



Sketch Map of PRE-MESOZOIC and MESOZOIC ROCKS, of a portion of the SIERRA NEVADA, between the North and Middle Forks of Feather River.

STRATIGRAPHY AND SUCCESSION OF THE ROCKS OF THE  
SIERRA NEVADA OF CALIFORNIA.

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## CONTENTS.

	Page.
Introduction.....	414
General Character of the Sierra Rocks.....	414
Division into two unconformable Groups.....	415
General Stratigraphy.....	415
General Features of the Sierra.....	415
Dual Character of the Range.....	415
Approximate Coincidence of successive Axes of Uplift.....	416
Position of Outcrops relative to Axes of Uplift.....	417
Axes of greatest Uplifting.....	418
Relative vertical Descent of eastern and western Slopes.....	418
Strike and Dip.....	418
Unconformity of the Mesozoic and pre-Mesozoic.....	418
Epoch of Tilting.....	419
Character and Extent of Uplifting.....	419
The District more particularly described.....	420
Pre-Mesozoic Rocks.....	421
Eruptive Granite.....	421
Sedimentary Slates and Quartzites.....	421
Pre-Mesozoic Rocks outside of upper Feather River District.....	423
Age of the pre-Mesozoic Rocks.....	424
Mesozoic Rocks.....	425
Principal Divisions.....	425
Lower Mesozoic Subgroup.....	426
Slates, Greenstones and Limestones.....	426
Fossiliferous Limestones.....	428
Jurassic or later Age of the Fossils.....	428
Mesozoic Conglomerate containing older Rocks.....	429
Unconformity on Claremont.....	430
Upper Mesozoic Subgroup.....	430
Thinly laminated Slates and Serpentine.....	430
Serpentine.....	431
Upper Slates.....	432
Limestones.....	433

	Page.
Mesozoic Rocks outside of upper Feather River District.....	433
Distribution of the Rocks.....	433
Fossiliferous lower Mesozoic Limestones.....	433
Eastern principal Area.....	435
<i>Ammonites colfaxii</i> .....	436
Mesozoic Exposures south of the American.....	436
Mesozoic Exposures south of the Merced.....	437
The Mesozoic Series.....	438
Natural Divisions.....	438
Fossil Horizons.....	439
Alteration Products.....	440
The quartzitic Alteration.....	440
Pyritous Character of the Rocks.....	440
Fissures and mineral Veins.....	440
Gold.....	441
Fissures containing Chalcopryite.....	442
Age of the mineral Veins.....	443

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#### INTRODUCTION.

*General Character of the Sierra Rocks.*—The great mass of the Sierra Nevada consists of crystalline rocks (granites) and highly metamorphosed, tilted and dislocated sedimentary and eruptive rocks. There are less metamorphosed strata of later age (Cretaceous and Tertiary) on the western flank at and near the foot of the range, and Tertiary and Quaternary lavas and sediments deposited by streams occur on the slopes and even on crests and peaks, especially of the northern half of the range. But the great mass of the range is made up of granites and of sedimentary and eruptive rocks so highly metamorphosed as to be quite generally designated as the metamorphic rocks of the Sierra.

J. D. Whitney showed in his report on the geology of California, and added confirmation in his work on the auriferous gravels of the Sierra Nevada, that a portion of these metamorphic rocks are of Mesozoic age, and in the same works he states, with less positiveness, however, that a part of them are of Carboniferous age.\* The Mesozoic age of the rocks regarded by Whitney as Jurassic is farther confirmed by C. A. White and G. F. Becker, though White assigns them to a position at the confines of the Jurassic and Cretaceous periods,† and Becker places them higher up in the Cretaceous;‡ but the limits of the groups of these rocks

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\*On identification of Mesozoic fossils by W. M. Gabb and F. B. Meek, and of Carboniferous fossils found outside of the Sierra proper by J. B. Trask and fragments of fossils found within the Sierra by W. M. Gabb.

† Bull. U. S. Geol. Survey, no. 15, 1885, p. 26.

‡ Bull. U. S. Geol. Survey, no. 19, 1885, pp. 9-18; also Bull. Geol. Soc. Am., vol. 2, 1890, pp. 201-208.

have not heretofore been defined, nor have the rocks within the groups been described with the order of their succession.

*Division into two unconformable Groups.*—By detailed examination of the rocks of one district within the range and comparison with those of other parts of it, I have been enabled to distinguish two unconformable groups definitely, and to determine the succession of rocks within the later of the two and partially within the older one, and, so far as my surveys have extended, to map the areas of exposure of each. The later group includes the rocks determined by Whitney to be Mesozoic, and, as will be shown hereafter, includes none other than Mesozoic. I shall call this group, for the purposes of this paper, the Mesozoic group, excluding from consideration the unaltered Cretaceous strata exposed along the western foot of the range.

The older group has thus far yielded no fossils within the Sierra proper, and I will designate it simply as the pre-Mesozoic group.

#### GENERAL STRATIGRAPHY.

*General Features of the Sierra.*—Before entering upon a detailed consideration of the two groups and the succession of rocks within them, it will be well to present some general features of the stratigraphy of the range, for they throw much light upon the order of succession; and among strata so tilted, faulted and altered it is necessary to use all the means at hand to determine which are the higher or lower in the series.

The Sierra Nevada, as now defined, extends about 370 miles in a north-westerly direction, with the general trend of the coast of this part of the continent, from near latitude  $34^{\circ} 48'$  to near latitude  $40^{\circ} 12'$  north. At its southerly end it curves westward around the southern end of the valley of California, and coalesces with the Coast range. At its northern end it might be difficult, on purely geographical grounds, to distinguish it from the Cascade range; but geological considerations leave no doubt that the Sierra ends northward where its metamorphic rocks pass beneath the lavas of the Lassen peak district; for that mountain and the lava field stretching out southward from it occupy an area where, as late as the Chico (upper Cretaceous) epoch, the sea passed around the northern end of the Sierra, and where, as late as Miocene time, there was still a depression occupied by fresh water.\* Other reasons, from structural geology, for thus limiting the range northward will be given hereafter.

*Dual Character of the Range.*—In its northern portion the Sierra is double, consisting of eastern and western divisions. The eastern division

\*Geology of the Lassen Peak District, by J. S. Diller, in 8th Annual Report of the U. S. Geol. Survey, part 1, 1889, pp. 395-432.

laps far southward by the southern end of the western, and is much the larger mountain mass of the two.\* It culminates near its southerly end in mount Whitney, at an elevation of between 14,000 and 15,000 feet † above sea-level. Its crest falls northward and, as a continuous crest, terminates on the southern side of the Middle fork of Feather river. This division of the range continues, however, northwestward from that stream in broken sections to the edge of the great lava field west of Big meadows. Besides being separated by the depression of the Middle fork of Feather river, it is farther divided crosswise by the canyon of the East branch of the North fork and the canyon of the main North fork of the same river. It is known next north of the Middle fork as Grizzly ridge, then as Hough mountain or mount Hough, and north of the East branch of the North fork as Green mountain. It loses its distinctness as a topographic feature north of the East branch, and ends north of the main North fork west of Big meadows, near Prattville, where the metamorphic rocks pass under the Tertiary lavas. The ranges east of the main crest and of the mountains just named are here considered as belonging to the Basin ranges.

The western division is highest near its northern end, and is most distinct topographically between the Middle and North forks of Feather river.‡ It rises there to 6,990 feet above sea-level at Spanish peak. It falls rapidly southward and, as a topographical member of the present range, disappears, merging into the western slope of the eastern division. Geologically, it can be traced to American river, if not farther southward, by the outcropping of granite and other older rocks of the series. Still farther southward the main western division is replaced by two or more minor uplifted masses on the western slope of the eastern division.

The duality of the northern part of the range is a very important geological feature. Each of the two divisions has its own axes, or, more accurately, its own areas of habitual greatest uplifting; and before the Mesozoic upheaval the two were separated, at least during the period of subsidence that preceded the upheaval, by an arm of the sea.

*Approximate Coincidence of successive Axes of Uplift.*—The present relief of the range, or at least of the northern half of the range, is due princi-

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\* This duality was recognized and, in a general way, described by Amos Bowman in a paper on the "Geology of the Sierra Nevada in its Relations to Vein Mining," published in the 7th Annual Report on Mineral Resources west of the Rocky Mountains by the U. S. Commissioner of Mining Statistics, 1875.

† "Hence we conclude that it is highly improbable that mount Whitney should be less than 14,650 feet high." J. D. Whitney, in *Auriferous Gravels of the Sierra Nevada*, 1879, p. 28.

‡ The western division of the range really lies along an extension southward of the axis of the Cascade range, and in a strict geological sense belongs to that range rather than to the Sierra proper; but it is probably impracticable to change the nomenclature so far as to make it conform to geological requirements in this respect.

pally to Tertiary and Quaternary uplifting,\* but the axes of greatest uplifting of the present range coincide approximately with axes of uplifting of previous ranges within the same area. In other words, repeated orographic movements have taken place along the same axes, and recurring uplifts along these axes have followed recurring erosion. In this way a pre-Mesozoic range arose, carrying up both crystalline and metamorphosed sedimentary rocks, and partially disappeared through erosion and subsidence; then a Mesozoic range arose and its strata became up-tilted, and it in turn was reduced by erosion and subsidence to very small proportions (in its northern half at least, nearly or quite to base-level of erosion) and then in Tertiary and Quaternary time has arisen the present range, which is now undergoing its erosion; but whether it is now rising or subsiding is not determined.

*Position of Outcrops relative to Axes of Uplift.*—The oldest rocks appear along the axes of greatest recurring or habitual uplifting, and as these are on the whole approximately coincident with the axes of the present range, the oldest rocks in a given section across the range outcrop quite generally along and near the crests and peaks of the present range, where they are not capped by Tertiary lavas and sediments, and on the whole the rocks highest in the series appear farthest from the crests. As already stated, the coincidence of axes is not complete, and the relative intensity or shear of uplift along the axes has varied greatly, as shown, for example, by the fact that the area of exposure of older rocks extends far southward of the crest of the western division of the present range. The succession is, moreover, frequently interrupted by faulting. However, the obscurity from these causes can be cleared away by noting the habitual or prevailing position of areas of outcrop of either of the groups of rocks relative to the axes or areas of greatest and least uplifting. The two principal axes of uplift are by no means the only axes of orographic movement; neither are the main or minor axes straight, unbroken lines. Each main uplift is made up of a series of uplifts, and the mountain masses are of very irregular shapes. They have, however, one prevailing characteristic, namely, that their longer axes have the trend of the portion of the range in which they occur.

The Tertiary and Quaternary uplifting to which the relative relief of the present range is due has been principally, if not entirely, by faulting. The history of the range includes also regional orographic movements, both of elevation and subsidence, the character of which has not been determined.

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\* This is abundantly proven by dislocation and uplifting of Tertiary and Quaternary deposits and by the obstructions to drainage which caused them; but I must leave detailed statement of proofs to a future paper.

*Axes of greatest Uplifting.*—A prevailing geographic characteristic of the range is that the crest of each of its two great divisions and of its individual mountains is near the eastern edge of the mass; in other words, the easterly slope is much steeper than the westerly one. The easterly slope may be called a fault-plane, though it is not by any means a simple plane, but a broken, jagged and irregular composite plane. The western slopes also rise in part, if not wholly, by faults; but they are, as a rule, of less shear, and form less prominent escarpments than those of the easterly slopes. This is not, however, a universal rule. The westerly slope of Grizzly ridge, for instance, rises from its foot by a fault, which I have called the Cromberg fault, which can be traced and measured by the dislocation of Tertiary deposits for over seven miles, and near the hamlet of Cromberg, on the Middle fork of Feather river (in sections 12 and 13, T. 23 N., R. 11 E., M. D. M.), the uplift is more than 1,100 feet vertically in 3,375 feet horizontally; how much more than 1,100 feet I cannot say, as the floor on which the Tertiary deposits rest at the down-thrown (southwestern) side of the fault is not exposed.

*Relative vertical Descent of eastern and western Slopes.*—The descent of the eastern slope of the range as a whole is much less in vertical extent than that of the western slope; for the interior basin, at the foot of the steep easterly face, is much higher than the valley of California, at the foot of the westerly slope. The elevation above sea-level of Owens lake, at the foot of the easterly face, nearly east of the summit of mount Whitney and 12 miles distant from it, is 3,618 feet,\* while Visalia, in the valley about 54 miles west of the summit of mount Whitney, is but 348 feet above sea-level.† Lake Tahoe is, according to Wheeler, 6,202 feet above sea-level, while the summit of Twin peak, about four miles away, is 8,824 feet, and the valley 54 miles west of Twin peak is 163 feet above sea-level.

*Strike and Dip.*—The metamorphic sedimentary rocks of the range are tilted to high angles with the horizon. The prevailing strikes are parallel to the general trend of the range and of the coast; the prevailing dips are between 40° and vertical, and the larger part of them between 60° and vertical. The direction of dip over much the larger part of the area is easterly; but in the northerly part of the eastern division of the range, namely, on Grizzly ridge, Hough mountain, and northward to the edge of the lava field, the prevailing direction is westerly. and north of the North fork of the Feather this direction of dip extends further westward.

*Unconformity of the Mesozoic and pre-Mesozoic.*—The strike and dip are but slightly affected by the Tertiary and Quaternary uplifting, and I

\*Capt. Geo. M. Wheeler, U. S. Geographical Surveys West of the 100th Meridian.

†U. S. Signal Office Reports.

have not been able to discover any unconformity of dip and strike between the strata of the pre-Mesozoic and Mesozoic groups; but the strata of the two groups are unconformable by erosion. Those of the older group were raised above sea-level and eroded, and then subsided to receive Mesozoic sediments. Moreover, they, or at least some of them, were metamorphosed before the erosion, for pebbles and boulders of pre-Mesozoic quartzites as well as granites occur in Mesozoic conglomerates, as will be hereafter shown. It is probable that the pre-Mesozoic uplifting was, like the Tertiary and Quaternary uplifting, principally by faulting, and therefore of little effect upon the prevailing dip and strike.

*Epoch of Tilting.*—The upper Cretaceous (Chico) and Tertiary strata at the western foot of the range dip westward at low angles. It follows, therefore, that the greater part of the tilting of the metamorphic rocks took place before the later Cretaceous strata were deposited and after the Mesozoic metamorphic rocks were deposited. According to Whitney's determination, the Mesozoic tilting was done at the end of the Jurassic; according to Becker's apparently tentative and still incomplete determination, it was later or "post-Gault."\*

*Character and Extent of Uplifting.*—A part, at least, of the pre-Tertiary uplifting was by fault, for on the easterly face of Claremont (see accompanying map, plate 13) pre-Mesozoic rocks are brought into contact with the highest subgroup of Mesozoic strata. The displacement is in part Tertiary and Quaternary; but the extent of this part can be measured by the dislocation of Tertiary sediments and lavas. At one point at the northern end of Claremont the vertical relative displacement of the Tertiary materials is but 1,300 feet, while the pre-Mesozoic slates there are brought into contact with the thinly laminated shales of the upper part of the upper Mesozoic subgroup. The greatest relative vertical displacement of Tertiary deposits at Spanish peak and Claremont is but about 3,300 to 3,400 feet, while the shear of the fault is several times as great. How much of the pre-Tertiary uplifting is due to pre-Mesozoic and how much to Mesozoic movement I have found no means of testing.

How the Mesozoic uplifting and tilting was effected is not clear. With the prevailing easterly dips, later rocks are often carried beneath older ones; in other words, the strata have been overturned. The most ready inference is that the strata were thrown into anticlinal and synclinal folds by approximately horizontal thrusting, that these folds were overturned, and that during or after the folding the mass was faulted. But the slopes of the range are steep, and over a large proportion of the area the rocks are bare, and deep canyons afford numerous and extended vertical sections; yet neither arches nor inverted arches appear, and I know

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\* Bull. Geol. Soc. Am., vol. 2, 1890, pp. 201-208.



of no reason for assuming that there ever were such in the region. The conditions point rather to tilting of irregular blocks formed by approximately vertical or steeply sloping faults, and included within and separated from the surrounding mass by fault planes. Such blocks have been formed by Tertiary and Quaternary uplifting; indeed, the uplifting has been by blocks, and each mountain is a block. Moreover, as a rule the block is raised higher near one of the two longer edges (more commonly the eastern edge) than the other—that is, the block is somewhat tilted. If the pre-Tertiary faulting was principally Mesozoic, and the tilting of the blocks was carried farther than the Tertiary and Quaternary tilting until commensurate with the Mesozoic faulting, the present structural conditions would result—that is, the strata would be thrown on edge and those of any given block would be without connection by arches or inverted arches with corresponding strata of adjoining blocks.

#### THE DISTRICT MORE PARTICULARLY DESCRIBED.

The district in which my studies and surveys have been most detailed lies between the eastern and western crests and between the North and Middle forks of Feather river, and as my most definite illustrations are from this district I shall describe it briefly.

The general topography and geology of the district are outlined on the accompanying sketch map (plate 13).<sup>\*</sup> Grizzly ridge, Hough mountain and Green mountain form the eastern division of the range. Grizzly ridge and Hough mountain rise on the northeastern side by steep escarpment—a broken and jagged fault-plane—and on the southwest partly by steep escarpment and partly by slope, which however is steep. The slopes and escarpments meet at the top in a sharp crest. At the westerly side of the district rises Spanish peak mountain, which presents a very steep escarpment eastward; but its crest is the eastern edge of a plateau, modified by erosion, some 13 to 14 miles wide. From the westerly edge of this plateau the surface drops rapidly to the Great valley of California.

Between the two divisions of the range north of the Middle fork of Feather river rises an intermediate mountain called Claremont. There are also other ridges and mountains formed by uplift with axes of various directions—one running nearly eastward from Spanish peak mountain along the southern side of the East branch of the North fork of the Feather, and one between Spanish creek and the Middle fork, formed by a southwesterly uplift from Claremont, and a southeasterly one from Spanish peak. Detailed surveys have proved that the topography, which appeared at first sight to be the result of erosion and a simple system of

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<sup>\*</sup>Scale reduced from 1 inch = 4 miles to 1 inch = 6 miles, or 1:380,000, in reproducing.

uplifts, is in fact principally the result of a very complicated system of orographic movements. These are clearly shown by dislocations of Tertiary and Quaternary deposits which I have surveyed and mapped, but to describe them is not practicable within the limits of this preliminary paper. The main features for the present purpose are the eastern and western divisions of the range, the intermediate mountain Claremont, and the depression partly occupied by the American valley on the north-eastern side of this mountain and Spanish ranch and Meadow valley on the southwestern side of it, which depression is drained by Spanish creek and its branches. Some of the principal elevations above sea-level are: Outlet of American valley, 3,353 feet; outlet of Spanish ranch, 3,618 feet; highest point on Grizzly ridge (barometrical), 7,952 feet; Spanish peak (barometrical), 6,990 feet; Claremont, 6,962 feet.

#### PRE-MESOZOIC ROCKS.

*Eruptive Granite.*—The principal exposures of the pre-Mesozoic rocks in the Sierra are the two areas of greatest uplifting already described. The eastern one extends from the southern end of the range to the northern flank of mount Haskell, between the North Yuba and the Middle Feather, where the pre-Mesozoic rocks pass beneath the Mesozoic. The western area of pre-Mesozoic rocks extends from the northern end of the range to the Great valley between Yuba and American rivers. Both areas include isolated and peninsular tracts of Mesozoic rocks.

The granites form by far the greater part of the pre-Mesozoic rocks; indeed, they make up the core and the great mass of the range and of each of the two divisions of the range. I have not seen granite overlying or penetrating sedimentary strata in the Sierra proper, but on the easterly slope of one of the nearer Basin ranges, a little south of Beckworth pass (which is at the head of the Middle fork of the Feather), there are dikes of granite penetrating gneiss. I must add that my observations of the granites have been, with few exceptions, limited to the northern half of the range.

*Sedimentary Slates and Quartzites.*—While the core and mass of Spanish peak mountain are of granite,\* and the upper part of its eastern face is also of granite, lower down on this face, next to the granites, a series of slates and quartzites outcrop. The quartzites are evidently the slates, altered by silicification, for they retain the slaty structure, sometimes

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\*Professor A. Wendell Jackson, who kindly examined microscopically a specimen of this granite for me, wrote of it, October 22, 1888: "The Spanish peak rock consists of quartz, orthoclase, plagioclase, hornblende and biotite as essential constituents; this makes it a hornblende-granite (after Rosenbusch). It is the most widely spread granitic rock in the Sierra, according to my present experience." It certainly is the prevailing granite of the northern half of the range.

laminated, but more often in distinct layers half an inch to an inch and more in thickness. The alteration occurs in all stages from that of somewhat siliceous slate to slaty quartzite and complete quartzite. The slates and quartzite are frequently contorted; the contortion being local and not caused by any general movement of the mass or by pressure from without, but by some locally acting force within the mass, probably molecular force accompanying the chemical and mineralogical changes of metamorphosis, causing alteration of volume and consequent displacement.

These pre-Mesozoic slates and quartzites lie on the granite, and were probably deposited upon it, as I have found no intrusions of the eruptive rock in the strata. They outcrop between the granite and Mesozoic rocks, and Mesozoic strata come in contact both with them and with the granite. It will be shown hereafter that fragments of both the granite and quartzite are found in a conglomerate of the lower Mesozoic group, and therefore that these rocks are older than those of that group and unconformable with them.

The Claremont uplift has brought to the surface a series of pre-Mesozoic strata. There are no granites or other eruptives among them, and they consist of highly metamorphosed slates. They retain more or less of slaty structure, though rarely cleavable into laminæ or sheets of considerable size, and they break with irregular, often more or less conchoidal, surfaces and into more or less prismoidal fragments. They are curled and contorted in much the same way as the slates and quartzites before described, but much more generally than they. There is a very general deposition or segregation of silica in the mass, evidently chemical. The silica is in part disseminated through the slate, but much of it is lodged in films on surfaces of cleavage or lamination, or in irregular bunches and lenticular bodies or veins, sometimes crossing, sometimes lying parallel with the surfaces of lamination. There are micaceous surfaces, and the mica and also an arrangement of the siliceous grains in the slaty laminæ sometimes give a gneissoid form to the rock; but there is not enough of mica or micaceous felting to form a true gneiss. The rock is sometimes chloritic, and some of the chloritic ledges have a massive form that suggests eruptive origin.

It will be shown hereafter that limestones and slates of the oldest Mesozoic subgroup of the district rest unconformably on these rocks. They are therefore older than the oldest Mesozoic rocks of the district. They are nowhere within this district exposed in contact with the granites or quartzites of Spanish peak mountain, and there are not any means here of determining directly the relative age of these and the Spanish peak pre-Mesozoic rocks; but farther northwestward, near the

northern end of the range, there is a nearly continuous exposure of the contact of granite and sedimentary pre-Mesozoic strata for at least seven miles from the West branch of Feather river, near the middle of T. 24 N., R. 4 E., M. D. M., northeastward along the divide at the headwaters of Kimsheew creek. The sedimentary rocks approximate in character the pre-Mesozoic rocks of Claremont; they are imperfectly gneissoid and chloritic in part. Their strike is nearly at right angles to the prevailing strikes of the Sierra, namely, northeasterly, parallel to the contact just mentioned; and they dip at comparatively low angles northwestward away from the granite. They pass by the northern end of the western area of granite exposure here at the northern end of the western division of the range, as the Mesozoic rocks pass by the granite of the crest of the eastern division between the Middle fork of the Feather and the North fork of the Yuba. Across the area of outcrop of these strata on the northwestern side of it, about  $4\frac{1}{2}$  miles from the contact with the granite, at the Chaparral house on the Oroville and Prattville stage road, in section 10, T. 24 N., R. 4 E., are quartzites like those on the easterly face of Spanish peak mountain, with the ordinary northwesterly strike and a nearly vertical dip. The metamorphosed, imperfectly gneissoid and chloritic strata outcrop here between the granites and quartzites, and are probably lower than the latter. They may be contemporaneous with or older than the granite, although I have seen no intrusions of the eruptive rock in these strata.

There are quartzites in the range contemporaneous with the granite and imbedded with it. Such occur at and near the western edge of the granite of the eastern division of the range, where the South Yuba flows off it, between five and six miles east of the village of Washington; also in granites outside of the Sierra proper, north of Sierra valley, at headwaters of the Middle fork of the Feather. In both cases the quartzite is probably a product of alteration of the granite itself.

*Pre-Mesozoic Rocks outside of upper Feather River District.*—The pre-Mesozoic rocks of this district are not typical of the whole group in the Sierra, inasmuch as they do not include limestones which occur in great masses among the pre-Mesozoic rocks of the western flank of the range from the Mokelumne to near the Tuolumne river. These limestones occur in a group consisting principally of micaceous schists and quartzites, lying next to granite and in places surrounding isolated areas of this granite. Whitney describes the group in the "Geology of California" and also in his "Auriferous Gravels of the Sierra Nevada." On the Mokelumne, at the mouth of the North fork, I found an exposure of this limestone 400 feet thick in a series of mica slates which, becoming gneissoid, join the granite about two miles east of the limestone. Pre-

Mesozoic rocks continue west of the limestone on the Mokelumne about eight miles. From this exposure of limestone on the Mokelumne to the most southerly one described by Whitney is about 40 miles. These gneisses, mica-slates and limestones underlie unconformably strata known to be Mesozoic, but no fossils have been found in them and their age is not definitely determined.

About midway between the Calaveras and Stanislaus rivers in the Great valley, about three miles west of its eastern edge, is a small area of granite. It adjoins Mesozoic rocks on the east and passes westward under Tertiary deposits. It suggests an extension of pre-Tertiary uplifting of the western division of the range far south of the Tertiary and Quaternary uplifting of that part of the range. There is an area of pre-Mesozoic gneisses and other rocks between the Mesozoic outcrops and the Tertiary deposits of the valley on the Stanislaus and a much larger one south of the Merced, about Hornitas. The eastern area of granite comes forward to meet the Tertiary of the valley near where the San Joaquin comes out of the mountains,\* and only isolated areas of sedimentary rocks are found on the western flank of the range farther southward.

*Age of the Pre-Mesozoic Rocks.*—I have treated the pre-Mesozoic rocks as of one group. It is not proven that they are all conformable or all of one period. It is entirely possible that a part of them are Archean and a part Paleozoic, and that the latter part may include rocks of different Paleozoic periods. Indeed, there remains a remote possibility that some of them may be early Mesozoic, older than the oldest group that is proved to be Mesozoic; but they are much more metamorphosed than these, are unconformable with them, and after having been deposited were certainly metamorphosed and uplifted, and the region had begun to subside again before the lowest known Mesozoic strata were deposited. It is not therefore within reasonable probability that any of these rocks are later than Paleozoic.

Besides being altered and tilted and faulted, the sedimentary rocks of this group are very widely overlain by Mesozoic rocks, and their outcrops are consequently disconnected; and fully to determine their order of succession will require examination and comparison of a large part of the areas of their exposure in the Sierra. The Mesozoic rocks, on the other hand, are not overlain except by comparatively thin Tertiary and Quaternary deposits, and therefore their sequence and natural division into subgroups are more readily determinable in spite of faulting, tilting, overturning and metamorphism. The district represented on the accompanying sketch map (plate 13) is a typical one for these rocks.

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\* According to map by Wm. P. Blake in his "Geological Reconnaissance in California," 1853.

## MESOZOIC ROCKS.

## PRINCIPAL DIVISIONS.

The Mesozoic group includes both sedimentary and eruptive rocks. The sedimentary rocks consist principally of slates often altered to quartzites, with, however, some limestones. The eruptive rocks may naturally, though rather roughly, be distinguished as medium basic lavas altered to diabase or greenstone, and very basic lavas more or less completely altered to serpentines. Both kinds are still further frequently altered to quartzites.

The whole group naturally falls into two subgroups, a lower and an upper one. The lower subgroup is characterized by a large proportion of the eruptive greenstones or diabases, while the upper one is characterized by deposits of serpentines, which in places attain enormous thickness. The proportion of eruptive matter in both subgroups varies exceedingly, and there is occasionally found a little serpentine in the lower division and greenstone in the upper one; but as a whole the two subgroups are characterized as stated.

Right at the confines of the two subgroups, but falling most naturally into the lower one, is a series of limy slates and limestones. These limestones are fossiliferous. The most numerous remains are of crinoidal stems, and, as hereafter shown, some of them belong to *Pentacrinus* or an allied genus, and cannot be of earlier age than Jurassic. We have, therefore, as a lower limit for the lower subgroup of Mesozoic rocks of the Sierra, the base of the Jurassic. They may, however, belong higher in the series. At the top of the upper subgroup is a long series of thinly laminated slates. I have found no fossils in these slates within the district of my more detailed examination represented on the accompanying sketch map lying between the North and Middle forks of the Feather; but comparison with exposures of similar slates south of Merced river (in Mariposa county) and at intermediate points proves conclusively that they are of the same horizon as the *Aucella*-bearing slates which Whitney, on the identification of F. B. Meek, determined to be Jurassic,\* and which White places on the confines of the Jurassic and Cretaceous† and Becker assigns to a higher horizon in the Cretaceous (post-Gault).‡

The fossils at these two horizons, one in each Mesozoic subgroup, show that the whole group is above the base of the Jurassic, and this is confirmed by an ammonite which, as hereafter shown, occurs at still another

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\* Geology of California, vol. i, 1865, p. 226.

† Bulletin of U. S. Geol. Survey, no. 15, 1885, p. 26.

‡ Bull. Geol. Soc. Am., vol. 2, 1890, pp. 201-208.

horizon in the lower subgroup. I have not found any certain unconformity between these subgroups. The whole group seems to be one long series of sediments and lavas deposited during a period of prevailing though perhaps not uninterrupted subsidence of the region.

LOWER MESOZOIC SUBGROUP.

*Slates, Greenstones and Limestones.*—The greenstones or diabases of this subgroup are of eruptive materials, but these materials have quite commonly been transported to their present position and deposited there by water. Stratification is not infrequently visible, and the transition from massive greenstone to slate is sometimes gradual. The greenstone is very often and over wide areas conglomeratic, made up of bowlders and pebbles in a cement or groundmass of the same material, all of altered lava except at times a small proportion of fragments of quartz and other rocks. The bowlders and pebbles and groundmass have undergone much the same kind and degree of alteration, and the surfaces and outlines of the bowlders and pebbles are more or less obscure, but still are readily recognized on fresh fracture, and often more plainly on weathered surfaces. The bowlders and pebbles are well rounded. The mechanical condition and admixture of these materials are very similar to those of much of the Tertiary andesite, which has been transported by water and deposited in the same district, often on the greenstones. Between the South Yuba and the American, as well as between the Mokelumne and Calaveras rivers and elsewhere, lavas of this subgroup are exposed in dikes, where, to the naked eye, at least, they are not chloritic, but of dark-gray colors or black, sometimes porphyritic, and often very similar to Tertiary andesite. Professor Whitney says of this rock: "It appears from Mr. Wadsworth's (not yet completed) examination to be a diabase tufa, a much metamorphosed volcanic deposit. \* \* \* Mount Bullion, Juniper ridge, Bear mountain (on the Merced) and Merced mountain are made up of this rock."\* I have seen the exposures on mount Bullion and Juniper ridge, and the rock there is chloritic and largely conglomeratic, like the greenstones of the district under more immediate consideration here. On mount Bullion they are also largely altered to quartzite.

The greenstones and slates of the lower Mesozoic subgroup form the crest of Hough mountain and of the greater part of Grizzly ridge, though covered in part by Tertiary deposits. At the southeasterly end of Grizzly ridge they come in contact with pre-Mesozoic granite. The main eastern crest of the range is of these rocks from its northwesterly end south of the Middle fork of the Feather to the northwesterly flank of mount Haskell.

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\* Auriferous Gravels of the Sierra Nevada, 1879, p. 44.

Here and southward granite forms the crest where not covered with Tertiary materials, and the contact of these rocks and granite, passing down the westerly slope of this part of the eastern division of the range, crosses the North fork of the Yuba about  $4\frac{1}{2}$  miles east of Sierra city.

On the other (southwesterly) side of this northeastern belt of the lower Mesozoic subgroup its rocks come in contact with those of the upper subgroup. The contact crosses the East branch of the North fork of Feather river, here known as Indian creek, a little northeast of Shoofly, near the crossing of the line between townships 25 and 26 N., R. 9 E., then passes on to the westerly slope of Hough mountain and of Grizzly ridge, and crosses the Middle fork of Feather river between Bells bar and Nelson point.

In the upper part of this subgroup where it crosses the Middle fork of Feather river and thence a little east of southward to the North fork of the Yuba, one to two miles below Sierra city, are numerous outcrops of limestone. For the most part they and the rocks accompanying them are very much altered, and I have seen no fossils in them. In sections 11 and 14, T. 21 N., R. 11 E., are several masses of iron ore which seems to be a product of alteration of the limestone. Near the Yuba there is some serpentine associated with the limestone. These limestones undoubtedly belong near the boundary of the two subgroups, at the same horizon as the fossiliferous limestones to be hereafter described. Whether the outcrops of limestone recurring at intervals continue south of the North Yuba I do not know.

There is limestone exposed with a little serpentine in Little Long Valley creek in section 12, T. 23 N., R. 11 E. It is highly metamorphosed, and I do not know to what part of the lower subgroup it belongs. There is a little serpentine near the crest of Grizzly ridge not far from its northwesterly end. But nowhere in this large eastern area of exposures of the lower subgroup of Mesozoic rocks does serpentine occur in considerable mass. Near the crest of Grizzly ridge and near the divide between the waters of the Middle fork of the Feather and of the North fork of the Yuba and at the Sierra buttes both slates and greenstones of this subgroup are very generally altered to quartzites.

On the easterly face of Spanish peak mountain there are isolated areas of greenstones and slates of the lower Mesozoic subgroup resting on the pre-Mesozoic slates and quartzites.

The Claremont uplift has brought pre-Mesozoic rocks in contact with members of both Mesozoic subgroups, as shown on the sketch map, and far northwestward of the present Claremont mountain the same uplift has dislocated the rocks and brought those of the two subgroups into contact out of the regular order of sequence; so that the rocks of the



lower subgroup which have the serpentines of the upper subgroup on the southwest in the order of sequence, have slates of the same subgroup on the northeast by fault.

*Fossiliferous Limestones.*—In the last named area of exposure of the upper part of the lower Mesozoic subgroup occur the fossiliferous limestones. The outcrops are not continuous, but occur at intervals from a point on the southwestern flank of Claremont, in the N. E.  $\frac{1}{4}$  N. E.  $\frac{1}{4}$  section 4, T. 23 N., R. 9 E., to and across Spanish creek and across the East branch of the North fork of Feather river and the main North fork of the same river to the divide between Mosquito and Yellow creeks, in the western part of T. 26 N., R. 7 E., not far from the edge of the lava field at the northern end of the range. The whole distance from the southeastern end to the northwestern end of this line of exposures is about  $19\frac{1}{2}$  miles. From the southeasternmost exposure on Claremont to the divide between the East branch of the North fork of the Feather and the main North fork, a distance of  $14\frac{3}{4}$  miles, I have made detailed examination and surveys of the area, including the outcrops of these limestones and of the rocks on either side. Thus examined and located, this long line of outcrops of fossiliferous limestones in the heart of the Sierra afford an available and definite horizon from which to measure and determine the position of rocks upward and downward in the series.

*Jurassic or later Age of the Fossils.*—The fossil remains are fragmentary, consisting principally of sections of crinoid stems, though fragments of brachiopod and gasteropod shells occur. Some of the crinoidal stem-joints are simple, round, and with round canal in the center; others, however, are pentagonal and have pentapetalous figures formed by crenated edges on the articulating facets. I sent some of these crinoidal stem-joints to Dr. Charles Wachsmuth, whose extensive and intimate knowledge of crinoids renders his identification of them most valuable. In a letter concerning these fossils, dated at Burlington, Iowa, November 18, 1891, he says:

“ \* \* \* I examined them carefully and have come to the conclusion that they must be at least of a later age than Triassic, possibly Jurassic. The stem-joints are pentagonal, with straight sides or reëntering angles, and the facets in all of them have that peculiar petaloid structure which characterizes the pentacrinidæ, and which occurs in no crinoid preceding the Jurassic. Scattered between these stem-joints there are numerous smaller pieces with a central canal, which I take to be joints of the cirri, and of which in specimen 4 some are still attached to the edge of the joint. On that specimen I also find a few perforated arm ossicles with deep fossæ, showing a highly developed articulation of the arms, such as is rarely found in Paleozoic crinoids. The root on specimen 1 offers no special interest; the lines of union between the joints are serrated, but that is found even in some of the earliest crinoids. That the stem is round at the distal end does not prove that it

was round also in the proximal part, as the form of the stem changes greatly in its downward course, and it seems to me the upper face of the root shows traces of that petaloid structure to which I alluded. The other specimens show the same thing as number 4, but less distinctly. The genus *Pentacrinus*, which made its appearance in the Jurassic, survived to our present day; and as the structure of the stem remained almost unchanged, it is difficult to refer your specimen to any definite age, but I am quite certain they are not older than Jurassic." \* \* \*

*Mesozoic Conglomerate containing older Rocks.*—The fossiliferous limestones alternating with slates and greenstones are at one point associated with a conglomerate containing pebbles and boulders of granite and quartzite. The locality is on Rush creek, a little less than a mile in a straight line from its confluence with the East branch of the North fork of the Feather, in the northern part of section 8, T. 25 N., R. 8 E. The conglomerate is in contact with the limestone, and its cement is limy. The granite of the pebbles and boulders is like that of Spanish peak mountain, and the quartzite like the pre-Mesozoic quartzites of the easterly and northeasterly faces of that mountain, and there is no other probable source of these boulders and pebbles than within this westerly area of uplifting. It is plain, therefore, that the granite had cooled and crystallized, and the slates had been deposited and had undergone quartzitic alteration and been raised above sea-level and subjected to subaërial erosion, before these conglomerates were deposited on the beach of the arm of the Mesozoic sea. These rocks are therefore unconformable with the pre-Mesozoic strata, although no unconformity of dip and strike is apparent. I saw one granite pebble or boulder of more than 500 cubic inches in size in the conglomerate.

The conglomerate is on the easterly edge of the limestones and limy slates, which are exposed for a width there of 5,300 feet and a thickness of about 4,600 feet. On the west of them and between them and the pre-Mesozoic rocks is the broad belt of serpentine three miles wide. I found no fragments of serpentine in the conglomerate. The serpentine, being an eruptive rock, may have been deposited on land or in water, but the slates and limestones were certainly deposited in the sea. If these and the serpentines had been deposited when the pebbles of this conglomerate were borne to the beach, they must have come across a width of some miles of water, unless the serpentines and slates had been uplifted. Of this there is no evidence; and as it is not possible that this beach material came across an arm of the sea (one pebble of granite containing more than 500 cubic inches), it follows that the conglomerate and the greenstones to the east of it are older than the slates and limestones and serpentines to the west of it. It is true that the serpentines now come in contact with the pre-Mesozoic rocks at the faulted easterly face of Spanish

peak mountain, but higher up on the face isolated areas of greenstones and slates occur and, as hereafter shown, the greenstones, slates and limestones come next to the same area of pre-Mesozoic exposures on the west between it and the Great valley, and in by far the greater number of cases throughout the Sierra the rocks of what I have called the lower Mesozoic subgroup outcrop between the serpentines and slates of the upper subgroup and the pre-Mesozoic rocks.

*Unconformity on Claremont.*—The fossiliferous limestones and accompanying slates lie unconformably on the pre-Mesozoic slates of Claremont. The contact and unconformity are plain to the eye where the road from Quincy to Oroville crosses the neck of the "Devil's elbow," on the left bank of Spanish creek, at the mouth of Rock creek, in section 18, T. 24 N., R. 9 E. The unconformity on Claremont is plainly by erosion, as no corresponding difference in dip and strike is apparent. There are greenstones and limestones and a little serpentine in isolated areas on and next east of the pre-Mesozoic area of this faulted northwestern end of the mountain mass.

#### UPPER MESOZOIC SUBGROUP.

*Thinly laminated Slates and Serpentines.*—The upper Mesozoic subgroup is the highest in the series of metamorphic rocks. Its exposures therefore lie generally in positions midway between the axes of greatest uplifting and between exposures of the lower subgroup on either side, the latter adjoining the pre-Mesozoic rocks still farther toward the right and left and nearer the axes of uplift. This prevailing order of succession on the surface is, however, often interrupted locally by faults. In the district here under more immediate consideration, the northeastern crest of the range is, as already described, of the lower Mesozoic subgroup; the southwestern crest and the face of the escarpment immediately below it on the east are of pre-Mesozoic rocks, with isolated areas of the lower Mesozoic greenstones and slates. Between the two mountains the greater part of the space is occupied with serpentines and slates of the upper subgroup. The slates occupy the eastern part and the serpentines the western part, and the two are separated by the long, narrow belt of protruding older Mesozoic and pre-Mesozoic rocks brought up by the Claremont uplift already described. As this belt approaches the Middle fork of the Feather it narrows and ends near the river, where the slates and serpentines of the upper subgroup come together. The area of exposure of the serpentines is from 1.6 to 3.5 miles wide, and that of the slates from 6.5 to 7.5 miles wide.

There is a narrow strip of serpentine outcropping on the easterly side of the exposure of slate, between it and the older Mesozoic greenstones

and slates of Grizzly ridge, along Spring Garden creek on both sides of it above the American valley (see sketch map, plate 13); but farther northwestward the serpentines are entirely absent and the older rocks brought into direct contact with the slates by faulting.\*

There is another narrow strip of serpentine on the southwestern side of the slates at contact with the limestones and slates of the upper part of the lower subgroup, on the left bank of the East branch of the North fork of the Feather. There are also small isolated patches of serpentine on the faulted northern end of Claremont near limestone and slates of the lower Mesozoic subgroup and on pre-Mesozoic rocks. As the Claremont uplift dies out southeastward, hornblendic slates come in on the northeastern side of the pre-Mesozoic exposure, which belong to the serpentine series.

Where the succession is uninterrupted and where least interrupted by faults the serpentine joins the slates and limestones at the head of the lower subgroup. This is the case for 20 miles along the line of exposures of fossiliferous limestones before described. The slates at the head of the Mesozoic series, for reasons to be hereafter given, may be designated as the thinly laminated slates. Where the Mesozoic series is complete or nearly complete the serpentines and slates which accompany them lie between the thinly laminated slates and the rocks of the lower subgroups. It is plain, therefore, that in the ascending series the serpentines and the slates which accompany and replace them come before the thinly laminated slates, and that the latter are at the head of the whole series of metamorphic rocks of the Sierra.

*Serpentine.*—Throughout the area between the North and Middle forks of Feather river the lower part of the upper subgroup of Mesozoic rocks is almost entirely of serpentine, although there are some schists with it, and a part of these are glaucophanic. The schists may be made up of lava transported and deposited by water wholly or in part. South of the Middle fork the proportion of serpentine diminishes and slates increase. These slates are much like those of the lower subgroup and less thinly laminated than those at the head of the series.

The serpentine is for the most part plainly (to the naked eye) a product of alteration of a basic lava. The massiveness, cleavage and absence of lamination or distinct planes of stratification all go to prove this. M. E. Wadsworth describes, under the heading "peridotites," five specimens of this rock from Sierra and Plumas counties within the district next south of the one here more particularly treated of, and infers

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\* This line of faulting along the western foot of Grizzly ridge and mount Hough is a line of recurring orographic movements, as shown by dislocations of Tertiary and Quaternary deposits and obstructions to Quaternary drainage.

from the structure as seen under the microscope that the serpentine has replaced olivine and enstatite.\*

Mr. J. S. Diller kindly gave me the results of microscopic examination of typical specimens which I took from the left bank of Spanish creek above the mouth of Rock creek and below Spanish ranch. He wrote of these January 25, 1887:

"Specimens numbered 1 and 2 are undoubtedly peridotites. Number 2 contains a great deal of olivine, but most of it has been altered to serpentine. Originally there was evidently a rhombic mineral, probably enstatite, associated with the olivine, but now it has all disappeared and serpentine with oxide of iron have taken its place. In specimens 1 and 4 no trace of olivine could be found; all has been altered to serpentine and magnetite; but the peculiar reticulated structure of the serpentine indicates clearly that it was derived from olivine. I have no doubt that these serpentines are altered eruptive rocks, peridotites."

These rocks can be found in all stages of alteration, from that of a dark gray or black trappean rock, sometimes porphyritic, massive, cleaving into irregular prisms, to that of an oil-green serpentine with conchoidal fracture and smoothed and rubbed or "slickensided" surfaces. It is sometimes fibrous. In a geological sense, the whole mass can most conveniently be designated as serpentine, but in a detailed lithological description it would be grouped under different heads according to original minor differences in the lava and to different degrees of alteration. A small proportion of the serpentine shows schistose structure and is more or less micaceous. Whether this is sedimentary lava or detritus of other rocks has not been determined.

The serpentine is in places altered to quartzite. Such quartzite after serpentine occurs at the outlet of Spanish ranch valley; also on Rock creek about three-quarters of a mile above its mouth.

*Upper Slates.*—These slates, as already stated, are at the head of the series of the metamorphic rocks of the Sierra. Wherever I have seen them freshly exposed by recent erosion or by artificial excavation they are of dark blue or bluish-black color and very commonly pyritous. The first effect of weathering is to cover the surfaces with red and yellow oxides of iron, frequently with efflorescences of alum; in later stages of weathering the red and yellow staining is removed and a light gray, nearly white, often powdery surface is left on the laminae of the slate. When thoroughly weathered the slates show themselves very thinly laminated and fragile. At the outcrop this thin lamination is a distinguishing characteristic. They are very largely altered to quartzite, and the alteration is of a characteristic kind in this district. The result-

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\*Lithological Studies: A Description and Classification of the Rocks of the Cordilleras, 1884, p. 158.

ing quartzites are of two kinds; in one the siliceous rock retains the slaty felting and in part the slaty lamination, and this quartzite may be described as silicated slate; in the other kind the felting and lamination have disappeared and the siliceous mass is often partially or completely oolitic. The one kind passes into the other by gradation, sometimes within a few feet. There are no sandstones among the slates in this district, and I conclude that the difference is due to different kinds or degrees of alteration, and not to original differences in the sediment of which the rock was composed. The quartzites frequently pass by farther alteration into clear, white massive quartz. The quartzite is commonly dark gray when freshly exposed, but weathers to some shade of yellow or red from oxides of iron, and then to gray.

*Limestones.*—There are limestones in these slates, as shown on the sketch map (plate 13). They replace quartzites in the line of strike and are otherwise so associated with quartzites as to indicate that the latter have replaced the limestones, but lithological examination is necessary to determine definitely whether this is so.

*MESOZOIC ROCKS OUTSIDE OF UPPER FEATHER RIVER DISTRICT.*

*Distribution of the Rocks.*—The greater part of the Mesozoic exposures of the range are included within two principal areas, an eastern and a western one. The eastern and larger one begins at the northern end of the range and there includes its eastern crest, and extends in width westward to the western pre-Mesozoic area, as shown on the sketch map (plate 13). Farther southward it has the eastern pre-Mesozoic area on the east, and lies between it and the western pre-Mesozoic area, and continues so to the southern end of the latter. There it lies between the eastern pre-Mesozoic exposures and the unaltered Tertiary deposits of the valley for the greater part of the distance to its southern end, which is about 15 miles southeast of the Merced, where the pre-Mesozoic rocks come forward to the Great valley. Three minor arms of pre-Mesozoic exposures already mentioned lie between it and the Tertiary of the valley, one between the Calaveras and Stanislaus, one on the Stanislaus, and one south of the Merced about Hornitas.

The western principal area of Mesozoic exposures lies along the western foot of the range, between the western area of the pre-Mesozoic exposures and the unaltered upper Cretaceous and Tertiary rocks of the Great valley, and extends southward from the northern end of the range to where the granite of the western granitic area comes forward to the valley between the Yuba and American rivers.

*Fossiliferous lower Mesozoic Limestones.*—I have not seen the laminated slates of the head of the series in the western area, though there may be

outcrops of them there; but the serpentines of the upper subgroup and all the members of the lower subgroup are represented there, and among them the fossiliferous limestones. These occur near the contact with the unaltered upper Cretaceous (Chico) and Tertiary deposits, along the West branch of Feather river, at intervals from Nelsons bar bridge at the mouth of a creek coming in from the right, to near the mouth of Cherokee run above the bridge on the road from Cherokee to Yankee hill. Nelsons bar is in the N. E.  $\frac{1}{4}$  section 7, T. 21 N., R. 4 E., and the mouth of Cherokee run in N. E.  $\frac{1}{4}$  section 21, of the same township, according to a map of Butte county. These limestones are referred to as near Pence's ranch by Whitney, and on identification of imperfect specimens of fossils by Gabb, he called them Carboniferous.\* They lie on both sides of the river, which here flows in a southeasterly course. They occur at different horizons in the section for about three-quarters of a mile in width of outcrop (dips, northeasterly at very high angle, or vertical).

At the northeasternmost outcrops, which are on the left bank of the river at Nelsons bar, serpentines are associated with the limestones. There are also serpentines further southwestward, but at the southwesternmost outcrops (all on the right of the river) the limestones are associated in places with greenstones, and a little farther southwestward the greenstones become massive and continuous and form the crest of a high ridge, on the southerly end of which is the village of Cherokee. These greenstones are largely conglomeratic. I found no fossils in the limestones on the left side of the river, but those on the right side of the river are commonly fossiliferous, the fossils consisting principally of fragments of crinoid stems. In my limited search I found no pentagonal sections of stems, but many that were round with round central canal, and some with lines radiating outward from near the canal.

These limestones lie about 34 miles directly across the western division of the range from the outcrops of limestone already described, stretching for 20 miles from the northern end of the range to Claremont. Here, as there, they lie in a series of slates, of nearly the same thickness in each case, between greenstones on the one side and serpentines on the other, with some greenstones associated with the lower limestones, and serpentines near the upper ones. It is true, I found no pentagonal crinoid stems in the limestone at the western foot of the range, but at some of the exposures between Claremont and the northern end of the range the sections of crinoid stems are also all round. I see no reason to doubt that these limestones, with accompanying slates, greenstones and serpentines, lying at the northern end of the range on the two sides

\* *Geology of California*, vol. i, 1865, p. 209; *Auriferous Gravels of the Sierra Nevada*, 1872, p. 88.

of the western pre-Mesozoic area, so closely allied in lithological character, position, sequence and character of fossils, were deposited under identical conditions, and are of the same age—Mesozoic.

About a mile southwest of the line of limestone outcrops, along the right side of the West branch of the Feather, in N. W.  $\frac{1}{4}$  section 19, T. 21 N., R. 4 E., are two small exposures of limestone containing crinoidal fragments. A short distance westward the metamorphic rocks pass beneath Tertiary deposits, and consequently it is difficult to determine the exact position of these limestones in the series. It is probable, however, that a fault intervenes, and that these are of the same horizon as those along the right side of the West branch.

*Eastern principal Area.*—In the eastern principal area of Mesozoic exposures the broad belt of serpentine, though varying in width and possibly interrupted in places, extends from the northern end of the range to and across the Middle fork of American river. It therefore furnishes convenient means of connecting the exposures of this area generally as far south as to the last-named stream with those of the district already described. I have followed it from this district southward to midway between the Middle fork of the Feather and the North Yuba. It is credibly reported as crossing the North Yuba between Downieville and Goodyears bar, and this is confirmed by Professor W. H. Pettee.\* Its eastern edge crosses the South Yuba at the village of Washington, the North fork of the American near Damascus, and the Middle fork of that river west of Michigan bluffs. Its western edge crosses the last-named stream in N. E.  $\frac{1}{4}$  section 1, T. 13 N., R. 10 E. Here, at its western edge, is a large outcrop of pyritous talc.

I have not had opportunity to study the rocks next east of this serpentine belt farther southward than midway between the Middle fork of the American and the North Yuba. To that point the outcrops of thinly laminated slate continue from the district already described on the eastern side of the serpentine. From the South Yuba to the Middle fork of the American a broad area of the thinly laminated shales at the head of the series adjoins the serpentine belt on the west. At one place between the North and Middle forks of the American, where I have had opportunity to locate it roughly, the width is about 3 miles.

West of the area of exposure of thinly laminated slates again comes serpentine, with talcose rocks and slates, not in so wide an area as on the eastern side of the thinly laminated slates or so constant; still, exposures of serpentine with some talc are frequent, and they and the slates of the same horizon (lower part of upper Mesozoic subgroup) are probably constant from near Nevada city to the Middle fork of the American. How

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\* Whitney's Auriferous Gravels of the Sierra Nevada, 1879, p. 34.



much farther they extend north and south of these limits I do not know. The serpentines show themselves on the railroad between Nevada city and Grass valley, and at the crossing of Greenhorn creek, and between there and the crossing of the Bear. On the same railroad, about a mile north of the Central Pacific railroad, is massive talc of the same horizon and very similar in character to that on the eastern side of the thinly laminated shales near the serpentines at the Middle fork of the American. Serpentines also occur west of the thinly laminated shales between the North and Middle forks of the American at a locality which is probably in section 13, T. 13 N., R. 9 E.

West of these serpentines and slates are exposures of the rocks of the lower Mesozoic subgroup, and they continue westward to the pre-Mesozoic gneiss and granite. The Central Pacific railroad crosses them from the contact with the gneiss about a mile southwest of Auburn to near Cape Horn. They consist largely of eruptive rocks (diabase), which have not here, as already stated, the prevailing chloritic character, but are of gray and black colors, sometimes porphyritic, and often resembling, to the naked eye, the Tertiary andesites. They often occur in dikes, traversing both slates and eruptive masses. East of Colfax, between it and Cape Horn, limestones occur, as they also do under Cape Horn, near the river. These limestones hold the same relative position at the head of the lower subgroup between the diabases or greenstones below and the serpentines above as at the northern end of the range.

*Ammonites colfaxii*.—One mile west of Colfax Professor Whitney found specimens of an ammonite which Gabb describes as *Ammonites colfaxii*, and referred with certainty to Mesozoic time and with some hesitation to the Liassic epoch. Whitney calls it a "secondary fossil."\* It was found in the slates and diabases which underlie the limestones at the head of the lower Mesozoic subgroup. It is therefore from a somewhat lower horizon than the fossils found in the limestones at the northern end of the range, and this affords confirmation of the Mesozoic age of the limestones near Pence's on the West branch of Feather river.

*Mesozoic Exposures south of the American*.—From the South fork of the American to Sutter creek I have not had opportunity to examine the rocks.

From Sutter creek to the Tuolumne the area of Mesozoic exposures lying between the pre-Mesozoic rocks on the east and the Great valley on the west is approximately 12 to 15 miles wide. Within the area are two prominent axes of uplift, having the general trend of the main range, and along these axes, between the Calaveras and Stanislaus rivers, are two of the minor mountains above mentioned, the western one rising from the

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\* *Auriferous Gravels of the Sierra Nevada*, 1879, pp. 37-41.

edge of the Great valley, called Gopher hill, the eastern one Bear mountain. The valley between the two is 3 to 4 miles wide. Along the axes of uplift the exposures are principally if not wholly of the greenstones and slates of the lower Mesozoic subgroup. Between the long narrow belts of these exposures lie outcrops of the upper subgroup, and south of the Calaveras, if not north of it, the serpentines and slates and the thin slates of the upper subgroup occur again east of the easterly one of the two axes of uplift, followed by the greenstones and slates of the lower subgroup, which continue eastward to contact with pre-Mesozoic rocks.

Large masses of limestone occur in this normal position in the series at the head of the lower subgroup in places. The exposures of such masses are especially frequent between the Calaveras and Mokelumne and between the greenstones and lower slates brought up along the easterly one of the two axes of uplift on the east and the serpentines and their accompanying slates on the west. I found a fossil coral at one of the exposures at a limestone quarry on the road from Campo Seco to Mokelumne hill, a little less than  $3\frac{1}{2}$  miles from the former in a straight line, in the N. E.  $\frac{1}{4}$  S. E.  $\frac{1}{4}$  S. W.  $\frac{1}{4}$  section 23, T. 5 N., R. 11 E.

A striking feature of this Mesozoic area is the great gold-bearing quartz lode called the "Mother lode." It occurs within the most easterly area of exposure of the lower subgroup, the one lying next to contact with the pre-Mesozoic rocks on the east. I have not had opportunity to determine its exact position in the subgroup north of the Calaveras, but between the Calaveras and Tuolumne it is, when present, at the head of the lower or greenstone-bearing subgroup and at or near contact with the serpentines and slates of the upper subgroup. At one place near Carson Hill village it passes over the line between the two subgroups a short distance and outcrops among serpentines and their accompanying slates.

Where the Tuolumne flows out to the valley at Lagrange there are greenstones of the lower subgroup and slates which are probably of the upper subgroup. Where Merced river comes out of the mountains at Merced falls the metamorphic rocks in contact with the Tertiary deposits of the valley are the thinly laminated slates at the head of the Mesozoic series. Farther southward, on the road from Merced falls to Hornitas, I saw a small isolated patch of these slates lying on pre-Mesozoic rocks.

*Mesozoic Exposures south of the Merced.*—East of the pre-Mesozoic area about Hornitas already briefly mentioned, and extending southeastward from the Merced about 15 miles to where the pre-Mesozoic gneisses and granites come forward to the valley, are two mountains, already noted; the western is called Juniper ridge, and the eastern mount Bullion. The

mass of both mountains consists, as before said, of greenstones and slates of the lower Mesozoic subgroup. The greenstones are largely conglomeratic and are largely altered to quartzite. In mount Bullion, at the west of the principal mass of greenstones, is a series of slates with limestones. Both slates and limestones are exposed on the Merced, and also nine miles southeast of the river. The limestones are siliceous, and no fossils have been found in them. Next west of these slates and limestones outcrop serpentines on both sides of the Merced and at points for 10 miles southeast. Farther southeastward they are replaced by talcose rocks, which probably belong to the same horizon as the serpentine, and these continue southeastward to the contact with pre-Mesozoic gneiss. The serpentines on the Merced are in part altered to quartzite, and this alteration is exhibited unmistakably and on a large scale on the right side of the river. Thinly laminated slates follow next west of the serpentines on the Merced, and they continue southeastward at least 11 miles. They form the floor of the narrow valley between the two mountains; at Bear Valley village the area of outcrop of these shales is about a mile wide. Here in these shales were found the *Aucella* and other fossils by which Professor Whitney established the Mesozoic age of this part of the metamorphic rocks of the Sierra. He, on the identification of Meek and Gabb, considered them Jurassic; while, as already stated, White places them at the confines of Jurassic and Cretaceous, and Becker places them still later in the Cretaceous.

There is faulting at the western foot of mount Bullion, as shown by excavations on the great quartz lode there. Professor W. P. Blake mentions a fault in the Princeton mine, which is on this lode 9 miles southeast of the Merced, in a report on the mine which I have not now at hand to refer to. It is plain from maps and reports of the mines, as well as from interruptions of the exposures at the surface, that the lode occupies a fissure at a fault plane. But the succession of the rocks, although obscured in places by the faulting, is essentially the same as at the northern end of the range.

#### THE MESOZOIC SERIES.

*Natural Divisions.*—The Mesozoic series is essentially the same throughout the two great areas of exposure, and is as follows in descending order:

- |                |   |
|----------------|---|
| Upper subgroup | { Thinly laminated slates ;<br>Slates and serpentines.                                |
| Lower subgroup | { Slates and limestones with some greenstones ;<br>Slates and greenstones or diabase. |

The limestones of the series are not continuous and are frequently absent, and they occur in places elsewhere than in the third member of the series; but they are characteristically frequent and extensive in this member. The serpentines are also not constant in the second member, or the diabase or greenstone in the lowest member; but there is no very large area of exposure of the former without serpentine or of the latter without greenstone or diabase. Serpentine sometimes occurs in small proportions in the lower subgroup, and south of Sutter creek the greenstones are not entirely confined to the lower subgroup, but occur in small proportions among the serpentines and slates accompanying them of the upper subgroup, and possibly among the thin slates at the head of the series. There are also in the more southerly exposures of the thin slates some sandstones, and at one place near Montezuma, between the Stanislaus and Tuolumne rivers, I have seen among them a fine conglomerate. I have not found limestone among these thinly laminated slates except in the district described, between the East branch of the North fork and the Middle fork of Feather river. The non-chloritic character of the diabase in a part of the exposures shows a difference in degree or kind of alteration, and there are other minor differences. Still, there are enough distinguishing characteristics of the several subdivisions of Mesozoic rocks common to each throughout the areas of exposure to render it readily identified.

The division of the Mesozoic rocks into upper and lower subgroups simply brings out to view the characteristic eruptive activity and deposition at the different horizons. The principal eruptives in the pre-Mesozoic series are granites; in the lower Mesozoic, diabase or greenstone, products of alteration of a medium basic lava; in the upper Mesozoic, serpentine, a product of alteration of basic lavas. The succession of lavas in the Sierra in Mesozoic time is similar in one respect to that of Tertiary time, when the principal outflow of basalt followed the principal outflow of less basic lavas.

I have not attempted to give the thickness of the Mesozoic series or any of its members, as it is obscured by faulting; but data are accumulating which will, I trust, make it practicable to eliminate the errors from this source. The whole series is certainly several miles thick.

*Fossil Horizons.*—In three of the four natural divisions of the Mesozoic series fossils have been found, namely, in the thinly laminated shales at the head of the series (*Aucella*, *Belemnites*, etc, on the Merced, Mariposa county); in the slates and limestones with greenstones (crinoids with pentagonal stems, etc, at the northern end of the range); and in the lowest division, consisting of slates and diabase or greenstone (*Ammonites colfaxii*, on the Central Pacific railroad).

## ALTERATION PRODUCTS.

*The quartzitic Alteration.*—The details of metamorphism belong to lithology, but the quartzitic alteration is so general and on so large a scale in the Sierra that it becomes an essential and characteristic feature of the geology of the range. As before shown, there is quartzite after granite near the Sierra, if not within the range, and on a large scale after slates, both pre-Mesozoic and Mesozoic, and after greenstone and serpentines, and less certainly perhaps but to all appearance, to the naked eye, after limestone. In places the quartzite passes into pure white quartz. Quartz is found in lenticular masses and veinlets isolated from any fissure, in the quartzites and in the slates, and in fact in all the rocks, and such deposits of quartz are especially numerous in the pre-Mesozoic slates; and finally, quartz occupies much the greater part of the space between the walls of fissures throughout the Sierra.

*Pyritous Character of the Rocks.*—Another characteristic which is so prevalent that it cannot be omitted from a geological account of the range is the abundance of pyrite in the slates. From the outcrops alone no adequate idea of the proportion of pyrites could be obtained, but the more recent erosion and the tunnels and other mining excavations show a widespread distribution of pyrite throughout the slates. On account of the presence of pyrite, the slates weather to yellow and red colors at their outcrops; indeed, the color of the débris resting on the outcrops can be taken as an indication of the age of the surface—the débris on surfaces formed by more recent erosion is of gray color, while at surfaces as old as early Quaternary, or, more decidedly, as old as late Tertiary, the débris is of red and yellow colors. Of the pyrite in the greenstones or diabases I cannot speak with confidence; near fissures I have seen greenstone very pyritous. From the results of microscopic examination before quoted, it is probable that the iron in the serpentine is in the form of oxides rather than sulphides. Masses of chromic iron ore are found in the serpentine.

*Fissures and mineral Veins.*—Quartz, which is so large a product of alteration of the rocks of the Sierra, forms the great bulk of the material filling fissures, and pyrite, which is so widely distributed in the slates though in far less proportion than quartz, is much more abundant than any other mineral except quartz among the contents of fissures. The fissures are generally, perhaps always, at fault planes; they are effects of uplifting forces, and the mass on one side of each fissure is usually, if not always, uplifted farther than on the other. As already stated, the prevailing direction of the axes of uplift is approximately parallel to the strike of the rocks, and consequently this is true of the prevailing direction of

the fissures. But they sometimes run in other courses. Between the Middle fork of the American and the Yuba there is a series of fissures trending directly across the strike of the rocks. One of these, on Jami-son creek at the Plumas Eureka mine, has yielded a large product of gold. At the same mine there are a number of so-called "flat veins" near and connected with the fissure, which are cleavage crevices enlarged and filled with quartz and pyrite containing gold.

*Gold.*—The occurrence of gold is not only most important economically, but is also a very important geological characteristic of the Sierra. The gold is associated with quartz, various sulphides (pyrite, chalcopyrite, galena, etc), and other minerals, but the essential accompanying minerals are quartz and pyrite. Gold mining in solid rock is called "quartz mining," and the treatment of gold ore consists principally in separating the valuable metal from quartz and "sulphurets." It occurs with quartz and pyrite both in fissures and outside of fissures where the quartz is a product of alteration of slates and other rocks, and its occurrence seems to be connected not only with the precipitation of quartz and pyrite in fissures, but also with the presence of pyrite and the quartzitic alteration in the rocks of the range generally. The richest deposits of gold in the solid rock, however, and all or nearly all that have been found rich enough to be profitably worked on a large scale in the Sierra are in fissures. The gold is very unequally distributed through the quartz of the fissure; frequently only a part of the thickness of the lode can be worked, and profitable mining, where it exists at all, is always limited to certain areas of the lode called "chutes" or "chimneys," and it would in nearly all cases effect a large saving of cost to find and use every available means of determining as early as possible the trend of the axes and outlines of these areas.

Gold-bearing fissures occur in both the pre-Mesozoic and Mesozoic rocks. In the granites gold quartz lodes have been found more or less productive, as at Granite basin, between the North and Middle forks of the Feather, also between the Sanislaus and Tuolumne south of Sonora and elsewhere, but I believe none such have been found far from contact with other rocks, and the great area of granite exposures, which includes much the larger part of the Sierra, has been barren ground for miners. In the pre-Mesozoic sedimentary rocks rich deposits have been found at and near Sonora, between the Sanislaus and Tuolumne rivers. These rocks are traversed by dikes of eruptive matter, which to the naked eye appears like the Mesozoic diabase, and the dikes were probably formed and filled in Mesozoic times. The gold occurs mostly in and near these dikes, and therefore it probably should be classed with the gold deposits of the lower Mesozoic subgroup. The pre-Mesozoic rocks of the district

south of Merced river, about Hornitas, have also yielded considerable quantities of gold.

Gold has been found in all the members of the Mesozoic series excepting the serpentine; but much the most productive part of the series and of all the rocks in the Sierra is what I have called the lower Mesozoic subgroup, which includes the slates and greenstones at the bottom of the Mesozoic series and the slates and limestones and greenstones next above. Nearly all of the deposits now most largely productive are in this part of the Mesozoic series, excepting some in fissures and dikes, which, though traversing older rocks, probably for reasons already given belong to the same Mesozoic age. As the lodes are generally if not always at fault planes, they are often at or near contact of this subgroup of Mesozoic rocks with others of a widely different horizon, as at Nevada city, where the contact is with granite.

Professor Whitney describes the before-mentioned great quartz vein, called the "Mother lode," extending (not continuously) from the Mariposa estate to Amador county, as "Made up of irregularly parallel plates of white compact quartz and crystalline dolomite or magnesite."\* There is a large vein in the greenstone-bearing group on the southeastern flank of Spanish peak mountain, which also consists largely of magnesian limestone. The "Mother lode" between the Calaveras and Tuolumne rivers and also in Mariposa county south of the Merced, if not for its whole length, is at the head of the lower Mesozoic subgroup. This is the horizon of the fossiliferous limestones, and it is possible that the limestone of the lode where it occurs belongs to this group of sedimentary deposits, but it is also possible that it is a chemical deposit like the quartz.

The fact that the most profitably worked quartz deposits are in the lower Mesozoic subgroup does not prove that the rocks of that subgroup contain the most gold, but that they contain it in the form most available. In the other Mesozoic rocks (excepting the serpentine) and in the pre-Mesozoic sedimentary rocks there must be much gold in a more diffused condition, for the gravels which are débris of these rocks are often very rich. But I cannot here treat of the occurrence of gold further than as it is characteristic of the geology of the series and its several members.

*Fissures containing Chalcopyrite.*—In a long line of fissures near the western foot of the range, chalcopyrite occurs with the quartz and pyrite as an important constituent of the vein matter. The fissures are among or near the greenstones of the lower part of the Mesozoic series. Such deposits occur on the southern side of the Yuba, near Spencerville; south of Sutter creek, about 2½ miles south of east of Ione; on the Mokelumne,

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\* Auriferous Gravels of the Sierra Nevada. 1879, p. 46.

near Campo Seco; and between the Calaveras and Stanislaus in the valley between Gopher hill and Bear mountain, and also near the western foot of Gopher hill at Quail hill; and such deposits are reported as far south as in Mariposa county, south of the Merced. At Copperopolis, between Gopher hill and Bear mountain, they are worked on a considerable scale for copper, and on a smaller scale at two or three other points. Why this series of fissures along the western foot of the range should differ from the fissures in the same rocks on the western slope of the range generally in containing so much larger proportion of copper pyrites with the quartz and iron pyrites is not clear, but the fact is of geological significance.

#### AGE OF THE MINERAL VEINS.

The fissures are younger than the rocks they traverse, and consequently those that traverse Mesozoic rocks were made or extended after these rocks were deposited. The period of their deposition was one of prevailing regional subsidence, as already stated, but it was a period of great eruptive activity, as shown by the miles of thickness of diabases (or greenstones) and serpentines. It is hardly probable that all this eruptive activity took place without dislocation as well as fissuring. Moreover, there are strong indications of faulting at that time, especially at or near the boundary of the two Mesozoic subgroups, although no unconformity among the Mesozoic rocks has been certainly established.

At the end of the deposition of the metamorphic Mesozoic rocks there followed great uplifting, tilting and metamorphism, and certainly great fissuring. A prominent part of the metamorphism was the quartzitic alteration, which resulted in the production of quartz with pyrite and gold, like that in the fissures. It is practically certain, therefore, that a large part of the fissuring and filling of fissures in the Mesozoic rocks occurred with the tilting and metamorphism at the time when the deposition of these rocks ceased and they were raised above sea-level. A long period of subsidence followed, with little if any dislocation, continuing through the later Cretaceous (Chico), the Eocene (Tejon), and the early Miocene. Then followed the Tertiary and Quaternary uplifting, to which is due the relief of the present range. In these Tertiary and Quaternary movements there has been great faulting along lines of old fissures, and probably new fissuring; but we have gravels deposited by streams at the time of the early Miocene movements, and they are made up largely of quartzite and quartz with gold from Mesozoic as well as pre-Mesozoic rocks, and much of the quartz and gold is from fissures. It is therefore certain that a large part, at least, of the fissuring of Mesozoic rocks and the filling of fissures with quartz, pyrite and gold took



place at the time of the tilting and metamorphism of these rocks, and that possibly a part of it took place during their deposition.

It has been shown that the pre-Mesozoic rocks were raised above sea-level and a part of them had undergone the quartzitic alteration before the Mesozoic rocks were deposited. They were probably also more or less fissured while being uplifted and altered, and the fissures may have been at that time filled with quartz containing pyrite and gold. It is entirely probable that a part of the gold of the Sierra is of pre-Mesozoic age, and it is certain that a large part of it is of Mesozoic age.

A large proportion of the gold product of the Sierra has been obtained from Tertiary and Quaternary and Recent gravels, and is of Tertiary, Quaternary and Recent age, in the sense of having been detached, concentrated and deposited by streams of those times; but whether gold has been deposited in veins within the Sierra proper since the Mesozoic uplift has not been certainly proved or disproved. Professor Whitney saw a vein of chalcedonic quartz traversing Tertiary gravels,\* and silica is not infrequently found forming a cement of such gravels, and silicified wood is not uncommon in them. There is chalcedony, evidently deposited by a now extinct hot spring, near the edge of a lava flow near Independence, south of the South fork of the Mokelumne. The fragments of chalcedony, resting on partially kaolinized slate, have been moved and washed for gold, but whether the gold was from the chalcedony or from the bed-rock on which it rested I could not learn in the short time spent there.

It is certainly not improbable that some gold-bearing quartz was deposited by the solfataric action that accompanied and followed the great Tertiary outflowing of lava; but the greater part of the gold-bearing quartz was deposited in veins older than the Tertiary lavas, for débris of such veins underlies the oldest of them.

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\*Geology of California, vol. i, 1865, p. 276; Auriferous Gravels of the Sierra Nevada, 1879, p. 330.