The form of the ore body is as a rule irregularly lenticular, of unequal planar diameters in the shear zone. Its extent along the strike is usually less than that along the dip. Its direction of greatest extent often makes a small angle to the dip and lies in the "rake" or pitch of the ore body. In size these lenticular bodies range from a fraction of an inch to hundreds of feet in diameter. They succeed one another in the same irregular, more or less continuous shear zone, or they may be in adjacent parallel shear zones. The greatest distance to which any closely related but disconnected series of ore bodies in the same shear belt has been traced is not over a mile.

Concerning the depths of ore deposits comparatively little can be said. The deepest mine is less than 1000 feet deep; another within the Redding quadrangle has not been followed more than 700 feet beneath the surface. The present character of the ore, however, indicates rather an increase than a decrease in its essential values with increasing depth.

ORE AND GANGUE MINERALS AND THEIR RELATIONS.

Pyrite (FeS_2) is generally by far the most common and abundant mineral of the ore deposits, sometimes occurring alone in relatively pure masses, but more frequently carrying a mixture of chalcopyrite and sphalerite. Not infrequently in such mixtures the ore has a decidedly schistose structure, the darker bands being formed chiefly of sphalerite. Pyrite occurs also locally disseminated through the country rock adjoining the ore bodies and elsewhere. The bulk of the pyrite is one of the primary minerals, but it occurs also to some extent among the minerals of later date, especially where it forms drusy linings on joint planes cutting the ore bodies.

Chalcopyrite ($CuFeS_2$) is the chief source of the copper mined, and, though occurring as rather pure irregular masses within the ore body, it is generally disseminated with sphalerite through the pyrite. It so grades into the pyrite in color that it is very difficult to estimate the relative proportions of the two minerals. In the copper region of California the chalcopyrite and pyrite appear to be of the same age and generally primary, except in the zone of enrichment beneath the gossan, where the former is occasionally found in joint planes cutting the ore body and is undoubtedly secondary.

Bornite ("horse-flesh ore" or "peacock ore," Cu_3FeS_3) has been observed locally in the Bully Hill mine, where it occurs at one point near the zone of oxidation and from there downward at intervals, intermingled with pyrite, chalcopyrite, galena, barite, and sphalerite, to the bottom of the mine, or the 570-foot level (October, 1903)—about 820 feet below the summit of Bully Hill and 1180 feet above sea level. On a fresh fracture it generally has a peculiar reddish-brown color which tarnishes on exposure and becomes iridescent purplish blue. In the ore deposits at Butte bornite originated in the alteration of pyrite. It is probable that the same is true at Bully Hill, where the bornite appears to penetrate the pyrite and chalcopyrite along the fissures, but the matter could not be definitely settled from the thin sections examined.

Chalcocite (copper glance, Cu_2S) occurs, generally in the form of nodules, but sometimes as a fine black powder, at Bully Hill, chiefly just beneath the zone of complete oxidation. It is often associated with green or rarely blue copper carbonates (malachite and azurite) at the bottom of the gossan, or in the sheared borders of the ore body to a depth generally of a few hundred feet. In November, 1903, it was found with bornite on the 570-foot level at Bully Hill, much deeper than ever before in that locality. It has a dull blackish lead-gray color and is massive rather than distinctly crystalline. As a source of copper thus far, even where it is most abundant, it is of much less importance than chalcopyrite, on account of the small size of the masses. Small veins of chalcocite occur in pyrite and chalcopyrite, and it is evidently of later origin than either of the others. It penetrates and envelops chalcopyrite in such a way as to suggest its derivation, at least in part, from chalcopyrite.

Tetrahedrite (gray copper ore, $Cu_8Sb_2S_7$) is reported by Mr. Keating and is possibly present locally in the ore of Bully Hill, for some antimony has been found by the assayers.

Cuprite (red oxide of copper, Cu_2O), in a nodule of considerable size, was observed and a specimen collected by Mr. Oxam, mine superintendent (1902), in the clay selvage at Bully Hill, about 6 feet from the ore body and 150 feet from the surface.

Malachite (green carbonate of copper, $Cu_2Co_4+H_2O$) forms a green stain, small streaks, and nodules on the sheared border of the ore bodies at Bully Hill, just below the gossan, with chalcocite, very rarely azurite, and a larger amount of secondary quartz.

Azurite (blue carbonate of copper, $Cu_3C_2O_7+H_2O$) is rare at Bully Hill, occurring with malachite.

Native copper (Cu) occurs sparingly at many places in the joint planes of the zone of oxidation or commingled with the oxidation products.

Chalcanthite (blue vitriol, $CuSO_4+5H_2O$) is common in the oxidizing portion of nearly all mines along water seepage and damp places, but is generally associated with melanterite (green vitriol or copperas, $FeSO_4+7H_2O$). Some bluish-green vitriol in the mine tested yielded much iron and only a trace of copper.

Sphalerite (zinc blende, ZnS) is widely but not uniformly distributed, occurring apparently in all the ore bodies with pyrite, chalcopyrite, and galena. Like the chalcopyrite, it is generally disseminated, but occasionally forms unsymmetrical masses of considerable size in which there is little else. Locally it occurs with pyrite and chalcopyrite in streaks, giving the mass a decided schistose structure. Although crystalline in structure, it has no crystal outlines, even when, like pyrite and chalcopyrite, it is scattered through the country rock. The occurrence of sphalerite, chalcopyrite, and galena in the unaltered ore bodies indicates that sphalerite is one of the primary minerals of the ore deposits.

Galena (PbS), like bornite and chalcocite, was observed only at Bully Hill, where it occurs in places rather abundantly in some of the ore bodies near the zone of oxidation as well as at the bottom of the mine (elevation, 1180 feet). It occurs also sparsely disseminated through the ores and country rock locally, but most commonly in connection with chalcopyrite, bornite, and sphalerite, and is the primary ore mineral that may carry the silver values.

Native silver (Ag) is of the same occurrence as native copper, but rarer.

Wad (impure hydrated oxide of manganese) is found in relatively small quantities, limited to the zone of oxidation at Copper City and possibly elsewhere. It occurs as nodules in the gossan or in the sheared country rock bordering the upper part of the ore body. Its brownish-black color and very light weight are features which readily distinguish it from the black powdery form of chalcocite.

Limonite (brown hematite, $Fe_2O_3+3H_2O$) forms the bulk of the gossan, which is often cavernous, with beautiful, iridescent, stalactitic, and botryoidal lining. It results from the oxidation of the pyrite and chalcopyrite, and is limited to the zone of oxidation near the surface.

Barite ($BaSO_4$) is the most abundant gangue mineral. It is distributed throughout the ores of the Bully Hill and Afterthought districts, but is always disseminated in fine particles, so small in amount compared with the ore minerals as to be scarcely visible to the naked eye. In the eastern districts it occurs from the surface to the greatest depths yet attained and appears to be one of the primary minerals of the ore bodies. Rarely it occurs in cavities as small tabular crystals, and at Copper City it has been found in small veins cutting the ore. There appear to be at least two generations of barite. In the Iron Mountain district, where quartz is the principal gangue, barite was found locally by Mr. A. H. Brown in the Golinsky mine, and traces were seen elsewhere north of Squaw Creek. Barite is most common among copper and lead ores, while quartz is associated with pyrite. As the feldspar of the rhyolite in Bully Hill contains barium, the barite may come from its alteration.

Quartz (SiO_2) is the usual gangue mineral of the copper ores in the Iron Mountain district, as barite is in the Bully Hill and Afterthought districts. It is even more finely disseminated than barite, though occasionally it is visible to the naked eye. Nowhere is it so abundant as to form a conspicuous part of the ore bodies, or to suggest that these are quartz veins. At Bully Hill it is not common, but was seen disseminated with pyrite on the 570-foot level, while near by barite occurs in the portion of the ore body richer in chalcopyrite and other copper minerals. Quartz was seen with pyrite nearer the surface in the north and elsewhere about Bully Hill to a very limited extent. The quartz intermingled with primary pyrite is regarded of essentially the same age, but it also occurs secondary as veinlets and irregular masses of small size with the carbonates in the zone of oxidation.

Calcite ($CaCO_3$) occurs locally as gangue in bands of chalcopyrite in the Afterthought, and rarely also elsewhere in the lower portion of the zone of oxidation.

LODES AND PROSPECTS.

The term lode is here used to include all the ore bodies in essentially the same shear zone. Rarely they are 100 feet in width and a mile in length, and several may occur in each ore-bearing tract within a district.

Bully Hill.—The Bully Hill district has two ore-bearing tracts, Bully Hill and Copper City, besides a number of prospects which have not yet revealed important ore bodies. At Bully Hill there are two lodes which are being worked—the eastern or Delamar lode in the Bully Hill mine, and the western or Anchor lode in the Rising Sun mine.

The Delamar lode was early opened on the southern slope of the hill, but the deeper workings are somewhat farther north. The general course of the lode is about N. 10° E. and the dip approximately vertical. Including interruptions, it has been traced less than half a mile, with a width varying from a few feet to nearly a score and a depth of about 800 feet (elevation, 1180 feet). The shear zone is more or less distinct throughout and contains irregularly lenticular ore bodies, some of which have been very rich. A dike of basaltic rock (the so-called porphyry), greatly altered, cuts through other igneous rocks and slates of the eastern slope of the hill, and the shear zone follows approximately the general course of the dike, either cutting the dike or on the contact between it and the rhyolite (Bully Hill quartzite), but, so far as yet observed, the shear zone of the Delamar lode does not enter the rhyolite. The walls are sometimes sharp, but in many places indistinct, grading into the material of the shear zone. The ore is, however, almost always easily separable from the country rock.

The ore bodies of the lode are very irregularly distributed in the shear zone in overlapping, en échelon, or linear-discontinuous arrangement, usually connected by small stringers. They vary in size from lenticular or sheet-like nodules a few inches wide up to bodies hundreds of feet in length and nearly a score of feet in thickness. The greatest extent of the ore bodies appears to be in a nearly vertical direction, pitching steeply to the north. The crushed rock of the shear zone is not always mineralized, but it is generally more or less richly impregnated with ores and sometimes completely replaced.

The zone of complete oxidation in the Delamar lode consists largely of limonite, but is frequently a breccia in which limonite is the cement binding the fragments of the country rock. Rarely the limonite forms small iridescent cavities lined with stalactites. It results from the oxidation of the ores by circulating waters, which carry away the copper, zinc, and lead, leaving most of the gold and silver behind with the iron. Some of the dissolved metals may have been entirely removed, but a large part of the copper found its way downward and was added to the ore body, greatly enriching the lode below the gossan. The lower limit of the gossan descends irregularly, deep into the ore body along fissures, but the contact is usually abrupt and marked by more or less black powdery ore.

In the upper part of the enriched zone the ore is usually black from the presence of chalcocite and galena, but at greater depths, with some exceptions, pyrite and chalcopyrite generally give their color to the ore. In the upper ores of the zone of enrichment, mined some time ago from the Delamar lode, the proportion of copper was so high that an iron flux had to be added in smelting; but in those below, which are now being removed, there is a greater percentage of pyrite, and no iron flux is necessary. Near the gossan copper carbonates occur, with chalcocite and rarely cuprite and native copper on the sheared borders of the lode. The body of the lode is composed of pyrite, chalcopyrite, chalcocite, bornite, sphalerite, and galena in varying proportions. Pyrite is generally most abundant, but locally it may be surpassed by an increase in one or more of the other ores. Chalcocite is generally limited to within a hundred feet of the gossan, but has lately (November 16, 1903) been reported by Mr. Keating to occur with bornite on the 570-foot level, where its occurrence is of especial interest as lowering the probable extent of the zone of enrichment.

The Anchor lode is approximately parallel with the Delamar and lies over 200 yards to the west, with a known length of about one-fourth mile. It is wholly within the rhyolite locally known as the "Bully Hill quartzite." It has been traced farther south than the Delamar lode and opened by a tunnel and shaft in the Rising Star mine to a depth of about 200 feet from the surface, or to an elevation of about 1300 feet above the sea. The gossan scarcely reached the surface at the Rising Star, but is well developed beneath. In the irregular ore body pyrite, chalcopyrite, sphalerite, and chalcocite vary greatly in relative proportions. Chalcocite penetrates the ore body in veins and is clearly secondary. Locally sphalerite is abundant, and near it chalcopyrite may prevail. Farther north on the same lode, where reached by tunnels 4 and 7, galena appears, as in the Delamar lode. The surface of the Anchor lode has been traced into the summit of Bully Hill, where granular pyrite prevails in old openings. Locally in this lode, as in the Delamar, quartz is the very sparse gangue of pyrite, while barite, somewhat more abundant, is the gangue of the richer copper ores. Generally in this district the greater values are found with barite. Little is known of the northern part of the Anchor lode in depth, but the persistence of the Delamar suggests interesting possibilities.

Ore bodies of comparatively small size have been found in the North Star, Ydalpom, and other openings in the rhyolite on the west slope of Bully Hill. They apparently belong to a third zone west of the Anchor lode. Pyrite, chalcopyrite, and other ores were observed, with a larger amount of quartz gangue and some calcite.

The Copper City lode has a known length of less than one-fourth mile and a width locally up to about 5 feet. It was discovered and mined as early as 1862, when some of the ore was shipped to Swansea, Wales, for reduction. Later, mills were erected to work the decomposed material of the zone of oxidation, but when the sulphide bodies were reached the project failed and mining activity nearly ceased. Recently the property has been developed, in connection with that of Bully Hill, to a depth of several hundred feet. The shear zone in which the lode occurs traverses rhyolite like that of Bully Hill and locally gives to it a decidedly slaty structure. In the main tunnel east of the lode the rhyolite clearly cuts the slates and includes slate fragments. Although ore bodies were seen close to the slates none were found in them. The shear zones of the Bully Hill and Copper City tracts may traverse the slates between them, but important mineralization appears to have taken place only in the igneous rocks.

The general course of the lode, where recently worked by the Bully Hill Company, is N. 50° E., and the dip is vertical. The ore is pyrite and sphalerite, with chalcopyrite in varying proportions and barite as gangue. In 1902 this lode was worked in connection with the Bully Hill mine, but in 1903 activity in the Copper City tract was confined chiefly to the Arps and Tamrack prospects.

West of the Bully Hill district, near the summit of Horse Mountain, is an interesting occurrence of native copper, very small particles of which are sparsely scattered through a mass of altered igneous material, chiefly of volcanic breccia or conglomerate of siliceous lavas. Farther southwest, near the head of Potter Creek, a number of prospects show distinct traces of copper ores, but as yet no considerable ore bodies have been disclosed.

Afterthought.—The Copper Hill lode, in the Afterthought district, was worked years ago and has lately been revived and become a producer. It consists, so far as known at present, of two short, nearly vertical ore bodies which strike about N. 55° W., parallel to the Copper City arch. The two bodies are nearly parallel and stand en échelon, approximately 350 feet apart. One of them in 1903 had been prospected to a depth of over 100 feet. They lie close to the contact in rhyolite that incloses fragments of slate. Like those of the other districts, they are composed largely of pyrite, sphalerite, chalcopyrite, and galena, with local traces of bornite. The gangue, which forms less than 5 per cent of the ore, is barite, with a trace of calcite.

Several years ago this property was purchased by the Great Western Gold Company. Development has since gone far beyond the limit of 1903. A smelter has been erected and is now said to be shipping matte to an eastern refinery.

The Donkey mine is on the strike of the Copper Hill lode, a mile farther southeast and in the same rocks, but the workings were water filled in 1903, and an examination of the ore in place was therefore impracticable.

Black Diamond.—The Black Diamond district is near the center of the copper region, about 14 miles northeast of Redding. Its ore bodies are contact deposits and therefore decidedly unlike those of other portions of the copper region.

The country rocks are limestone and quartz-augite-diorite. The former is the McCloud limestone, of Carboniferous age, and is cut to pieces by the fine-grained quartz-augite-diorite. Both rocks extend from the end of the Sacramento Valley northward across the quadrangle, and along their very irregular contact at a number of points masses of ore have been found, of which three will be described. The first of these is in the Black Diamond district and is largely copper ore, but the last two, one $1\frac{1}{2}$ miles southeast of Baird and the other near Johns camp, about 10 miles farther up McCloud River, are ores of iron and will be noted under the appropriate heading.

The ore bodies thus far discovered in the Black Diamond region are small, rarely over a few inches in diameter, irregular in form, and scattered locally throughout the gangue. The ore consists of chalcopyrite, pyrite, pyrrhotite, or magnetite, occurring separately or in aggregates. The pyrrhotite was examined for nickel, but there is none present. To a very limited extent the ores have been observed locally disseminated in the adjacent limestone. The existence of large bodies of magnetite along the contact at the two localities referred to above suggests the possibility of the occurrence of similar bodies of copper ore, but none have yet been found.

The ore is associated with contact minerals, hedenbergite and garnet, resulting from the interaction between the intruded igneous material and the limestone. These contact minerals may therefore be regarded as the gangue of the ore. Hedenbergite is a pyroxene rich in lime and iron. It is the most striking mineral of the contact, occurring in coarse, crystalline, green, fibrous masses, with the fibers arranged perpendicular to the contact between the limestone and the diorite. Hedenbergite readily alters under the influence of the weather, and as it is rich in iron its decomposition yields much limonite. Magnetite, too, oxidizes readily and gives rise to limonite, so that from both these sources the contact region becomes deeply stained reddish yellow with hydrous oxide of iron.

One of the best exposures of the contact phenomena is on the crest of the limestone ridge Gray Rocks, where it is cut across by a number of diorite dikes running east and west and ranging from 5 to 100 feet in width. Along the edges of these dikes, in contact with the limestone at many points, pits have been dug into the iron-stained fibrous mass of pyroxene, which is mixed occasionally with garnet, another mineral resembling vesuvianite, and traces of the ores.

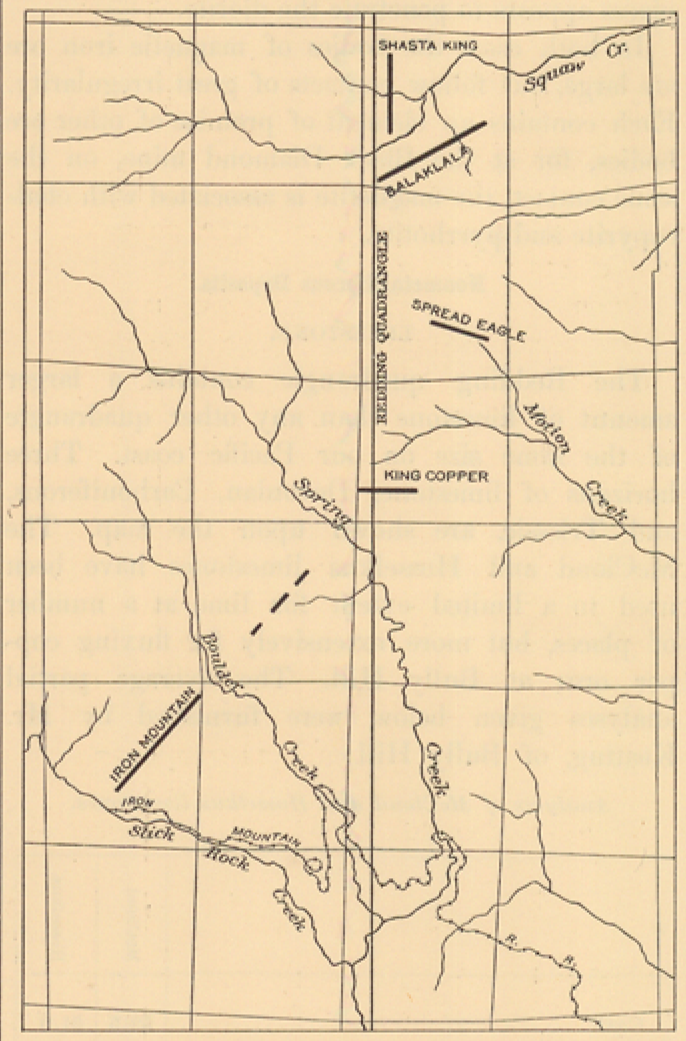


FIG. 1—Sketch map showing relation of Iron Mountain lode to other lodes of the same district.

Iron Mountain.—The Iron Mountain lode, as shown on the sketch map (fig. 1), lies wholly outside the Redding quadrangle, but close to its western border. On account of its great economic importance and close relation to the other lodes of the same district within the quadrangle, it may be mentioned here. It has been traced from the head of Slick Rock Creek northeast to beyond Boulder Creek, a distance of fully a mile, and embraces a number of approximately parallel ore bodies, two of which are much larger than the others. The large and prominent gossan, which in places extends to a depth of 100 feet, but is practically absent at some points, early attracted attention and was worked for silver and gold. Since 1895, when the great bodies of sulphide ore were discovered beneath the gossan, it has been worked mainly for copper. The principal ore body is said to have been 800 feet long, 100 to 400 feet wide, and was traced to a depth of 600 feet. It consists predominantly of pyrite, with chalcopyrite and sphalerite in varying proportions and scarcely a trace of gangue minerals. Chalcocite and bornite also have been reported. Calcite is occasionally found in chalcopyrite, and quartz in pyrite, but barite was not observed.

The ore is occasionally schistose and affected by small transverse faults. The pyritous ore comes immediately in contact with the bottom of the gossan, but in some places is disintegrated, forming a fine, brassy-yellow powder. The Hornet ore body, which forms the north end of the lode and has been fully prospected but not yet mined, is perhaps longer than the Iron Mountain ore body, but is not so thick nor of so high-grade ore. Its borders are sheared and sometimes polished by movements since the ore was formed. In dip it is vertical, with pitch apparently at a high angle to the northeast.

The annual average of copper in the Iron Mountain lode, judging from the reports of the company, thus far has ranged from less than 5 to over 7 per cent, with an average value of precious metals of less than $1 in gold and a little more in silver to the ton. Up to the end of 1902 the mine had yielded approximately 62,000 tons of fine copper.

Some years ago the Mountain Copper Company prospected under bond with diamond drills a number of the lodes northeast of its own.

Proceeding northeast from the Iron Mountain lode, which is closely in line with the workings at Sugarloaf, one enters the Redding quadrangle and finds the King Copper, Spread Eagle, and Loraine lodes in the same course. All have been prospected, but the most extensive workings are at Spread Eagle, where there is a large mass of gossan on the steep slopes at the head of Motion Creek. This has been penetrated by tunnels, which have cut a mass of sulphide ore that appears to strike N. 70°–80° W. and to dip 75° SW. This is traversed by sheared fissures, some nearly parallel to the strike and others transverse. The pyrite ore beneath the gossan is generally wet, soft, and incoherent, and in places it is cemented by quartz gangue in varying proportions. In the lower tunnel some small masses of chalcopyrite are seen.

The general trend of the small ore body of the King Copper, on the slope of Spring Creek, is N. 70°–76° W. It dips 84° SW. and apparently agrees quite closely with the position of the Spread Eagle ore body, transverse to the general direction of the Iron Mountain lode.

The Balaklala lode is one of the most prominent in the Iron Mountain district. It is well marked in places by heavy gossan and has been traced more or less continuously for over half a mile. It lies in and nearly parallel with the slope of South Fork of Squaw Creek, and strikes about N. 70° E., with a northwesterly dip somewhat steeper than the slope on which it occurs. The principal ore body yet known in this lode, the Windy Camp body, has been followed along the strike for nearly 1000 feet and on the dip for over 500 feet. It has an irregular thickness ranging from a few feet to over a score, and appears to pitch to the northeast. The rocks on the borders of the ore body are generally sheared, with but little clay, and are not much impregnated by sulphides. The ores are chiefly pyrite, with more or less chalcopyrite, but are generally of low grade. Quartz is the only gangue mineral, and forms a larger percentage of the ore than at Iron Mountain. At the north end of the lode, where the great masses of gossan occur, comparatively little is known of the unaltered ore bodies.

The Shasta King ore body lies on the west slope of South Fork of Squaw Creek, nearly opposite the Windy Camp ore body and at a lower level. As the general dip of the Windy Camp body is toward the Shasta King, they have been regarded as belonging to the same shear zone. This view is strengthened by the occurrence of smaller ore bodies on the steep slope between them, suggesting a former connection which has been severed by the erosion of Squaw Creek; but the relations are not yet clearly understood and can not be fully worked out until the deeper parts of the Windy Camp body are disclosed in detail.

The Shasta King body is somewhat irregularly basin shaped. It is some hundreds of feet in width, with a longer axis running nearly north and south and rising somewhat to the north. It is limited for the most part by fissures, along which there has been decided shearing. Exceptions are found in places on the upper surface of the ore body where it is solidly "frozen" to the country rock. The ore is like that of Balaklala. The region is one of much disturbance, and the ore bodies appear to have suffered greater deformation than the adjacent quartz veins.

The Mammoth lode, exposed in the Mammoth mine, has an apparent course N. 80° E., and has been traced less than half a mile. Thus far only one ore body has been extensively prospected, showing a length of over 300 feet and a depth at least 200 feet from the upper gossan croppings. On the principal level it dips 30° NW., and cross-cut tunnels show an extensive development in that direction, which may be accounted for, in part, at least, by a change to gentler dip. The ore, composed chiefly of pyrite, is locally rich in chalcopyrite and carries considerable sphalerite. Quartz is the gangue mineral, but in much of the ore there is scarcely a trace of it. This lode supplies the ore for the Mammoth smelter, recently erected at Kennett.

About a mile northeast of the Mammoth mine is the Golinsky, which contains an ore body that extends over 150 feet N. 70° E. and to a depth, so far as known, of not over 100 feet. It is approximately parallel to the Mammoth ore body, and though the ore is more variable the two may be closely related. Recently the Golinsky has been bonded and extensively prospected by the Trinity Copper Company.

The Friday and Lowden prospect is a mile southwest of the Mammoth and is approximately in line with the Balaklala and Golinsky mines. Much development in richly impregnated rock has revealed at least one ore body, whose principal dimension, though small, appears to lie N. 40° W., or nearly transverse to the general course of the principal deposits of this part of the copper district, but nearly parallel to a number of more or less prominent auriferous quartz veins in the vicinity. Some of the ore rich in chalcopyrite is very heavy, suggesting the presence of barite, which is known thus far to occur locally in at least one other of the mines in the northern portion of the district.

The northernmost openings of the district are near the head of Little Backbone Creek, where the Summit mine tunnels show much impregnated rhyolite with included slate and small, indistinctly banded veins in which chalcopyrite is most prominent, with smaller amounts of quartz and pyrite.

MINOR METALLIFEROUS DEPOSITS.

Chromite.—Chromite is mined on Shotgun Creek, but the serpentine in which it occurs reaches as far south as Slate Creek, and it is not improbable from the trend of the chromite bodies that some may yet be discovered within the northwestern portion of the Redding quadrangle. At the forks of Shotgun Creek, about a mile from the Southern Pacific Railroad, a series of lenticular chromite bodies occurs in a somewhat indefinite shear zone which is vertical and courses S. 40° W., through the serpentine. Five bodies, ranging from 200 to 1500 tons each, connected by more or less distinct vein-like leaders, have been mined to a depth of not over 40 feet within a distance of 250 yards. Except for these leaders the ore masses have nothing in them resembling vein structure. Generally the ore separates easily from the serpentine, but in some cases it is "frozen" firmly to it. Other parallel but as yet less productive zones have been found in the same region. A partial analysis by Dr. E. T. Allen of an average sample of the chromite selected in the mine gave the following results: Cr_2O_3, 43.87 per cent; FeO, 15.86 per cent (total iron reckoned as FeO); platinum, gold, and silver, none. The ore is used for furnace linings, and 315 tons were shipped in 1903.

Iron.—Iron ore (magnetite) occurs in the Redding quadrangle at many places on the contact between the McCloud limestone and the quartz-augite-diorite. Although not mined, it occurs at two points in quantities well worth noting. The first is 1¼ miles southeast of Baird, and the second on the northeast slope of Hirz Mountain, near McCloud River. The ore in both cases is chiefly magnetite, with abundant limonite on the surface. At the first locality the material was formerly (1901–2) quarried for flux at Bully Hill. The occasional presence of small bands of garnet and traces of other related minerals locally in the magnetite indicate that it is a contact phenomenon similar to that in the Black Diamond region. The ore body has been opened to a width of 40 feet without exposing its limits. It appears to be nearly vertical, and its occurrence on the north slope of the hill suggests an ore body of considerable size. According to Mr. J. B. Keating, general superintendent at Bully Hill, it contains about 70 per cent of iron, 1 or 2 per cent of insoluble material, and only a trace of sulphur.

On the northeastern slope of Hirz Mountain the iron ore has a somewhat wider distribution, but this may be due to the gentle dip to the east, parallel to the slope of the limestone. It has been prospected by a number of open cuts, and, as in the other case, is generally a contact deposit on the borders of the limestone and diorite, but in places appears to penetrate the diorite.

In both cases the bodies of magnetic iron ore are large, but follow contacts of great irregularity. Each contains an element of promise of other ore bodies, for at the Black Diamond mine, on the same contact, the magnetite is associated with chalcopyrite and pyrrhotite.

Nonmetalliferous Deposits.

LIMESTONE.

The Redding quadrangle contains a larger amount of limestone than any other quadrangle of the same size on our Pacific coast. Three horizons of limestone, Devonian, Carboniferous, and Triassic, are shown upon the map. The McCloud and Hosselkus limestones have been used to a limited extent for lime at a number of places, but more extensively for fluxing copper ores at Bully Hill. The average partial analyses given below were furnished by Mr. Keating, of Bully Hill:

Analyses of McCloud and Hosselkus limestones.

	McCloud.	Hosselkus.
CaO	52.5	51.0
Fe_2O_3 } Al_2O_3 }	1.5	1.5
Insoluble	2.0	4.0

The McCloud limestone contains nearly 94 per cent of carbonate of lime, while the Hosselkus contains less than 93 per cent, but both are good for the purposes used. The intrusion of igneous rocks into the McCloud limestone usually makes it more difficult to quarry than the Hosselkus, which now supplies the Bully Hill and Afterthought smelters.

The Devonian limestone near Kennett is the only one extensively quarried, and furnished the material from which 18,500 barrels of lime were burned in 1902 at Kennett, besides 3500 tons of rock shipped chiefly to the Keswick smelter. It is used also by the Mammoth smelter, at Kennett. Exact chemical analyses are not available, but it is said to make excellent lime and to serve well for flux. Isolated masses of the limestone south of Larkin and east of Newton have been used for lime, but they are too far from the railroad to compete with that near Kennett.

CLAY.

Clays of two sorts, occurring under entirely unlike conditions, have been used in the Redding quadrangle. In the copper region clay selvage to the ore bodies is never very abundant, but in some of the upper workings of the Bully Hill mine there is enough for local use in the smelter as lining for converters.

Bricks were made several years ago from the sandy alluvial clay in the flood plain of Sacramento River several miles south of Redding, where there is a large deposit; and a few miles farther down the valley, beyond Clear Creek and near Anderson, there is a brickyard in more continuous operation, which supplies much of the trade of the Sacramento Valley.

BUILDING STONE.

Stone of several varieties has been used locally for structural purposes, but scarcely any is shipped from the quadrangle. The Chico sandstone from Sand Flat and from Clear Creek near Texas Springs was formerly used for some of the railroad culverts, and furnished trimmings for several buildings in Redding. It is soft, grayish red or bluish, and is easily worked, but is occasionally marred by mud spots.

A granodiorite of lively gray color forms a hill at the southwest corner of the quadrangle and is locally used to a limited extent for tombstones, for street curbing in Redding, and for doorsteps. The granitic rock weathers gray, with slight discoloration from the decomposition of the ferromagnesian minerals. It is only 6 miles from the railroad, with an easy grade, and deserves consideration for any large structure in the northern part of the Sacramento Valley.

The Tuscan tuff stands fire well and, being soft, is easily hewn to any shape. It is commonly used for chimneys and fire places, and in the vicinity of Millville a small church and several smokehouses are made of it. The Tuscan tuff is similar to the trass of the Rhine Valley, which is so extensively used in the manufacture of puzzolan cement, and there appears to be no good reason why it might not be used in the Redding region for the same purpose, especially since the necessary lime for admixture is abundant.

COAL.

Traces of coal occur in the Ione formation at a number of places, but more particularly in sec. 12, T. 33 N., R. 2 W., about 2 miles southeast of the Afterthought mine, where it has been pretty thoroughly prospected and found to be of little value.

SOILS.

The cultivated soils of the Redding quadrangle are almost wholly alluvial, resulting from stream transportation and deposition of fine material on the flood plains, where at least three-fourths of the farming of the region is carried on. The soil of the upland plain of the Sacramento Valley is for the most part gravelly and in general so dry as to require irrigation for successful farming. The dry, rocky plains of the Piedmont are sterile, but the basalt flows, where decomposed, make good soils. Although this quadrangle is richer in limestone than any other of the same size in California, these rocks occur on steep mountain slopes not suited to agriculture. Irrigation is practiced to a considerable extent, but in a small way by individuals. It is evident, however, that with proper irrigation the soil would generally be productive, and it is gratifying to know that steps are being taken in that direction.

WATER SUPPLY.

Irrigation.—The Sacramento, where it enters the Sacramento Valley above Redding, has a large and regular volume of water, even at its lowest stage during the dry summer seasons and early autumn, when water is needed for irrigation.

There is an extensive area of land in the north end of the Sacramento Valley where the surface streams fail during the dry season and the ground water lies 20 feet or more beneath the surface, so that irrigation is required for the most successful farming. The large supply of water in the Sacramento affords the opportunity to meet the demand, but the river in this vicinity flows in a narrow valley 150 feet below the general level, and to render the water available for irrigating the higher plains would require works of great magnitude.

Artesian water.—The problem of obtaining artesian water in the north end of the Sacramento Valley has not been solved. No deep wells have been made, though there are structural features suggesting that some of the ground water of that region may be under sufficient pressure to bring it to the surface. This end of the Sacramento Valley is part of a basin which is filled with formations younger than the Cretaceous. Below is the Ione, overlain by the Tuscan tuff, and this in turn is covered by the Redding gravels, which form the surface in the middle portion. The Tuscan tuff and Ione, cropping out more or less continuously only around the border of the valley and dipping generally toward the middle portion, form a basin, except toward the south.

The Ione, owing to the sand and gravel which make up its bulk, is porous and capable of holding much water entering through the outcropping edges. On the other hand, the overlying Tuscan tuff, as shown by the fact that it brings the water of the Red Bluff gravels to the surface, though somewhat porous, is practically impervious to the water in the Ione and may hold it under pressure. If this be true, deep borings reaching through the tuff would tap the water in the Ione sands and gravels and allow it to rise in favorable situations, possibly as far as the surface.

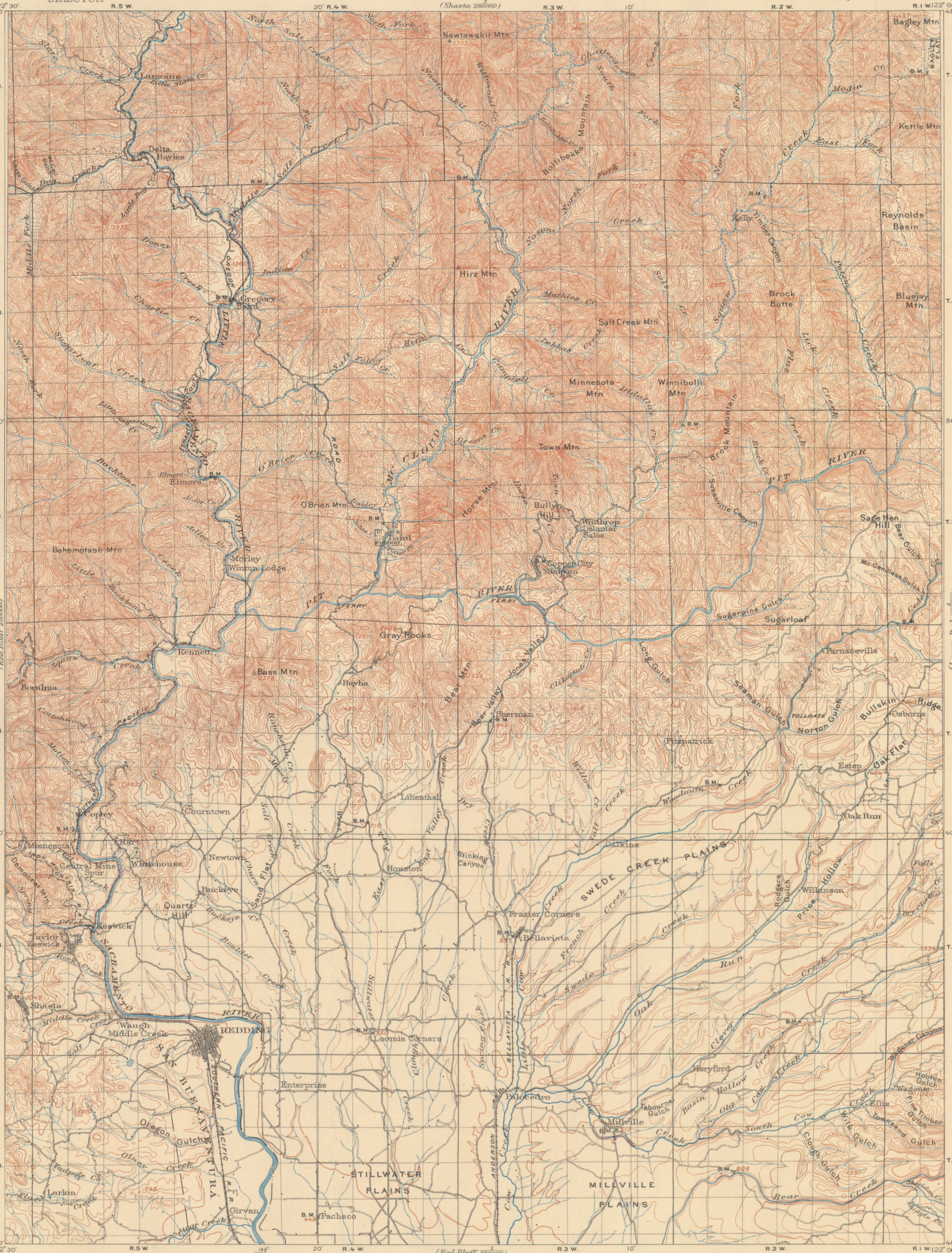
Around the northwest corner of the valley, where Sacramento River enters, the Tuscan tuff was worn away and, by affording an outlet, relieved the pressure at all points higher than 500 feet above sea level. To the south, also, the water is not confined. It may flow to the sea, and, unless the friction of flow is so great as to give rise to pressure, the ground water of the Ione could not reasonably be expected to be under artesian conditions.

April, 1905.

U.S. GEOLOGICAL SURVEY
CHARLES D. WALCOTT
DIRECTOR

TOPOGRAPHY

CALIFORNIA
(SHASTA COUNTY)
REDDING QUADRANGLE



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)

DRAINAGE
(printed in blue)

Streams

Intermittent streams

Lakes and ponds

CULTURE
(printed in black)

Roads and buildings

Churches and school houses

Private and secondary roads

Trails

Railroads

Tunnels

Bridges

Ferries

Dams

U.S. township and section lines

Reservation lines

Land grant lines

Triangulation stations

Bench marks

R.U. Goode, Geographer in charge.
Triangulation by C.F. Urquhart.
Topography by R.H. Mc Kee and A.B. Searle.
Surveyed in 1900.

APPROXIMATE MEAN DECLINATION 1902.

Scale $\frac{1}{125000}$

Contour interval 100 feet.
Datum is mean sea level.

DIAGRAM OF TOWNSHIP

Edition of Nov. 1901, reprinted Feb. 1906.

U.S. GEOLOGICAL SURVEY
CHARLES D. WALCOTT
DIRECTOR

AREAL GEOLOGY

CALIFORNIA
(SHASTA COUNTY)
REDDING QUADRANGLE

LEGEND

IGNEOUS ROCKS
(continued)

Post-Potem and pre-Chico — LATE JURASSIC OR EARLY CRETACEOUS

- Jsp — Serpentine *(stock of altered peridotite)*
- Ja, Jdp, Jhd, Jh — Various dikes *(andesite-porphyry, Ja; dacite-porphyry, Jdp; quartz-hornblende-diorite, Jhd; and hornblendite, Jh)*
- Jad — Quartz-augite-diorite *(intrusive masses and dikes)*
- Jhd, Jmd — Quartz-hornblende-diorite *(batholith and stocks; includes a stock of quartz-mica-diorite, Jmd)*

Pre-Potem — JURASSIC

- Jb — Bagley andesite *(flows and tuffs)*

Pre-Hosselkus — TRIASSIC

- Trbh — Bully Hill rhyolite *(flows and tuffs; includes some dikes and sheets of later age)*
- Trd — Dekkas andesite *(chiefly flows and tuffs, with some fossiliferous tuffaceous shale)*

Mississippian — CARBONIFEROUS

- Cbm — Bass Mountain diabase *(flows and tuffs partly interbedded in Bragdon formation)*

Pre-Kennett — DEVONIAN OR OLDER

- br — Balaklala rhyolite *(altered rhyolitic lava and tuff, also dikes.)*
- cma — Copley meta-andesite *(lava and tuff)*

Sections

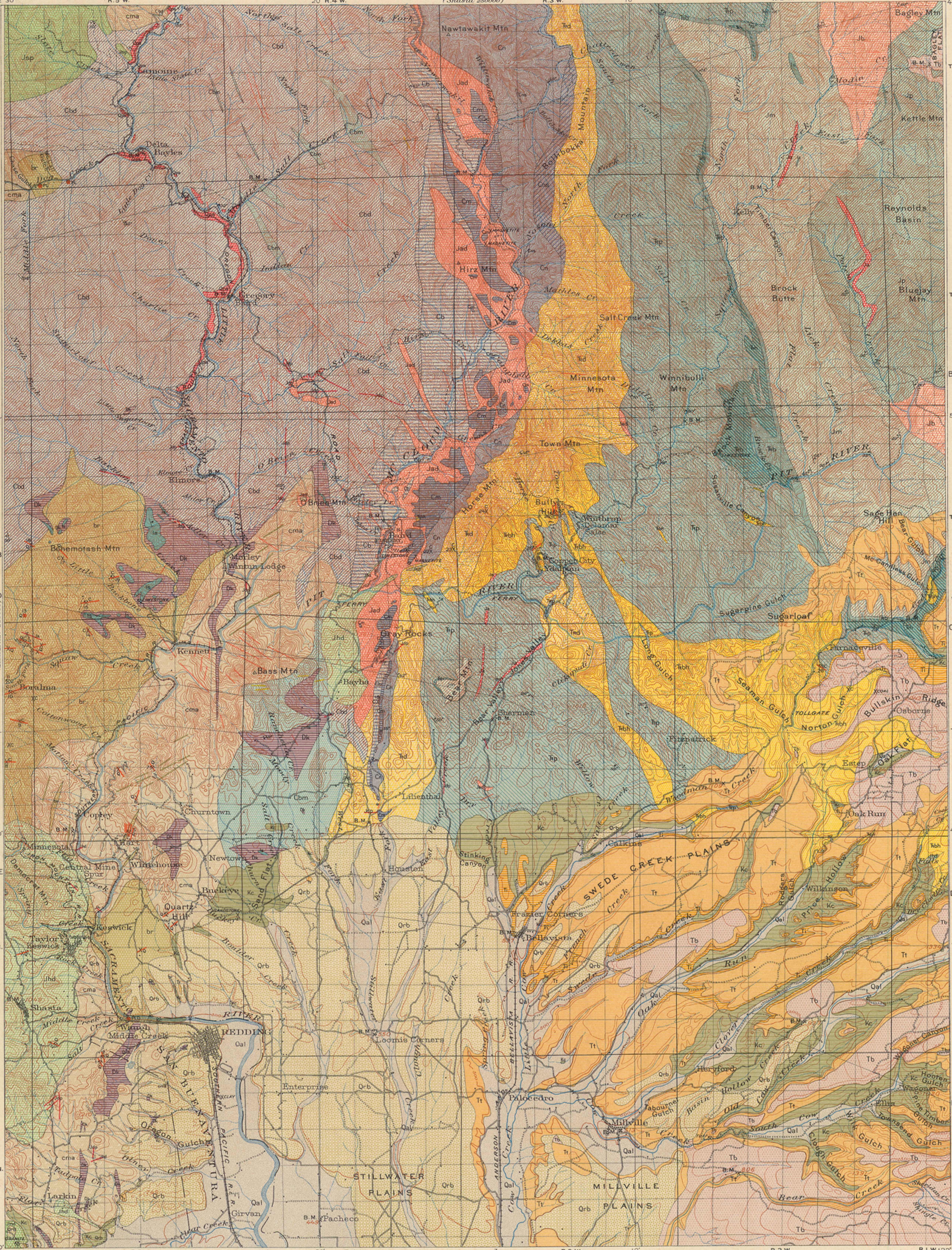
A, B, C, D, E

- 35 Strike and dip of stratified rocks
- Gold and copper veins
- Mines and quarries
- X Prospects
- Q Gold quartz
- PL Gold placer
- PLD Gold placer (dredge)
- C Copper

NAMES OF MINES AND PROSPECTS.

Position indicated on map by numbers.

1. Q. Crown Deep.
2. Q. Bracket.
3. Q. Old Spanish.
4. Q. Quartz Hill.
5. Q. Old Diggings group.
6. Q. Star of Hope.
7. Q. National.
8. C. King Copper.
9. C. Spread Eagle.
10. C. Balaklala.
11. C. Shasta King.
12. Q. Uncle Sam group.
13. Q. Clipper.
14. C. Friday and Lowden.
15. C. Mammoth.
16. C. Golinski.
17. C. Summit.
18. Q. Beien.
19. C. Memorial.
20. C. Black Diamond.
21. C. Roseman.
22. C. Alex and Allen.
23. C. Graham.
24. C. Tip Top.
25. C. Copper City group.
26. C. Rising Star.
27. C. Bully Hill.
28. C. Afterthought.



R. U. Goode, Geographer in charge.
Triangulation by C. F. Urquhart.
Topography by R. H. Mc Kee and A. B. Searle.
Surveyed in 1900.

APPROXIMATE MEAN DECLINATION 1902.
TRUE NORTH
MAGNETIC NORTH
18½°

(Red Bluff 1/250000)

Scale 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 Mar. 1906.

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 J. S. Diller,
assisted by James Storrs,
H. R. Johnson, Chester Washburne,
G. B. Richardson, and Frank L. Hess.
Surveyed in 1901–1904.

LEGEND

SEDIMENTARY ROCKS

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

QUATERNARY

- Qal — Alluvium *(silt, sand, and gravel in flood plains)*
- Qrb — Red Bluff formation *(gravels with layers of sand and a few large bowlders)*

UNCONFORMITY

TERTIARY

- Pliocene: Tt — Tuscan tuff *(chiefly tuff, in large part coarse agglomerate, and some gravel and sand.)*
- Miocene: Ti — Ione formation *(sand containing gravel above and clay and coaly material below)*

UNCONFORMITY

CRETACEOUS

- Kc — Chico formation *(conglomerate overlain by sandstone and shale)*

UNCONFORMITY

JURASSIC

- Jp, ls — Potem formation *(shale and thin-bedded sandstone with small limestone lentils, ls, and some tuffaceous conglomerate)*
- Jm, ls — Modin formation *(tuffaceous beds, chiefly conglomerate, overlain by gray sandstone and shale, with small limestone lentils, ls)*

UNCONFORMITY

TRIASSIC

- Trb — Brock shale *(dark below, reddish and sandy above)*
- Trh — Hosselkus limestone *(gray limestone above, thinner bedded and darker below)*
- Trp — Pit formation *(black and gray shale, with thin-bedded sandstone and much interstratified tuff)*

CARBONIFEROUS

- Pennsylvanian: Cn, Cns — Nosoni formation *(chiefly tuffaceous beds with interstratified shale, Cns, and sandstone, and a few limestone lentils)*
- Cm — Mc Cloud limestone *(massive gray limestone with chert layers and nodules; toward the south occurs only in lenses)*
- Mississippian: Cb — Baird formation *(chiefly red to white tuffs and overlying fossiliferous tuffaceous sandstone and shale)*
- Cbd — Bragdon formation *(thin-bedded shale, sandstone, and conglomerate composed chiefly of fragments of Kennett formation)*

UNCONFORMITY

DEVONIAN

- Dk, ls — Kennett formation *(black shale, chert, and thin-bedded sandstone, with large lentils of limestone, ls)*

- ls — Limestone lentils *(in Kennett, Modin, and Potem formations)*

IGNEOUS ROCKS

(Areas of igneous rocks are shown by patterns of triangles and rhombs; metamorphism is indicated by hachures)

QUATERNARY

- Qpa — Pyroxene-andesite *(lava flow from Mount Shasta)*

TERTIARY

- Tuscan: Tb — Basalt *(lava flows contemporaneous with Tuscan tuff)*

Legend is continued on the left margin.

U.S. GEOLOGICAL SURVEY
CHARLES D. WALCOTT
DIRECTOR

STRUCTURE SECTIONS

CALIFORNIA
(SHASTA COUNTY)
REDDING QUADRANGLE

LEGEND

IGNEOUS ROCKS
(continued)

SHEET SYMBOL — SECTION SYMBOL

Post-Potem and pre-Chico — LATE JURASSIC OR EARLY CRETACEOUS

Jsp — **Serpentine** *(stock of altered peridotite)*

Ja, Jhd, Jdp, Jh — **Various dikes** *(andesite-porphyry, Ja; dacite-porphyry, Jdp; quartz-hornblende-diorite, Jhd; and hornblendite, Jh)*

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Pre-Hosselkus — TRIASSIC

Ŧbh — **Bully Hill rhyolite** *(flows and tuffs; includes some dikes and sheets of later age)*

Ŧd — **Dekkas andesite** *(chiefly flows and tuffs, with some fossiliferous tuffaceous shale)*

Mississippian — CARBONIFEROUS

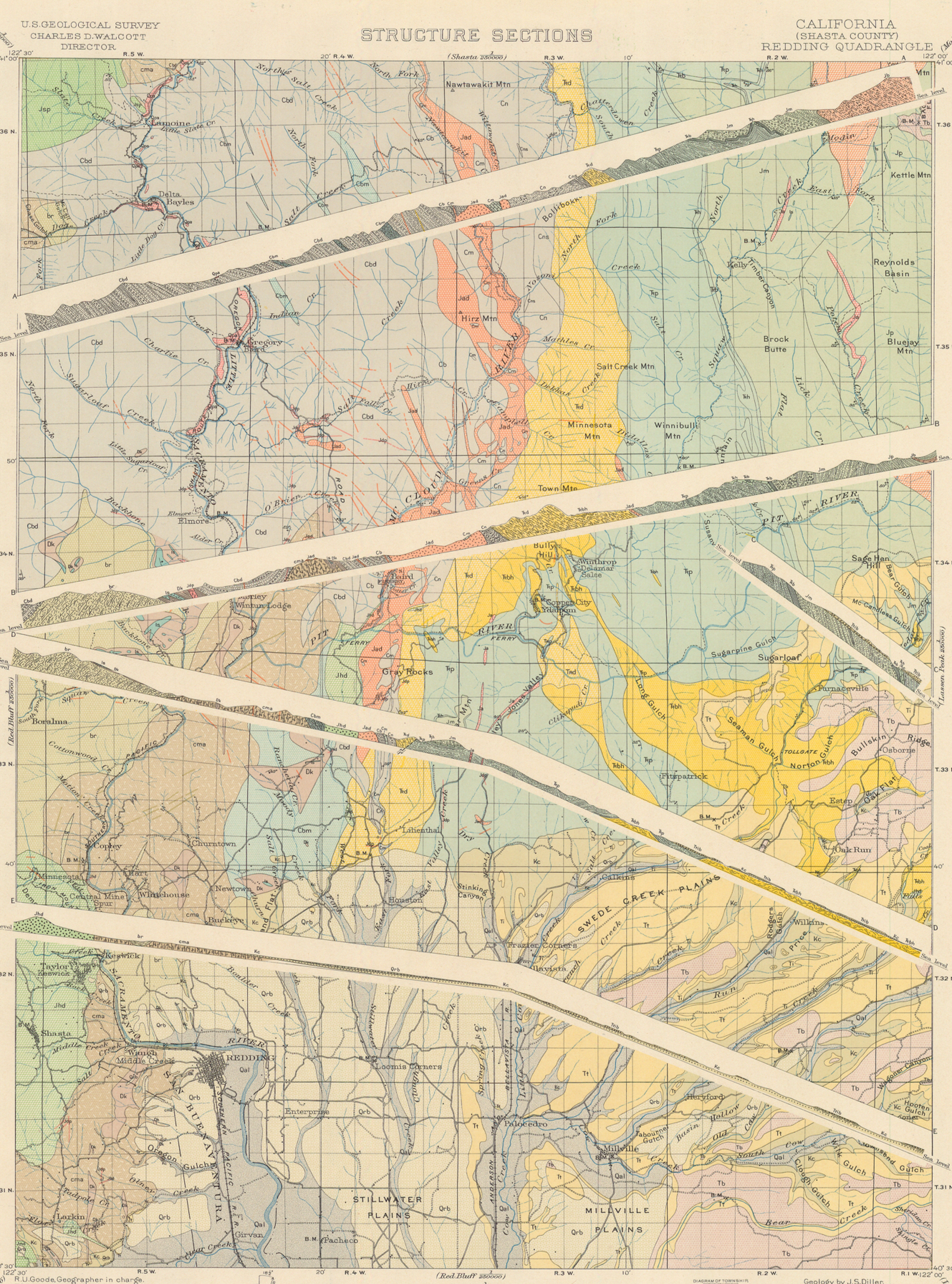
Cbm — **Bass Mountain diabase** *(flows and tuffs partly interbedded in Bragdon formation)*

Pre-Kennett — DEVONIAN OR OLDER

br — **Balaklala rhyolite** *(altered rhyolitic lava and tuff; also dikes)*

cma — **Copley meta-andesite** *(lava and tuff)*

35° *Strike and dip of stratified rocks*



R. U. Goode, Geographer in charge.
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TRUE NORTH — MAGNETIC NORTH — 18½°
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Scale 1/125000
1 ½ 0 1 2 3 4 5 Miles
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Edition of Mar. 1906

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Surveyed in 1901–1904.

LEGEND

SEDIMENTARY ROCKS

SHEET SYMBOL — SECTION SYMBOL

QUATERNARY

Qal — **Alluvium** *(silt, sand, and gravel in flood plains)*

Qrb — **Red Bluff formation** *(gravels with layers of sand and a few large bowlders)*

UNCONFORMITY

TERTIARY

Pliocene: Tt, Ttib — **Tuscan tuff** *(chiefly tuff, in large part coarse agglomerate, and some gravel and sand)*

Miocene: Ti — Combined with Tuscan tuff on sections — **Ione formation** *(sand containing gravel above and clay and coaly material below)*

UNCONFORMITY

CRETACEOUS

Kc — **Chico formation** *(conglomerate overlain by sandstone and shale)*

UNCONFORMITY

JURASSIC

Jp, ls — **Potem formation** *(shale and thin-bedded sandstone with small limestone lentils, ls, and some tuffaceous conglomerate)*

Jm, ls — **Modin formation** *(tuffaceous beds, chiefly conglomerate, overlain by gray sandstone and shale, with small limestone lentils, ls)*

UNCONFORMITY

TRIASSIC

Ŧb — **Brock shale** *(dark below, reddish and sandy above)*

Ŧh — **Hosselkus limestone** *(gray limestone above, thinner bedded and darker below)*

Ŧp — **Pit formation** *(black and gray shale, with thin-bedded sandstone and much interstratified tuff)*

CARBONIFEROUS

Pennsylvanian: Cn, Cns — **Nosoni formation** *(chiefly tuffaceous beds with interstratified shale, Cns, and sandstone, and a few limestone lentils)*

Cm — **Mc Cloud limestone** *(massive gray limestone with chert layers and nodules; toward the south occurs only in lenses)*

Mississippian: Cb — **Baird formation** *(chiefly red to white tuffs and overlying fossiliferous tuffaceous sandstone and shale)*

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UNCONFORMITY

DEVONIAN

Dk, ls — **Kennett formation** *(black shale, chert, and thin-bedded sandstone, with large lentils of limestone, ls)*

ls — **Limestone lentils** *(in Kennett, Modin, and Potem formations)*

IGNEOUS ROCKS

QUATERNARY

Qpa — **Pyroxene-andesite** *(lava flow from Mount Shasta)*

TERTIARY

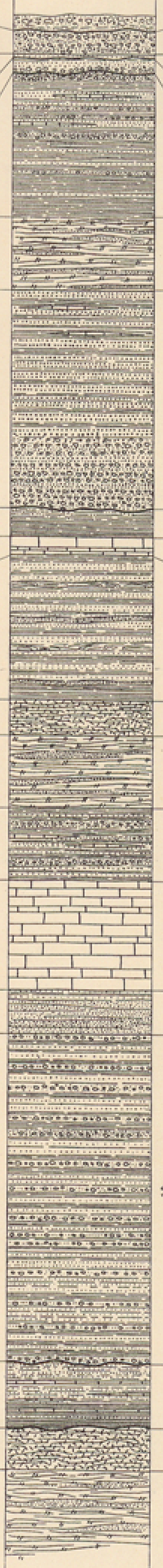
Tuscan: Tb — Combined with Tuscan tuff on sections — **Basalt** *(lava flows contemporaneous with Tuscan tuff)*

Legend is continued on the left margin.

COLUMNAR SECTION

GENERALIZED SECTION FOR THE REDDING QUADRANGLE.

SCALE: 1 INCH=2000 FEET.

System.	Series.	Formation Name.	Symbol.	Columnar Section.	Thickness in Feet.	Character of Rocks.	Character of Topography.
QUATERNARY	PLEIS.	Red Bluff formation.	Qrb		200+	Gravel with few bowlders and some sand.	Gravelly plains of Sacramento Valley.
		UNCONFORMITY					
TERTIARY	PLIOCENE	Tuscan tuff.	Tt		10–400+	Volcanic conglomerate, agglomerate, and stratified tuff of andesitic material.	Stony plain of the Piedmont.
	MIOCENE	Ione formation.	Ti		1–50	Chiefly sand, gravelly above, shaly and partly carboniferous below.	Canyon walls in the Piedmont plain.
		UNCONFORMITY					
CRETACEOUS	UPPER C.	Chico formation.	Kc		10–300	Sandstone and shale with conglomerate at the base.	Sandy flats, hollows, and canyons in the Piedmont plain.
		UNCONFORMITY					
JURASSIC		Potem formation.	Jp		2000±	Largely shaly with interbedded sandstones, a few lentils of limestone, and considerable tuffaceous conglomerate.	Prominent ridges in sandstone portion, valleys in shaly portion.
		Bagley andesite.	Jb		1000±	Succession of andesitic flows and tuffs.	Rugged mountains.
		Modin formation.	Jm		3000±	Upper portion gray shaly sandstone and shale, with few lentils of limestone; lower portion volcanic conglomerate containing fragments of fossiliferous Hosselkus limestone.	Ridges and hills.
		UNCONFORMITY					
TRIASSIC		Brock shale.	Ŧb		400	Dark calcareous shale, sandy and reddish above.	No pronounced effect on topography.
		Hosselkus limestone.	Ŧh		250	Massive gray limestone above, thinner-bedded, darker limestone below.	Rugged crest of Brock Mountain.
		Pit formation.	Ŧp		2000+	Black and gray shale, weathering whitish, thin-bedded, fine sandstone, and interbedded rhyolitic tuff.	Hills, valleys, and low mountains.
		Bully Hill rhyolite.	Ŧbh		500±	Bedded tuffs and lava flows, andesitic below, rhyolitic above, all more or less altered. Tuffaceous shale with minute marine organisms in andesitic portion.	Prominent peaks and mountains.
		Dekkas andesite.	Ŧd		1000±		
CARBONIFEROUS	PENNSYLVANIAN	Nosoni formation.	Cn		1000±	Chiefly tuff and tuffaceous conglomerate, with some shale, sandstone, and occasional lenses of fossiliferous limestone.	Mountains and high spurs.
		McCloud limestone.	Cm		200–2000	Massive gray limestone with cherty nodules; extensively intruded by dioritic rocks.	Prominent ridges and spurs.
	MISSISSIPPIAN	Baird formation.	Cb		600	Chiefly tuff, with thin-bedded sandstone and siliceous shale at top.	Mountain slopes and narrow ridges.
		Bragdon formation.	Cbd		2900–6000	Thin-bedded, black shale, sandstone, and conglomerate composed largely of pebbles of Devonian sediments containing Kennett fossils and fragments of contemporaneous flows and older volcanics.	Deeply dissected highlands forming the valley of Little Sacramento River.
		UNCONFORMITY					
DEVONIAN		Kennett formation.	Dk		865+	Chiefly black shale, often cherty, with some thin-bedded sandstone containing fossiliferous limestone lentils.	Low ridges with limestone ledges.
		UNCONFORMITY					
DEVONIAN OR OLDER		Balaklala rhyolite.	br		500±	Andesite and rhyolite flows with some tuffs; andesite altered and green in color; rhyolite gray, but stained by iron on surface.	Prominent ridges and plains.
		Copley metaandesite.	cma		1000±		

J. S. DILLER,
Geologist.

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

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

It is often difficult or impossible to determine the age of an igneous formation, but the relative age of such a formation can sometimes be ascertained by observing whether an associated sedimentary formation of known age is cut by the igneous mass or is deposited upon it.

Similarly, the time at which metamorphic rocks were formed from the original masses is sometimes shown by their relations to adjacent formations of known age; but the age recorded on the map is that of the original masses and not of their metamorphism.

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

Symbols and colors assigned to the rock systems.

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

Patterns composed of parallel straight lines are used to represent sedimentary formations deposited in the sea or in lakes. Patterns of dots and circles represent alluvial, glacial, and eolian formations. Patterns of triangles and rhombs are used for igneous formations. Metamorphic rocks of unknown origin are represented by short dashes irregularly placed; if the rock is schist the dashes may be arranged in wavy lines parallel to the structure planes. Suitable combination patterns are used for metamorphic formations known to be of sedimentary or of igneous origin.

The patterns of each class are printed in various colors. With the patterns of parallel lines, colors are used to indicate age, a particular color being assigned to each system. The symbols by which formations are labeled consist each of two or more letters. If the age of a formation is known the symbol includes the system symbol, which is a capital letter or monogram; otherwise the symbols are composed of small letters. The names of the systems and recognized series, in proper order (from new to old), with the color and symbol assigned to each system, are given in the preceding table.

SURFACE FORMS.

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

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

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

THE VARIOUS GEOLOGIC SHEETS.

Areal geology map.—This map shows the areas occupied by the various formations. On the margin is a *legend*, which is the key to the map. To ascertain the meaning of any colored pattern and its letter symbol the reader should look for that color, pattern, and symbol in the legend, where he will find the name and description of the formation. If it is desired to find any given formation, its name should be sought in the legend and its color and pattern noted, when the areas on the map corresponding in color and pattern may be traced out.

The legend is also a partial statement of the geologic history. In it the formations are arranged in columnar form, grouped primarily according to origin—sedimentary, igneous, and crystalline of unknown origin—and within each group they are placed in the order of age, so far as known, the youngest at the top.

Economic geology map.—This map represents the distribution of useful minerals and rocks, showing their relations to the topographic features and to the geologic formations. The formations which appear on the areal geology map are usually shown on this map by fainter color patterns. The areal geology, thus printed, affords a subdued background upon which the areas of productive formations may be emphasized by strong colors. A mine symbol is printed at each mine or quarry, accompanied by the name of the principal mineral mined or stone quarried. For regions where there are important mining industries or where artesian basins exist special maps are prepared, to show these additional economic features.

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

The geologist is not limited, however, to the natural and artificial cuttings for his information concerning the earth's structure. Knowing the manner of formation of rocks, and having traced out the relations among the beds on the surface, he can infer their relative positions after they pass beneath the surface, and can draw sections representing the structure of the earth to a considerable depth. Such a section exhibits what would be seen in the side of a cutting many miles long and several thousand feet deep. This is illustrated in the following figure:

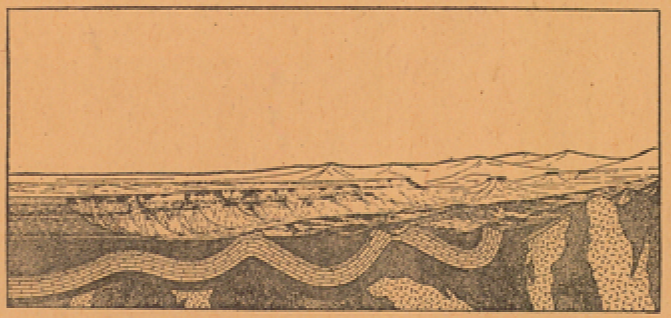


Fig. 2.—Sketch showing a vertical section at the front and a landscape beyond.

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

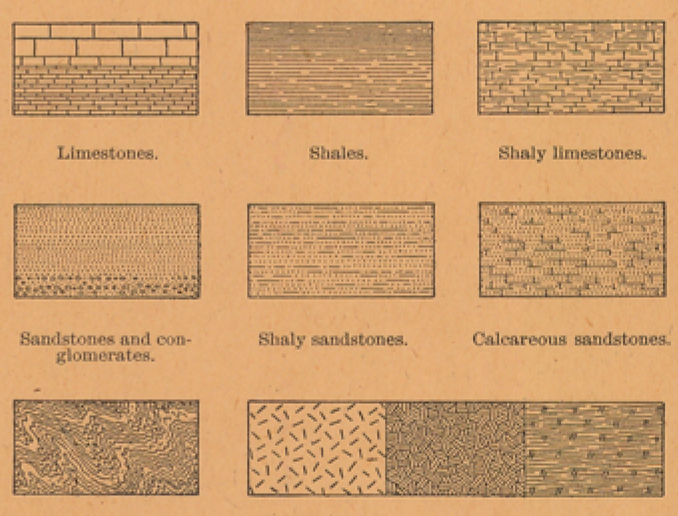


Fig. 3.—Symbols used in sections to represent different kinds of rocks.

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

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

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

On the right of the sketch, fig. 2, the section is composed of schists which are traversed by masses of igneous rock. The schists are much contorted and their arrangement underground can not be inferred. Hence that portion of the section delineates what is probably true but is not known by observation or well-founded inference.

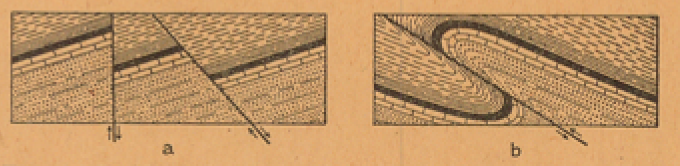


Fig. 4.—Ideal sections of strata, showing (a) *normal* faults and (b) a *thrust* fault.

The section in fig. 2 shows three sets of formations, distinguished by their underground relations. The uppermost of these, seen at the left of the section, is a set of sandstones and shales, which lie in a horizontal position. These sedimentary strata are now high above the sea, forming a plateau, and their change of elevation shows that a portion of the earth's mass has been raised from a lower to a higher level. The strata of this set are parallel, a relation which is called *conformable*.

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

The horizontal strata of the plateau rest upon the upturned, eroded edges of the beds of the second set at the left of the section. The overlying deposits are, from their positions, evidently younger than the underlying formations, and the bending and degradation of the older strata must have occurred between the deposition of the older beds and the accumulation of the younger. When younger rocks thus rest upon an eroded surface of older rocks the relation between the two is an *unconformable* one, and their surface of contact is an *unconformity*.

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

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

Columnar section sheet.—This sheet contains a concise description of the sedimentary formations which occur in the quadrangle. It presents a summary of the facts relating to the character of the rocks, the thickness of the formations, and the order of accumulation of successive deposits.

The rocks are briefly described, and their characters are indicated in the columnar diagram. The thicknesses of formations are given in figures which state the least and greatest measurements, and the average thickness of each is shown in the column, which is drawn to a scale—usually 1000 feet to 1 inch. The order of accumulation of the sediments is shown in the columnar arrangement—the oldest formation at the bottom, the youngest at the top.

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

CHARLES D. WALCOTT,
Director.

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