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VOLUME 3

ANDREW C. LAWSON, *Editor*

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ERRATUM.

On page 365, lines 3 to 8, inclusive, are out of place. They should be inserted after the word ''examples'' in line 22 of the same page.

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UNIVERSITY OF CALIFORNIA PUBLICATIONS

Bulletin of the Department of Geology

Vol. 3, No. 1, pp. 1-30, Pl. 1. ANDREW C. LAWSON, Editor

THE QUATERNARY

OF

SOUTHERN CALIFORNIA

BY

OSCAR H. HERSHEY

BERKELEY

THE UNIVERSITY PRESS

APRIL, 1902

PRICE 20 CENTS

THE BULLETIN OF THE DEPARTMENT OF GEOLOGY OF THE UNIVERSITY OF CALIFORNIA is issued at irregular intervals in the form of separate papers or memoirs, each embodying the results of research by some competent investigator in geological science. It is designed to have these made up into volumes of from 400 to 500 pages. The price per volume is placed at $3.50, including postage. The papers composing the volumes will be sent to subscribers in separate covers as soon as issued. The separate numbers may be purchased at the following prices from the University Librarian, J. C. Rowell, to whom remittances should be addressed:—

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Vol. 3, No. 1, pp. 1-30, Pl. 1. ANDREW C. LAWSON, Editor

THE QUATERNARY OF SOUTHERN CALIFORNIA.

BY

OSCAR H. HERSHEY.

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INTRODUCTION.

Less attention has been given to the Quaternary geology of the State of California than the subject deserves. It has not proved attractive because of its simplicity. Impressive evidences of startling events, such as stimulate the student of glacial geology in the Eastern States, are here confined to isolated and often difficultly accessible localities. The Pleistocene fauna and flora were too nearly like the present to be of great interest, until quite recently, to palæontologists in a land where there is such a wealth of older fossil remains. So it happens that, when all the fragments of knowledge which we possess in print of the Quaternary history of California are gathered together and sorted out, they do not even furnish us a satisfactory provisional scheme of classification to which to refer the various surficial deposits of the State.

It is impracticable to apply here the scheme (with its various glacial and interglacial epochs) which has been evolved in the eastern portion of our continent. There is some analogy between our Quaternary events and those of the country east of the Rocky Mountains, but there is never any certainty that we are dealing with chronologic equivalents. In time, certain datum planes may be traced across the Cordilleran belt and our classification tied to that of the Eastern States. In the meantime, only confusion could result from the use of the same epoch titles on the Pacific as on the Atlantic Coast. We have the same reasons for setting up an independent classification as exist in regard to Europe and the eastern portion of the United States.

The above conviction will not prevent the writer from attempting to rationally refer, by means of erosion studies, the deposition of certain of our California deposits to about the same stages of the Quaternary era as certain drift sheets and associated phenomena in the Mississippi Basin. This is the special purpose of this paper, and Southern California is selected as the field of operation because in that section of the State the sequence of Quaternary events is most complete and the relative ages of the formations are most easily determined.

Mr. Ralph Arnold has recently completed an extended study of the marine Pleistocene deposits of the Southern California coast. He presented a paper on the subject at the last meeting (December, 1901) of the Cordilleran Section of the Geological Society of America, but the full memoir is not yet in print. Through the courtesy of Mr. Arnold, I am in possession of his correlation table and can avail myself to a certain extent of the results of his work. I shall discuss this marine Pleistocene only so far as to fix upon its probable age as indicated by the erosion accomplished on it since its uplift. Aside from the marine terraces pretty thoroughly discussed by Lawson,* Fairbanks,† and Smith,‡ and the associated sands and gravels studied by Arnold, the Quaternary of Southern California is virtually a virgin field.

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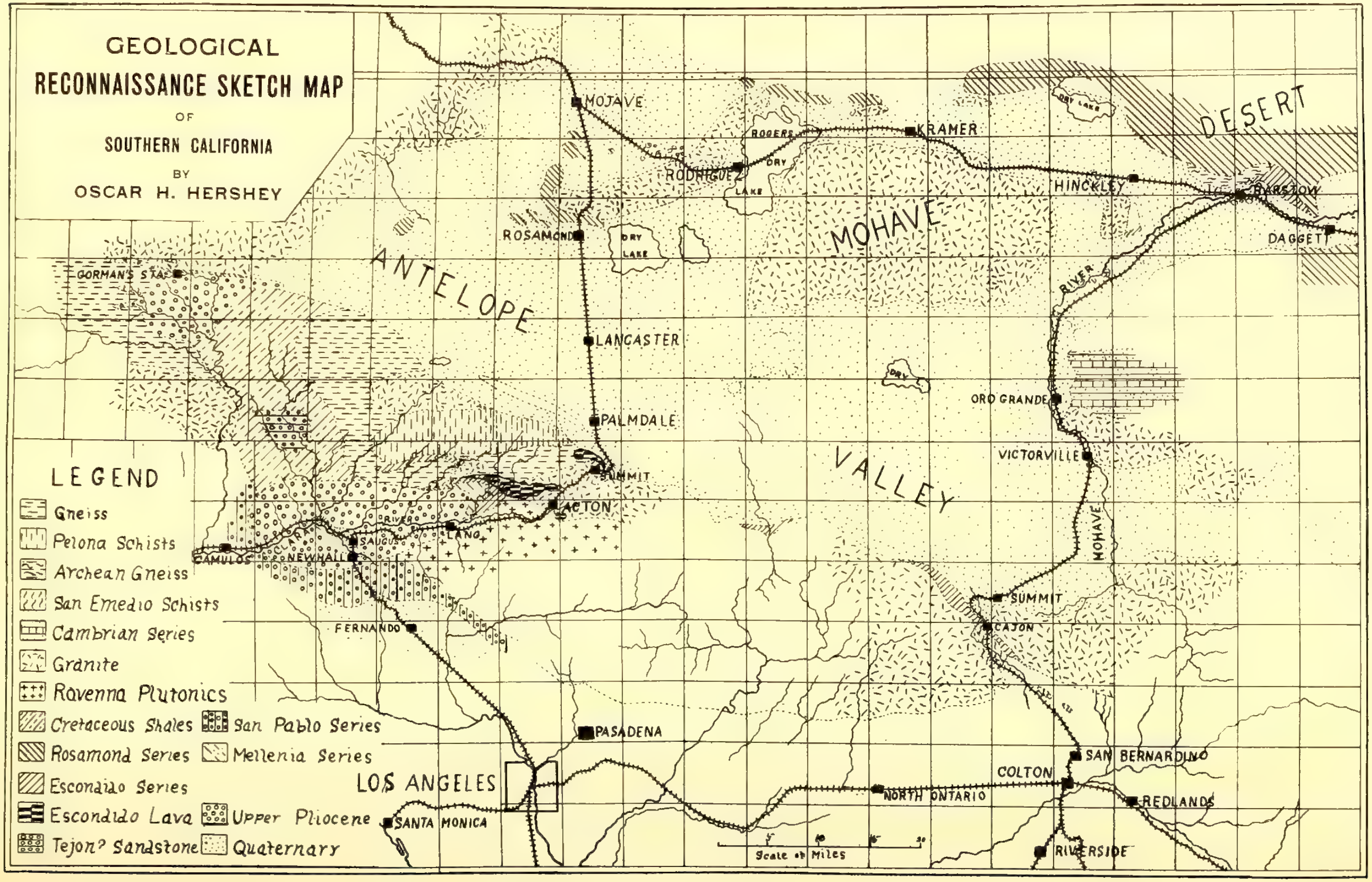
*The Post-Pliocene Diastrophism of the Coast of Southern California, Bull. Dept. Geol., Univ. Calif., vol. 1, No. 4, 1893, pp. 115–160.

†Oscillations of the Coast of California During the Pliocene and Pleistocene, American Geologist, vol. XX, October, 1897, pp. 213–245.

‡A Topographic Study of the Islands of Southern California, Bull. Dept. Geol., Univ. Calif., vol. 2, No. 7, September, 1900, pp. 179–230.


GEOLOGICAL
RECONNAISSANCE SKETCH MAP
OF
SOUTHERN CALIFORNIA
BY
OSCAR H. HERSHEY
LEGEND
Gneiss
Pelona Schists
Archean Gneiss
San Emedio Schists
Cambrian Series
Granite
Ravenna Plutonics
Cretaceous Shales
San Pablo Series
Rosamond Series
Mellenia Series
Escondido Series
Escondido Lava
Upper Pliocene
Tejon? Sandstone
Quaternary
ANTELOPE
VALLEY
MOHAVE
DESERT
MOJAVE
KRAMER
ROGERS
DRY
LAKE
RODRIGUEZ
HINCKLEY
BARSTOW
DAGGETT
ROSAMOND
DRY LAKE
DRY LAKE
GORMAN'S STA.
LANCASTER
PALMDALE
SUMMIT
ACTON
LANG
SAUGUS
RIVER
NEWHALL
CAMULOS
FERNANDO
ORO GRANDE
VICTORVILLE
RIVER
MOHAVE
SUMMIT
CAJON
PASADENA
LOS ANGELES
SANTA MONICA
NORTH ONTARIO
COLTON
SAN BERNARDINO
REDLANDS
RIVERSIDE
Scale of Miles

THE EARLY QUATERNARY OROGRAPHIC DISTURBANCE.

In the hydrographic basin of the Santa Clara River of the South, in Los Angeles and Ventura counties, there is an oval Upper Pliocene area about twenty miles long and ten miles in greatest width. After about 8,000 feet in thickness of gravel, sand, and clay (in part marine and in part alluvial, but all indisputably laid down in approximately a horizontally-bedded position and near sea-level) had accumulated, the basin was uplifted, compressed and the strata plicated. Around the border the gravel was tilted at angles prevailingly 20° to 30°, but near the center there was formed a distinct anticline, in the southwest limb of which the strata, even the very latest member, stand at angles varying from 30° to 60°, but prevailingly 45°. The orographic disturbance which thus tilted these late Pliocene beds was not an unimportant or local one.*

Another and smaller isolated basin of Upper Pliocene strata, lying mainly in the extreme northwestern corner of Los Angeles County, near Gorman's Station, has been elevated bodily to an average altitude of 3,000 or 4,000 feet, tilted toward the center at angles of 10° to 30°, and profoundly eroded. On the eastern flank of Fraser Mountain, immediately northwest of this basin, there are several high mesas (altitude about 6,000 feet). They are remnants of old detrital slopes of light brown sub-angular gneissic debris, built up over tilted and eroded pink Upper Pliocene sandstone, and subsequently by uplift of Fraser Mountain, tilted more steeply away from the center of the mountain, raised high on its flank and deeply eroded. The detrital capping is late Quaternary.

Fraser Mountain and the neighboring Sierra de la Liebre have beautiful dome shapes, and, as seen from a distance, smooth contours contrasting strongly with the rugged and no higher Alamo, San Emedio, Sierra Madre, part of the Tehachapi Range and the Coast Ranges in general in that region. These mountains and the similarly smooth ridge just north of Gorman's

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* These beds are unconformably above a series of sandstones and conglomerates which are recognized as San Pablo in age, and on structural and lithologic grounds they are correlated with the Paso Robles formation, the Salinas Valley equivalent of the Merced series.

Station were probably largely buried under detrital slopes and the Upper Pliocene sandstones until the opening of the Quaternary era. To explain the presence in late Pliocene time of the sea in that basin some mountain has to be eliminated, and the evidence indicates the highest of the region, the Fraser-Pinos Range. Even if we will not agree that the Upper Pliocene sandstone was at one time more extensive and covered the site of Fraser Mountain, a projection of the plane of the base of the sandstone series up the slope of the mountain will convince the student that in late Pliocene time the site of Fraser Mountain was a surface not appreciably elevated above sea-level. There is no faulting or any unusual type of deformation apparent. In Quaternary time Fraser Mountain has been lifted to an altitude exceeding 8,000 feet, and most of this elevation was accomplished during the disturbance immediately succeeding the Pliocene period.

The same argument applied to the Upper Pliocene basin in the Santa Clara Valley will lead to the same result. The high mountains almost enclosing the basin owe their present prominence chiefly to uplift in early Quaternary time. This is especially true of the great mother range of Southern California, the Sierra Madre-San Bernardino Range, which has an average altitude exceeding 6,000 feet and several peaks reaching 10,000 and 11,000 feet.

The only extensive portion of Southern California, so far as seen by the writer, apparently remaining nearly in its late Pliocene condition is the Mohave Desert. Professor N. S. Shaler says* of it: "The most complete effacement of the original valleys appears to have taken place in the region known as the Mohave Desert. Here the detrital slopes have risen to near the tops of the ranges." I entered the region with that idea in mind and came out convinced that it requires a radical modification. There are, indeed, thick accumulations of detrital material that have been built up close to the foot of such prominent ranges as the Tehachapi and the Sierra Madre, and may have buried the foot-hills, but in the central and by far the larger portion of the desert region I do not believe the detrital

* Broad Valleys of the Cordilleras, Bull. Geol. Soc. Amer., Vol. 12, p. 290.

slopes have filled the broad basin-like valleys to a depth greater on the average than several hundred feet. Low knobs of granite occur at many places near the center of these basins, and where cañons have been cut into the detrital material, as by Mohave River, hard rock has been encountered at many points at no great depth. There is an area thirty miles long by three to four miles wide, and another thirty miles long by twelve to fifteen miles wide, of undulating granite comparatively free of detritus and characterized by long, broad, low, smoothridges in which the granite (much weathered and softened,) is rarely more than ten feet beneath the surface, and is often uncovered by railway cuts at three to five feet. These ridges are surmounted by knolls of broken pegmatite, and in places rise into short, rugged hill ranges, but rarely reach the dignity of mountains.

So strong was the impression that I was traveling over a country that had been reduced nearly to a uniform level by erosion, that it seemed natural to refer to it in my field notes as the granite platform. I should hardly like to call it a peneplain, as evidences of actual and completed base-leveling, if they ever existed, are now obscured by the more recent detrital slopes and alluvial deposits that floor the broad basins. It is a land whose topographic forms have reached the stage of old age but not that of senility. On the granite areas denudation effaced most of the rugged mountains and left only a few standing widely separated from each other. On a peneplain these would be classed as monadnocks. Where the rocks were more resistant, as on the gneiss, schist, quartzite, and limestone east of the main granite area, residuals were more numerous, and that region now has many rugged ranges.

The relation between the granite and an overlying volcanic series, apparently of Eocene age, indicates that the surface of the former had been reduced nearly to its present level early in the Tertiary era, and the country was probably even more uniform in the Eocene period than at the present time. Many of the rougher ranges in the desert are composed of rhyolite resting on granite at a level not much above or below the general level of the basins. Faults of small throw are common, but do not appreciably affect the present topography.

Dr. H. W. Fairbanks thinks that we have in the Mohave Desert essentially the same topography as characterized the site of the Southern Sierra Nevada area before the great uplift to which the Sierran valleys are due; and also that the Sierra Madre-San Bernardino Range is a portion of this old lowland which was elevated by faulting at the close of the Pliocene period,* in which view I concur with some reservations. As Antelope Valley is a structural basin with a thick Tertiary and Quaternary filling, I am not quite certain that the high range on its southern border was not outlined during a disturbance prior to that which opened the Quaternary era. Further, I suspect that some of its higher and more broken portions represent residuals on the late Pliocene plain such as are so common in the Mohave Desert, and with as much reason may have remained in force on the orographic block which was subsequently thrust up into the present high range. However, I will agree that the attitude of the Upper Pliocene strata bordering on it and the many deep, extremely narrow cañons trenched into its mass, make it reasonably certain that the range owes its present great prominence to uplift at the close of the Pliocene period.

The Mohave Desert and Antelope Valley were elevated as a whole, without any great deformation, something exceeding 2,000 feet. On the north, the Tehachapi Range was thrust up by the sharp tilting of a series of narrow fault blocks. At the same time the Sierra Nevada Range rose to its present prominence by the uplift of its eastern border to the extent probably of from 7,000 to 10,000 feet. The disturbance extended throughout the State. The Klamath Mountain region was deformed into great domes and arches, with elevation along the axes of several to the extent of 4,000 feet. The Coast Range region was uplifted and deformed from end to end. Among the best-known local evidences of this may be cited the faulting, tilting, and erosion of the Merced series on the San Francisco Peninsula and associated upthrust of Montara Mountain as described by Lawson,† and the upthrust of Mt. Diablo

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* Communicated.

† Bull. Dept. Geol., Univ. Calif., vol. 1, No. 4, pp. 148–151.

as determined by Turner.* It is evident that the territory of California at a time closely following on the deposition of the recognized Upper Pliocene marine deposits was the site of a profound orographic disturbance which radically modified its surface conditions. The wide extent and great importance of this disturbance have recently been recognized by other investigators.† It properly terminated the Pliocene history and inaugurated typical Quaternary conditions, so that it is perfectly natural to consider it the opening event of the Quaternary era in the State of California.

I am informed that palæontologists (including Arnold) are finding a typical Pleistocene marine fauna in the upper portion of the Merced series and its Southern California equivalent, a series the greater portion of which is by common consent considered Upper Pliocene in age; and by them it is proposed to place the inferior boundary of the Quaternary era chronologically below the great orographic disturbance outlined above, a proposition to which I most vigorously demur. The line dividing the Pliocene and Pleistocene should be so drawn as to be of the greatest convenience to the greatest number of geologists. If the line is placed in the conformable strata below the physical break, it can only be recognized in a few limited basins, but if the great orographic disturbance which suspended deposition in those basins be accepted as the first Quaternary event, no difficulty will be experienced in properly placing it throughout the State. At most, there can be no great difference between a late Pliocene and an early Quaternary fauna. A mere shifting of ocean currents might bring about the change observed. It would be too insignificant an event to counterbalance the radical change in physical conditions which must have resulted from the upthrust of the California mountains. The latter has by far the greater right to fix the limit of the Tertiary era. It has been customary for many years to place the division between eras in chronological positions corresponding to non-conformities among the strata and the introduction of

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*Bull. Geol. Soc. Amer., vol. II, p. 402.

†The Physiography of California, by Dr. H. W. Fairbanks; Bull. Amer. Bur. Geog., vol. 11, Sept. and Dec., 1901.

some of the genera of the new fauna, or, at any rate, a suggestion of its general character has been expected to appear below the physical break.

It is probable that in time this great California orographic disturbance will be definitely and reasonably correlated with the marked epeirogenic (and locally slightly orogenic) uplift which is conceded to have inaugurated Quaternary conditions in the Eastern States. In that case, the Lafayette formation will be recognized as the equivalent, in part at least, of the Upper Pliocene of the Pacific Coast. If we base our determination of the beginning of the Quaternary era in California on palæontological evidence, we would then have a longer era on this coast than east of the Rocky Mountains, and more or less confusion would result. On the whole, I think it more convenient, more rational and therefore more scientific to place all the strata which are structurally below the physical break, in the pre-Quaternary periods, and that view will be adopted in the following pages.

In any case, the conclusions of this paper in the matter of the probable length of the Quaternary era will not be seriously affected; for the strata in dispute are thin and represent a very short time in comparison with that of all of the Tertiary and Quaternary eras. Indeed, it is rather remarkable that the palæontological evidence based on the percentage of living species in faunas should so nearly combine with the physiographic evidence in establishing a natural and well-marked line of division between the two eras. We can fix the line on this coast much more satisfactorily than on the Atlantic Coast, as in the latter region the supposed latest Pliocene strata, the Lafayette formation, are lamentably barren of fossils.

THE SIERRAN VALLEYS.

Piru Creek rises in the high mountains west of the Upper Pliocene basin near Gorman's Station and flows toward it, but instead of following its old and apparently most natural course across the area of soft rocks, it skirts the southwestern border, keeping in the gneissic area and flowing in a deep cañon. Tributary streams have eroded broad, shallow valleys in the

Pliocene sandstone, and then deep, narrow, rocky gorges before they enter Piru Creek. It is evident that once the soft rocks extended as far as the present site of the stream, which, in the course of its wanderings on a broad late-Pliocene flood-plain, aided perhaps by a slight tilting of the basin, came to flow along the southwestern border, and subsequently, when uplift enabled it to trench far beneath the level of the old plain, it encountered the hard gneissic rock and cut its present cañon while the area of softer rock on the northeast was being generally reduced. This is one of the finest cases of a superimposed stream that has come under my observation.

For many miles Piru Cañon has an average depth of 1,000 feet. In the crystalline rocks, granite and gneiss, its bottom is little wider than the stream-bed. For more than five miles it is trenched into Cretaceous shales and sandstones, and here widens in places to several hundred yards, but throughout it remains a rocky, winding cañon abounding in precipitous bluffs, a sheer precipice of 500 feet height not being uncommon. It is identical in character and dimensions with Sierran cañons eroded in the Sierra Nevada region in similar rock as the granite and gneiss of the Alamo mountain, by streams of similar size. Piru Cañon, we know, dates entirely from a time succeeding the uplift and tilting of a late Pliocene formation, thus corroborating the post-Pliocene age of the Sierra Nevada cañons as heretofore inferred from other data.

As in the Sierra Nevada cañons, the erosion of Piru Cañon has continued practically uninterrupted to the present day. No line can be drawn in the cañons corresponding to a widely distributed, rather late Quaternary deposit in neighboring lowland areas. The term Sierran can have no epochal value, as it is derived from these cañons and must be applied to the whole time occupied by their erosion. It is simply the designation of a type of deep, narrow valleys in the California mountains which are of later age than the Tertiary era, but it can have no part in the scheme of classification which is going to be proposed.

The Santa Clara River, between Acton and Lang, is also a superimposed stream, flowing in a deep, narrow Sierran cañon trenched in the hard crystalline rocks on the south of the main

Tertiary depression. The Sierra Madre and San Bernardino ranges abound in such deep, narrow gulches and cañons. They are strongly contrasted on the one hand with the broad basins which separate the ranges and on the other with the insignificant valleys eroded from the Pleistocene deposits of the neighboring regions.

THE SANTA CLARAN EPOCH.

The Soledad Cañon, between Saugus and Lang stations, is a steep-sided valley, from one-half to one mile in width and 400 to 600 feet in depth. It is terraced, and of these terraces there are remnants to indicate four principal flood-plains. The upper and best defined has an estimated height above the river of 400 feet, and the others are about equally spaced down to twenty-five feet above the river. These terraces are benches cut into the inclined Upper Pliocene strata and covered with five to fifteen feet of horizontally-stratified, coarse alluvial gravel and boulders. Each marks a halt in the down-cutting of the valley, perhaps dependent upon an uplift by stages. Tributary cañons are proportional in size to the main valley. Among them they have cut up the basin into an extremely broken country, with a youthful type of topography. The erosion accomplished since the uplift of the first alluvial plain is about equal to that on certain portions of the Illinoian area in the Mississippi Basin.

Throughout the Upper Pliocene basin the hills have been reduced to a comparative uniformity, none falling much below or rising much above a plane which is far below the summits of the surrounding mountains. This uniformity was produced by degradation nearly to a base-level represented by the highest river-terrace. It was approximating to a peneplain. I should hardly like to call it a peneplain, because, although the streams flowed leisurely in very broad, shallow valleys which were thoroughly graded and occupied the larger part of the surface, these valleys had distinct bluffs and the interfluvial surfaces were in places sharply undulating. It was a land in the condition of topographic old age.

A careful study of the structure will make it evident that in places as much as several thousand feet in thickness of the

Upper Pliocene gravel and sand were eroded before the Santa Clara River and tributaries trenched below the plane of the 400-foot terrace, and an estimate for the average of the basin of 1,000 feet is quite conservative. More than ten times as much material was removed from the basin down to the completion of the first alluvial plain than has been removed since. This 400-foot terrace divides the Quaternary era into a very long early part and a much shorter late part. To satisfy those critics who plead unknown factors, we will make only the conservative claim that the 400-foot terrace belongs to the last one-fourth of the Quaternary era; for, no reasonable decrease of rainfall could vitiate this estimate.

On the strength of comparative erosion studies, I correlate the 400-foot terrace of Soledad Cañon with the highest of the marine terraces on the coast and with the depression to which the Red Bluff formation in the Great Valley is due. Indeed, I know of no older Quarternary deposit in the State, with the exception of a few limited flood-plain remnants in mountain cañons of the Sierran type and a gravel formation at Cajon Pass. The first three-fourths of the Quaternary era in California is represented virtually only by degradation. There is no portion of the State in which this epoch is so clearly defined as on the Upper Pliocene area of the Santa Clara River Valley of the South. Therefore, I suggest for it the name *Santa Claran* as being eminently appropriate.

THE RED BLUFF EPOCH AND ITS DEPOSITS.

The Red Bluff area in the Great Valley of California, as usually mapped, includes two formations. The older has a gently undulating surface, due to unequal interstream erosion. Broad, shallow valleys were excavated into its surface, and they were floored with a sheet of alluvium consisting of the same material as the Red Bluff proper. Subsequently, another uplift caused the streams to trench broad, shallow, steep-walled valleys beneath these old flood-plains, leaving them as somewhat discontinuous remnants. They are so near the level of the surface of the Red Bluff proper and so like it in lithologic character as often to escape notice. The surface is flat and distinctly lower than the undulating areas of the main Red Bluff.

The Red Bluff formation belongs to the last one-fourth of the Quaternary era. On the northern border of the Sacramento Valley, in Shasta County, there are flats one to two miles wide, consisting of the Red Bluff gravel resting on the truncated edges of the highly inclined metamorphic formations. They are elevated one hundred to two hundred feet above the present streams, as Clear Creek and the Sacramento River, which have trenched narrow cañons below them. The Red Bluff terrace can be traced for several miles up into the mountain valleys of such main streams as those mentioned above, and it is thus made evident that at the very least three-fourths of the erosion of the Sierran valleys had been accomplished by the time of the opening of the Red Bluff epoch.

Since the uplift of the Red Bluff formation, it has been eroded to about the same extent under approximately similar conditions as the Illinoian drift sheet of the Mississippi Basin. In the same manner I arrive at the conclusion that the trenching of the old alluvial plains, or second formation of the Red Bluff area, as mapped, dates from about the Iowan epoch of the classification adopted in the Eastern States. I do not wish to convey the idea that I consider them chronologic equivalents, respectively, of the Illinoian and Iowan drift sheets of the Mississippi region. The Red Bluff formation may have been deposited entirely during the interglacial epoch preceding the Illinoian epoch or that succeeding it. I mean simply that the erosion on the Red Bluff formation has been very much less than that on the Kansan drift area of Northern Missouri and Southern Iowa, and very much greater than that on the Iowan drift area of Northwestern Illinois and Northeastern Iowa, but that it has been remarkably alike, in general character and amount of material removed, that accomplished on the Illinoian drift area of Western Illinois and Southwestern Iowa, so that if there could be any particular object in referring the Red Bluff formation (or, rather, the time of its uplift and inception of erosion) to one of the glacial epochs, the Illinoian would undoubtedly be the one fixed upon.

There are those who will criticize even the above very generalized correlation. They will maintain that the conditions of erosion are so very different in separate areas and on different formations that a comparison of valleys excavated has little value.* So well aware of this am I that I usually purposely avoid figures or the comparison of particular valleys in the different areas. Erosion studies have not yet been reduced to the precision of mathematics. The personal element enters very largely into this department of geology. So many factors have to be considered and given their true value, as the relative resistance to erosion of different formations, the protection afforded by vegetation, the slope of the surface, the annual precipitation, and the distribution of the rainfall through the year, that it is impracticable to subject the study to precise rules.

I have a mental picture of a great number of valleys in, say, the Illinoian drift area of the Mississippi Basin. Some of these are rock gorges, some are excavated in stiff boulder-clay and some in loose sands. Some were eroded on steep hillsides and some were carved from nearly flat plains. The whole taken together give me an *impression* of the relative age of the Illinoian drift sheet. As I travel over the Red Bluff area I observe valleys excavated into solid and very resistant rock beneath it, others in coarse gravel, and still others in loose, easily eroded sand, as in the San Joaquin Valley. The whole system, *considered in connection with the conditions under which it was eroded*, gives me an *impression* of the approximate age of the Red Bluff formation. When two impressions thus derived are similar, I assume that the formations eroded do not very greatly differ in time of uplift. Occasionally there will be encountered a valley which seems to have been eroded under such definite conditions as make it profitable to directly compare it with some particular valley in the other area, thus giving the "impression" more

*It is a matter of regret that no complete discussion of the erosion on the various drift sheets of the Eastern States has yet been published. Perhaps the most extensive references to the subject, so far, at least, as the older sheets are concerned, may be found in Leverett's report on "The Illinois Glacial Lobe," published as Monograph XXXVIII of the U. S. Geol. Survey.

value than a mere guess. Several such cases will be discussed in the succeeding pages, but figures will be avoided.

In the City of Los Angeles there were observed three Quaternary formations. The first and oldest is the marine Pleistocene, which was laid down in an approximately horizontal position on the truncated edges of a very thick Pliocene series dipping at angles varying between 30° and 85°, but prevailingly 45°. Great erosion is evident between the deposition of the latest Pliocene and the marine Pleistocene. The latter reached a thickness in places exceeding one hundred feet, but in the northwestern part of the city thinned out to five or ten feet over the submarine shelf near the sea-cliff. Erosion has here pretty thoroughly dissected the bench, and the Quaternary gravel and sand remain only in limited areas capping the principal hills. On the east side of the Los Angeles River, on Boyle Heights and in the vicinity, interstream erosion has given the surface of the marine Pleistocene a rolling topography precisely as on the Red Bluff of the Great Valley where the material is similar. The Los Angeles River excavated a valley in the marine Pleistocene which is about one mile in average width and one hundred feet deep. Subsequently this was partly silted up and the second Quaternary formation deposited.

This is best developed in East Los Angeles, particularly near the County Hospital, but it also forms the low terrace in the business portion of the city east of Main Street. It consists of at least twenty-five feet in thickness of indistinctly stratified, fine silty sand (no pebbles) of light brown color. The surface remains flat, except that valleys about twenty feet deep have been eroded in it. The erosion since its uplift has been about equal to that on the Iowan loess of the Mississippi Basin, and it is apparently equivalent to the old flood-plain deposit of the Red Bluff area of the Great Valley.

The third Quaternary formation is the Modern alluvium, an irregularly stratified, light gray, fine gravel and sand. It is the present flood-plain of the Los Angeles River and tributaries, and forms the floor of the valleys excavated below the surface of the preceding formation.

After taking into consideration the easily eroded nature of the marine Pleistocene material but the rather light rainfall of Los Angeles, I conclude that the sea retreated and sub-aerial erosion began on this portion of the formation at about the time of the uplift of the Red Bluff formation proper in the Great Valley; in other words, they are probably chronologic equivalents. The latter formation seems to have been the result of a depression of the Great Valley, perhaps part of it below sea-level. I imagine that there was temporarily formed a great shallow geosyncline, having its axis approximately parallel to that of the Great Valley. This axis prolonged southward would intersect the plain of Los Angeles. Why may not the marine Pleistocene of Southern California and the terraces on the coast be due to this same depression? I believe that the Red Bluff subsidence was rather general throughout the broad valleys of the State and has given rise to most of our Quaternary deposits. This period of subsidence constituted the Red Bluff epoch, and all the deposits due to it are parts of the Red Bluff formation. It seems proper to extend the term Red Bluff to the marine Pleistocene in Los Angeles and to the alluvial material of the 400-foot terrace of Soledad Cañon.

In going from the town of San Pedro directly up to the summit of San Pedro Hill (altitude 1482 feet) I counted ten terraces including the flattened summit, besides traces of several other strands too indefinite to more than notice. These terraces mark elevated marine shore-lines and were fully described years ago by Prof. A. C. Lawson* and have since been discussed by various writers. The three lower terraces are broad and not much dissected. They consist of loose, stratified sand and some fine gravel—a formation very easily eroded by running water. Narrow cañons have eaten back from each sea-cliff into the body of each terrace but their floors rapidly rise, and in the case of the broader terraces the inner portions remain nearly undissected. The attitude of these terraces with their steeply-sloping outer margin, is identical with that of the loess terrace following the margin of the Iowan drift sheet in Northwestern Illinois and Northeastern Iowa. The Iowan

* Bull. Dept. Geol., Univ. Calif., vol. 1, No. 4, pp. 122–128.

loess is slightly more resistant to erosion than the loose sand of these lower San Pedro terraces. Also, it is probable that in prehistoric times, the San Pedro terraces were less protected by vegetation than was the loess terrace. This is made up to approximate equality by the rainfall of the San Pedro region being less than that of the Illinois-Iowa region. The San Pedro terraces are on the border of the sea, in the rainiest part of Southern California, so that the conditions are not by any means those of the arid region. The average annual precipitation at the neighboring city of Los Angeles is about 17 inches, and that of the Illinois-Iowa area about 33 inches. It is believed that the greater rainfall of the latter region very nearly balances the less resistant nature and poorer protection of the sand of the lower San Pedro terraces.

The amount of erosion accomplished in the two areas is the same. Both systems of terraces are dissected by small cañon-shaped valleys and ravines and the same amount of the surface retains its original flatness. I was very strongly impressed by the evidence that the lower terraces are approximately Iowan in age. Certainly they cannot be much older.

The upper terraces are on a steeper slope, are narrower, consist mostly of benches cut into the Miocene rocks, and show greater erosion than the lower three. Loose fragments of the soft sandy shales of the Miocene, showing the peculiar and characteristic marine abrasion, are scattered on each terrace including the summit of the hill where they are in sufficient abundance to remove any doubt of the submergence of the very highest point. The old sea-cliffs can be traced and several of the originally best developed terraces are yet quite distinct. Ravines of considerable size have been excavated in the soft rock of the steep slopes of the hill and these upper terraces are not by far as well preserved as the lower three even though they consist of a much more resistant material. The evidence of their age is less conclusive than in the case of the first discussed members of the series, but I am pretty well satisfied that the higher terraces are considerably older than the last three. Apparently the elevation began in the Quaternary era at a time long preceding the Iowan epoch and continued intermittently until that epoch.

The first or highest terrace I should refer to about the Illinoian epoch. This reference is made not alone upon a conviction derived from the study of the Quaternary in other parts of Southern California that a marked uplift of the entire southern portion of the State began at the close of the Red Bluff (Illinoian?) epoch, but is also based upon a study of the erosion of the upper terraces of San Pedro Hill. It is difficult to express this in exact terms. However, to a student of geomorphology, the impression is inevitable that had these upper terraces been exposed to the action of subaerial forces as long as has been occupied in the erosion of the deep Sierran cañons of the Sierra Nevada region, they should not remain in a recognizable form to-day. It must be understood that these upper terraces even when newly completed, were very subordinate features of the topography and no considerable layer of the rocks of San Pedro Hill could be removed without destroying all traces of them. Erosion since the uplift of the terraces has etched the hill on all sides, but only in a minor degree modified its general topography. All the territory along the coast of Southern California which was submerged during any part of the period of terracing has comparatively smooth contours. If we transfer our attention to the Sierra Madre and other ranges of Southern California or to the Pliocene basin of the Santa Clara Valley, and study the character of demonstrably post-Pliocene erosion, we are forced to the conclusion that the oldest terraces on San Pedro Hill are young, quite young, in comparison with the whole of Quaternary time. They certainly belong to its latter portion. The Sierran cañons were already approaching completion when San Pedro Hill last emerged from the sea as a tiny wave-swept rock. The Ozarkian valleys of the Eastern States were completed, the Kansan ice-sheet had come and gone in the Central Mississippi region, and it is only when we reach the Illinoian epoch, in our imaginary flight through time, that we turn our eyes westward and look expectantly for that new island in the Pacific Sea.

At the time that Lawson first investigated the marine terraces of the California coast, the length and complexity of the Quaternary era and the significance of the Sierran valleys were not fully appreciated by students in general and he was not favored by finding these terraces cut on undoubted Upper Pliocene strata which had been tilted and much eroded before the submergence to which the terraces are due, so he placed the upper terrace early in the Quaternary era although recognizing the comparative recency of the lower ones. Fairbanks was fortunate in encountering the terraces eroded into tilted, very late Pliocene strata and he discovered that a period of land elevation must have occurred between the subsidences to which are due, respectively, the Upper Pliocene deposits and the terraces. More recently, Lawson has attacked the subject from the same standpoint as the writer, namely, by observing the degree of preservation of the terraces and now is in substantial accord with the present writer in placing all of those of the San Pedro region very late in the Quaternary era.*

Near the head of Mint Cañon, about six miles north of Lang Station, there is a basin several miles wide. Its floor is a dissected detrital slope, built up at the base of the Sierra Pelona schist mountain and declining toward the opposite side of the basin. Granite and highly tilted, cemented Tertiary breccia-conglomerate were planed off evenly and capped by a bed of partly waterworn schist and quartz from the Sierra Pelona, fifteen to fifty feet thick and apparently spread over the basin floor by torrential floods during abnormally heavy but very localized rains. Uplift and possibly some tilting have caused the erosion in the floor of the basin of very narrow cañons 100 to 300 feet deep, by which the detrital slope is cut up into mesa-like remnants. The rock excavated was chiefly soft semi-decomposed granite and the cañons do not indicate an age for the alluvial capping of the mesas greater than the Red Bluff epoch. I correlate the detrital slope with the 400-foot terrace of the neighboring Soledad Cañon as their dissection was evidently due to the same disturbance.

It may be well at this stage of the discussion to notice the fact that the erosion of cañons into and beneath the detrital slopes does not necessarily imply an uplift of the area, as it is well known that an increased and better distributed rainfall

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* Communicated.

would cause a certain amount of dissection. However, in the particular area investigated there is evidence aside from the dissection of alluvial plains and detrital slopes that an uplift did occur at the time the dissection began and I feel that we are warranted in considering the relation between them to have been that of cause and effect. The undoubted uplift of the marine Pleistocene is positive proof of an orogenic disturbance of no mean magnitude. Far inland, as at Cajon Pass, (as will be discussed later), there was orogenic deformation in addition to simple uplift. In several places the dissection of the detrital slopes is clearly due to such deformation and neighboring slopes which were not tilted are not dissected. I suppose that there has been throughout the Quaternary era more or less of variation in the rainfall of Southern California, but such slight evidence as I have been able to gather rather negatives the hypothesis that the time of inception of dissection of the detrital slopes corresponds to a marked increase in the rainfall.

Above Acton, Soledad Cañon is broad and is flooded by a gravelly plain of waterworn and water-deposited material. It is bounded by terraces from fifteen to seventy-five feet high. These terraces are of horizontally stratified material as exposed in the railway cuts but they rise at a considerable angle to the bases of the surrounding mountains. They represent the detrital slopes of a late Quaternary period. Some disturbance, probably an uplift, caused them to be trenched by the main Soledad Cañon and by small tributary cañons so that they remain somewhat as mesa-like patches. Considering the dry climate, the erosion accomplished places them in the Red Bluff epoch.

These detrital slopes extend to the summit which the railroad crosses in a rather deep transverse valley (Soledad Pass) suggesting that it was once the course of a river draining Antelope Valley; but the material exposed on the floor of this valley, while it is largely waterworn and somewhat stratified, is local in origin, varying as greatly as the composition of the neighboring mountain slopes. These are mostly of a light colored granite until lava is approached just east of Vincent Station, when the valley floor is occupied by a dark red deposit mostly of lava debris, but disposed precisely as is the light colored granite debris elsewhere in the valley. No stream has flowed through the pass since the Red Bluff epoch.

North of the range, on the south border of Antelope Valley, there is a broad old detrital slope which has been eroded into a series of low hills. Beyond this the detrital slopes are not dissected for many miles to the north and east.

Antelope Valley, extending from Gorman's Station on the west to the Mohave River on the east, a distance of eighty-five miles, and from Palmdale to Rosamond Station about twenty miles due north, is a gently rolling plain without ordinary stream courses, the Mohave River excepted. The soil is a uniform light brown, coarse, rather angular granite sand with some silt particles. The altitude of the central portion is about 2,300 feet, and it rises gradually thence to the mountain areas on both sides but principally that on the south. A low portion of this basin at Lancaster has artesian wells. Slightly depressed areas are lake-beds, usually dry. I believe the basin to be underlaid by Tertiary formations, but the surface deposit everywhere is late Quartenary, although hardly Recent in age.

The largest of a chain of three lake-beds extending eastward from near Rosamond is "Rogers dry lake," said to be twelve miles long by six miles in average width. The railway crosses it for seven miles. The lake-bed is flat and in many places as hard almost as an asphalt pavement. It is of clay containing much fine gravel, probably scattered over the lake-bed by the wind. A low beach ridge of cross-bedded sand and fine gravel, trending north-south, cuts off a broad arm of the dry lake. This latter is bordered on the north, east, and south by a broad belt of dune ridges of coarse, partly angular sand. On other shores of the lake-bed the beach phenomena are very weak. It seems to have a foot of water in rare years, and I am told that, once in every three or four years, an unusually prolonged rainy spell causes several inches of water to cover the remarkably even floor. All the phenomena found in connection with this lake-bed indicate a very recent age, and probably even its inception long post-dated the close of the Red Bluff epoch.

From the dune belt east of Rogers lake-bed the Santa Fé railway courses eastward through a broad basin-like valley.

Gently sloping plains of granite debris meet near the center, where there is a distinct but slight depression. About five miles east of Kramer the broad basin becomes decidedly rolling but not hilly, and in the central depression are evidences of stream action such as low bluffs and dry waterways. Everywhere the detrital slopes are more or less distinctly stratified and part of the material is clearly waterworn. It is not as perfectly stratified nor as as well waterworn nor horizontally disposed as an alluvial deposit in a humid region, nor yet is it as free from evidences of the action of water as an ordinary talus or the soil on our mountain slopes. I can unreservedly accept the theory lately applied by Professor N. S. Shaler in explanation of similar detrital slopes in the Cordilleran region,* namely, that the material is brought from the mountain sides and gulches by torrential floods caused by "cloud-bursts," the form of precipitation so characteristic of desert regions, and accumulates on the near-by plains because there are no perennial trunk streams to slowly carry it away into the depressions.

From a point near Daggett to about five miles west of Barstow the old Mohave River Valley, lying south of the present valley, is obstructed by a broad, low ridge of a uniform light brown color and smooth topography except for many small shallow ravines. It is apparently an old detrital slope of late Quaternary age which has been disturbed and extensively eroded, At four miles west of Barstow it was found to be composed of angular and sub-angular debris of many kinds of rocks, including various old crystallines, basic lavas, and limestone. This deposit extends up the Mohave River Valley on the southeast side of the Santa Fé railway for many miles, and between mile-posts 10 and 16 south from Barstow it has clearly the form of a detrital slope, much eroded, but in many places retaining its even but sloping surface. It merges into a gravel deposit, to be described later. A long, even detrital slope of later age bounds the low ridge on the valley side near Daggett and Nebo stations. This has been eroded into a very low bluff or bank by Mohave River, and the present broad, sandy flood-plain lies lower.

*Bull. Geol. Soc. Amer., vol 12, pp. 285–286.

The Mohave River crosses the eastern end of Antelope Valley in a comparatively straight course from south to north, and has excavated in the loose gravelly material of the floor of the basin a broad shallow valley (one-half to one mile wide and one hundred to two hundred feet deep), bounded by bluffs, in places abrupt and exposing horizontal beds of gravel, and floored by very fine sandy alluvium. The gravel is splendidly exposed in railway cuttings at mile-posts 19 and 20 south from Barstow. There is about one hundred and twenty feet in thickness of light brown, imperfectly but horizontally stratified, waterworn and water-deposited, moderately fine gravel composed of a great variety of rock species, not showing the localization of the ordinary detrital material but evidently largely derived from the San Bernardino Range about the headwaters of Mohave River. The character of the deposit is clearly alluvial. It is overlaid by a bed cemented by travertine, and this by forty feet of regularly bedded, light red, fine sand and sandy clay. The whole series is tilted very slightly toward the northeast.

West of the Mohave River Valley, north of Victorville, the gravel plain has little slope and is not dissected to any great distance from the river, as there are no tributaries here owing to the arid conditions; but on the east of the river the same gravel plain rises at an almost abnormally great angle for a detrital slope to the flank of the low range east of the railroad. This resembles a much-eroded detrital slope, but the typically alluvial nature of the material may postulate a slight tilting to the west since deposition.

In cutting down into this loose Quaternary gravel, Mohave River encountered some spurs from the mountain range on the east and was compelled to excavate through them narrow rock gorges. The principal one, north of Victorville, is about one mile in length and fifty to one hundred feet in depth. It is no wider than the river and has very steep, in places perpendicular, walls. The rock is a hard granite, not easily eroded. The climatic conditions do not favor rapid erosion, but it must be remembered that Mohave River rises in the high San Bernardino Range and flows through this gorge as a perennial stream. At the time of my visit it was at its lowest stage, yet the stream extended from wall to wall. From the rate at which it was hurrying the coarse granite sand along its bed, I gained the idea that it has considerable eroding power. It seems rational to compare this gorge with certain rock gorges in the drift area of the Eastern States. Considering the hard rock and the nature of the stream, the absence of falls or rapids indicates that the gorge-cutting was begun at a date earlier than the Iowan epoch, and probably as far back nearly as the Illinoian. This corroborates an estimate which I derived from the broad valley that the uplift and consequent dissection of the Quaternary detrital and alluvial gravels which bound Mohave River Valley in bluffs two hundred feet high for many miles, began at the close of the Red Bluff epoch.

I also gained the idea in the Mohave Desert country that the great detrital slopes were virtually completed by the close of the Red Bluff epoch. They do not seem to be appreciably increasing to-day. If they were growing as vigorously now as they once were, here and there they should be found creeping into the cañons which have been in process of erosion since the Red Bluff epoch. In places these cañons cut off the outer portion of a detrital fan, stopping its growth at the end of the Red Bluff epoch, yet it continues to correspond to the slope above. A later series has formed in the larger cañons, but its members are insignificant in comparison with those which form the floors of the broad basins. I believe that the greater part of the detrital and old alluvial material of the Mohave Desert region (Antelope Valley excepted) belongs to the Red Bluff formation. The general depression of the Red Bluff epoch brought about some climatic conditions which especially favored the formation of detrital slopes, and the subsequent uplift terminated those favorable conditions.

Just south of Victorville the Mohave River traverses another granite spur in a short gorge no wider than the stream at low water and having very steep walls. Above it the river crosses a broad basin occupied by the Quaternary deposits and has excavated its usual broad, shallow valley.

The floor of Antelope Valley rises steadily from Victorville to Summit Station (altitude about 4,000 feet). The railway cuts splendidly expose the material forming the floor of the basin. It is everywhere in this region stratified gravel and sand, the bedding being of the irregular sort common to alluvial deposits. Fine cross-bedding is developed in certain layers. The material is not strictly local, as in ordinary detrital slopes, and is more or less waterworn.

Close to the mountains, as at the northern end of Cajon Pass, the gravel deposit has been somewhat disturbed, and in consequence deeply and extensively eroded. A western tributary of Mohave River heads at Summit Station, and, flowing easterly, has eroded a valley between the gravel deposit on the north and a granite mountain on the south. Near the head this valley is five hundred feet deep and a veritable cañon.

By headwater erosion, Cajon Creek has cut back through the pass into the gravel on the north of the mountains, so that the present summit is a ridge of Quaternary gravel and sand north of the gap in the high granite range. The gulches at the head of Cajon Creek are cut down into the gravel and sand deposit to a depth exceeding 1,000 feet, and they splendidly expose its interior to the very base. From Hesperia to near Summit, the deposit remains in virtually a horizontal position, only sloping to the north with the general and even slope of the basin floor; but in the vicinity of Summit the gravel begins to show tilting toward the northeast at a low angle, and from there to the border of the granite mountains it is nearly everywhere tilted to the north and northeast at angles of 10° to 15°, or locally even greater. Looking toward Cajon Pass from Oro Grande or Helen Station, the floor of the basin is seen to rise evenly till near the pass, where a low and somewhat broken ridge extending across the gap shows an abnormal elevation of the gravel by orographic uplift near the mountains.

The total thickness of the deposit as exposed in the head of the valley of Cajon Creek must be about 2,000 feet. No unconformities are apparent, but toward the base the deposit becomes finer and more regularly stratified, much of it being sand and sandy clay, with no pebbles or boulders. This lower portion somewhat resembles the Upper Pliocene deposits. Gravel occurs in abundance higher and some boulder beds are present. By observing the inclination of flattened cobbles I once thought the stream had flowed south through the pass, but on other grounds I now think it did not. The cobbles and boulders are of a great variety of granite and schistose rocks, which are in place in the mountains about the pass. There is little Tertiary volcanic material (none was with certainty identified), such as must have been brought by a stream flowing from the north. The gravel deposit is not developed in the pass proper nor on the south side of the mountains. My explanation of it is as follows:

At about the opening of the Quaternary era the Sierra Madre-San Bernardino Range was differentiated from the country on the north by the formation of a great fault along the northern face of the mountains. This converted the Antelope Valley area into a topographic depression, an enclosed basin. Mohave River and its headwater tributaries carried sand and gravel out of the high mountains about Cajon Pass and spread it over the floor of Antelope Valley. Being in virtually an enclosed basin, this alluvial gravel and sand began to accumulate at the time of inception of the fault (which is presumed to have been at about the close of the Pliocene period) and continued uninterruptedly until about the close of the Red Bluff epoch, when the deposit was uplifted and its dissection began. It may, therefore represent the whole of the Quaternary era until about the Illinoian epoch of Eastern States geology. The deposit is, in fact, a gigantic alluvial fan, 20 miles or more in length, gradually thinning from a maximum thickness of at least 2,000 feet, and merging into the ordinary detrital slopes, I suppose the early Quaternary portion of the deposit to be confined to this one fan, or, at any rate, to Antelope Valley.

Near Newhall, in the valley of the Santa Clara River, there has been, over an area of possibly fifty square miles, a most remarkable tilting of the late Quaternary river terraces. They are inclined toward a northwest-southeast axis on the line of Newhall and Castaic stations. The slope is not infrequently 2° to 5° and may even reach 10° in places. This is too steep for detrital slopes in that region; besides, the same terraces in Soledad Cañon nearby remain horizontal. There are no mountains back of the terrace east of Newhall (which is tilted toward the southwest) to form a detrital slope. The material is clearly river-deposited and not due to ephemeral "cloud-burst" floods. Near Castaic Station the present valley is not quite on the axis of the synclinal trough, but the river passes to the north of it, leaving a fragment of the southwest-sloping terrace on the south of the river. Slight faulting is also apparent near Castaic Station. The deformation was one of depression of the central portion of the trough and not of uplift of its borders. The "400-foot terrace" in the axis of the trough is several hundred feet lower than in the surrounding country where it is undisturbed except by an uplift general to the whole region. The abnormally broad Newhall Valley is due to the ease with which it was widened by lateral corrasion on the site of this local sag in the "400-foot terrace" plain. Most of the tilting seems to have been affected at about the opening of the Modern epoch but it may have continued later.

THE LATER QUATERNARY EPOCHS.

On the basis of erosion studies, I will correlate in a general way the three lower marine terraces of San Pedro Hill, the second Quaternary deposit in the City of Los Angeles, the lower river terrace of Soledad Cañon, and the second formation of the Red Bluff area in the Great Valley. I am inclined also to place in this same category the marine Pleistocene sands resting horizontally on the Merced series near Lake Merced on the San Francisco Peninsula. These various deposits may not be strictly contemporaneous, but they seem to have been the product of a stage of the Quartenary era when there was a tendency of the land to subside, or at any rate, the conditions were those of a land temporarily somewhat below its normal level. The silt terraces of Los Angeles apparently indicate a slight depression. The two lower terraces of San Pedro were formed while the land was regaining its normal level. Hence, the silt terraces of Los Angeles may be older than the two lower marine terraces of San Pedro Hill, but the difference in their ages is very, very slight. Deposits of about this age are sufficiently developed in California and sufficiently distinct from an older series and a newer series as that the time of their deposition deserves to be erected into an epoch.

Arnold has divided the marine Pleistocene of the Southern California region mainly between two formations, which he designates, respectively, the Lower San Pedro and the Upper San Pedro series. I am unable positively to identify the first with my series inland, although it may correspond, in part at least, with the Red Bluff formation. The Upper San Pedro series seems to include the deposits of the three lower terraces of San Pedro Hill, and perhaps it might be convenient to extend the name, in the form of *San Pedran*, to the epoch as well.

Between the Red Bluff and San Pedran epochs we have abundant evidences of an erosion interval, to which belong the middle terraces of San Pedro Hill, but which is perhaps better represented by the valley of the Los Angeles River in the City of Los Angeles. For this I propose the term *Los Angelan* epoch.

In constructing a scheme of classification for the California Quaternary, the period of glaciation in the high mountains must not be forgotten. The *Glacial* epoch is not represented by its characteristic deposits in any part of Southern California so far as I know and its chronologic relation to the deposits of the San Pedran epoch can only be determined by means of erosion studies. Glaciation *in extenso* of the California mountains is usually referred to the Wisconsin epoch of Eastern States geology. Fairbanks has recently expressed the opinion that the terraces on the coast are more recent in age than the period of glaciation of the Sierra Nevada region,* which is quite the contrary of my view on the subject. Turner is probably as familiar with the glacial phenomena of the Sierra Nevada Range as any one and he has tentatively correlated the oldest glacial deposits that he could find in the region with the older series of terminal moraines of the Wisconsin drift area of the Eastern States.† It is beyond any possibility of mistake that at least the older of the coastal terraces are pre-Wisconsin in age.

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*The Physiography of California, Bull. Amer. Bur. Geog., vol. 11, Sept. and Dec., 1901.

†The Pleistocene Geology of the South Central Sierra Nevada, With Especial Reference to the Origin of Yosemite Valley, Proc. Calif. Acad. Sci., Third Series, vol. 1, No. 9, p. 270.

If I am correct in considering the San Pedran epoch as approximately equivalent to the Iowan of Eastern States geology, a considerable interval of erosion is due between the San Pedran and Glacial epochs. I know of no particular set of valleys or of deposits so characteristic of that epoch as to deserve to give it a name, and I will merely recognize its existence, leaving it unnamed for the present.

The present flood-plains of all the streams in the lowland areas of Southern California mark the *Modern* epoch. South of the Sierra Madre Range, as in the San Fernando Basin, there are some large alluvial fans not much removed in character from the ordinary "detrital slope" type, whose upper portion belongs to this latest division of the Quartenary era. It appears also that there has been a slight subsidence of the coast and certain of the outlying islands in this Modern epoch as discussed by Lawson,* Fairbanks,† and Smith.‡

SUMMARY.

The conclusions expressed in the preceding pages as to the Quaternary history of Southern California and the provisional scheme of classification proposed for it may be briefly summarized into the following table:

Quaternary Era	Recent Period		Modern Epoch	Deposition	Land Level Below Normal	Length Ratio 5
Quaternary Era	Pleistocene Period		Glacial Epoch	*Not represented*	*Not known*	5
Quaternary Era	Pleistocene Period	LeConte's Sierran Period	*Not named*	Erosion	Normal	10
Quaternary Era	Pleistocene Period	LeConte's Sierran Period	San Pedran Epoch	Deposition	Below Normal	5
Quaternary Era	Pleistocene Period	LeConte's Sierran Period	Los Angelan Epoch	Erosion	Normal	75
Quaternary Era	Pleistocene Period	LeConte's Sierran Period	Red Bluff Epoch	Deposition	Below Normal	10
Quaternary Era	Pleistocene Period	LeConte's Sierran Period	Santa Claran Epoch	Erosion	Normal	890

* Bull. Dept. Geol., Univ. Calif., vol. 1, No. 4, pp. 138–139.

† Amer. Geol., vol. XX, Oct., 1897, pp. 236–237.

‡ Bull. Dept. Geol., Univ. Calif., vol. 2, No. 7, p. 226.

The last column represents the writer's suspicions as to the relative lengths of the different epochs, but should not be taken too seriously.

Berkeley, California,
February 17, 1902.

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COLEMANITE

FROM

SOUTHERN CALIFORNIA

A description of the crystals and of the method of measurement with the two-circle goniometer.

BY

ARTHUR S. EAKLE

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COLEMANITE

FROM

SOUTHERN CALIFORNIA.

A DESCRIPTION OF THE CRYSTALS AND OF THE METHOD OF MEASUREMENT WITH THE TWO-CIRCLE GONIOMETER.

BY

ARTHUR S. EAKLE.

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DESCRIPTION OF CRYSTALS.

Introduction.—The mineralogical collection of the University of California includes several excellent specimens of colemanite, showing beautiful crystals in the druses and geodes of the massive material, and the abundance of good measurable crystals afforded an opportunity to make a very complete crystallographic study of this borate. The suite of crystals selected for measurement included probably all of the habits, and possibly all of the forms, possessed by the mineral.

The measurements were made with the two-circle *(Zweikreisige)* goniometer, designed by Goldschmidt. Since the method of measurement with this instrument and the gnomonic projection are as yet not generally understood by American readers, a detailed statement of the work follows the description of the crystals, which will make clear the steps used in the calculation and projection of the forms.

Colemanite was first discovered in Death Valley, Inyo County, California, in 1882, and in the following year the more extensive deposits were found in the Calico District, about five miles from Daggett, San Bernardino County. Most of the fine geodal specimens are from the Calico District and it is presumed that the crystals described here are from this locality, as the labels indicate.

The crystal forms of colemanite were first described by Jackson.* His description of the crystals was quite complete and forms the basis of what is at present known regarding their forms. Some of his crystals were from the Death Valley deposits, but the majority came from the Calico District.

Others who have measured the crystals are: Hiortdahl,† who published a short description of the forms and optical properties, with a chemical analysis of a few crystals from Death Valley; Bodewig and vom Rath,‡ who likewise described some of the Death Valley crystals, and also gave an account of the origin of the deposits, and Arzruni,§ who described one crystal.

The crystals commonly line geodal-shaped cavities and some are quite large, one in the collection having a width of ten centimeters. They are colorless transparent, to white, although a few are stained yellowish by iron. Most of them

---

* A. W. Jackson. Bull. of Cal. Acad. Sciences, 1885, No. 2, 2–36, and 1886, No. 4, 358–365.

† Th. Hiortdahl. Zeitschrift fur Krystallographie, 1885. 10, 25–31.

‡ C. Bodewig und G. vom Rath. Idem, 179–186.

§ A. Arzruni. Idem, 272–276.

are attached to the matrix by one end of the vertical axis, leaving one end well terminated by front and rear forms. This circumstance rendered but one mounting on the goniometer usually necessary in order to measure all of the forms on a crystal, and measurements consequently could be rapidly made. Complete measurements were made of thirty crystals, and many more were examined for additional forms

Elements.—The axial ratio and angle β generally accepted for colemanite are those determined by Jackson. He derived his elements from the measurements of one crystal, but subsequently verified his calculations by the examination of more crystals. By the two-circle method of measurement all of the readings can enter into the computation of the axial lengths; consequently a ratio obtained by using a large number of readings from the best faces, is presumably more exact than when calculated from a few interfacial angles. As shown later in the detailed description of the work, the axial ratio and angle β, obtained for colemanite by the writer were as follows:

$$a:b:c = 0.7768:1:0.5430 \; ; \; \beta = 110^\circ \, 7'$$

For comparison the elements calculated by others are as follows:

Jackson,	$a:b:c = 0.7755:1:0.5415$;	$\beta = 110^\circ 13'$
Hiortdahl,	$a:b:c = 0.7747:1:0.5418$;	$\beta = 110^\circ 13'$
Bodewig and vom Rath,	$a:b:c = 0.7759:1:0.5416$;	$\beta = 110^\circ 16\frac{3}{5}'$

Forms.—The number of forms observed was forty-seven, of which thirteen were new. The forms are arranged in three columns below, those in the last column being new. The lettering is the same as that given by Dana in his "System of Mineralogy." Goldschmidt's and Miller's symbols are given for each form.

The commonest forms are c, b, a, m, t, α, κ, h, β, y, v, d, and o. Less common, yet of quite frequent occurrence, are k, λ, i, σ, ω, ϵ, ψ, x, U. The remainder of the known forms are rare: Q occurred four times, γ three times, r, h, V, twice, and e, q, B, Θ, each once. W is common on one type of the crystals, but occurred only twice in the others.

Letter.	Symbol. Gdt.	Symbol. Miller.
c	0	001
b	0∞	010
a	∞0	100
t	2∞	210
m	∞	110
z	∞2	120
H	∞3	130
κ	01	011
a	02	021
λ	+20	201
V	+10	101
i	−10	$\bar{1}01$
h	−20	$\bar{2}01$
W	−30	$\bar{3}01$
ψ	−40	$\bar{4}01$
U	−60	$\bar{6}01$
β	+1	111

Letter.	Symbol. Gdt.	Symbol. Miller.
k	+31	311
C	+10.1	10.1.1
e	+12	121
σ	+3	331
ω	+13	131
y	−1	$\bar{1}11$
v	−2	$\bar{2}21$
q	−3	$\bar{3}31$
B	−41	$\bar{4}11$
Θ	−31	$\bar{3}11$
o	−21	$\bar{2}11$
γ	−32	$\bar{3}21$
ϵ	−23	$\bar{2}31$
d	−12	$\bar{1}21$
Q	−24	$\bar{2}41$
x	−13	$\bar{1}31$
r	−1$\frac{3}{2}$	$\bar{2}32$

Letter.	Symbol. Gdt.	Symbol. Miller.
l	3∞	310
ρ	+30	301
g	−$\frac{5}{2}$0	$\bar{5}02$
f	−80	$\bar{8}01$
ϕ	+$\frac{5}{2}$1	522
p	+$\frac{1}{2}$2	142
n	+14	141
u	+$\frac{1}{4}\frac{3}{2}$	164
μ	+$\frac{1}{5}\frac{6}{5}$	165
η	+1$\frac{3}{2}$	232
P	−$\frac{1}{3}\frac{2}{3}$	$\bar{1}23$
w	−$\frac{1}{2}$4	$\bar{1}82$
s	−34	$\bar{3}41$

The unit prism *m* is the predominating form, and the other prismatic forms are very narrow. Usually the rear face of *a* is much broader than the front one; *b* is usually present as cleavage faces, and when the natural face does occur it is small. When the base *c* and orthodome *h* are broad, the remainder of the terminal forms are small and usually few in number; on the other hand, when these two forms are absent, or very narrow, the other terminal forms are well-developed. As a rule the negative forms, that is, the upper rear forms, are larger and better developed than the positive ones. A steep pyramid occurs on a few of the crystals, but the faces gave very poor reflections. The best readings indicate the symbols {10.1.1} for the form, which are the same as determined by Jackson and cited as doubtful.

Eight forms given by Jackson were not observed by the writer. These are {370}, {10.19.0}, {19.19.6}, {771}, {$\bar{4}$12}, {731}, {$\bar{7}$21}, and {711}. According to him, the faces of all these forms were extremely narrow, and gave either broad bands of light or no wedge-reflections whatever. In all probability {370} and {10.19.0} are {120}, and {19.19.6} is {331}. Many of his original crystals were examined by the writer for these forms, but they could not be identified.

New Forms.—With the exception of $\{\bar{3}41\}$, each of the new forms was observed but once.

$l = 300\{310\}$. This form was represented by a narrow face between $\{100\}$ and $\{210\}$. The reflection was bright and good.

	ϕ	ρ
Measured	76°29′	90°0′
Calculated	76 20	90 0

$\rho = +30\{301\}$. This was a narrow bright face, but the image was only fair, and the ρ-angle varied somewhat from the calculated one.

	ϕ	ρ
Measured	90°2′	69°33′
Calculated	90 0	68 57

$g = -\frac{5}{2}0\{\bar{5}02\}$. This form occurred as a small triangular face, giving a good reflection.

	ϕ	ρ
Measured	90°7′	56°20′
Calculated	90 0	56 12

$f = -80\{\bar{8}01\}$. This was a very narrow dome face, and the reflection was poor. The face occurred between $\{\bar{1}00\}$ and $\{\bar{2}01\}$ in the same zone.

	ϕ	ρ
Measured	89°23′	80°13′
Calculated	90 0	79 51

$\phi = +\frac{5}{2}1\{522\}$. This form occurred as a narrow face between $\{311\}$ and $\{111\}$. It gave a fair reflection, but the angles vary somewhat from those calculated for the symbols. The symbols are the simplest and probably the most correct for the form.

	ϕ	ρ
Measured	75°49′	65°46′
Calculated	76 18	66 26

$p = +\frac{1}{2}2\{142\}$. This was a very small triangular face with a bright image.

	ϕ	ρ
Measured	34°33′	52°47′
Calculated	34 12	52 43

$u = +\frac{1}{4}\frac{3}{2}\{164\}$. This occurred on the same crystal as the preceding, and was also small and bright.

	ϕ	ρ
Measured	34°23′	44°28′
Calculated	34 8	44 32

The next five of the following forms occurred on the same crystal.

$n = +14\{141\}$. Two faces of this form occurred. They were both well developed and gave good reflections.

	ϕ	ρ
Measured	27°11′	67°53′
	27 9	67 33
Calculated	27 5	67 42

$\mu = +\frac{1}{5}\frac{6}{5}\{165\}$. This was a very bright small face which gave a good reflection.

	ϕ	ρ
Measured	38°11′	39°40′
Calculated	38 19	39 43

$\eta = +1\frac{3}{2}\{232\}$. This was a narrow face with a bright reflection.

	ϕ	ρ
Measured	53°41′	54°10′
Calculated	53 44	54 1

$P = -\frac{1}{3}\frac{2}{3}\{\bar{1}23\}$. This form was represented by a small, well developed face which gave a bright image.

	ϕ	ρ
Measured	18°30′	21°10′
Calculated	18 5	20 51

$s = -34\{\bar{3}41\}$. Two large well developed faces of this form occurred on this crystal, and it was afterwards also observed on one other. The reflections were good.

		ϕ	ρ
Measured	1	40°50′	70°50′
	1	40 48	70 46
	2	40 32	70 52
Calculated		40 40	70 45

$w = -\frac{1}{2}4\{\bar{1}82\}$. The edge between $\{\bar{1}31\}$ and $\{110\}$ was replaced by a narrow face which was somewhat rounded, and did not lie exactly in the same zone with these two forms. The symbols are the nearest simple ones to agree with the readings, although the measured and calculated angles do not closely agree.

	ϕ	ρ
Measured	0.16	63°41′
Calculated	0.09	64 16

Crystal Habit.—Four quite distinct habits are noticeable, and these will be designated as Habits 1, 2, 3, and 4.

Habit 1.—Crystals of this habit are characterized by a broad base (001) and rear orthodome ($\bar{2}01$), the two faces meeting in a long edge, almost the width of the crystals. The prism (110) is long and almost meets the base, the unit pyramid (111) being merely a narrow truncating form. The pyramidal forms are small and grouped at the extreme right and left corners of the crystal. The clinodomes (011) and (021) are often absent. This habit exhibits the monoclinic symmetry of the crystals in a more pronounced way than the other habits do. This type of crystal is seen in Figure 1, Plate 2. The rear orthopinacoidal face ($\bar{1}00$) is generally broad like the dome ($\bar{2}01$). The clinopinacoid occurs only as broad cleavage faces, and many of the crystals are cleaved into tabular plates parallel to this form.

Habit 2.—In this habit the base and orthodomes are either very narrow or completely wanting. The clinodomes and rear pyramids are large and about equal in size. The crystals have a characteristic pointed appearance at the ends of the orthodiagonals, the points being truncated by small natural faces of the clinopinacoid. Most of the crystals seem to be of this habit. Figure 2, Plate 2, shows this habit.

Habit 3.—In this habit the front upper terminal faces are quite small, while the unit prism faces and the orthodome ($\bar{2}01$) are large. This gives a somewhat flattened appearance to the crystals, and at the same time causes them to be pointed at the ends of the vertical axis. This habit is quite striking, and the specimens are quite suggestive of dog-tooth spar. This type is seen in Figure 3, Plate 2.

Habit 4.—The crystals of this habit consist essentially of the prism (110) and a broad steep orthodome ($\bar{3}01$). The combination of these two forms makes a very thin wedge-shaped crystal with sharp edges. Some of the other forms also occur, but they are quite subordinate to these, and do not cause a variation in the habit. The dome ($\bar{3}01$) has a rounded or wavy surface and seems to grade into a still steeper dome, probably ($\bar{4}01$) or ($\bar{6}01$). The form ($\bar{3}01$) is characteristic of this habit, and was only observed twice on crystals of the other habits. Figure 4, Plate 2, shows this habit with curved edges resembling spear heads. This habit was first described by H. S. Washington.*

Combinations.—The crystals are so rich in forms that many of them have thirty or more faces. The various combinations observed were as follows:

1. $c, a, t, m, \kappa, \alpha, h, W, \psi, \sigma, \beta, y, v, d, C, o, f.$
2. $b, a, t, m, z, \kappa, \alpha, \sigma, \beta, v, d, p, u.$
3. $c, b, a, t, m, \kappa, \alpha, h, \sigma, \beta, y, v, d, x, o, \epsilon, w, Q.$
4. $a, t, m, h, \psi, v, o.$
5. $b, t, m, z, y, e. \gamma, n, s, p, \mu, \eta.$
6. $c, b, a, t, m, \kappa, \alpha, h, \beta, y, v, d, k, o.$
7. $c, b, a, t, m, z, \kappa, \alpha, h, \beta, y, v, d, x, o, l.$
8. $b, a, t, m, z, \kappa, \alpha, \lambda, i, \beta, y, v, \omega, d, o, g, Q.$
9. $c, b, t, m, \kappa, \alpha, \sigma, \beta, y, v, \omega, d, \epsilon.$
10. $c, b, a, t, m, \kappa, \alpha, \lambda, i, h, \sigma, \beta, y, v, \omega, d, C.$
11. $c, b, a, t, m, z, \kappa, \alpha, \lambda, i, h, \sigma, \beta, y, v, d, C, o, Q.$
12. $c, b, a, m, z, \kappa, \alpha, i, U, \beta, y, d, x, \epsilon.$
13. $c, b, a, t, m, \kappa, \alpha, i, h, \psi, U, \beta, \sigma, y, v, \epsilon, d.$
14. $b, a, t, m, \lambda, i, W, y, q, d, \gamma, s, \rho.$
15. $b, a, t, m, V, h, \psi, U, \beta, y, v, d, o.$
16. $c, b, a, t, m, \kappa, \alpha, i, h, \beta, y, v, o, d.$
17. $b, m, z, H, \kappa, \alpha, \beta, d, x.$
18. $c, b, a, t, m, \kappa, \alpha, h, \beta, y, v, \omega, d, k, o.$
19. $b, t, m, z, \kappa, U, \beta, y, v, \omega, r, d, \epsilon.$
20. $b, t, m, h, W, y, v, d.$
21. $c, b, a, t, m, z, \kappa, \alpha. \sigma, \beta, y, v, \omega, d, \epsilon.$

*H. S. Washington. Amer. Journ. of Science (3), 1887, 34, 281–287

22. *c, b, a, t, m, z,* κ, α, *h, U,* β, *y, v,* ω. *d, x, o,* Θ, *B,* ε.
23. *c, b, a, t, m, z, H,* κ, α, λ, *i, h,* σ, β, *y, v,* ω, *d, k, o,* φ.
24. *b, a, t, m.* α, *h,* ψ, *y, v, d.*
25. *c, b, a, t, m,* κ, α, *h,* ψ, *U,* β, *y, v, d, o.*
26. *c, b, t, m,* κ, α, *i, h,* ψ, *U,* β, *y, v,* ω, *r, d,* ε.
27. *c, a, t, m,* κ, α, λ, *i, h,* β, *y, v, d, x, o,* ε, γ.
28. *c, b, a, t,* κ, α, *h,* ψ, σ, β, *y, v, q, d, o.*
29. *c, b, t, m, z,* κ, α, β, *y, v, q, d,* ε, *Q.*
30. *c, b, a, m,* κ, α, *i, h,* ψ, *y, v, q, d, o.*

Projections.—Figures 1–10, Plates 2 and 3, are clinographic projections to show the habits and some of the combinations. Figure 10 is a drawing of Crystal No. 5, which has the five new forms besides the two rare ones, *e* and γ. The new form $(\bar{3}41)$ is a large face on this crystal. About two-thirds of the crystal is broken, otherwise it would probably have shown a rich combination of forms, as most of the common terminal forms are missing.

Figure 11, Plate 3, shows an orthographic projection on the base of all the forms, with their relative predominance.

Plate 4 exhibits a gnomonic projection of the forms. The pole of the projection, represented by the dark circle, is almost midway between the projection of the base (001) and the dome $(\bar{1}01)$, and since e' is almost $\frac{p_0}{2}$, the angles ϕ and ρ for the faces on the positive side of the pole vary only a few minutes from those at corresponding distances from the pole on its negative side. The crystals of colemanite therefore have an apparent orthorhombic symmetry, and the definite orientation of some of the crystals had to be determined by the direction of extinction on the clinopinacoidal section, this direction making an angle of about 6° with the vertical axis, in the acute angle β.

The projection shows the excellent series of zones in which the forms lie. Most of the prominent zonal intersections on the negative side of the pole are occupied by faces, while on the positive side, several of these prominent intersections are not represented by forms, as, for instance, the cross zone $2p_0$ has only the one form (201) in it. Two of the negative pyramids, $p(\bar{1}23)$ and $w(\bar{1}82)$ have their projections on the positive side of the pole, and the latter form lies almost on the first meridian. The pyramidal forms which are new are represented by two circles, and the direction of the prism (310) and dome ($\bar{8}01$) by double-headed arrows. In this projection the prismatic forms necessarily have no points of intersection, but their directions are shown by the arrows.

METHOD.

The two-circle goniometer, with which the measurements were made, has been fully described by Goldschmidt, together with detailed instruction in the calculation and gnomonic projection of the forms based on measurements with the instrument,* and also in a briefer way by Palache.†

Advantages.—This goniometer possesses manifest advantages over the ordinary reflection-goniometer, not alone in the simplicity and greater rapidity with which forms can be calculated from its measurements, but also because the two angular coördinates definitely locate the form, and when these angles have been recorded for every known form on crystals, as Goldschmidt has done in his "Winkeltabellen," a new form can readily be detected by comparing its angles with those recorded. It would be practically impossible to record all of the interfacial angles between known forms, consequently, as often happens, the measured interfacial angle is not given in the standard works on mineralogy, and quite frequently after long trigonometrical calculation the measured form turns out to be well known. The instrument, however, can also serve for the measurement of interfacial angles, and, in the opinion of the writer, is superior for this kind of measurement, as it really requires less time for the adjustment of the crystal.

One adjustment of a crystal in true polar position is often sufficient for the measurement of all the forms, and in the case of colemanite, less than an hour was required to measure the most complex combination.

* V. Goldschmidt.—Goniometer mit zwei Kreisen. Zeitschrift fur Krystallographie 1893. 21, 210–232. Die zweikreisige Goniometer (Modell 1896) und seine Justirung. *Idem* 1898, 29, 333–345.

† Charles Palache,—On Crystal Measurement by means of Angular Coordinates and on the Use of the Goniometer with two Circles.. American Journal of Science, 1896 (4), 2, 298.

Polar Orientation.—Every face of a crystal has its position defined with reference to a pole and a direction assumed as first meridian, when its two angular distances, respectively, from these are known. By means of the graduated vertical and horizontal circles of the instrument, these two angular coördinates, ϕ and ρ, are readily derived. The plane, normal to the prismatic zone is preferably chosen as the pole-face, and the great circle passing through the pole and the normal to the side pinacoid (010) as the first meridian. In systems with rectilinear axes the pole-face would then correspond to the basal-pinacoid, and the angles for the three pinacoids would be

	ϕ	ρ
001	0°00	0°00
010	0 00	90 00
100	90 00	90 00

Since monoclinic crystals have no plane normal to the prismatic zone, the position of such a plane is best defined if prismatic faces are present. Colemanite possesses a well-developed prismatic zone, including both pinacoids, so the polar orientation of the crystals was readily accomplished. Each face of a crystal comes into reflection when it is normal to the line bisecting the angle between the telescope and collimator of the instrument, and this normal position must first be determined. Its angle on the horizontal circle H, is the h_0 reading for all measurements. The method of finding h_0 is quite simple. Having the telescope tightly clamped at a convenient distance from the collimator, a bright reflecting surface is then mounted approximately parallel to the vertical circle, V, and centered. It is then brought at the intersection of the crosshairs by turning H and V, and the reading on H taken, $= h_1$. V is then turned 180° and the reflection again brought into position by the adjustment tables and H. This reading on $H = h_2$. Then is $h_0 = \frac{1}{2}(h_1 - h_2)$. This can be repeated until the reflection remains rigidly fixed at the intersection of the crosshairs, during a revolution of V. This final position of H is then the h_0, and need never be changed.

The crystal of colemanite was mounted with its prismatic zone approximately normal to V, and H was clamped at

$90° + h_o$. The reflection from the prismatic faces were, by means of the centering and adjusting tables, brought to revolve directly in the line of the vertical crosshair, on turning V, and the crystal thus brought into true polar position, because a plane normal to the prismatic zone would then be at h_o. The reading on V for the clinopinacoid is the v_o for this circle, which would be different for each crystal. Owing to imperfect centering or other causes, readings on V or on H for certain faces vary, when they should be the same; consequently both v_o and h_o can be corrected by averaging the different readings.

When the reflection of each face is brought at the intersection of the crosshairs, two readings, one on $V = v$, and one on $H = h$, are made; the face is then defined by two angular coördinates, $\phi = v - v_o$ and $\rho = h - h_o$.

Symbols p q.—In place of the three indices of Miller for a terminal form, Goldschmidt uses the two indices p and q, and for calculations, and in the gnomonic projection, the two indices are preferable. The indices of Miller are readily transposed into those of Goldschmidt by making the last one equal to unity and not expressing it; thus 522 (Miller) becomes $\frac{5}{2}1$ (Gdt). Furthermore $001 = 0$, $100 = \infty 0$, $010 = 0\infty$, $110 = \infty$, $210 = 2\infty = \frac{p}{q}\infty$, $120 = \infty\frac{q}{p}$. When p and q are equal, but one is expressed, thus $331 = 3$. The zonal relations of forms are better shown by the two symbols, because all forms having the same p, or the same q, lie in the same straight line or zone; for example, it can be seen that the forms $\frac{5}{4}\frac{3}{2}$, $\frac{1}{3}\frac{3}{2}$, $\frac{4}{5}\frac{3}{2}$ are tautozonal, whereas their Miller equivalents (564), (296), (8.15.10) do not show this relation so well.

Gnomonic Projection.—This projection shows the points of intersection of the face-normals, drawn from the center of the crystal, upon a plane lying preferably normal to the prismatic zone and at a unit's distance from the center of the crystal. If **h** is the distance of this plane above the center and is equal to the c-axis, and r_o is the length of the base normal, then in crystals with rectilinear axes $r_o = \mathbf{h} = 1$. In monoclinic crystals the base is oblique to the plane of projection, and with $\mathbf{h} = 1$, r_o is equal to $\frac{1}{\sin\beta} = \frac{1}{\sin\mu}$; whence it follows that with $r_o = 1$, then $\mathbf{h} = \sin\mu$.

If with a radius of $h = 1 = c$-axis, a circle is described, then this circle would represent in ground plan a sphere of projection. The plane of projection would be tangent to this sphere at the end of the c-axis, S would be the pole of the projection, and SY the first meridian. Any face pq would have the point of intersection of its normal with this plane, located by the angle ϕ which it makes with the first meridian SY, and the distance from the pole $d' = \text{tg}\ \rho$. (Figure 1). The face pq is further defined by the two rectangular coördinates $x'\ y'$, whose values deduced from the right triangles are

$$x' = \sin\phi\ \text{tg}\ \rho$$
$$y' = \cos\phi\ \text{tg}\ \rho.$$

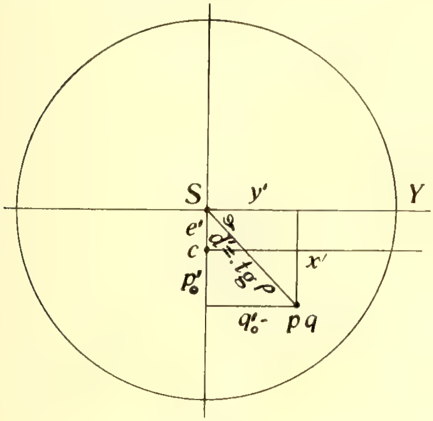

Fig. 1.

By means of the measured angles ϕ and ρ, all forms can be plotted on cross section paper, and the coördinates $x'\ y'$ give graphically the symbols for any form in terms of the $x'\ y'$ of the unit form pq. In monoclinic crystals the projection of the base-normal lies in front of the pole at a distance $e' = \text{tg}\ \rho$, and the distances p'_0 and q'_0 are the coördinates for the unit pyramid pq reckoned from the base; therefore for any values of pq, $x' = pp'_0 + e'$ and $y' = qq'_0$.

Determination of e', μ, and β.—An average of twenty readings on the basal pinacoid gave $\rho = 20°7$, with $\phi = 90°$; $e' = \text{tg}\ \rho = 0.3663$. This value of e' was also obtained from the readings of the clinodomes. For these forms $x' = e'$, and an average of forty-four values of x' for the domes 01 and 02 gave $x' = 0.3663$; thus agreeing with the direct measurements. Also $e' = \cot\mu = 69°\,53'$ and $\beta = 180° - \mu = 110°\,7'$.

Determination of p'_0 and q'_0.—By means of the two formulae

$$x' = \sin\phi\ \text{tg}\ \rho$$
$$y' = \cos\phi\ \text{tg}\ \rho$$

the coördinates $x'\ y'$ were calculated for all the best faces. For the positive forms $pp'_o = x' - e'$, and for the negative $pp'_o = x' + e'$. The symbols pq are simple multiples of the coördinates, $p'_o q'_o$ of the unit form, therefore the values $p'_o q'_o$ are readily deduced for each form. Taking fifteen of the best crystals as sufficient for the calculation of the elements, the averages of p'_o and q'_o were as follows:

$p'_o = 0.7431$	12	meas.	$q'_o = 0.5438$	12	meas.
7431	9	"	5426	9	"
7441	4	"	5435	9	"
7425	7	"	5426	7	"
7447	17	"	5426	17	"
7452	11	"	5435	11	"
7452	14	"	5432	14	"
7444	8	"	5429	8	"
7449	10	"	5417	10	"
7435	14	"	5424	9	"
7450	16	"	5436	16	"
7447	13	"	5423	13	"
7453	6	"	5437	6	"
7446	8	"	5425	8	"
7448	16	"	5431	16	"
Average 0.7443	165	"	0.5430	165	"

The elements for colemanite are therefore

$$p'_o = 0.7443\ ;\ q'_o = 0.5430\ ;\ e' = 0.3663\ ;\ \mu = 69^\circ\ 53'.$$

Determination of the Polar Elements p_o, q_o, *and* e.—The values p'_o, q'_o, and e'_o are the elements when $\mathrm{h} = 1$ and $r_o = \frac{1}{\sin \mu}$; therefore when $r_o = 1$, these values must be multiplied by $\sin \mu$, to obtain the polar elements p_o, q_o, and e. Thus $p_o = p'_o \sin \mu$, $q_o = q'_o \sin \mu$, and $e = e'_o \sin \mu = \cos \mu$. The elements for colemanite then become

$$p_o = 0.6989\ ;\ q_o = 0.5098\ ;\ e = 0.3439.$$

Determination of the Axial Lengths a *and* c.—In systems with rectilinear axes $q'_o = \mathrm{tg}(001:011)$ and $p'_o = \mathrm{tg}(001:101)$; therefore with axis $b = 1$, the formulae for such systems become $c = q'_o$ and $\breve{a} = \frac{c}{p'_o} = \frac{q'_o}{p'_o}$.

In monoclinic crystals, c is also equal to the coördinate q'_0; the clino-axis $\grave{a}$, however, is equal to $\frac{\breve{a}}{\sin\mu}$, therefore the formulae for monoclinic crystals, in terms of $p_0 q_0$ or $p'_0 q'_0$, when $b = 1$, become

$$c = q'_0 = \frac{q_0}{\sin\mu}\ ;\ \grave{a} = \frac{q'_0}{p'_0 \sin\mu} = \frac{q'_0}{p_0} = \frac{q_0}{p_0 \sin\mu}\ .$$

From these equations, $\grave{a} = 0.7768$ and $c = 0.5430$; giving the axial ratio for colemanite $\grave{a} : b : c = 0.7768 : 1 : 0.5430$.

Record of the measurements.—As an illustration of the actual measurements and method of deriving the symbols for the forms, the work on Crystal 23 is given. Each crystal was sketched before measuring in order to show the relative size of the faces, and the faces were provisionally lettered. The kind of reflection was designated as good, fair, or poor (g. f. p.). Starting with the angle on the side pinacoid (010) = 139° 44′, and plotting the v-angles in a circle in the direction of the hands of a watch, it is easily determined which forms are positive and which negative. The $h_\circ$ for the instrument was 57° 54′, and the v_0 for the crystal was 139° 44.

From the columns $pp'_\circ$ and $qq'_\circ$ the symbols $p\,q$ are at once apparent, since $p'_\circ = 0.7443$ and $q'_\circ = 0.5430$. The record is simply a sample page of the note book, and it illustrates the simplicity and shortness of the work required to determine any form, as well as the neatness and compactness of the whole method.

Reflections.	Letter.	v	h	$\phi = v - v_0$	$\rho = h - h_0$	Prisms = tg ϕ: lg sin ϕ lg tan ρ lg cos ϕ	lg x' lg y'	x' y'	pp'_0 $= x' - e'$ (positive) $= x' + e'$ (negative)	qq'_0	Symbols p q
g.	b	139°44	147°54	0°00	90°00			0 ∞			0 ∞
g.	m	193 40	147 54	53 56	90 00			1.3730 ∞			∞
f.	t	209 27	147 54	69 43	90 00			2.7058 ∞			2 ∞
g.	a	229 44	147 54	90 00	90 00			∞ 0			∞ 0
g.	t'	249 46	147 54	69 58	90 00			2.7400 ∞			2 ∞
g.	m'	265 44	147 54	54 00	90 00			1.3755 ∞			∞
f.	b'	319 44	147 54	0 00	90 00			0 ∞			0 ∞
f.	t''	354 20	147 54	34 36	90 00			0.6898 ∞			∞ 2
f.	l	345 07	147 54	25 23	90 00			0.4745 ∞			∞ 3
g.	m	13 43	147 54	53 59	90 00			1.3752 ∞			∞
g.	x	229 43	119 35	89 59	61 41	0 0.268556 ∞	0.268556 ∞	1.8559 0	1.4896	0	+2 0
g.	c	229 43	78 01	89 59	20 07	0 9.563811 ∞	9.563811 ∞	0.3663 0	0	0	0
g.	p	203 42	108 54	63 58	51 00	9.953537 0.091631 9.642360	0.045168 9.733991	1.1096 0.5420	0.7433	0.5420	+1 1
g.	g	217 55	127 12	78 11	69 18	9.990697 0.422659 9.311289	0.413356 9.733948	2.5903 0.5419	2.2240	0.5419	+3 1
g.	g'	241 30	127 15	78 14	69 21	9.990777 0.423807 9.309474	0.414584 9.733281	2.5977 0.5411	2.2314	0.5411	+3 1
f.	h	243 55	123 40	75 49	65 46	9.986555 0.346674 9.389211	0.333229 9.735885	2.1539 0.5443	1.7876	0.5443	$+\frac{5}{2}$ 1
p.	i	261 51	129 39	57 53	71 45	9.927867 0.481814 9.725622	0.409681 0.207436	2.5685 1.6123	2.2022	1.6123	+3 3
g.	p'	255 45	108 57	63 59	51 03	9.953599 0.092406 9.642101	0.046005 9.734507	1.1117 0.5427	0.7454	0.5427	+1 1
g.	o	158 24	106 42	18 40	48 48	9.505234 0.055738 9.976532	9.560972 0.032270	0.3639 1.0771	0.0024	1.0771	0 2

Reflections.	Letter.	v	h	$\phi =$ $v - v_0$	$\rho =$ $h - h_0$	Prisms = tg ϕ lg sin ϕ lg tan ρ lg cos ϕ	lg x' lg y'	x' y'	pp'_0 $= x' - e'$ (positive) $= x' + e'$ (negative)	qq'_0	Symbols p q
g.	s	173°43	91°05	33°59	33°11	9.747374 9.815555 9.918659	9.562929 9.734214	0.3656 0.5423	0.0007	0.5423	0 1
g.	s'	285 44	91 06	34 00	33 12	9.747562 9.815831 9.918574	9.563393 9.734405	0.3659 0.5425	0.0004	0.5425	0 1
g.	o'	301 03	106 46	18 41	48 52	9.505608 0.058796 9.976489	9.564404 0.035285	0.3668 1.0846	0.0005	1.0846	0 2
p.	f	285 47	120 59	33 57	63 05	9.746999 0.294397 9.918830	0.041396 0.213227	1.1000 1.6339	0.7337	1.6339	+1 3
g.	v	120 28	106 50	19 16	48 56	9.518468 0.059817 9.974969	9.578285 0.034786	0.3787 1.0834	0.7450	1.0834	—1 2
g.	w	104 47	91 21	34 57	33 27	9.758050 9.819959 9.913630	9.578009 9.733589	0.3785 0.5415	0.7448	0.5415	—1 1
g.	n	49 45	78 39	90 01	20 45	0 9.578486 ∞	9.578486 ∞	0.3789 0	0.7452	0	—1 0
g.	w'	354 41	91 24	34 57	33 30	9.758050 9.820783 9.913630	9.578833 9.734413	0.3792 0.5425	0.7455	0.5425	—1 1
g.	v'	339 00	106 53	19 16	48 59	9.518468 0.060582 9.974969	9.579050 0.035551	0.3794 1.0853	0.7457	1.0853	—1 2
g.	d	49 45	106 14	90 01	48 20	0 0.050647 ∞	0.050647 ∞	1.1237 0	1.4900	0	—2 0
g.	k	23 58	109 14	64 14	51 20	9.954518 0.096803 9.638197	0.051321 9.735000	1.1254 0.5433	1.4917	0.5433	—2 1
g.	u	5 44	115 18	46 00	57 24	9.856934 0.194141 9.841771	0.051075 0.035912	1.1247 1.0862	1.4910	1.0862	—2 2
g.	k'	75 30	109 11	64 14	51 17	9.954518 0.096027 9.638197	0.050545 9.734224	1.1234 0.5423	1.4897	0.5423	—2 1

Calculated Table.—Following is a calculation of the 47 forms to correspond to the tables arranged by Goldschmidt in his "Krystallographische Winkeltabellen." The calculations of colemanite given by the writer are based on the elements p_o = 0.6989 ; q_o = 0.5098, and e = 0.3439, and therefore show a slight difference in the angles from those given by him on page 100.

$a = 7768$	$\lg a = 9.890309$	$\lg a_0 = 0.155509$	$\lg p_0 = 9.844415$	$a_0 = 1.4306$	$p_0 = 6989$
$c = 5430$	$\lg c = 9.734800$	$\lg b_0 = 0.265200$	$\lg q_0 = 9.707463$	$b_0 = 1.8416$	$q_0 = 5098$
$\left.\begin{matrix}\mu - 180\\ \beta\end{matrix}\right\} 69° 53'$	$\left.\begin{matrix}\lg h\\ \lg \sin\mu\end{matrix}\right\} 9.972663$	$\left.\begin{matrix}\lg e =\\ \lg \cos\mu\end{matrix}\right\} 9.536474$	$\lg \frac{p_0}{q_0} = 0.136952$	$h = 0.9390$	$e = 3439$

No.	Letter.	Gdt.	Miller.	ϕ	ρ	ξ_0	η_0	ξ	η	x' (Prisms) $(x:y)$	y'	$d' = \operatorname{tg}\rho$
1	*c*	0	001	90°00	20°07	20°07	0°00	20°07	0°00	0.3663	0	0.3663
2	*b*	0∞	010	0 00	90 00	0 00	90 00	0 00	90 00	0	∞	∞
3	*a*	∞0	100	90 00	90 00	90 00	0 00	90 00	0 00	∞	0	"
4	*l*	3∞	310	76 20	"	"	90 00	76 20	13 40	4.1227	∞	"
5	*t*	2∞	210	69 58	"	"	"	69 58	20 02	2.7419	"	"
6	*m*	∞	110	53 53·	"	"	"	53 53·	36 06·	1.3709	"	"
7	*z*	∞2	120	34 26	"	"	"	34 26	55 34	0.6854	"	"
8	*H*	∞3	130	24 33·	"	"	"	24 33·	65 26·	0.4570	"	"
9	κ	01	011	34 00	33 13·	20 07	28 30	17 50·	27 01	0.3663	0.5430	0.6550
10	α	02	021	18 38	48 54	"	47 22	13 56	45 34	"	1.0860	1.1461
11	*Γ*	+10	101	90 00	47 59	48 00	0 00	47 59	0 00	1.1106	0	1.1106
12	λ	+20	201	"	61 40	61 40	"	61 40	"	1.8549	"	1.8549
13	ρ	+30	301	"	68 57·	68 57·	"	68 57·	"	2.5992	"	2.5992
14	*i*	—10	$\bar{1}01$	$\overline{90}$ 00	20 42·	$\overline{20}$ 42·	"	$\overline{20}$ 42	"	$\bar{0}.3781$	"	0.3781
15	*h*	—20	$\bar{2}01$	"	48 18	$\overline{48}$ 18	"	$\overline{48}$ 18	"	$\bar{1}.1223$	"	1.1223
16	*g*	—[illegible]0	$\bar{5}02$	"	56 13	$\overline{56}$ 13	"	$\overline{56}$ 13	"	$\bar{1}.4944$	"	1.4944
17	*W*	—30	$\bar{3}01$	"	61 49	$\overline{61}$ 49	"	$\overline{61}$ 49	"	$\bar{1}.8666$	"	1.8666
18	ψ	—40	$\bar{4}01$	"	69 02	$\overline{69}$ 02	"	$\overline{69}$ 02	"	$\bar{2}.6109$	"	2.6109
19	*U*	—60	$\bar{6}01$	"	76 17·	$\overline{76}$ 17	"	$\overline{76}$ 17	"	$\bar{4}.0996$	"	4.0996
20	*f*	—80	$\bar{8}01$	"	79 51	$\overline{79}$ 51	"	$\overline{79}$ 51	"	$\bar{5}.5882$	"	5.5882
21	σ	+3	331	57 55	71 56·	68 57	58 27·	53 40	30 19·	2.5992	1.6290	3.0675
22	β	+1	111	63 56·	51 02	48 00	28 30	44 18	19 58	1.1106	0.5430	1.2362
23	*y*	—1	$\bar{1}11$	$\overline{34}$ 51	33 29·	$\overline{20}$ 42	"	$\overline{18}$ 23	26 55·	$\bar{0}.3781$	"	0.6617
24	*v*	—2	$\bar{2}21$	$\overline{45}$ 56·	57 22	$\overline{48}$ 18	47 22	$\overline{37}$ 14·	35 51	$\bar{1}.1223$	1.0860	1.5617
25	*q*	—3	$\bar{3}31$	$\overline{48}$ 53	68 01	$\overline{61}$ 49	58 27·	$\overline{44}$ 19	37 34	$\bar{1}.8666$	1.6290	2.4776
26	*n*	+14	141	27 05	67 42	48 00	65 17	24 54·	55 28	1.1106	2.1720	2.4396
27	ω	+13	131	34 17	63 06·	"	58 27·	30 09	47 28	"	1.6290	1.9716

$a = 7768$	$\lg a$ 9.890309	$\lg a_0 = 0.155509$	$\lg p_0 = 9.844415$	$a_0 = 1.4306$	$p_0 = 6989$
$c = 5430$	$\lg c$ 9.734800	$\lg b_0 = 0.265200$	$\lg q_0 = 9.707463$	$b_0 = 1.8416$	$q_0 = 5098$
$\left.\begin{matrix}\mu = \\ 180 - \beta\end{matrix}\right\}$ 69° 53′	$\left.\begin{matrix}\lg h = \\ \lg \sin \mu\end{matrix}\right\}$ 9.972663	$\left.\begin{matrix}\lg e = \\ \lg \cos \mu\end{matrix}\right\}$ 9.536474	$\lg \frac{p_0}{q_0} = 0.136952$	$h = 0.9390$	$e = 3439$

No.	Letter.	Gdt.	Miller.	ϕ	ρ	ξ_0	η_0	ξ	η	x' (Prisms) $(x : y)$	y'	$d' = \operatorname{tg} \rho$
28	e	+12	121	45°38	57°13·	48°00	47°22	36°57	36°00·	1.1106	1.0860	1.5533
29	η	$+1\frac{3}{2}$	232	53 44·	54 01	"	39 10	40 44	28 35·	"	0.8145	1.3772
30	r	$-1\frac{3}{2}$	$\bar{2}32$	$\overline{24}$ 54	41 55·	$\overline{20}$ 42	"	$\overline{16}$ 20	37 18	$\bar{0}$.3781	1.1100	0.8980
31	d	−12	$\bar{1}21$	$\overline{19}$ 11·	48 59·	"	47 22	$\overline{14}$ 22	45 27·	"	1.0860	1.1500
32	x	−13	$\bar{1}31$	$\overline{13}$ 04	59 07	"	58 27·	$\overline{11}$ 11	56 43·	"	1.6290	1.6724
33	C	+10.1	10.1.1	86 01·	82 43	82 42·	28 30	81 42·	3 57	7.8093	0.5430	7.8281
34	k	+31	311	78 12	69 22	68 57·	"	66 21	11 02	2.5992	"	2.6553
35	ϕ	$+\frac{5}{2}1$	522	76 18	66 2(	65 49	"	62 56	12 32·	2.2270	"	2.2922
36	o	−21	$\bar{2}11$	$\overline{64}$ 11	51 16	$\overline{48}$ 18	"	$\overline{44}$ 36·	19 52	$\bar{1}$.1223	"	1.2468
37	Θ	−31	$\bar{3}11$	$\overline{73}$ 47	62 47	$\overline{61}$ 49	"	$\overline{58}$ 38	14 23	$\bar{1}$.8666	"	1.9441
38	B	−41	$\bar{4}11$	$\overline{78}$ 15	69 26·	$\overline{69}$ 02·	"	$\overline{66}$ 27	10 59	$\bar{2}$.6109	"	2.6663
39	ϵ	−23	$\bar{2}31$	$\overline{34}$ 34	63 11	$\overline{48}$ 18	57 27·	$\overline{30}$ 25	47 18	$\bar{1}$.1223	1.6290	1.9782
40	Q	−24	$\bar{2}41$	$\overline{27}$ 19·	67 45	"	65 17	$\overline{25}$ 08·	55 19	"	2.1720	2.4450
41	s	−34	$\bar{3}41$	$\overline{40}$ 40·	70 45	$\overline{61}$ 49	"	$\overline{37}$ 58·	45 43·	$\bar{1}$.8666	"	2.8640
42	γ	−32	$\bar{3}21$	$\overline{59}$ 48·	65 09	"	47 22	$\overline{51}$ 39·	27 09	"	1.0860	2.1598
43	w	$-\frac{1}{2}4$	$\bar{1}82$	$\bar{0}$ 09·	65 17	$\bar{0}$ 20	65 17	$\bar{0}$ 08·	65 17	0.0058	2.1720	2.1715
44	p	$+\frac{1}{2}2$	142	34 12·	52 43	36 26·	47 22	26 34	41 08·	0.7384	1.0860	1.3133
45	u	$+\frac{1}{4}\frac{3}{2}$	164	34 08·	44 32·	28 55	39 10	23 11	35 29·	0.5523	0.8145	0.9841
46	μ	$+\frac{1}{5}\frac{6}{5}$	165	38 19·	39 43	27 15	33 05	23 20·	30 05	0.5151	0.6516	0.8306
47	P	$-\frac{1}{3}\frac{2}{3}$	$\bar{1}23$	$\overline{18}$ 05	20 51	$\bar{6}$ 44	19 54	$\bar{6}$ 20·	19 46·	0.1182	0.3620	0.3808

University of California,

April, 1902.

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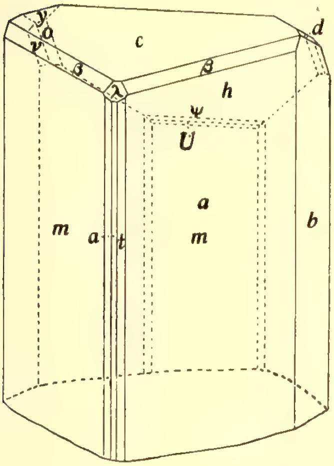

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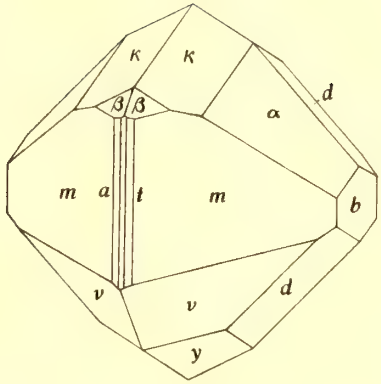

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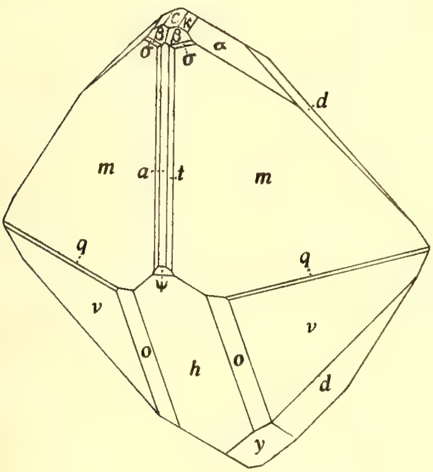

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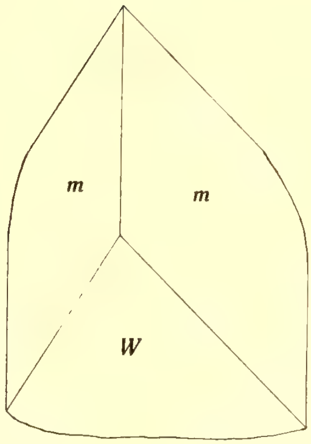

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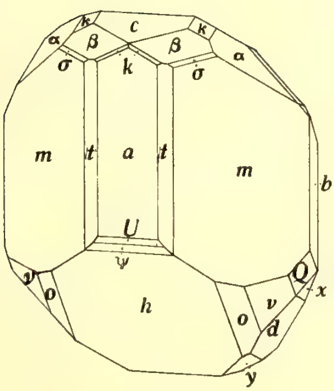

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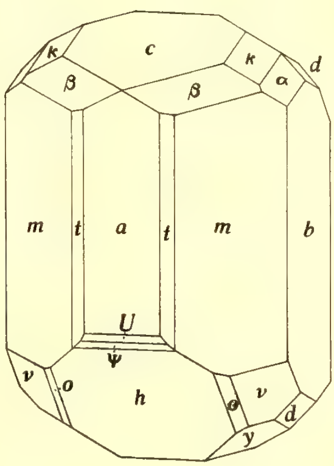

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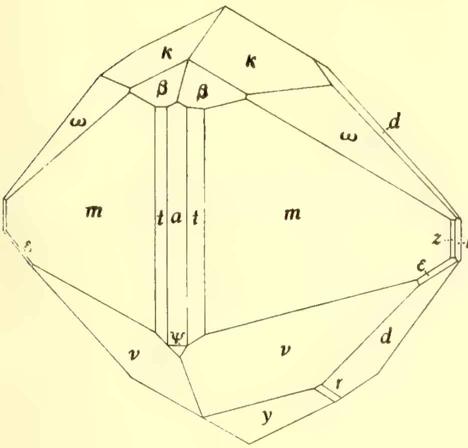

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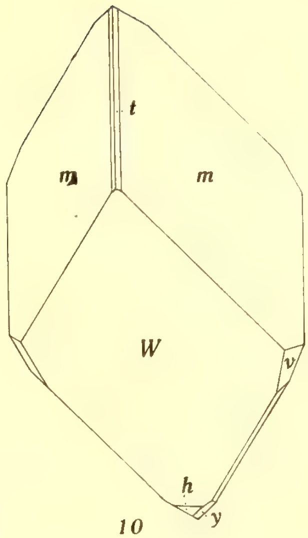

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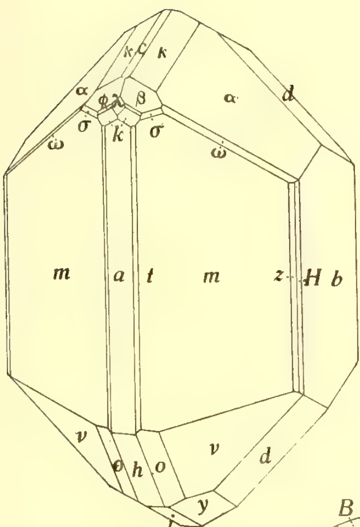

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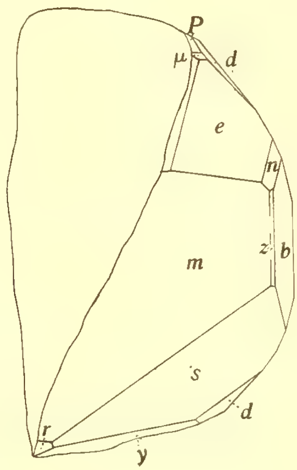

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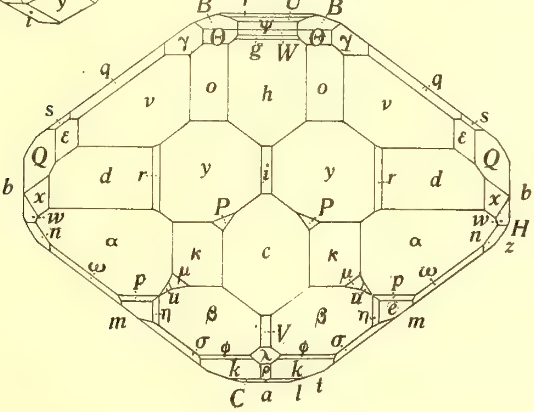

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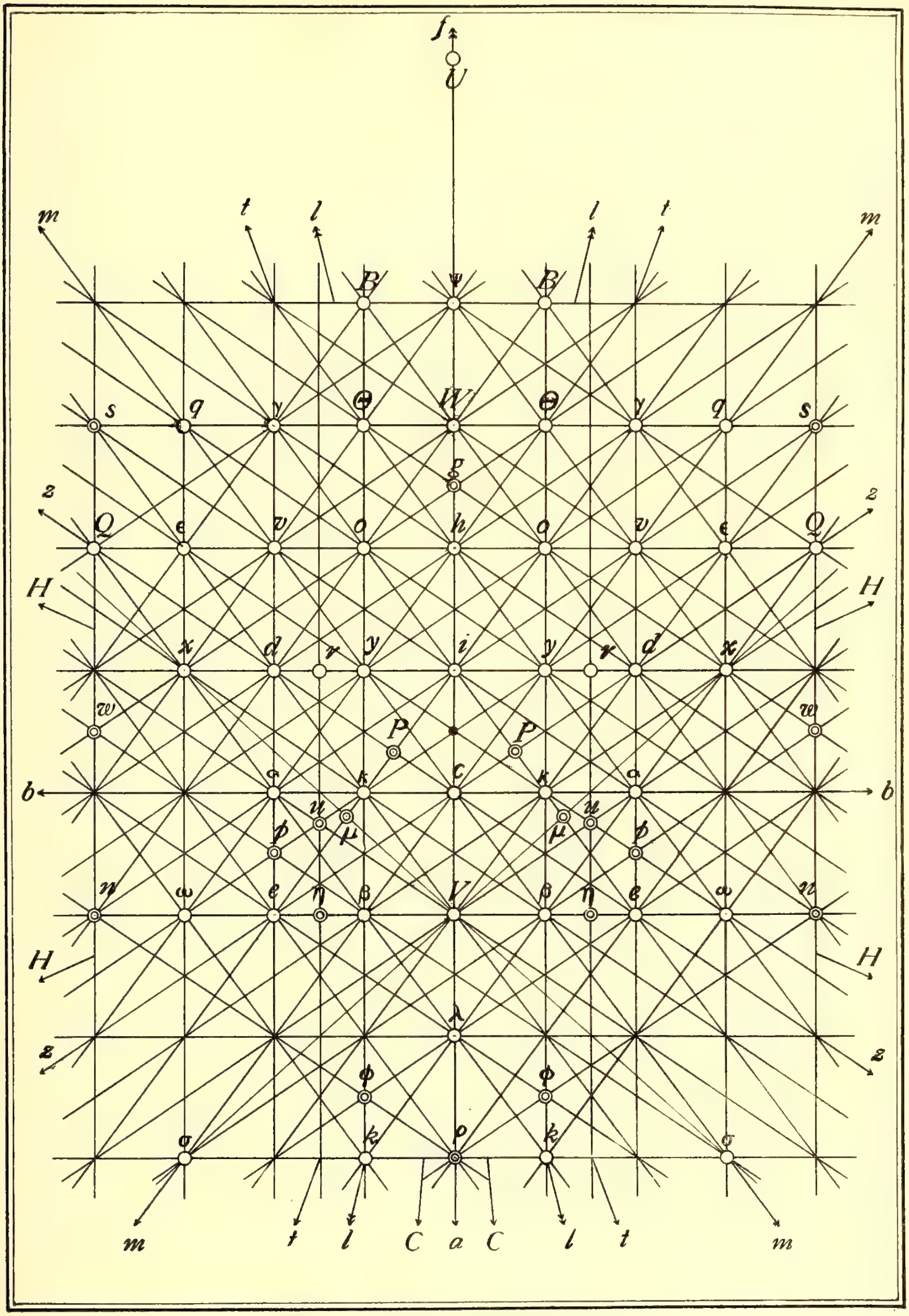

Gnomonic Projection of Colemanite.

UNIVERSITY OF CALIFORNIA PUBLICATIONS

Bulletin of the Department of Geology

Vol. 3, No. 3, pp. 51-62. ANDREW C. LAWSON, Editor

THE EPARCHÆAN INTERVAL

A criticism of the use of the term Algonkian

BY

ANDREW C. LAWSON

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THE EPARCHÆAN INTERVAL

A CRITICISM OF THE USE OF THE TERM ALGONKIAN

BY

ANDREW C. LAWSON

In the year 1854 Logan proposed the name Laurentian for a series of rocks, which he and his assistants on the Geological Survey of Canada had been studying for the preceding nine years in the region of the St. Lawrence and Ottawa rivers. He had in earlier reports referred to the same rocks as the "metamorphic series," and had shown conclusively that a part of them at least, comprising limestones, quartzites and conglomerates, were clastic rocks. In subsequent reports, and especially in the summary report of 1863, the term became very much extended, and vast terranes of granite-gneisses, anorthosites, etc., were included under it, as well as more evenly banded or bedded gneisses. By reason of their association with the recognizably clastic rocks, these granite-gneisses, anorthosites and banded gneisses were regarded as also of metamorphic derivation from original clastic sediments, and various attempts were made to treat them stratigraphically. With the progress of exploration it became apparent that this vast complex was resolvable into three subdivisions, and these became known as the Lower, Middle and Upper Laurentian, the first consisting of granite-gneiss, the second of limestones, quartzites, conglomerates and banded gneiss, and the third of anorthosites. These subdivisions were also known as the Fundamental gneiss, the Grenville series and the Norian series, respectively.

To-day, no one qualified to speak upon the question entertains the idea that the Fundamental gneiss or the anorthosites of the Norian series are other than true igneous rocks. The Grenville series, however, remains as Logan interpreted it, a stratigraphic sequence of clearly recognizable clastic rocks, with perhaps certain admixtures of igneous material.

The term Huronian was first used by Logan and Hunt* in 1855 for the rocks of the north shore of Lake Huron and their supposed equivalents on Lake Superior, now known as the Keweenawan series. The rocks were at this time thought to be probably of Cambrian age. In the work of the next few years, the Upper Copper-bearing rocks of Lake Superior were segregated from those on Lake Huron and the term Huronian retained for the latter. In the report of 1863 the Huronian was described and mapped as a clastic series of pre-Potsdam age, with certain volcanic admixtures. Although it is probable, as I first suggested,† that the Huronian as described in the report of 1863 embraces more than one series of rocks, yet no one has ever called in question the essentially *clastic* character of the great bulk of the rocks so designated.

Both of these terms, Laurentian and Huronian, signalized most important discoveries in geological science. They were immediately adopted and widely used both on this continent and in Europe. The rocks comprised in these two series were regarded as of exceptional interest because they antedated the Paleozoic and were separated from it by a profound and widespread unconformity. This gave them a certain individuality as a whole which it seemed desirable to recognize by the use of a comprensive designation. Moreover, there might be other pre-Cambrian series of clastic rocks resembling the Laurentian or Huronian, the correlation of which with either of these series might be very doubtful, and the progress of the science demanded a comprehensive term which would not necessitate correlation of its members in widely distant regions. These considerations

*Sketch of the Geology of Canada. Paris, 1855.

†Geol. and Nat. Hist. Survey of Canada, Ann. Rpt. 1885, p. 12CC.

were first clearly appreciated by James D. Dana, and in 1872 he proposed *Archæan* as a general term including the Laurentian, Huronian and other pre-Cambrian rock series which might or might not be the correlatives of these. The term Azoic had earlier been used for the non-fossiliferous, pre-Silurian rocks, but the use of the name implied the adoption of a very questionable theory, and it fell into disuse very rapidly after Dana's suggestion. Few terms in geology have met with wider or more rapid acceptance than Dana's *Archæan*. It has become firmly established in the literature of many languages, and particularly in the literature of North American geology.

The rocks of Archæan age, as it is universally understood, undoubtedly comprise a vast quantity of igneous rocks which were at one time supposed to be metamorphic sediments, but it also comprises the unquestionably clastic Grenville and Huronian series.

These facts were as well known in 1889 as they are to-day, yet in that year a remarkable proposal was made for the overthrow of the term Archæan as a designation embracing pre-Cambrian clastic rocks. A conference of the geologists of the United States Geological Survey in that year, considering the nomenclature to be used in the publications of the Survey,* agreed: That the term *Algonkian* be used as the designation of the time of deposition of clastic rocks older than the Cambrian; and further that the oldest time division shall cover the time of formation of the ancient crystalline rocks and its designation shall be the *Archæan*. This is virtually a substitution of the term Algonkian for Archæan in stratigraphy, in spite of the well established use of the latter term, which cannot be maintained except in direct violence of the law of priority and by an official *fiat* which is generally recognized as without force in scientific matters. The term Archæan already covered the pre-Cambrian clastics known as the Grenville and Huronian series.

The term Algonkian being inadmissable by the law of priority for the clastic rocks of the Archæan, it remains to inquire whether there be any justification for the use of the term. Clearly,

*U. S. G. S., Tenth Ann. Rpt., Pt. I.

if there be one or more series of clastic rocks which are of pre-Cambrian age, and which are at the same time post-Archæan, there can be no objection to the application of the term to such rocks. In order to determine this point it will be necessary to define the proximate limits of the Archæan as commonly understood. Fortunately this may be done for a large portion of the continent without danger of confusion. About the southern borders of the Archæan terranes of Canada, and about the inliers of the same terranes in the Paleozoic province of the northern United States, the most notable feature in the geology, from a historical point of view, is a profound and persistent unconformity which has been recognized for the last half century as marking off the rocks which Dana named Archæan from the rocks of later age which repose upon them discordantly. This unconformity represents without question an important interval of geological time for which we have as yet discovered no equivalent sediments, and for which we have, therefore, no name on our time scale, so wedded are we, even yet, to marking off geological time in terms of sedimentation merely.

Being greatly impressed with the duration of this period of geological time, although its record is only one of erosion, and being under necessity of referring to it frequently in the sequel, I propose to name it the *Eparchæan* Interval or Period.

This Eparchæan Interval intervenes between the Archæan of Lake Superior and the Animikie series, the oldest post-Archæan sedimentary series of which we have knowledge in that region. The Animikie series is followed unconformably by the Keweenawan series, and this in turn, also unconformably, by rocks of Cambrian age. Here, then, we have two distinct series of rocks which are not only post-Archæan, but post-Eparchæan, which, if pre-Cambrian, might be designated Algonkian; and it was for these very series of rocks, and no other, that the new name was proposed by Irving, which finally took the form of Algonkian, to signalize their supposed pre-Cambrian and certainly post-Archæan age. But even as to their pre-Cambrian age there is still an element of doubt. It is admitted that the Keweenawan is pre-Potsdam, but that is a long way from establishing its pre-Cambrian age. The Potsdam is upper Cambrian, and in other portions of the continent many thousands of feet of strata, comparable in volume to the aggregate volume of the Animikie and Keweenawan, were laid down in Middle and Lower Cambrian time. It is, therefore, easily within the limits of possibility that these two series represent the Middle and Lower Cambrian. I do not contend for a moment that they are of Cambrian age; I merely point out that as a matter of fact they are only known to be of pre-Upper Cambrian age, and that there remains an element of doubt in designating them pre-Cambrian clastics under the term Algonkian. However, setting that doubt aside for the present, and assuming the truth of the hypothesis that the Animikie and Keweenawan are pre-Cambrian, I am perfectly willing to recognize the utility of the term Algonkian as a designation for the period of time represented by these two series.

This limitation of the term Algonkian to these two series, together with any others that may be discovered to be of pre-Cambrian and post-Archæan age, appears to be unsatisfactory to certain eminent geologists engaged in the study of Lake Superior geology, and one of the most noteworthy features of the important body of literature which has appeared in the last ten years on that region, has been the persistent and ingenious attempts to make the term Algonkian straddle this great gap between the Animikie and the Archæan. Even if the definition of Algonkian as a term embracing *all* pre-Cambrian clastics were not precluded by the previous establishment of the term Archæan, it would seem most unfortunate, if not subversive of all geological practice, to have a single term embrace formations on either side of so vast a period of non-deposition as the Eparchæan Interval. Properly restricted, the term Algonkian should have a taxonomic value co-ordinate with Cambrian, Silurian, Cretaceous, etc. But even if it were found desirable to erect a new term co-ordinate with Paleozoic and Mesozoic, as is the evident purpose of those who seek to have it displace Archæan, the attempt to make the new term bridge the Eparchæan Interval is indefensible. The intense disturbances which inaugurated that interval and the erosion which it represents, taken into consideration with the vast geographical extent of that erosion, constitute a break in the record of sedimentation much more profound than the breaks which exist between the Paleozoic and the Mesozoic, or between the Mesozoic and the Tertiary. The formations on the proximate side of that Interval are very much more closely connected with those of the Paleozoic, both in their physical characters and in their time of accumulation, than they are with anything on the far side of it. The mere failure to find fossils in the strata is but a poor reason for grouping them with the metamorphosed clastics beneath the great gap. Any pre-Paleozoic subdivision of the time scale co-ordinate in value with the Paleozoic naturally has the Eparchæan Interval for its upper limit, and the Algonkian, being upon the proximate side of that break, should be regarded, as above suggested, as a subdivision of the Paleozoic co-ordinate with Cambrian.

The preconceived theory involved in the original impossible definition of the term Algonkian, that the Archæan is composed of non-clastic rocks, the fascination that seems to have attended the erection of the new division of the geological scale, and the natural desire to magnify its import, seem to have obscured the great significance of the Eparchæan Interval and the remarkable irruptive relationships which exist between the Archæan plutonic rocks and so much of the sedimentaries with which they are associated. In this obscuration of the Eparchæan Interval and in the slurring over of the irruptive relations of granite gneisses to the metamorphic clastics and volcanics of Dana's Archæan, we have serious objections to any term used in the sense which it has been sought to give Algonkian. It is extremely doubtful, moreover, whether we know at the present time any "Ancient Crystallines," such as are reserved for the Archæan in the proposed new sense, which antedate the oldest clastics. Certainly the more these rocks are studied the more generally do they appear to be intrusive in the oldest clastics. We cannot, therefore, refer these "Ancient Crystallines," so far as we know them at present, to anything but the Algonkian, if that term is to include the pre-Cambrian clastics. This conclusion of course throws Archæan not only out of stratigraphy, but also out of geology. The term Algonkian is thus not merely in direct conflict with Archæan in the established use of that term, but it is inconsistent with the same term in the narrow and emasculated sense to which it is proposed to restrict it.

The obscuration of the importance of the Eparchæan Interval has been promoted further by certain erroneous correlations in the Lake Superior province. Nothing could be clearer in stratigraphy than the unconformable superposition of the Animikie of the Thunder Bay District upon the Archæan complex, including the Keewatin invaded by granite-gneiss. Yet the Animikie series was correlated before the invention of the term Algonkian both with the Keewatin schists to the west of Lake Superior and with the Huronian of Lake Huron. Both of these correlations were, in the opinion of the writer, errors; and they were the forerunners of a fundamental misconception of Lake Superior geology which persists to this day, and which has become entrenched chiefly owing to the extraordinary use to which the term Algonkian has been put. The correlation of the Animikie with the Keewatin schists west of Lake Superior would probably not be urged to-day, but the correlation of the Animikie with the (Upper) Huronian is still a living doctrine, upon which is based the whole scheme of nomenclature of the rock series of the south shore. Its vitality is, however, no proof of its truth, and I entertain no doubt whatever but that scheme of nomenclature must undergo radical revision in the near future.

This correlation of the Animikie with the Upper Huronian, made as it was in connection with the correlation of the same series with the Keewatin schists to the west, indicates an entire lack of appreciation of the significance and importance of the Eparchæan Interval. The correlation was avowedly made on petrographical grounds. This being the case we might reasonably expect a close parallelism between the Animikie rocks and those of Lake Huron. No such parallelism exists. Several hundred feet of carbonaceous shales constitute the most characteristic stratigraphic feature of the Animikie. These shales are absent from the Huronian (Upper) of Lake Huron. Limestones are practically absent from the Animikie. They occur at several horizons in the Huronian of Lake Huron. There are no volcanics in the Animikie of Thunder Bay, while they occur in the Huronian. The characteristic "slate conglomerate" of the

Huronian is not present in the Animikie. Conglomerates are scarce or absent in the Animikie; they abound in the Huronian. Laminated cherts occur in the Animikie; they are absent in the Huronian. Quartzites, it is true, occur in both series, but even here the physical condition of the rocks in the two series is distinctly different. Iron ores characterize the Animikie; they are lacking in the (Upper) Huronian. Silver ores characterize the veins of the Animikie; they are lacking in the (Upper) Huronian. The (Upper) Huronian is pierced by granites; the Animikie is not. Such is the *lack* of petrographic and stratigraphic parallelism upon which the Animikie and (Upper) Huronian are correlated on purely petrographical grounds!

But it may be urged that the Animikie of Thunder Bay and the Huronian of Lake Huron are sufficiently far separated geographically to account for the difference in stratigraphic composition in the two areas. If this be conceded, so much the worse for a correlation based on petrographical characteristics, and unsupported by other evidence. But the Animikie basin is not so remote from the Huronian. On the north side of Lake Superior I have followed the characteristic black shales (slates) of the Animikie to the islands east of Battle Island, their last outcrop above the waters of the lake being not more than 190 miles from the Huronian area. On the south shore, the Lake Superior syncline brings up the characteristic Animikie strata in the Penokee Range. No one has ever questioned the correlation of the Penokee with the Animikie. The Penokee has been correlated by Van Hise and his collaborators on the geology of the south shore with the Upper Menominee, the upper series at Crystal Falls and with the Upper Marquette; and Marquette is only about 140 miles from the Huronian area in the line of the general strike of the rocks.

These upper series of the south shore, the Penokee, the Upper Menominee and Upper Marquette have the same general petrographic and stratigraphic character as the Animikie, viz: A lower quartzite formation and an upper slate formation, with subordinate beds of siderite and ferruginous chert. With such a persistence of character, indicating widespread uniformity of continental conditions during the time of accumulation of the series, we might reasonably expect similar characters in its supposed correlative north of Lake Huron, only 140 miles distant. There is, however, no resemblance between these upper series of the south shore and the (Upper) Huronian, and it is exceedingly difficult to get at the evidence upon which that correlation is based. The correlative of the Penokee, Upper Menominee and Upper Marquette seems to be entirely lacking in the region north of Lake Huron. The (Upper) Huronian of Lake Huron, on the contrary, bears a striking resemblance in its stratigraphic make up to the Lower Menominee and Lower Marquette, and is much more probably their equivalent, as has been recently suggested by Willmott.*

If this latter correlation be sustained, as I believe it ultimately will be, it would of course effectually dispose of the current correlation of the Animikie and its south shore equivalents with the (Upper) Huronian. But if it be denied, or even eventually disproved, that will not support the correlation of the Animikie and (Upper) Huronian, for in the Lake Huron region there appears to be nothing with which the Animikie may be correlated either on the basis of petrographic and stratigraphic similarity or on the basis of sequence of series.

A profound erosion interval is recognized everywhere on the south shore below the Penokee, Upper Menominee and Upper Marquette, just as there is below the Animikie of Thunder Bay, and since all these rock series are correlated without question, this erosion interval must also be correlated. The Eparchæan Interval, therefore, separates the Upper and Lower Marquette. We may place the Upper series in the Algonkian, but we *must* place the Lower in the Archæan of Dana. This leaves the (Upper) Huronian where it belongs, on the far side of the Eparchæan Interval.

If now we turn our attention to the sequence of rock series within Dana's Archæan, we find a rather remarkable parallelism, not only as regards sequence, but also as regards the petrographic character of the different members of the sequence and their relation to the granite-gneisses, in western Ontario, in Minnesota, on the south shore of Lake Superior and on the north shore

*Journal of Geology, Vol. X., No. 1.

of Lake Huron. Leaving out of consideration for the moment the Coutchiching series, which appears to be rather characteristic of the west than of the east, we have in western Ontario and Minnesota the Lower Keewatin invaded by granite-gneisses and overlain unconformably by the Upper Keewatin, with a basal conglomerate, (Ogishke conglomerate) all antedating the Eparchæan Interval; i. e., overlain unconformably by the Animikie. On the south shore we have various crystalline schists, without doubt the metamorphic products of clastic and volcanic rocks, invaded by granite-gneiss and overlain unconformably by the Lower Marquette, and all antedating the Eparchæan Interval; i. e., overlain unconformably by the Animikie. North of Lake Huron we have similarly, the Lower Huronian invaded by granite-gneiss and overlain unconformably by the (Upper) Huronian. In view of this parallelism of sequence we may formulate a tentative correlation as a reasonable working hypothesis, correlating the Upper Keewatin, Lower Marquette and (Upper) Huronian as having the same position in the general sequence, and much resemblance from a stratigraphic and petrographic point of view. Similarly we may correlate the Lower Keewatin with the Lower Huronian, and with the crystalline schists of the south shore which unconformably underlie the Lower Marquette. Such a scheme of correlation is, to say the least, much more satisfactory and consistent as an hypothesis than that which has been put forward by the geologists of the south shore of Lake Superior. It detracts in no way from the splendid contributions to geology which have been made by those geologists, but, on the contrary, illuminates their results and adds to them the element of consistency which they at present lack. It expresses the views which I have held steadily for many years as to the erroneous correlation of the Animikie with the Huronian, it accords with the recent facts and opinions advanced by Coleman and Willmott, and, if I mistake not, it expresses the views entertained by the Canadian geologists, whose pioneer work in this great field deserves a better fate than to be lost in the awful gulf of the Algonkian—all the pre-Cambrian clastics—the bottomless pit itself.

As regards the scheme of nomenclature which would ensue from the adoption of the correlation here suggested, it may be simply remarked that *Upper* Keewatin would have to give way to Huronian, while Keewatin has priority over *Lower* Huronian. The following tabulation expresses my understanding of the standard *time* sequence of the more important groups of rocks of the Lake Superior province, with appropriate designations and indications of the essential features of the correlation, certain granites that are intrusive in the Huronian being omitted from the scheme. It is not supposed that the scheme is complete; other rock groups will doubtless be discovered and necessitate its enlargement. But it is a fairly consistent statement of what I conceive to be our knowledge of the relationships of the rock groups of the region.

PALEOZOIC
- CAMBRIAN (Upper division or Potsdam only)
- Unconformity.
- ALGONKIAN
  - Keweenawan.
  - Unconformity.
  - Animikie = Penokee = Upper Marquette.

EPARCHÆAN INTERVAL.

ARCHÆAN
- HURONIAN = Upper Keewatin = Lower Marquette, etc.
- Unconformity.
- LAURENTIAN, so called, granite gneisses, etc., (intrusive in the Ontarian) and the Carltonian anorthosites.
- ONTARIAN
  - Keewatin = Lower Huronian = Crystalline schists of south shore invaded by [granite-gneisses
  - Unconformity.
  - Coutchiching.

In conclusion, I rejoice to see that the Algonkian wave is beginning to break. Professor Van Hise, in a paper which has not yet reached me, but which is quoted with very pertinent comment by Willmott,* announces the discovery that the Algonkian, comprehensive as it is by definition, does not embrace *all* of the pre-Cambrian clastics. This is an important admission, and implies the abandonment of the definitions of both Archæan and Algonkian which have been promulgated by the publications

*loc. cit.

of the Survey. It opens the door immediately to the reconsideration of the whole question, and it is to promote this reconsideration that this brief note has been written. Our sense of justice has been injured by the attempt to displace *Archæan* by *Algonkian*. The rights of the older geologists have been ignored in the effort to establish a new name. No one objects to the use of the term for the few thousand feet of strata which intervene in the Lake Superior region between the Upper Cambrian and the Archæan, but the extension of the Algonkian across the Eparchæan Interval is entirely unwarranted, not only on this claim of justice to the earlier writers, but also on account of the departure from our practice in historical geology, and on account of the confusion which must inevitably ensue if this departure is persisted in.

I trust that this criticism may be taken in the impersonal spirit in which it is offered. I have a warm regard and a high admiration for the men who are doing so much to advance our knowledge of that difficult branch of geology, the pre-Cambrian. But in regard to the principles herein touched upon I believe them to be in error. If I am right, that error can only be eliminated by a free discussion of the questions involved. I am further strongly of the opinion that, where there are clearly two sides to a scientific question, so powerful an organization as the United States Geological Survey should use a nomenclature which is non-committal as to the theories involved. The present seems to be an opportune occasion for a discussion and reconsideration, inasmuch as the Canadian geologists are taking a more active interest in the problem, which is peculiarly theirs; the United States Geological Survey is reconsidering the scheme of nomenclature which involves the objectionable definitions of Algonkian and Archæan; and Professor Van Hise has abandoned those definitions as inconsistent with the facts as he finds them.

University of California,

May, 1902.

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TRIASSIC ICHTHYOPTERYGIA

FROM

CALIFORNIA AND NEVADA

BY

JOHN C. MERRIAM

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JOHN C. MERRIAM.

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INTRODUCTION.

In the spring of 1895, the writer received from Professor James Perrin Smith of Stanford University a number of vertebræ and limb bones collected by him in the Triassic of Shasta County, California. In the same year, these remains were described and figured under the name of *Shastasaurus pacificus*

(Merriam, 1895). The genus was stated to have its closest affinities with the Ichthyosauria but to differ in some important particulars from all known forms in that group.

During the summer of 1901, the writer visited the Triassic areas of Shasta County in company with Professor Smith and a party of students from Stanford and California universities. On this expedition a considerable quantity of new material was obtained. In the fall of 1901, Miss A. M. Alexander generously contributed funds for another expedition into the Shasta region. Under the direction of Mr. H. W. Furlong, this party spent two months in the field and obtained some very valuable specimens.

In working up these collections, it was found necessary to compare the Californian material with that which had been described from the Triassic of Nevada by Dr. Joseph Leidy, and through the kindness of Dr. Charles R. Eastman the type specimens of Leidy's species were obtained for study from the Whitney collection at Harvard University. In examining them it was discovered that Leidy had overlooked the most important characters of the species which they represent. The writer has, therefore, included in this paper a redescription of the known Nevada forms.

Practically all of the saurian material that is known to have been collected in the Triassic of this coast has been brought together in preparing the following discussion. Forms which are not recognized as representatives of the Ichthyopterygia are reserved for description in a later paper.

For the present, two groups of species are recognized, those generically identical with *Shastasaurus*, from the upper Triassic of Northern California; and the middle Triassic forms from Nevada, which are all included in *Cymbospondylus* Leidy. These genera are probably closely related and form a well defined subdivision of the Ichthyopterygia. As yet but little is known concerning the structure of *Cymbospondylus*, while *Shastasaurus* is represented by specimens showing nearly all of the skeleton, so that the principal discussion of the structure and affinities of this group naturally falls in the description of the better known genus.

For the preparation of the drawings used in illustrating this paper, the writer is much indebted to Mr. Raymond Carter The photographs were all taken by Mr. B. F. White.

FORMS FROM UPPER TRIASSIC OF NORTHERN CALIFORNIA, SHASTASAURUS GROUP.

OCCURRENCE.

All of the saurian material which has so far been discovered in the Shasta region has been found in two limestone areas lying in the northern part of the county. Most of the specimens have been obtained from a large area between Squaw Creek and Pitt River, a few miles north of Winthrop Post Office. It was in this region that Professor Smith made the first discovery of saurian remains in, 1893. A few fragmentary but interesting specimens have also been found in a small outcrop on the western slope of Bear Mountain, twenty miles northeast of Redding. Mr. O. B. Sherman of Bear Valley was the first to notice saurian bones at this locality.

The beds in which these remains occur have been described by Dr. H. W. Fairbanks* and Professor James Perrin Smith.† They are considered by Professor Smith as the equivalent in age of the Hosselkus limestone. The following extract from his paper cited above gives unquestionable evidence as to their age:

"The Hosselkus limestone may be conveniently divided into three divisions, the lowest of which is the *Trachyceras* beds, so called from the large number of that genus found at this horizon.

"These beds are about fifty feet thick, and are composed of rather hard, pure limestone, made up almost entirely of fossils; a large majority of all the Triassic species were taken from this horizon.

"The best collecting ground was found on the ridge between Squaw creek and Pitt river, about three miles northeast of Madison's ranch. The following fossils were collected at this locality:

Arpadites aff. A. *cinensis*, Mojsisovics.

Balatonites sp. group of B., Arietiformes.

Balatonites sp. group of B., Gemmati.

Polycyclus conf. *henseli*, Oppel.

Tirolites conf. *foilaceus*, Dittmar.

---

* Am. Geol. July, 1894, Vol. XIV, p. 27.

† Jour Geol. Oct., 1894, Vol. II, p. 606.

Trachyceras conf. *aon*, Muenster.
" aff. *aonides*, Mojsisovics.
" conf. *archelaus*, Laube.
" aff. *armatum*, Muenster.
" conf. *ladinum*, Mojsisovics.
" conf. *hylactor*, Dittmar.
" sp. (like *Tirolites* in youth).
" sp. (with fine costæ in youth, coarse in age).
Tropites subbullatus, Hauer.
" sp. (with narrower coil than *T. subbullatus*).
" sp. (with smooth narrow coil).
" sp. (with rough narrow coil).
" *saturnus*, Dittmar
" conf. *janus*, Dittmar.
Sagenites conf. *erinaceus*, Dittmar.
Halorites conf. *ramsaueri*, Gabb. (not Hauer).
Entomoceras conf. *sandlingense* Hauer.
" sp.
Acrochordiceras sp.
Ptychites.
Nannites conf. *spurius*, Muenster.
Lecanites sp.
Arcestes conf. *californicus*, Hyatt.
Sageceras or *Beneckeia ?*
Nautilus triadicus, Mojsisovics.
" sp.
Orthoceras sp.?
Atractites ap.
Aulacoceras sp.
Pecten sp.
Gervillia sp.
Halobia superba, Mojsisovics.
Posidonomya conf. *wengensis*, Wissmann.
Modiola sp.
Capulus sp.
Natica sp.
Rynchonella conf. *solitaria*, Hyatt.
Terebratula sp.

"*The Atractites beds.*.—These beds form the middle division of the Hosselkus limestone; they are very hard and siliceous, and while fossils are very numerous it is almost impossible to get out good specimens. The thickness of these beds is about 100 feet, but this is often seemingly increased by faulting. The rock is cut through in several directions by joints, and the weathering of the strata along these lines of weakness has given a rugged outline to the ridges, of which the *Atractites* beds usually form the top.

"At the locality three miles northeast of Madison's ranch the following fossils were collected from this horizon:

Polycyclus conf. *henseli* Oppel.
Trachyceras (like Tirolites in youth).
" conf. *aon*, Muenster.
Tropites subbullatus, Hauer.
" sp. (with narrow coil).
" sp. (with high-ribbed whorl).
" *saturnus*, Dittmar.
Halorites conf. *ramsaueri*, Gabb.
Entomoceras sandlengense, Hauer.
Entomoceras sp.
Acrochordiceras sp.
Lecanites sp.
Arcestes, sp.
Nautilus triadicus, Mojsisovics.
Orthoceras.
Atractites (very common).
Aulacoceras sp. (rare).
Gervillia sp.
Modiola sp.
Margarita, sp.
Natica sp.
Rhynchonella conf. *solitaria*, Hyatt.
Nothsaurus sp.

"The bones referred to *Nothosaurus** consist of a portion of the backbone about thirteen inches in length, together with several ribs, and fragments of other bones. Most of the species

* *Shastasaurus pacificus* Merriam.

were found in much greater numbers and better preservation in the underlying *Trachyceras* beds, so that there is no great faunal distinction between the two horizons.

"*The Spiriferina beds.*—These beds are made up of about 50 feet of limestone like that of the *Atractites* beds, but harder and more silicious. They contain numerous fossils, especially brachiopods, which, however, cannot be got out without dissolving the matrix. The most common fossil is a *Spiriferina*, or more probably, two species of this genus. Besides these are found:

Rhynchonella conf. *solitaria*, Hyatt.

Terebratula sp.

Trachyceras sp.

Modiola sp.

Gervillia sp.

Pentacrinus sp.

Cidaris sp.

"*Relations of the fauna of the Hosselkus Limestone.*—The fauna of the lower part of the Hosselkus limestone is undoubtedly that of the zone of *Tropites subbullatus* and *Trachyceras aon* of the Tyrolean Alps, that is of the lower Karnic. Several species are identical in the two regions, and many others very closely related. More than this, the stage of development of the ammonites is identical, which is quite as good a proof of similarity in horizon as identity of species."

The saurian bones are found in all three divisions of the Hosselkus limestone, but are best preserved and most common in the Atractites and Trachyceras beds.

Nearly all of the specimens are very firmly united with the matrix in which they are embedded. They are generally much like the rock in color and structure, so that in many cases it has been almost impossible to separate them from it or even to define their limits. In some specimens the difficulty in preparation has been increased by the presence of irregular bodies of silicious material replacing the limestone. Fortunately, many of the bones are partly silicified, or a film of silicious material has covered the walls of the canals and cavities, so that it has been possible to bring out their form and structure quite distinctly by the careful application of acids.

Practically the whole work of preparation was done by Mr. Eustace Furlong, to whom the writer is greatly indebted for his patient and skillful handling of this most refractory material.

CHARACTERISTICS OF SHASTASAURUS.

The material serving as the foundation for this discussion includes considerable parts of seven individuals, together with many isolated bones and teeth. They represent nearly the whole of the skeleton, excepting the anterior part of the skull and the distal portions of the paddles.

All of the specimens seem to belong to one group, which is recognized as the genus *Shastasaurus.* Considerable differences among them are held to be of less than generic value. In addition to the type species, *S. pacificus*, five new forms *perrini*, *osmonti*, *alexandræ*, *careyi*, and *altispinus* have been recognized.

Vertebræ and Ribs.—Good material for the study of the vertebral column is furnished by a specimen of *osmonti* (Pls. 8 and 9) with which there is a good series of thirty-five vertebræ extending back from a point close to the head, with few if any interruptions. A specimen of *perrini* (Pls. 5 and 7) has an unbroken series of eighty vertebræ running from the anterior dorsal region to the posterior portion of the tail. In a specimen of *alexandræ* (Pl. 12) fourteen or fifteen vertebræ lie immediately behind the skull.

The centra are deeply biconcave in all regions of the column. The concave surface begins close to the periphery and slopes sharply but evenly to the the middle. No case of normal perforation of the centrum has been discovered, though the partition between the concave surfaces is frequently very thin. In a single specimen it was possibly cut through by a minute canal. The upper arches are always free from the centra, and seem to have been separated from them by thick pads of cartilage. Excepting in the dorsals and anterior caudals of *perrini*, the longitudinal diameter of the centra is very much shorter than either the vertical or the transverse. In the vertebræ of *perrini* just mentioned the length may be two-thirds to three-fourths of the height.

In the cervical region the centra are somewhat broader than high. Through the greater part of the dorsal region these two dimensions are nearly equal and the cross-section circular or pear-shaped. In the caudal region the centra are laterally compressed and elliptical or pentagonal in cross-section.

The upper arches are slightly longer in the dorsal than in the cervical or caudal regions. Throughout the whole column they show a more or less pronounced tendency to the development of a heavy, lateral rib, produced by a sudden thickening of the median portion of the spine.

In the fifth and sixth cervicals of *alexandræ* the spines are very long and practically circular in cross-section near the summits. A loose cervical arch of *osmonti* shows a similar section. The anterior spines of the *perrini* specimen are somewhat thinner than those of *osmonti* but are probably not from the most anterior portion of the column. In what is taken to be an anterior dorsal arch of *osmonti* (Pl. 9, figs. 3 to 5) the antero-posterior diameter just above the posterior zygapophyses is 25 mm. and the thickness 13 mm. In an individual from the middle dorsal region the arch is 35 wide and 15 thick. In *perrini* the spines of the middle dorsals are much wider than in the anterior portion of the column, but continue to show the median thickening. In the type species, *pacificus*, (Pl. 14, fig. 1) distinct ribbing appears on what are probably posterior dorsals. In *altispinus* (Pl. 15, figs. 3 and 4) the median or posterior dorsals seem to have higher and relatively thicker and narrower spines than in any other form. Excepting the blade-like anterior and posterior margins, their cross-sections are almost circular. Particular notice has been taken of this ribbing by Dames (1895, p. 1045) who calls attention to its presence in *Mixosaurus*. Either ribbing or a decided thickening of the arch would certainly seem to be a characteristic of Triassic Ichthyopterygia.

In the anterior dorsals and cervicals the pedicels of the upper arches are greatly extended laterally, so that they almost, if not quite, touch the ribs. This gives them an elongated triangular form at the base. The surfaces on the centrum, above which the upper arches rest, are excavated and considerably roughened. The excavation is extended laterally as a shallow groove upon the upper portion of the diapophysial ridge in the cervicals and anterior dorsals (Pl. 9, fig. 1). In the posterior dorsal region where the ribs are lower down on the side of the centrum, the pedicels lose their lateral projections.

On all excepting the posterior caudals, the arches are held together by well developed zygapophyses. In the cervicals they are large, strong, and wide. In the posterior dorsals they are weak but still effective, and are placed a little higher up on the spines. In all cases the facets are paired and separated by a narrow depression. They tend, however, to approach the same plane. In *osmonti* (Pl. 9, fig. 3) those in the anterior portion of the column if extended would ordinarily intersect at an angle between 150° and 160°, while in the middle or posterior dorsal region they practically come into the same plane. Their surfaces are slightly roughened, indicating the presence of considerable cartilage. They seem to be about intermediate in form between the type found in *Mixosaurus*, in which the facets cut each other at a fairly sharp angle, and that of the later Ichthyosaurs with the facets reduced, brought into the same plane, and united. The primitive form of zygapophysis is retained longest in the cervical and anterior dorsal vertebrae, or in those which have been least affected in the development of the powerful sculling tail of the Ichythyopterygia.

The mode of articulation of the dorsal ribs with the vertebrae furnishes one of the most important characters of this genus. In the anterior nine or ten vertebræ of *osmonti* (Pl. 8) and in those immediately behind the skull of *alexandræ* (Pl. 12), two distinct prominences with articular surfaces for the reception of the ribs are present. On the first and second vertebræ present in *osmonti*, the parapophysis has about half the vertical diameter of the diapophysis and is slightly anterior to it. Farther back on the column the parapophyses gradually decrease in size and were certainly not functional beyond the ninth or tenth. On the eleventh, there is a mere tubercle without an articular surface for the rib. The last trace is seen on the seventeenth, where a minute rudiment is present on one side only. In *alexandræ* the parapophysis of the fourth vertebra behind the skull is considerably less than half the length of the diapophysis, and the parapophysis of the tenth is so small that it was probably not functional.

The articular surfaces of the diapophyses are confluent with those for the reception of the upper arches from the anterior end of the column at least as far back as the thirty-fifth or thirty-seventh vertebra in *osmonti* (Pl. 8). In the specimen of *perrini* these two surfaces are confluent as far back as the twenty-seventh vertebra, where they are suddenly separated and the diapophysis moves to a lower position on the side of the centrum (Pl. 7, fig. 2). It is certain that some of the anterior vertebræ belonging to this specimen are absent. If they were all present, the point in the vertebral column at which the lowering of the diapophyses takes place would be close to the thirty-fifth vertebra, as in *osmonti*. In the posterior dorsal region the diapophyses are low down on the centra and remain in that position on the anterior caudals, but rise again slightly on the middle portion of the tail.

Compared with the height and length of the centrum, the diapophyses of the dorsals are longer and narrower than those of the cervicals. In *osmonti* the centrum of the first vertebra has a height of 39 mm., the diapophysis a height of 20 mm. In the thirty-fifth, the corresponding dimensions are 73 and 50.

On those vertebræ from which the parapophysis is disappearing, a slight constriction may be seen about the middle of the diapophysial ridge, and from this point the lower extremity swings forward to the anterior margin of the centrum. This character becomes more strongly marked toward the middle of the dorsal series (Pl. 8, fig. 5).

Corresponding to the form of the vertebrae, the cervical *ribs* (Pl. 12) possess a large tuberculum and a small capitulum, the latter disappearing with the parapophyses. The two surfaces of articulation are separated by a notch corresponding to the depression between the di- and parapophyses of the centrum. Numerous ribs associated with the anterior dorsals of *perrini* and *osmonti* show no trace of the capitulum (Pl. 7, fig. 4 and Pl. 9, fig. 6). In the middle and anterior dorsals, the rib head exhibits variation in form corresponding in a manner to that already described as occurring in the diapophyses. Though the heads are of approximately the size and form of the diapophysial surfaces, they cannot be closely fitted to them, as the middle of each face is more prominent than the superior and inferior ends, and when the lower portions of the opposed surfaces are in contact, the upper ends are separated by a considerable cleft (Pl. 15, fig. 6). That the upper portions of the opposite surfaces were normally not so near together as the lower is indicated by the impossible position taken by the rib when they are brought together, the shaft being then directed upward instead of downward. Their roughness, as compared with the lower surfaces, shows that there was more cartilage between them. It has already been noted that the lateral extension of the depression beneath the pedicel of the upper arch may stretch over the upper portion of the diapophysis. In the cervicals this groove is short and covered by the spine-like, lateral projection of the pedicel. In the middle dorsals, where the pedicels are not greatly expanded, the groove is even longer than in the cervicals and extends into the roughened upper surface of the diapophysis, where it is opposed to the rib head (Pl. 8, fig. 5). The roughened and grooved upper surface of the diapophysis was evidently not a surface of direct articulation, but was covered by cartilage which connected it with the upper portion of the rib head, while the smoother lower surface articulated almost directly with the portion of the rib opposite it.

As is apparent, the whole plan of rib attachment through the greater part of the dorsal region is quite different from that of the typical Ichthyosauria. In *Ichthyosaurus* the diapophysis and parapophysis are both present, are quite distinct, and are of approximately equal size as far back in the column as the posterior dorsal region, where they unite. Also, the articular surfaces of the diapophyses which are confluent with the neurapophysial surfaces in the cervical region, as in *Shastasaurus*, become separated from them at about the fourteenth or fifteenth vertebra instead of at the thirty-fifth or a later one. In *Shastasaurus* true double articulation is found in only a few of the most anterior vertebræ, and even there the parapophysis is relatively very small. The loss of the lower articular surface has been compensated for in the dorsal region, next the lungs, by elongation of the diapophysis and development of the method of attachment of the ribs just described. This permits a rocking movement of the ribs on the vertebræ, such as would be advantageous in inhalation by marine, air-breathing animals expanding the lungs considerably both at the beginning and the end of a period of long-continued submergence.

Short, robust ribs are seen in *alexandræ* close to the first vertebræ, and similar ones are associated with the anterior cervicals of *osmonti*. Toward the anterior dorsal region they elongate rapidly. In the posterior dorsal region they are shorter and heavier. Well developed diapophyses are present in the middle caudals in *perrini* (Pl. 5, fig. 1), but no ribs from this region have been uncovered. Contrary to the original description, the rib-shaft is usually grooved on both anterior and posterior sides (Pl. 5, fig. 1.) This is most noticeable in the dorsal ribs, on which the grooves may be very deep. On the fragments of posterior dorsal ribs described with the type of the genus the grooves are not well marked. Both grooves begin close to the superior side of the shaft near the head and run out beyond the middle of its length. Excepting the head, the proximal half of the rib is narrow and rounded below. A broad, flat superior surface is bounded by the anterior and posterior grooves. The distal portion is almost circular in cross-section. The rib-head is rather sharply twisted from the plane of the flattened proximal portion of the shaft so that the upper portion is turned backward. This is so pronounced in the middle dorsal region of *perrini* that the plane of the rib-head is turned almost eighty degrees from that of the shaft (Pl. 7, fig. 4).

Associated with the distal ends of the dorsal ribs of *osmonti*, there are on one slab a large number of rib-like bodies very much smaller than the true ribs. Though it has not been possible to make out their form definitely, they appear to vary in shape somewhat, and almost certainly represent the several elements of a series of *abdominal ribs*. In *perrini* also, a number of fragments of very small ribs under the trunk may represent abdominal ribs.

Evidence of the existence of *intercentra* is found on the first three known cervicals of *osmonti* (Pl. 8, fig. 1), and the first four of *alexandræ*. A prominent apophysis on the middle of the lower side of the first cervical present in *osmonti* shows an anterior and a posterior facet, each extending to the intervertebral articular surface of the centrum. Although somewhat broken, the anterior facet appears to be larger than the posterior. On the second vertebra the inferior apophysis is situated on the anterior half of the centrum and possesses a large anterior facet similar in form but smaller than that on the rear of the vertebra in front of it. The posterior border of the second cervical is slightly elevated, as is also the anterior border of the third, and a small ossicle may have been situated between them. A small bone found with the anterior cervicals has the form and dimensions required for the intercentrum in front of the first vertebra and probably represents that element.

The facets for the reception of the intercentra on the first cervical in this series are much like those figured by Owen* for the second vertebra of *Ichthyosaurus longifrons*. It is, however, very doubtful whether the most anterior vertebra here is either atlas or axis, as the anterior end of the centrum presents a deep concavity similar to that in all the subsequent vertebræ, and entirely unlike either the anterior or posterior face of the atlas or the anterior face of the axis in *Ichthyosaurus*, as described by Owen. On the other hand, the small size of the vertebra, as compared with those behind it, and the rapid decrease in the size of the intercentra posteriorly indicate that the first centrum is probably not far removed from the skull. In *alexandræ* there is evidence of the existence of intercentra, at least as far back as the fourth cervical. It is pretty clear that there were more cervical intercentra in *Shastasaurus* than in *Ichthyosaurus*, as the last intercentrum in *Ichthyosaurus* is between the axis and the third vertebra.

Through a large part of the caudal region *hæmapophyses* are well developed. Unlike the lower arches of *Ichthyosaurus*, their inferior extremities unite to form long spines, or in other words, produce Y-shaped chevron bones (Pl. 5, fig. 1, and Pl. 7, fig. 3). In *perrini* the spinous portion of the arch may be double the length of the pedicels. The articulation of the lower arches is intervertebral, and pairs of small facets are developed on the adjoining posterior and anterior margins of the centra with which they are in contact.

* Liassic Reptilia. Pl. 23, fig. 5.

The specimen of *perrini* shows the greater portion of the caudal region well preserved, and furnishes some interesting evidence concerning the character of the tail fin. The middle portion of the tail seems to be somewhat wider or higher than that of *Ichthyosaurus*, owing to the length of the hæmal spines, and was, consequently, more effective as a sculling organ. As is shown in Plate 5, fig. 1, the posterior portion of the caudal series is quite sharply deflexed, and evidently extended into the lower lobe of a fin like that now known to have existed in *Ichthyosaurus*. The bend in the caudal series is present at the place where it occurs in *Ichthyosaurus*, and as other portions of the vertebral column have not suffered much disturbance, it is probably due to normal curvature in the vertebral column of the living animal.

Arches.—The pectoral girdle of *Shastasaurus* is represented by a nearly complete arch in a specimen of *alexandræ* (Pl. 12) and the greater portion of a girdle belonging to *osmonti* (Pl. 10, fig. 1). Both specimens show this arch to be formed essentially as in *Ichthyosaurus*. In the specimen of *alexandræ* the arch lies on the top of the partly inverted cervical vertebræ. The left scapula and coracoid are brought into the same plane, while on the right side the scapula was doubled under the coracoid. The distal ends of the coracoids almost touch, and the left clavicle lies in front of the coracoid on that side. Being very slightly disturbed and above the partly inverted vertebræ, it is evident that it is the inferior surfaces of the arch bones that are exposed. As the superior side of the skull is uppermost, the body probably first lay on its side, and, in crushing down, the head turned slightly, coming into a horizontal position.

From this specimen the mutual relations of all of the arch bones can be made out with absolute definiteness. In the specimens of *osmonti* the elements, although not advantageously placed for study, were associated with the anterior limbs and cervical vertebræ and certainly belong to one individual.

The *coracoids* are quite different from the element figured with the original description of the genus. The bone which the author and others* supposed to be the coracoid has little in

* Dames, Frass. See Dames 1895, p. 1049.

common with that element, though it shows some resemblance to the scapula. As will be shown later, it does not come from the pectoral arch at all, but probably belongs to the pelvic girdle. The coracoid of *alexandræ* resembles that of *Ichthyosaurus communis* somewhat, but is not so much expanded distally. In *osmonti* it is still narrower. It is very thick and heavy in both species, particularly so in *osmonti*, in which the distal end is 71 mm. thick, the greatest length of the bone being 150 mm.

The *scapula* has a broad trianglar base (Pl. 10, fig. 5), on which is a large surface of articulation for the reception of the humerus, and a much smaller one on the anterior side where it rested against the coracoid. The thinner distal end is much expanded, and turns downward and forward, forming a sharp hook. It is quite different from that of any Ichthyopterygian previously known to the writer, but is somewhat similar to that of the Pythonomorpha. Its great distal expansion and anterior hook are distinguishing characters. It is not so large as the coracoid, but has about the some relative dimensions as in *Ichthyosaurus*.

A nearly perfect *clavicle* in the specimen of *alexandræ* is a long and rather slender bone with a very deep groove on the end next to the median line of the body. Along this depression it probably fitted over the transverse bar of an *episternum*. This latter bone is not well shown in any specimen, but is possibly represented in *alexandræ* by a fragment which looks like the left end of the transverse bar.

The complete *pelvic arch* is known only from *perrini*, where all of the elements from both sides are preserved (Pl. 5, and Pl. 6, fig. 1). In this specimen the bones referred to the pelvic region and the posterior limbs lie immediately in front of the first chevron-bearing caudals. That they have not wandered back from the pectoral region is shown by the fact that a considerable portion of an arch bone, probably a coracoid, much larger than any of those in question, is present immediately below the anterior dorsals; while the femurs and the whole six elements of the pelvic girdle are accounted for.

All three of the bones of the arch of *perrini* are so unlike anything which the writer has found referred to *Ichthyosaurus* that it has been necessary first to discover whether their position in the matrix can furnish a clew to their normal place in the arch. As the skeleton is resting on its left side, it is probable that the arch and limb bones on that side were next the sea bottom and immediately covered by the body, and would be subject to less disturbance than the corresponding elements of the upper or right side. The latter would be separated by a large mass of flesh from the sea floor, and in settling down after the body had decomposed might easily have been separated or moved out of their natural order. As the arch bones lie on the slab, one of them, *Isl*, is covered by a femur, another, *Pl*, seems to have had ribs lapping over it, and a third, *Il*, is partly covered by *Isr*. These three bones seem to have been on the lower side of the body. They are, moreover, grouped about the head of the femur *Fl* in such a way as they might be if they belonged with it. The other three bones are grouped with the corresponding ends near each other. Of these elements *Pl* and *Pr* are anterior to *Isl* and *Isr*. *Il* is nearer the vertebral column than the others from that side, and is probably the *ilium*. *Ir* does not occupy the same relative position, but may be displaced. *Pl* and *Pr* may be considered tentatively as the *pubic bones*, *Isl* and *Isr* as the *ischia*.

In comparing these elements with those of other swimming saurians, the supposed pubes and ischia are found to show some resemblance to those of *Plesiosaurus* and *Cimoliosaurus* and also to *Palaeohatteria*, though their positions are reversed. The elements which have been considered as the ilia are unlike any bone of the Ichthyosaurian or Plesiosaurian pelvis that has been accessible for comparison. An approach in form would be found in an inverted pubis of *Ichthyosaurus*, the ilium of the later Plesiosauria, or in the most common form of ischium of the Pythonomorpha. From all of these it differs so much that the writer has been unable to do better than depend for tentative determination upon their present position in the matrix, as previously stated. As careful a preparation as can be made of the proximal ends of the pelvic elements of *perrini* fails to show definitely more than a single articular surface, excepting in the ilium; so that it has not been possible to ascertain how they could be fitted together to receive the head of the femur. In what is considered as the pubis in *pacificus* (Pl. 14, fig. 2), a small articular surface seems to be present just below the hook, and on this the ischium may have been received.

This arch, as it is supposed to have been constructed, would bear a greater resemblance to that of the Plesiosauria than to any known relative of the Ichthyosaurs. It is so different from that of *Ichthyosaurus* that no doubt can exist as to this genus representing a separate line of descent. The arch of the known Jurassic forms could hardly be derived from it.

To the pubis of *perrini* the supposed coracoid of *pacificus* (Pl. 14, fig. 2), the type of the genus, shows a stronger resemblance than it does to any bone of the pectoral girdle, and inasmuch as it was associated with posterior dorsal vertebræ, it may be considered as representing that element. Particularly in the form of the proximal end it differs from both coracoid and scapula and resembles the pubis (text Fig. 1, p. 103). In this connection it may be noted that the writer's association of the posterior dorsal vertebræ with the supposed coracoid, as doubtful anterior dorsals, was not without reason. His first opinion regarding the vertebræ was that they were anterior caudals, but the evidence in favor of their belonging with the undisturbed supposed coracoids was so strong that he accepted as a possibility the occurrence of a single articulation of the rib low down on the centrum. This belief was strengthened by the discovery of long single-headed ribs.

Extremities.—The *anterior limbs* are best represented in the specimen of *osmonti* (Pl. 10, fig. 1, and Pl. 11). With this there were found the right humerus, radius, ulna, radiale, and a fifth bone that may be an intermedium; and from the left side the humerus, radius, radiale, and a phalanx. The elements that are considered as belonging to the right limb were found together and in their natural positions in a small slab at the foot of the bluff. Close to them was what is known by comparison with *alexandræ* to be the right scapula. The proximal end of the right coracoid was exposed in the face of the cliff near by. The left coracoid was buried in the limestone just below the right, and the left humerus lay with its proximal extremity next that of the coracoid.

The *humerus* of this form, instead of being more slender than that of the later genera, as one would conjecture, is remarkably short and broad. Measurements of the right and left elements of the specimens of *osmonti* give the greatest length, taken from a point between the radius and ulna, as 170 mm. The greatest transverse diameter across the proximal end is 174 mm., and across the distal extremity approximately 180 mm. The least diameter, measured across from a deep, narrow notch on the anterior side to a broader posterior emargination, is 136 mm. As nearly as the writer has been able to determine, this is the shortest propodial segment known in the limb of an Ichthyopterygian form.

The anterior notch, to which attention has just been called, reminds one of those found in the radius of the longipinnate Ichthyosauria, and in other elements belonging to the middle portion of the limbs of both longipinnate and latipinnate forms. Lydekker* suggests that in these cases "were it not for the difficulty of explaining the presence of the same feature in the carpals and tarsals the notch in the anterior border of the radiale, tibiale, and phalangeals, might be regarded as the last trace of the shaft of a "long bone." . . . . In *osmonti* this notch is very narrow. In a portion of a much less robust humerus with the specimen of *alexandræ* (Pl. 12) it is much wider. The greatly shortened humerus of *Shastasaurus* presents almost exactly the conditions which Lydekker supposed necessary for the development of a notch, and its occurrence here tends to strengthen his theory.

The proximal end of the humerus is very convex, the cartilaginous portion extending far around both anteriorly and posteriorly. It is greatly thickened on the inferior or posterior face by a prominent ridge, extending three-fourths the length of the bone, and giving to this end a thickness of about 85 mm. The prominence is like the proximal end of the pectoral ridge of the Mosasaurian genus *Platecarpus*. The upper surface immediately opposite the proximal end of the inferior ridge shows a considerable excavation, which is bounded by a faint ridge in front and a broad, prominent elevation behind. The ulnar

* Catalogue of Fossil Reptilia and Amphibia in Brit. Mus. Part ii. p. 70.

corner of the upper side is separated from the remaining surface by a well-marked groove, running from the posterior emargination to the posterior end of the radial border. The radial border is considerably longer than the ulnar and is slightly thicker, excepting the posterior portion of the latter, which is added to by a prominence on the distal end of the upper surface.

The *radius* is a quadrate element, somewhat wider than long (width 110–115 mm., length 95). The proximal margin is nearly straight, the distal slightly convex, the posterior concave, and the anterior is marked by a deep, narrow notch, like that in the longipinnate Ichthyosauria. The *ulna* is considerably smaller than the radius in all of its dimensions (length 71 mm., width 85) and runs out to a comparatively thin edge on its posterior border. Its proximal margin is nearly straight, the small portion of the distal edge present is convex, the posterior side is also convex. The anterior border is slightly concave.

The form of the adjacent margins of the radius and ulna shows that they must have been separated by a considerable cleft. Their positions with reference to the humerus, causing them to diverge distally, would probably increase the distance, so that there would be quite a wide space between them.

The *radiale* is somewhat larger than the ulna and might have been mistaken for it, had not their positions in the matrix been such as to preclude the possibility of such a confusion. The lower end of the bone is broken off, but as the break is evidently below the middle the absence of a notch on the portion present may be taken to indicate that the anterior margin was entire, since the emargination always occurs in the middle. If notching were caused by shortening of the shaft, as suggested by Lydekker, it could easily be present in the radius without having developed in the carpus.

Resting in the angle between the distal ends of the radius and ulna and the proximal extremity of the radiale was an elliptical ossicle, which possibly represents the *intermedium*. The border is deeply concave and was evidently surrounded by a thick layer of cartilage. A careful examination of the adjacent angles of the radius and ulna reveals no sign of a facet for contact with an intermedium. The posterior, distal corner of the radius is sharply angular, and the adjacent corner of the ulna is only slightly rounded, while the surfaces of both have been thickly covered with cartilage. The intermedium evidently did not fit closely between the radius and the ulna, but lay near them in a thick plate of cartilage. The form and position of the ossicle just described are such as would be found in the intermedium, and it will be considered as representing that element. The dimensions are about what one would expect it to possess (long diameter 50 mm., short diameter 42, thickness 23).

Two small ossicles, one of which probably represents a *phalanx*, were found mingled with the cervical vertebræ and ribs. One of them is similar to the element which has been considered as an intermedium, but is slightly shorter and about one-half as thick. It may be either a distal carpal or a phalanx.

On the other bone the proximal and distal ends are thickened and convex. One lateral margin is convex, the other deeply concave and considerably thinned. The length is 40 mm., the width 50, the thickness at the ends 20, and in the middle 14. The thinness of the middle portion and the concavity of one margin in this element may indicate the remnant of a shaft of a phalanx with thickened posterior margin and ends. This bone is possibly a part of one of the elements at the back of the skull.

The *hind limbs* are known only from the *perrini* specimen, with which there are present both femurs, a tibia, a fibula, and four small ossicles of doubtful relationships (Pl. 6). The tibia and fibula are associated with one of the femurs in such a way that there can be no doubt as to their relation to it. Two of the small bones may also belong with this limb. The other two and the second femur are not definitely connected with any of the other limb bones.

Compared with the humerus of *osmonti* and *alexandræ* the *femur* is relatively slender. Its length, 55 mm., slightly exceeds its greatest transverse diameter, which is found at the distal extremity. The shaft is considerably contracted in the middle, where its width is only a little more than half of its length. The expanded and flattened distal and proximal ends are twisted away from each other so that their long diameters intersect at an angle of about sixty degrees. The fibular facet is only about sixty per cent. as long as the tibial, and is inclined about thirty to forty degrees away from the plane of the latter.

The larger of the elements next the distal end of the femur has been considered as probably the *tibia*. Its length is almost the same as its greatest width. The anterior border shows a shallow median notch. The posterior margin has suffered considerably from weathering, and it is not possible to determine its outline with absolute definiteness. As it now appears, this side is concave, and, judging from the structure of the bone, it was so originally.

The *fibula* is better preserved than the tibia, and little doubt can exist as to its original form. The distal end is considerably wider than the proximal. The well-preserved posterior margin is deeply concave. The anterior side has suffered considerably, but appears to have had much the same form as the posterior edge. Its length is the same as that of the tibia, but it is a much slenderer bone. Its width at the proximal end is less than two-thirds that of the tibia, the shaft is also much narrower. The distal end is almost as wide as the corresponding part of the tibia in its present weathered condition. Although the distal extremities of the tibia and fibula may have been in contact, there can be little doubt concerning the existence of a gap between their middle or shaft portions.

A portion of a small ossicle which originally lay between the distal ends of the tibia and fibula may have been the *intermedium*, or was possibly some other carpal or a phalanx. Another, which is between the anterior proximal corner of the tibia and the femur, is probably a loose *phalanx*, belonging with two seen a short distance in front. This element might possibly be considered as a pre-tibial ossicle, but the space into which it seems to fit would be largely closed up if the tibia were in its normal position. As the tibia now lies, it is moved a little to the rear. It would also be possible to make this a post-fibular ossicle like that seen in some Plesiosauria and Ichthyosauria, if this were considered the posterior side of the limb. It should, perhaps, be stated that if both the limbs and the arches were considered as reversed, or facing backward in the slab, they would come near to agreement with the general plan of Pleisosaurian posterior limbs and arches.

Judging from a comparison of the limbs with the middle dorsal vertebræ, it would appear that the posterior limbs were smaller and less specialized than the anterior.

Skull.—The posterior half of a cranium belonging to an undoubted representative of *Shastasaurus* was found with the type specimen of *alexandræ* (Pls. 12 and 13). This skull is typically Ichthyosaurian in nearly every particular. The small frontals are overlapped anteriorly by very large nasals. The superior portions of the parietals form a narrow ridge in which is a parietal foramen. The orbit is of enormous size, and the structure of its bony rim, as also that of the single temporal arch, is similar to that in *Ichthyosaurus*. The form of the jugal, lachrymal, and the prefrontal, is essentially as in *Ichthyosaurus*. The postfrontal meets the prefrontal above the middle of the orbit and considerably in advance of the temporal opening. The upper portion of the postorbital extends backward beneath the supratemporal and squamosal, which are partly broken away from this specimen. The quadratojugal is missing or moved from its natural position. The quadrate is of the Ichthyosaurian type. The end of the maxillary is present but is unfortunately broken off behind the posterior teeth. The otic bones, the supraoccipitals, and the lateral occipitals could be only partly exposed and their relations cannot be definitely determined. Sclerotic plates like those of *Ichthyosaurus* appear in both orbits.

On the lower side of the cranium the pterygoids and palatines have been well exposed and are similar to these elements in *Ichthyosaurus longifrons*, as figured by Owen. Portions of what are probably the basioccipital and basisphenoid and one of the quadrates are also shown. Close to the pterygoids there is present on each side a long rod-like bone, representing the thyrohyal of Owen, such as has been described by him from *I. tenuirostris*. Considerable portions of both rami of the mandible are present. The break at the anterior end of the left ramus shows the dentary, splenial, supra-angular, and angular. The splenial extends the whole height of the jaw at this point. The portion of the dentary shown is the thin posterior end supported by the supra-angular. The angular is hidden on the outside by the overlapping supra-angular. Toward the posterior end of both rami the angular is seen resting below the supra-angular. The sutures between these two elements are fairly well defined along the greater part of their contact, but are unfortunately obscured at several points. On the broken posterior portion of the right ramus there is visible the cross-section of a small bone, which may represent the coronoid. No trace of it is seen on the inner side of the left ramus; it is, however, possible that the angular has slipped over it, or that it has been destroyed in preparation. Concerning the form of the articular little can be said, as the region in which it should occur is very poorly preserved. Judging from the form of this part of the ramus, the articular might be somewhat different from that described for *Ichthyosaurus*, but this point must be settled by the study of better material.

Dentition.—In a recent note (Merriam, 1902) the writer stated that the dentition of *Shastasaurus* is differentiated. This information was based on the study of a small skull, supposed to belong to this genus. Later preparation of this specimen by the use of acids has made a more careful study of it possible, and it is found to differ so much from the typical Ichthyosaurs, and apparently also from *Shastasaurus*, that its reference to this group appears at present unwarranted.

A number of loose, conical teeth, with striated enamel crowns, have been collected in the limestones in which *Shastasaurus* remains occur, but as yet none have been found with recognizable specimens of that genus. Similar teeth occur in these beds in small jaws belonging to other groups, so that while some of them quite probably belong to *Shastasaurus* we cannot refer any of them to it with certainty.

AFFINITIES AND CLASSIFICATION.

In the outlines of its structure, *Shastasaurus* shows itself clearly a member of the Ichthyopterygia. The skull, vertebræ, tail fin, extremities, and pectoral arch are of the type of those in *Ichthyosaurus*, and quite unlike the general aspect of the skeleton in any other group. In some of its characters, particularly the rib articulation in the dorsal region, the fusion of the hæmacentra to form chevron-bones, the form of the elements in the pelvic arch, and the specialization of the humerus in at least two species, it differs from the previously known genera of this order.

So far as approximation to a primitive type is concerned, the probable existence of a larger number of cervical intercentra than appear in other forms of this family is about the only really primitive character recognized. The separation of the radius and ulna, and the tibia and fibula, and the greater development of the pelvic arch are characters which, with the separate zygopophysial facets, indicate less complete accommodation of the Shastasaurian skeleton to purely aquatic conditions than we find in the Jurassic *Ichthyosaurus.* These characters are found also in the Triassic *Mixosaurus*, excepting those of the pelvic girdle, which has not yet been described from that genus; and to them should be added, as a common characteristic, the thickened spines of the upper arches. Others, notably the modification of the dorsal rib articulation, the formation of chevron-bones, and the shortening of the humerus, are specializations not found in this genus. The closest affinities of *Shastasaurus* are evidently with *Mixosaurus*, from which it is, however, sharply separated by the characters just mentioned, unless the structure of the forms in that genus be very different from that which has been ascribed to them.

The primitive characteristics found in the epipodial segments of the limbs and in the zygapophyses would probably be considered as sufficient to indicate somewhat greater age for this genus than the lower Jura with its longipinnate forms, in which a very small gap may exist between the epipodial bones. The specializations in the rib articulation, chevrons, and humerus, indicate a distinct line of descent which started with a form like *Mixosaurus*, and which in the upper Trias still retained some of its early characteristics, but had already gone a considerable distance along several lines of specialization that were never followed in the other genera. So far as we now know this line ended in the late Trias. Through the kindness of Professor W. C. Knight of the University of Wyoming, and Dr. Charles R. Eastman of Harvard University, the writer has been enabled to examine a series of vertebrae of *Baptanodon* from the Jurassic of Western North America, in order to determine whether possibly that genus is descended from *Shastasaurus*. The vertebra are, however, of the *Ichthyosaurus* type, and *Baptanodon* can not be considered as derived from the typical Triassic forms of this region.

Should the classification of Baur (1887, p. 4) be accepted and the Ichthyopterygia be divided into three families, the Mixosauridæ, Ichthyosauridæ, and Baptanodontidæ, it will be necessary to add the representatives of the *Shastasaurus* group as a fourth division, for which the name Shastasauridæ is proposed. The distinguishing characters of this family will be founded in the peculiar articulation of the dorsal ribs, the form of the pelvic arch, and the presence of long-spined chevrons. If it is found advisable to bring all the genera of the Ichthyopterygia together in one family, *Shastasaurus* and its relatives should be grouped in a distinct sub-family, the Shastasaurinæ.

DISTRIBUTION AND SYNONYMY.

That of a group of marine reptiles with the characters of *Shastasaurus* would be confined within very narrow geographic limits is improbable, particularly as the occurrence of its remains points toward a fairly deep and open sea as its habitat. With a view to determining whether any of the Triassic Ichthyosaurian material described from other regions could possibly be considered as Shastasaurian, the writer has gone over such literature as is accessible to him, and the following list of species referred to the Triassic, outside of California and Nevada, has been compiled.

Mixosaurus atavus Quenstedt.
Mixosaurus cornalianus Bassani.
Mixosaurus nordenskjöldi Hulke.
Ichthyosaurus (?) polaris Hulke.
Ichthyosaurus (?) rhæticus Sauvage.
Ichthyosaurus (?) carinatus Sauvage.
Ichthyosaurus (?) hectori Lydekker.

Practically all of these species have been founded on very fragmentary material, in which a genus with characters like those of *Shastasaurus* might escape detection unless nearly perfect type specimens were available for comparison. Of the species mentioned, *hectori*, *polaris*, and *nordenskjöldi* do not appear to have yet been figured. The illustrations of *carinatus* and *rhæticus* are very imperfect. An outline drawing giving the limb structure of *cornalianus* was furnished by Baur, and Frass has published good figures of scattered vertebræ of *atavus*, together with jaw fragments and a doubtful humerus.

The figure of *cornalianus* shows the structure of its anterior limb to be more primitive than that of either the anterior or the posterior limb of *Shastasaurus*, but gives us no hint as to the most important characters of that genus. The figures of the vertebræ of *atavus minor*, given by Frass, show separate diapophyses and parapophyses low down on the centra, indicating that it is entirely different from *Shastasaurus*. The zygapophyses of the upper arches are also more nearly vertical and do not come so near to being in the same plane. It is clear that no very close relationship can be found with these two species or the genus which they represent.

In his description of *rhæticus*, Sauvage states that the diapophysis and parapophysis on one dorsal vertebra are united, and one might almost suppose that there existed here the modification found in the Californian species. However, in the description of another dorsal, he states that they touch in forming a figure eight, and in his illustration of this specimen, they are seen to be close together but quite distinct. The diapophysis appears also to be separate from the neurapophysial surface of the centrum so that the similarity to *Shastasaurus* is not so great as might appear from the description. On the other hand, notice should be taken of the very large di- and parapophyses, such as are not, to the writer's knowledge, found in *Ichthyosaurus*.

Concerning *carinatus*, little can be said excepting that both diapophyses and parapophyses are mentioned as being on a centrum which is evidently a dorsal.

Of the unfigured forms very little can be determined. According to the descriptions, Hulke's *polaris* agrees very well with the posterior dorsals of *Shastasaurus*, and later examination may show that it belongs to that genus.

It is hardly to be doubted that future exploration and investigation will bring to light remains of *Shastasaurus* at numerous points outside of the Pacific Coast region of North America.

DESCRIPTION OF SPECIES.

Shastasaurus perrini. n. sp.

PLS. 5, 6 AND 7.

The only specimen of this species known was discovered in the Cove some years ago by a collecting party working under the direction of Professor James Perrin Smith. Being too large to to be handled without special appliances, it was left in the field till the fall of 1901, when Professor Smith generously turned it over to the University of California party then working in the Cove.

This specimen exhibits an unbroken series of eighty vertebræ, beginning near the anterior end of the dorsal region and ending well beyond the middle of the tail. The majority of the ribs from the lower side of the body and a number from the upper side lie next the vertebræ to which they were attached. The whole of the posterior arch and the most important parts of the hind limbs are present. Of the anterior girdle only a large fragment is left. The head and anterior limbs were in a portion of the slab which had been weathered or broken off. As yet no trace of them has been discovered.

This skeleton was found a considerable distance below the top of the layer of shaly limestone of the Trachyceras beds. As may be seen in Plate 5, fig. 1, the slab upon which it lies is largely made up of molluscan shells, among which *Halobia superba* is the most common form. A large specimen of *Tropites* rests against the lower side of the tail.

One of the most important characters of this species is found in the form of the vertebral centra, which are much longer than in the other known forms of the genus. In the second vertebra the ratio of length to height is 1:1.83, in the twenty-fifth 1:1.33, and in the fifty-fifth 1:54. The later caudals rapidly become shorter and higher. In the tenth vertebra of *osmonti*, which is near the place of the second of the *perrini* specimen, the ratio is 1:2.21. The variation in the relation of width to height of centra between the anterior and posterior ends of the column is much the same in *perrini* as in *osmonti*. The centra are deeply excavated on the anterior and posterior surfaces, which slope sharply from the margins to the centre. In those which could be examined the bony partition is not perforated, though it may be very thin.

The character of the rib articulation is not essentially different from the typical form described for the genus. The fifth to the fourteenth vertebræ present are covered by ribs and could not be examined. The fourteenth to the nineteenth are twisted away from the arches, and turned so that the inferior surfaces are uppermost. The ribs which covered these centra were removed and a cut made below the column to expose the dorsal surfaces. The rib articulations were successfully uncovered on the sixteenth to nineteenth and were found to be the same as those on the twenty-fifth (Pl. 5, fig. 2). The paraphophysis is gone, and the diaphophysis is connected with the superior articular surface. The lower side of the diapophysis, which swings forward to the anterior margin of the centrum, is somewhat narrower than in *osmonti*. On the twenty-seventh centrum the diapophysis is separated from the superior articular surface by a wide space. Unfortunately the twenty-sixth is turned over, and could not be examined without injury to the upper arch.

Opposite the pelvic girdle, or at about the fortieth vertebra, the diapophyses reach the lower side of the centra. They have here, however, nearly the same form as on the twenty-seventh. Back of the pelvic arch they rapidly become shorter, changing to an elliptical or circular outline. In this region they also move up the sides of the centra. On the sixtieth centrum they are about half way up the side. Beyond this point they could not be traced with certainty.

The upper arches do not vary greatly in height between the cervical and anterior caudal regions. Those of the anterior and middle dorsal region attain a slightly greater height than the others. In the cervicals and anterior dorsals the spines are relatively thicker than elsewhere, and the pedicels are much extended laterally. Back of the twenty-sixth vetebra, where the diapophyses separate from the upper articular surface, the bases of the pedicels show little, if any, lateral extension.

The lower arches begin at about the forty-fifth centrum. Possibly they were present anterior to this point, but no traces of them could be discovered. Articular surfaces for the chevrons are seen as far back as the sixty-fifth centrum. No indications of their existence are found beyond the bend in the tail.

The ribs in *perrini* do not have the peculiar modification of the head found in *altispinus* strongly marked. The articular surface shows a little of the outward and backward curvature seen in that species, but it is not so pronounced. In the dorsal region the whole proximal end of the rib is sharply twisted, so that its long diameter is moved almost eighty degrees from that of the middle of the shaft. In this twist the lower portion of the head and the flattened superior surface of the shaft are directed forward. The anterior side is deeply furrowed by a groove which begins on the upper side near the head, and may extend about two-thirds the length of the shaft. The posterior side is similarly channelled for about the same distance. The distal end of the shaft is always nearly circular in cross-section.

In the posterior portion of the dorsal region the ribs have broad heads, but the shafts are short and apparently without grooving.

Excepting the fragment probably representing the shoulder girdle, the limb and arch elements present have been described in detail in the general discussion of the genus.

The fragment resting upon the anterior dorsal ribs is too imperfect for satisfactory determination, but is probably the distal end of a coracoid. Its transverse diameter and thickness bear about the same relation to the dimensions of the anterior dorsal vertebræ as in *alexandræ*.

The following table of measurements gives the dimensions of the more important parts of this skeleton. All measurements are in millimeters. The letter *a* preceding a measurement indicates that it is approximated on a slightly broken specimen.

VERTEBRÆ.

Number of vertebra in the series.	Height of centrum.	Width of centrum.	Length of centrum.	Height of upper arch.	Width of upper arch.	Thickness of spine near summit.	Length of lower arch.
2nd	22	*a* 24	12	....	....	....	....
3rd	....	....	*a* 13½	37	11.5	7.5	....
5th	....	....	*a* 14	39	....	....	....
9th	....	....	....	42	15	6.5	....
12th	....	....	....	45	18	6.5	....
15th	....	....	....	44	19.5	6.5	....
16th	....	....	20	....	....	....	....
17th	....	29	20	46	20	....	....
23rd	....	36	27	44	26	....	....
25th	37	....	27	45	27.5	9	....
27th	38	....	29	46	....	10	....
32nd	34.5	....	29	42	29	7	....
37th	*a* 38	....	29	44	*a* 28	7	....
46th	38	....	25	38	25	6.5	54
55th	37	....	24	30	*a* 19	5	....
62nd	34	....	15	....	....	....	....
78th	*a* 28	....	10	....	....	....	....

RIBS.

	Width of head.	Width of shaft 45 mm. from head.
Rib opposite 6th vertebra	19	12.5
" " 22nd "	17	9
" " 30th "	17	....
" " 37th "	25	8
" " 40th "	23	7

Length of apparently unbroken shaft of rib opposite 37th vertebra 155

ARCHES.

Coracoid (?)	
Greatest diameter of fragment	66
Thickness of unbroken end	18
Ilium	
Greatest length	44
Width of distal end	20
Thickness of distal end	9
Greatest diameter of proximal end	24
Ischium	
Greatest length	53
Greatest width	44
Width of proximal end	33
Thickness of proximal end	27
Thickness of distal end	9
Pubis	
Greatest length	48
Greatest width	52
Width of proximal end	26
Thickness of proximal end	12.5
Thickness of distal end	7

LIMB BONES.

Femur	
Length	55
Width of proximal end	44
Width of middle of shaft	29
Width of distal end	52
Thickness through distal end at tibial articulation	22
Thickness through proximal end	24
Tibia	
Length	36
Width of proximal end	36.5
Width of middle shaft	27
Thickness of distal end	12(?)
Fibula	
Length	35
Width of proximal end	22
Width of middle of shaft	20
Width of distal end	32.5

Shastasaurus osmonti n. sp.

PLS. 8, 9, 10 AND 11.

The type material of this species includes thirty-five vertebræ with the most important parts of the anterior arch and limbs. It was discovered by Mr. V. C. Osmont in the limestones near the Cove in June, 1901. About half of the bones, including the right limb, were embedded in several loose slabs lying at the foot of a limestone cliff, from which they had evidently but recently been separated, as other vertebræ and ribs were seen protruding from the rock close to them. The remains in the solid rock of the cliff were worked out in the fall of 1901 by Mr. H. W. Furlong, and were found to include part of a left limb of exactly the same dimensions as the right limb in the loose slab. The coracoids, and many of the cervical vertebræ, were found with the left limb. There can be no doubt that all of these remains belong to the one animal.

The vertebræ comprise individuals belonging to the cervical and dorsal regions. It is not certain that the series is complete, but judging from the gradual increase in size toward the posterior end, there are few, if any, gaps.

The most anterior individual is deeply biconcave and is, therefore, possibly neither atlas nor axis. On the other hand the large size of the intercentrum between it and the succeeding individual indicates that it was close to the anterior end of the column. It is not probable that it was further back than the third.

The following are the measurements of some of the best preserved centra and arches in the series. The position of the 7th, 11th, 17th, and 35th vertebræ could not be determined with absolute certainty, but is in each case not more than one or two vertebræ removed from the point in the column to which it is here referred. The height of the 1st and 3rd centra is given without and with (*h*) the inferior apophysis. Measurements in millimeters.

Centrum of series.	Height.	Width.	Length.	Height of diapophysis.	Height of parapophysis.
1st	40–48 *h*	43	21	20	10.5
3rd	40–46 *h*	48	22	23	10
7th	46	52	23	23	8
11th	49	53	27	29	4
17th	56	58	28	38	
25th	66	66	30	44	
35th	73	68	32	50	

Upper arch of cervical vertebra	
Height	60
Width half way between summit and posterior zygapophyses	17
Thickness half way between summit and posterior zygapophyses	15
Upper arch of anterior dorsal	
Height	66
Width half way between summit and posterior zygapophyses	25
Thickness half way between summit and posterior zygapophyses	13
Length of posterior zygapophysis	18.5
Width of anterior zygapophysis	10
Upper arch of middle dorsal	
Height	65
Width half way between summit and posterior zygapophyses	32
Thickness half way between summit and posterior zygapophyses	15
Length of posterior zygapophysis	18.5
Width of anterior zygapophysis	7

The dorsal ribs of this species show the characteristic backward twist of the rib-head and the flattening of the superior surface of the shaft (Pl. 9, fig. 6). The grooving of the shaft is stronger on the posterior side. The rib-head is slightly bent so that the posterior side is somewhat concave, also the upper part of the proximal surface turns outward. Both of these characters are much less pronounced than in *altispinus*.

The anterior arch (Pl. 10) is characterized by extreme thickness and relative narrowness of the coracoids (figs. 2 and 3). The scapula (figs. 4 and 5) is relatively heavier than that of *alexandræ*. The distal end of a clavicle present shows no distinguishing characters.

Following are the principal measurements compared with those of *alexandræ:*

	osmonti.	*alexandræ.*
Coracoid		
Length	160	170
Greatest width	*a*170	205
Width of proximal end	*a*110	144
Thickness of distal end	71	65
Greatest thickness of proximal end	60	62
Scapula		
Length	120	150
Greatest thickness of proximal end	52	52

a Approximate.

The anterior limbs of *osmonti* have been described in detail in the general discussion of the genus. As yet they are the only known bones representing the anterior limbs of this genus, except the fragment of a humerus with the specimen of *alexandræ*. The humerus of *osmonti* differs from that of *alexandræ* in being much thicker and in possessing a much narrower notch in the anterior border.

	osmonti.	*alexandræ.*
Humerus		
Greatest axial length	170	*a*190
Width of distal end	180	.....
Greatest thickness proximal end	80	68
Thickness distal end	50	38
Width of anterior notch	10–20	40
Radius		
Length	95	.....
Width	115	.....
Thickness of proximal end	50	.....
Ulna		
Length	71	.....
Thickness of proximal end	30	.....
Radiale		
Width	95	....
Thickness of proximal end	30	....

Shastasaurus alexandræ, n. sp.

PLS. 12 AND 13.

This species is represented by a specimen collected a quarter of a mile south of the Cove by the party under Mr. H. W. Furlong. It was found a short distance below the contact between the Atractites beds and the Trachyceras beds. The specimen includes the greater part of a skull, nearly all of the pectoral girdle, part of a humerus, fifteen or sixteen vertebræ belonging to the anterior portion of the column, and numerous ribs.

The cranium has already been described in detail as the only one certainly known to belong to a member of this genus. It is essentially like that of *Ichthyosaurus*. The portion of a humerus which is present shows that element to have been much thinner at both extremities than in *osmonti*. The anterior notch is also very different, being much wider and relatively shallower.

The coracoids like the humerus are thinner at both extremities than in *osmonti* and are much wider distally. The anterior

a Approximate.

distal hook is in consequence of this somewhat longer and the anterior notch deeper. The clavicle is long and slender. The interclavicle is unknown.

The anterior portion of the vertebral column runs up to the foramen magnum and is probably complete. Immediately behind the back of the skull, and in close proximity to it, are two small indeterminate ossicles in the position which the separate pieces of the upper arch of the atlas would naturally occupy. Following them is a vertebra-like body, which does not seem to be biconcave. Its dimensions are nearly the same as those of a deeply amphicœlous centrum immediately behind it, and it is possibly the atlas. The first certainly determinable vertebra is the second large element behind the parietals. It is deeply biconcave, the excavated end surfaces sloping gradually to the center. On one side of this centrum there is an oblique truncation at each end. Against one of these there rests a small piece of bone which is probably an intercentrum. The second centrum behind this one, the fourth, is well exposed, showing the sides and anterior end. The lower side of the anterior end is produced downward as an apophysis, against the anterior face of which an intercentrum has rested. The inferior apophysis gives to the front face of this centrum a height as great as the breadth and makes the cross-section pentagonal. On this centrum, as on the three following it, the diapophyses are high and broad. They narrow toward the top and are connected with the upper articular surfaces. The parapophyses are relatively small, their height being considerably less than half that of the diapophyses. On the eighth the parapophysis is abnormally large and is also entirely out of its natural position, being on the posterior margin. On the ninth it is in its normal position and very small.

The upper arches, which are well shown on the fifth and seventh, are high and rather slender. The spines are very thick, being almost circular in cross-section. The zygapophyses are large and strong. The bases of the pedicels project laterally over the diapophysial ridges.

Two or three of the ribs which are present show both the capitulum and tuberculum. The former is, however, in all cases very small. On several other well preserved ribs there is only a broad tuberculum, such as is seen in thoracic ribs of the other species.

Measurements:

4th vertebra	
Height of centrum including inferior process	49 mm.
Width of centrum	49
Length of centrum	22
Height of diapophysis	22
Height of parapophysis	9
6th vertebra	
Height of centrum, approximately	44
Length of centrum	27
Height of upper arch	74
Width of upper arch half way between summit and posterior zygapophyses	18
Thickness of upper arch at summit	18
Height of diapophysis	24
Height of parapophysis	9
8th vertebra—Length of centrum	28
9th vertebra—Length of centrum	30

Shastasaurus careyi n. sp.

Pl. 16, figs. 3 and 4.

Among the most interesting remains that have been obtained from the Shasta County Triassic are several gigantic vertebræ and portions of ribs belonging with them. The first determinable specimens were found by Mr. E. R. Carey in the small exposure of limestone on Bear Mountain, twenty miles northeast of Redding. Other less perfect examples were obtained by Mr. V. C. Osmont, Mr. H. W. Furlong, and the writer at the Cove, near Madison's ranch.

The vertebræ collected by Mr. Carey are considerably wider than high (180 mm. to 160 mm.), and the short, broad diapophyses do not reach below the middle of the centrum. The parapophyses are very rudimentary, being represented only by small, rounded tubercles near the anterior margin of the centrum. The length of the centrum (60 mm.) is relatively less than in any of the other species. A rib-head resting against the side of one of the centra shows no trace of a capitulum. Part of a thick upper arch which is present shows strong zygapophyses.

The width of the centra and the shortness of the diapophyses of these vertebræ seem to indicate that they belong in the cervical or anterior dorsal region. The height of the rib-head shows that the diapophysis is not abnormally shortened owing to extensive articulation of the tuberculum against the upper arch. The very rudimentary parapophyses would, taken by themselves, point to a more posterior position in the column than is suggested by the other characters. The form of the cross-section and length of the diapophysis are, however, more nearly constant characters than the relative size of the disappearing parapophysis, and it seems to the writer that in this form the reduction of the parapophyses has possibly gone farther in the cervical region than in the other known species.

The dimensions of these vertebræ and ribs show that the individuals to which they belonged ranked among the largest known Ichthyopterygia. If the centrum just described be supposed to belong as far back in the column as the tenth in *osmonti*, and if the ratio of its size to that of the thirty-fifth were the same as in that species, the thirty-fifth would have a diameter of 245 mm.

Although the quantity of material at hand is insufficient for satisfactory diagnosis of this form, it would seem that the shortness of the centra, the possible unusual reduction of the parapophyses, and the large size, indicate a distinct species. It is, of course, possible that all of these characters could belong to old individuals of some of the other forms described. It appears very doubtful to the writer, however, whether the centra would become relatively shorter with age; while greater reduction of the parapophyses would almost be expected in one of the larger species of the genus.

The following are the measurements of the type specimens of *careyi:*

Width of rib-head 55 mm. from proximal end	55 mm.
Estimated width of rib-head at proximal end	75
Width of second centrum	180
Height estimated certainly within 5 mm. of actual size	160
Length of centrum	60

Shastasaurus altispinus n. sp.

PL. 14, FIG. 5, AND PL. 15.

The specimens representing this species were found embedded in two loose slabs lying close together at the foot of a steep bluff near the Cove, three miles from Madison's Ranch, on Squaw Creek. The horizon at which they occurred seemed to be near the base of the Atractites beds. The bones all appear to belong to one individual. They include five vertebræ from the posterior and middle dorsal regions, several well preserved ribs, one complete limb bone, a fragment of another, and a piece of a large arch bone.

On four of the vertebræ the summits of the diapophyses are below and disconnected from the upper surface of the centrum, while the lower ends are relatively near the inferior surface (Pl. 15, fig. 1). The diapophysial ridges on these individuals are long, slender, and much constricted at the point where the lower part swings forward. As is shown in the table of measurements following, the height of the centrum is slightly greater than the width. The greatest breadth is considerably below the middle, which gives the centrum a pear-shaped cross-section.

Measurements of a centrum on which the diapophyses do not reach the summit.

Height	97 mm.
Greatest width	92
Length	46
Height of diapophysial ridge	62
Width of diapophysis at constriction	9
Greatest width of lower extremity of diapophysis	21
Height of upper arches with these centra	120
Antero-posterior diameter of spines at widest point above posterior zygapophyses	34–32
Transverse diameter at the point where antero-posterior was taken	27–27

The other vertebra (fig. 2) has a length of 41 mm. and is consequently somewhat smaller than the four already discussed. Its diapophysial ridge reaches the summit of the centrum, and the articular surface is confluent with that for the reception of the upper arch. This centrum belongs apparently to a middle dorsal and the other four followed close behind, probably separated from it by only a few individuals.

One of the distinguishing characters of this species is found in the form of the upper arches, which are remarkably high and thick (figs. 3 and 4). The margins of the spines are very thin, particularly on the lower portion of the anterior side. Excepting these blade-like edges, the cross-section of the shaft of the spine is almost circular near the summit. The height of the spine is relatively greater than in the other forms. As indicated in the table of measurments, this dimension is relatively greater than in vertebræ from a portion of the column of *osmonti* slightly anterior to that from which these came, and also greater than that of the late dorsals of *pacificus*. The zygapophyses are not well preserved, but enough is present to show that they are rather slender and that the right and left facets are not united. The pedicels of the arches show no lateral projection. The general form of the arches present is somewhat similar to that of the cervicals of *alexandræ*. They are, however, too large for cervicals at all comparable to those of other species as regards the relation of their dimensions to those of the middle dorsals. The pedicels are also narrower than in the cervicals. Should it ever appear that cervical arches are here mingled with dorsal vertebrae, this species would be even more sharply separated from the others than it is now held to be.

The *ribs* (figs. 5 and 6) associated with the vertebræ just described were most of them lying in such a position as to permit of little doubt as to their having been practically undisturbed. On the broad heads a marked constriction of the middle portion of the articular surface is produced by profound excavation of the posterior side. The upper portion of this surface is considerably smaller than the lower and its long axis inclines backward and away from it. The surface also bends sharply outward, deviating as much as thirty-five degrees from the plane of the lower face The shaft of the rib is almost triangular in cross-section. The upper surface is slightly convex, while the anterior and posterior sides are grooved. Such ribs as those that have just been described are ordinarily associated with vertebræ in which at least the superior portion of the articular surface rests against the upper arch. There seems to be no question that there is represented here a peculiar mode of attachment, in which the loss of the lower rib head is compensated for in the manner described above (page 73).

MEASUREMENTS OF A RIB.

Length of portion of proximal surface of head below constriction	31 mm.
Breadth of lower surface	20
Length of portion above constriction	32
Breadth of portion above constriction	14
Height of shaft 90 mm. from proximal end	24
Width of flattened superior surface	19

The two *limb bones* are like the notched elements on the anterior borders of the limbs of the longipinnate Ichthyosauria. Excepting on the notched side, their margins show a regularly rounded outline and it is, therefore, not probable that they represent either the radius or the tibia, but were situated in the metapodial or phalangial segments. The perfect specimen is represented by fig. 5, Pl. 14. The following are their dimensions:

	Perfect specimen.	Fragmentary specimen.
Greatest transverse diameter	85 mm.	....
Greatest axial diameter	67	74 mm.
Greatest thickness	35	37
Depth of notch	20	25

Shastasaurus pacificus. Merriam.

PL. 14, FIGS. 1 AND 2.

Shastasaurus pacificus Merriam. Am. Jour. Sci. Vol. 4, 1895, p. 56.

The type species of the genus *Shastasaurus* was based on a series of eight vertebrae with several fragments of ribs and two arch bones, one of which was very fragmentary, the other being practically perfect. The vertebræ were recognized as pre-caudals, and, being associated with what were supposed to be certainly coracoids, they were described as doubtful anterior dorsals. A re-examination of the type shows the vertebræ to have been without chevrons, while the diapophyses occupy the same position as those near the pelvic arch, so that they may be considered as posterior dorsals.

The elements which were taken to be coracoids (Pl. 14, fig. 2) are very different from both the coracoid and the scapula of the two species in which these bones are known. This difference appears in the general outlines, and more particularly in the form of the proximal end (text fig. 1), which is very characteristic on both coracoid and scapula. The whole form is most closely approximated, although not exactly duplicated, in the pubis of *perrini*, and inasmuch as the vertebræ with which they were associated are quite distant from the region of the shoulder girdle, they probably correspond to that element.

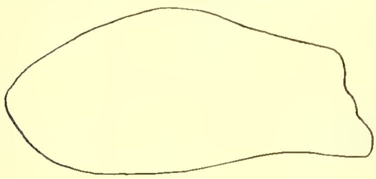

FIG. 1.

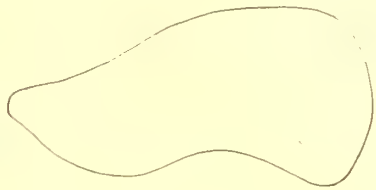

FIG. 2.

FIG. 1.—Cross-section of proximal end of left (?) pubis. *S. pacificus.*

FIG. 2.—Cross-section of proximal end of right coracoid. *S. alexandræ.*

The only other specimen showing vertebræ from this portion of the dorsal region is the skeleton of *perrini*. From this it differs very considerably in length of centrum and thickness of neural spine. The centra are much shorter than in *perrini*, and somewhat longer than in all of the other known species. At the present time we cannot determine definitely the relations of *pacificus* to the better known species, and it is not impossible that when other parts of the skeleton of those forms are known it will be found that some one of them should be included in *pacificus*.

Measurements:

Vertebrae	
Height of first centrum in cross-section*	68 mm.
Width	70
Length of fourth centrum	36
Height of second upper arch	67
Width " " "	35
Thickness of spine of sixth upper arch	14
Pubis	
Greatest length	130
Width of proximal end	95
Thickness	46

* The original measurement of height was made on an imperfectly exposed vertebra and measured only to the neural groove.

FORMS FROM MIDDLE TRIASSIC OF NEVADA, CYMBOSPONDYLUS GROUP.

CYMBOSPONDYLUS LEIDY.

Proc. Philad. Acad. Sci. 1868 v. 20 p. 177.

This genus was founded by Leidy upon several fragmentary and imperfectly prepared vertebræ "from the Triassic rocks of Star Cañon, Humboldt Co. (Nevada), and from the Toiyabe Range, northeast of Austin, Nevada." With the type specimen from New Pass, in the Toiyabe Range, are "two shells which appear to be *Ammonites blakei* Gabb and *Posidonomya stella* Gabb."

According to Professor James Perrin Smith the presence of *Am. blakei* indicates that these beds are middle Triassic and consequently older than those from which the saurians were obtained in Northern California. These remains, therefore, represent the oldest known Ichthyopterygians of this coast, and among the oldest that have ever been discovered. Two species were described by Leidy, *C. piscosus* and *petrinus*. *C. piscosus* is the first mentioned and must be taken as the type of the genus. Following are the principal parts of Leidy's description of the type specimen, which consists of portions of five vertebræ.

Cymbospondylus piscosus Leidy.

PL. 16, FIGS. 1 AND 2.

"The body of the vertebræ is deeply biconcave, as in *Ichthyosaurus*. The length is considerably less than the breadth. The under side is plane fore and aft, but the margins are slightly prominent and bevelled. The sides are slightly concave and provided with a short and robust process for the head of a rib. The neural arch, with its spine visible in one vertebra along the broken margin of the specimen, rises above the body about one and one-half times its depth, and its abutment exhibits the remains of another articular process for the rib. The neural canal is triangular."

From New Pass, in the Toiyabe Range, northeast of Austin, Nevada.

From this diagnosis the writer found it impossible to determine the affinities of *Cymbospondylus*, and through the kindness of Dr. Charles R. Eastman, the type specimens of Leidy's species of Nevada Triassic saurians were obtained for study from the Whitney collection at Harvard University. The type of *C. piscosus* was not sufficiently well prepared to show the characters of the vertebræ, which Leidy apparently did not understand. The matrix was, therefore, removed from the sides of the centra and arches. The form of the vertebræ shows them to belong to the anterior dorsal region. The centra are a little longer than in most Ichthyosauria and are deeply amphicœlous, the concave surfaces beginning close to the periphery and sloping sharply the whole way to the centre. There is but one surface of articulation for the rib-head. This is situated on a long, broad, and prominent ridge, which begins on the upper side of the centrum and runs downward and forward to the anterior margin. At the superior end it is very broad. It narrows in the middle and widens again at the lower end. The upper portion of the articular surface seems to be continuous with that upon which the upper arch rests. The broad lower end runs to the anterior margin of the centrum. The pedicels of the upper arches are seen to be considerably extended laterally toward the ribs. The spines are moderately high and quite thick, but show no trace of a lateral rib. The zygapophyses are large and strong. They are not brought into the same plane on the right and left sides and are evidently paired. They come nearer to being perpendicular to the long axis of the spine than in *Shastasaurus* and the arches are more nearly erect.

The lateral ridge of the centrum corresponds to the diapophysis. No trace of a parapophysis is present. The diapophysial ridge is divided into a rough upper face and a smoother lower surface by a salient portion situated at the point where the lower end bends forward. The rib articulation was solely upon the diapophysis and principally with the smoother lower surface.

Measurements of vertebræ of *C. piscosus:*

Height of centrum, 4th vertebra	36 mm
Width " " "	38
Length " " "	23
Height of upper arch, 2nd vertebra	49
Width of spine " "	23
Thickness of spine " "	8½

Cymbospondylus petrinus Leidy.

Pl. 16, figs. 4 and 5.

The second species, consisting of the greater part of three centra with portions of two arches, is described by Leidy as follows:

"They apparently indicate a much larger species of the same genus as the former, the vertebral body having the same form. The sides of the articular funnels are convex outwardly from the centre, which deepen more rapidly at the inner third of the surface. One specimen retains the neural arch without its spine, and a short, robust, costal process, extending from near the bottom of the arch almost half the depth of the body. A second vertebra is singularly distorted, apparently as if the bone had been in a plastic condition."

From Humboldt, Nevada.

After uncovering the costal processes of the vertebræ of this species they were seen to be essentially the same as those of *C. piscosus*. The centra are, however, much shorter than in the type species, the ratio of length to height being 1:2.35. The form of the anterior and posterior surfaces of the centra is also very different. Instead of sloping sharply from margin to centre, the concave surfaces slope gently from the periphery for about two-thirds of the distance to the centre and then drop down very rapidly to the middle, making a central depression which almost meets a similar one on the opposite side.

The vertebræ present are evidently middle dorsals of a species much larger than *piscosus*.

The measurements of a somewhat distorted centrum are as follows:

Height of centrum		87 mm
Width	"	87
Length	"	37

Cymbospondylus (?) grandis Leidy.

Pl. 16, fig. 3.

Chonespondylus grandis Leidy. Proc. Phila. Acad. Sc., Vol. 20, 1868, p. 178.

A third species, based on a fragment of a caudal from Star Cañon, Humboldt Co., was made the type of a new genus, *Chonespondylus*, by Leidy. There is, however, nothing to indicate that it represents a group distinct from *Cymbospondylus*. So far as can be determined from the fragmentary type specimen, this species has combined in it the length of vertebra found in *C. piscosus* and the peculiar flaring articular funnels of *C. petrinus*. The animal from which this vertebra came was very much larger than that indicated by the types of *piscosus* and *petrinus*.

MEASUREMENTS OF TYPE SPECIMEN.

Estimated height of centrum	120 mm
Estimated width of centrum	84
Length of centrum	58

AFFINITIES OF CYMBOSPONDYLUS.

So far as can be determined with the material at hand, *Cymbospondylus* is closely related to *Shastasaurus*, having the peculiar form of rib articulation which has been described for that genus, and it is possible that it will be shown later that the two are identical. The species which we now have, differ from *Shastasaurus* in possessing much broader and heavier diapophyses, the lower ends of which are continuous with the anterior margin. In the well preserved upper arches of *C. piscosus* the spines are relatively thin, there is no trace of a lateral rib, the zygapophyses stand more nearly at a right angle to the axis of the spine than in *Shastasaurus*, and the whole arch comes nearer to an erect position than in the anterior dorsal region of that genus. With the material available, it is advisable to keep the older *Cymbospondylus* type distinct from the *Shastasaurus* group of the Upper Triassic. Later discoveries may show that they cannot be separated generically, or may bring out differences much more important than those indicated in the specimens now known.

POSTSCRIPT.

After the description of *Cymbospondylus* was partly printed, a good collection of saurian material was obtained from the middle Triassic of Nevada. The bones are all embedded in blocks of very hard limestone, from which it will require many months of careful work to free them. At the present time little more can be determined than that several specimens, which appear to belong to *C. petrinus*, show a number of peculiar characters not heretofore noticed in any of the forms which have been examined. The results of a study of this material will appear in a later paper.

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EXPLANATION OF PLATE 5.

Shastasaurus perrini n. sp.

All figures are from the type specimen.

Fig. 1.—Skeleton in relief on the original slab. About one-tenth natural size.

Fig. 2.—Right ilium, posterior side. Three-fourths natural size.

Fig. 3.—Right ilium, lateral view. Three-fourths natural size.

Fig. 4.—Right ischium. Three-fourths natural size.

Fig. 5.—Right pubis. Three-fourths natural size.

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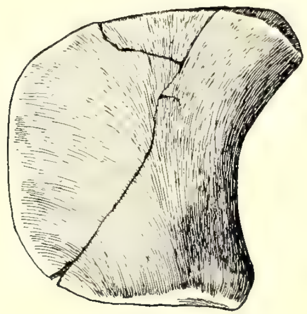

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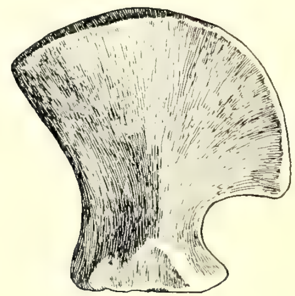

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EXPLANATION OF PLATE 6.

Shastasaurus perrini n. sp.

All figures are from the type specimen.

Fig. 1.—Posterior arch and limbs, showing position of elements in the matrix. Ir, right ilium; Il, left ilium; Isr, right ischium; Isl, left ischium; Pr, right pubis; Pl, left pubis; Fr, right femur; Fl, left femur. One-third natural size.

Fig. 2.—Right femur, side view. Three-fourths natural size.

Fig. 3.—Right femur, proximal end, showing the position of its longer transverse diameter with reference to that of the somewhat damaged distal end. Three-fourths natural size.

Fig. 4.—Left posterior limb. Fb, fibula; T, tibia. The small ossicle between the tibia and femur is probably a loose phalanx like two near the proximal end of Pl in figure one. The fragment of an ossicle shown in outline between the tibia and fibula possibly represents the intermedium. Three-fourths natural size.

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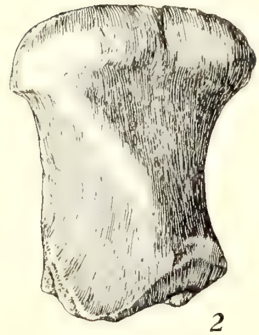

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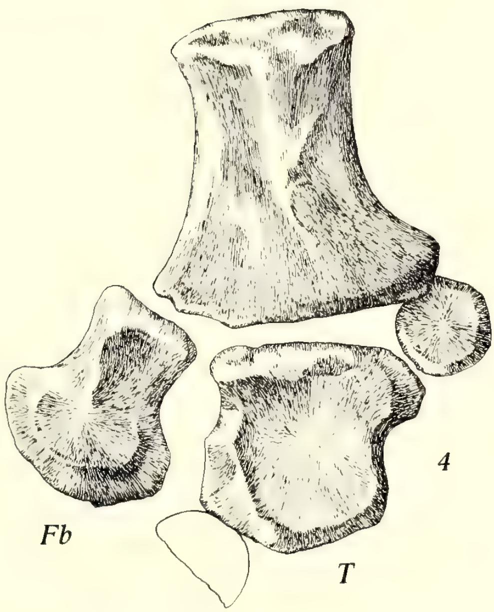

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EXPLANATION OF PLATE 7.

Shastasaurus perrin n. sp.

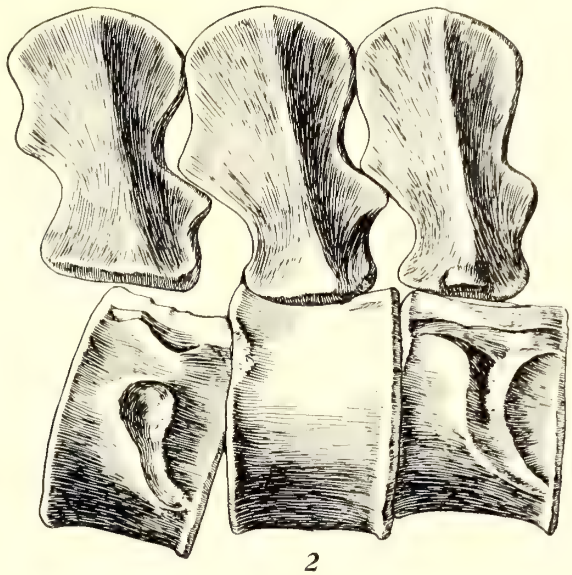
All figures are from the type specimen, and are represented three-fourths natural size.

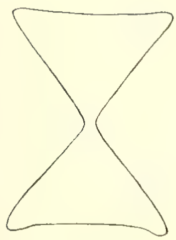
Fig. 1.—Antero-posterior section of posterior dorsal vertebra. Constructed from the 32nd and 33rd vertebræ of this series.

Fig. 2.—Dorsal vertebræ; 25th to 27th of this series.

Fig. 3.—Caudal vertebra, with lower arches in side and front view; 47th vertebra of this series.

Fig. 4.—Anterior side of a left dorsal rib. Opposite 22nd vertebra of this series.





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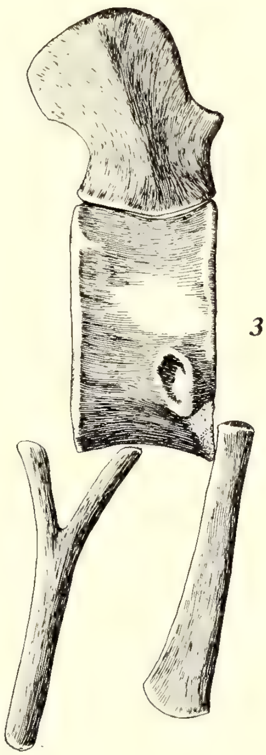

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EXPLANATION OF PLATE 8.

Shastasaurus osmonti n. sp.

All figures are from the type specimen, and are represented three-fourths natural size.

Fig. 1.—Cervical centra showing well developed di- and parapophyses and facets for reception of intercentra. First three vertebræ in this series.

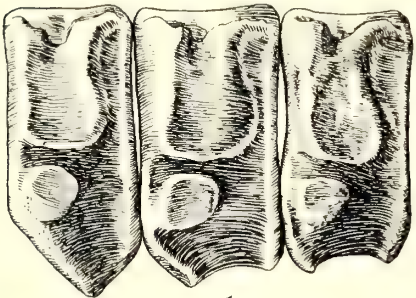
Fig. 2.—Cross-section of 3rd cervical centrum of this series. The position of the base of this centrum behind the inferior apophysis is shown by a dotted line.

Fig. 3.—Anterior dorsal centrum showing greatly reduced parapophysis; 11th vertebra of this series.

Fig. 4.—Cross-section of 11th vertebra of this series.

Fig. 5.—Posterior or middle dorsal centrum, 35th of this series.

Fig. 6.—Cross-section of 35th centrum of this series.



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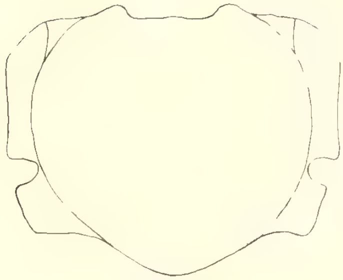

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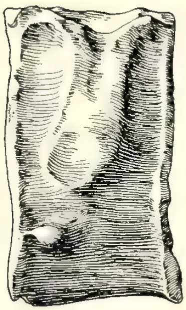

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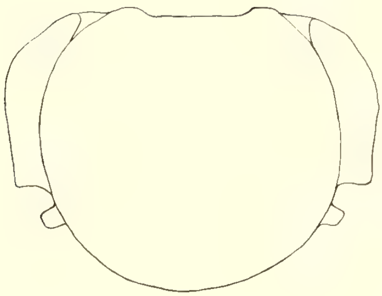

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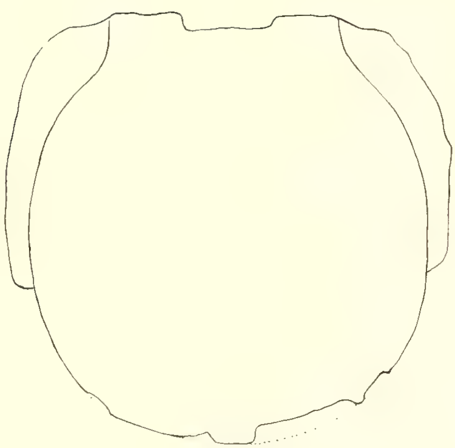

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EXPLANATION OF PLATE 9.

Shastasaurus osmonti n. sp.

All figures are from the type specimen, and are represented three-fourths natural size.

Fig. 1.—Superior side of 11th centrum of this series.

Fig. 2.—Antero-posterior section of 35th centrum of this series.

Fig. 3.—Posterior view of an anterior dorsal arch, showing separate zygapophysial facets. The summit of the spine should probably be represented as slightly excavated, but could not be sufficiently well prepared to show this character.

Fig. 4.—Side view of anterior dorsal arch shown in figure three.

Fig. 5.—Anterior view of anterior dorsal arch shown in figure three.

Fig. 6.—Posterior view of a right dorsal rib.

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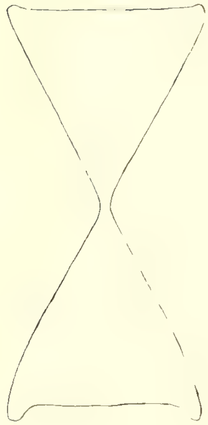

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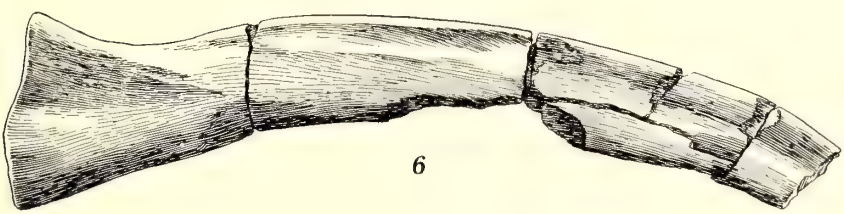

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EXPLANATION OF PLATE 10.

Shastasaurus osmonti n. sp.

All figures are from the type specimen.

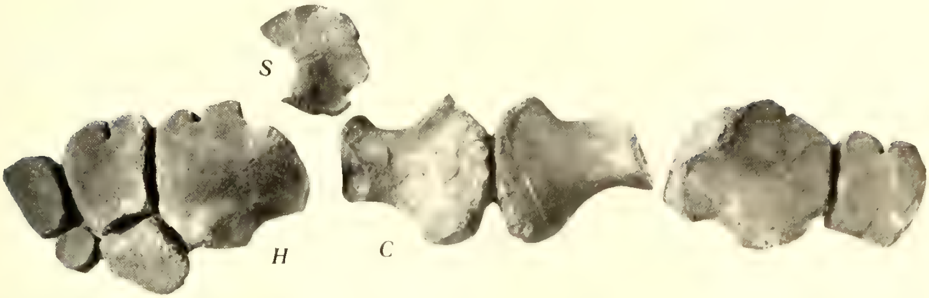
Fig. 1.—Lower side of anterior arch and limbs. S, right scapula; C, right coracoid; H, right humerus. A little less than one-eighth natural size.

Fig. 2.—Upper side of right coracoid. A little more than one-fourth natural size.

Fig. 3.—Cross-section of proximal end of right coracoid, one-third natural size.

Fig. 4.—Upper side of right scapula, about three-tenths natural size.

Fig. 5.—Proximal end of right scapula, one-half natural size.



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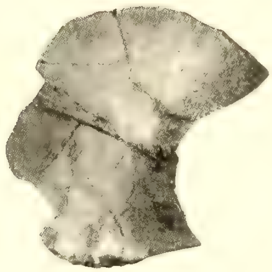

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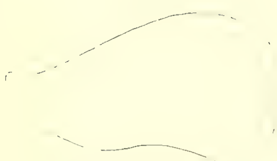

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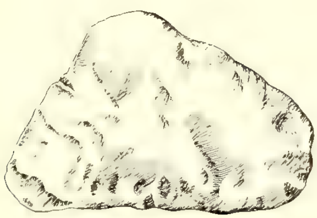

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EXPLANATION OF PLATE 11.

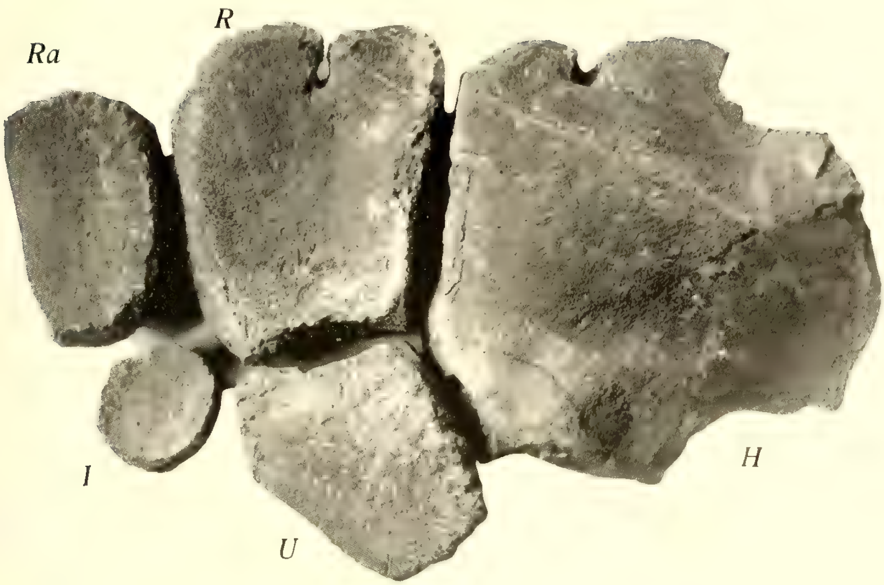
Shastasaurus osmonti n. sp.

All figures are from the type specimen.

Fig. 1.—Lower side of right limb. H, humerus; R, radius; U, Ulna; Ra, radiale; I, intermedium. A little more than one-third natural size. (.36.)

Fig. 2.—Upper side of left humerus. One-third natural size.

Fig. 3.—Proximal end of left humerus. One-half natural size.



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EXPLANATION OF PLATE 12.

Shastasaurus alexandræ n. sp.

The type specimen, represented two-ninths natural size.

Excepting the right scapula and the left humurus, the bones have not been moved from the positions which they occupied in the matrix. The right scapula was doubled underneath the coracoid and the humerus fragment partly covered the left coracoid. The right scapula and coracoid were cut by a somewhat irregular vein of calcite.

Co, left coracoid.	Sp, splenial.	Ptf, postfrontal.
Sc, left scapula.	Mx, maxillary.	Pa, parietal.
Cl, left clavicle.	L, lachrymal.	St, supratemporal.
H, left humerus.	J, jugal.	Sq, squamosal.
D, dentary.	N, nasal.	Po, postorbital.
A, angular.	F, frontal.	Scl, sclerotic plates.
Sa, supra-angular.	Pr, prefrontal.	


Scl.
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EXPLANATION OF PLATE 13.

Shastasaurus alexandræ n. sp.

Lower side of the skull of type specimen, represented one-third natural size.

V, cervical vertebra, probably the third.

R, cervical rib. The head slightly injured in preparation.

H, thyrohyal.

A, angular.

Sa, supra-angular.

Sp, splenial.

X, coronoid. (?)

Mx, maxillary.

Pl, palatine.

Pt, pterygoid.

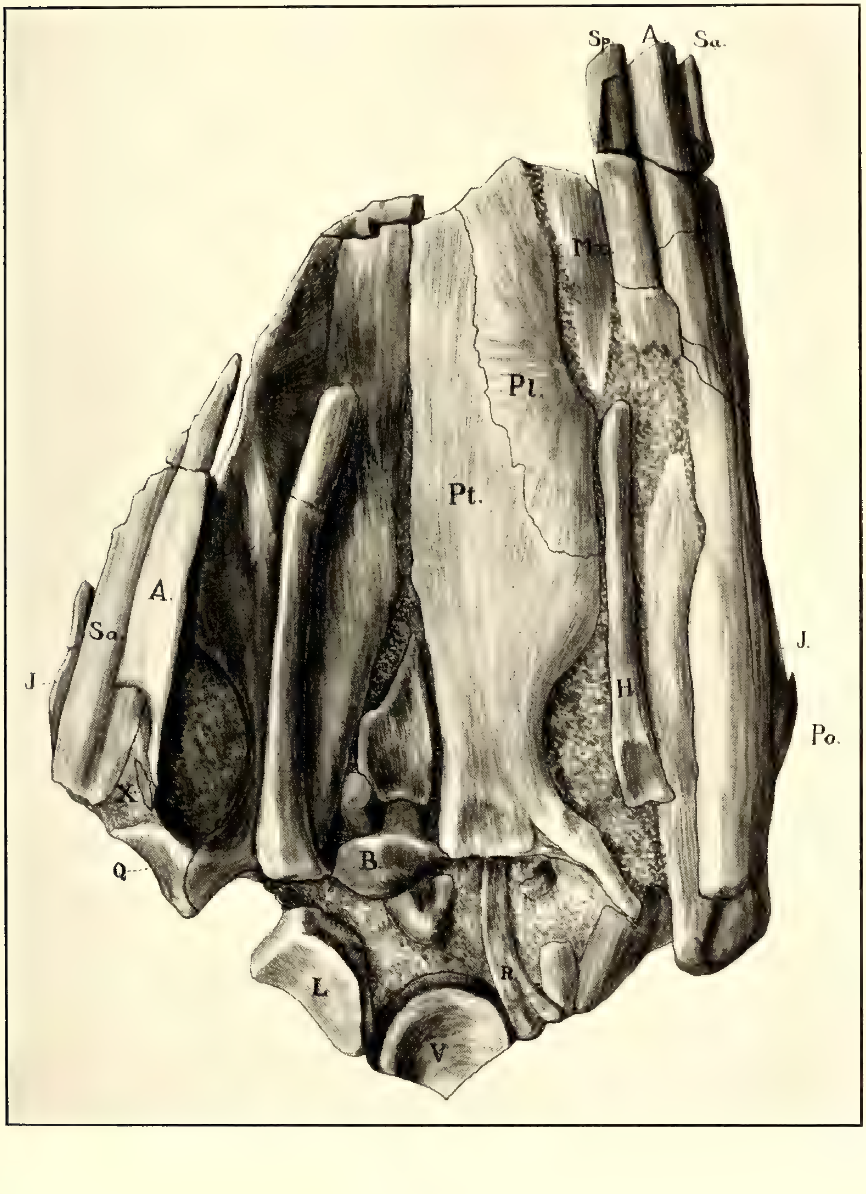
Q, quadrate.

J, jugal.

Po, postorbital.

B, basioccipital.

L, undetermined element.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EXPLANATION OF PLATE 14.

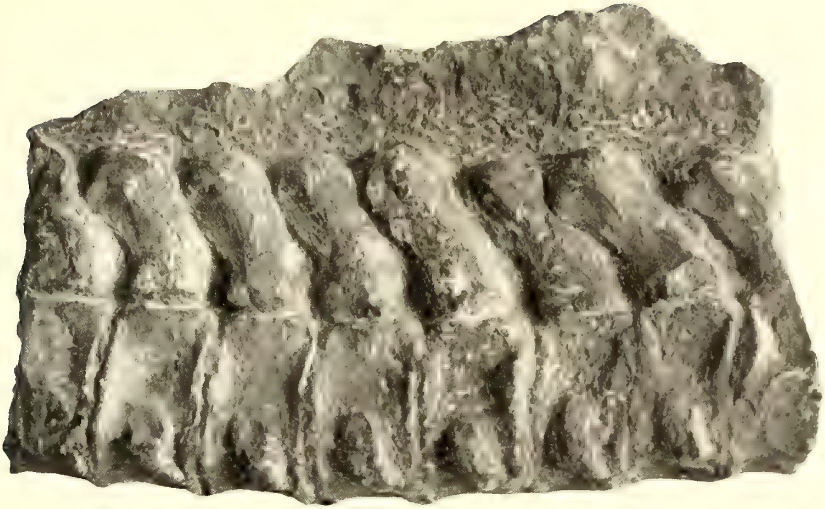
Fig. 1.—**Shastasaurus pacificus,** Merriam. Posterior dorsal vertebræ of type specimen, represented about four-tenths natural size.

Fig. 2.—Left (?) pubis from type specimen of S. pacificus. Somewhat more than one-fourth natural size (.28).

Fig. 3.—**Shastasaurus careyi** n. sp. Posterior cervical or anterior dorsal vertebræ. About one-third natural size.

Fig. 4.—Cross-section of posterior of two centra seen in figure three, showing rudiment of parapophysis. One-fourth natural size.

Fig. 5.—**Shastasaurus altispinus** n. sp. Element from anterior margin of a limb. One-half natural size.



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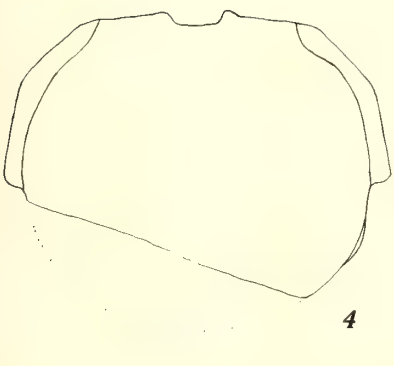

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EXPLANATION OF PLATE 15.

Shastasaurus altispinus n. sp.

All figures are from the type specimen, and are represented three-fourths natural size.

Fig. 1.—Centrum of posterior dorsal vertebra, showing the long, constricted diapophysis separated from the superior articular surface.

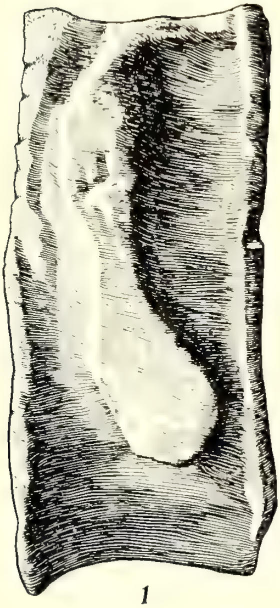
Fig. 2.—Centrum of a middle dorsal vertebra. The articular surface of the diapophysis is directly connected with that on the superior side of the centrum.

Fig. 3.—Posterior view of the spine of a dorsal arch.

Fig. 4.—Cross-section of the spine shown in figure three. The section is taken through the plane indicated by dotted lines on figure three. *r* indicates posterior side of spine.

Fig. 5.—Articular surface of head of a left dorsal rib.

Fig. 6.—Posterior side of head of a right dorsal rib.



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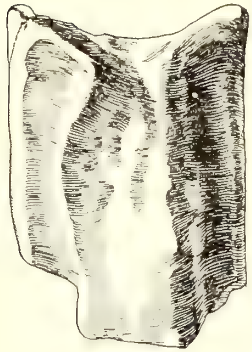

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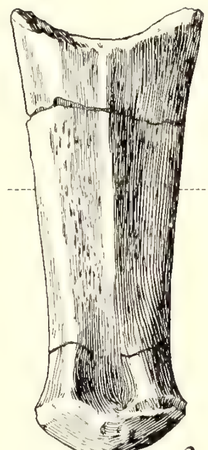

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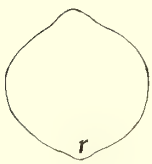

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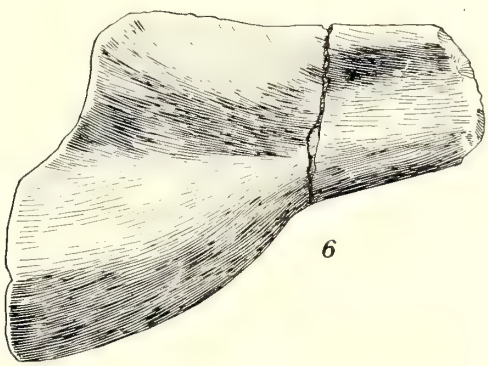

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EXPLANATION OF PLATE 16.

All figures are from the type specimens, and are represented three-fourths natural size.

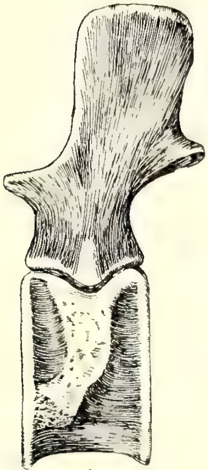
Fig. 1.—**Cymbospondylus piscosus** Leidy. Anterior dorsal vertebra.

Fig. 2.—Antero-posterior section of centrum shown in figure one.

Fig. 3.—**Cymbospondylus (?) grandis** Leidy. Anterior-posterior section of a caudal centrum.

Fig. 4.—**Cymbospondylus petrinus** Leidy. Centrum of an anterior dorsal vertebra. It is probably slightly distorted.

Fig. 5.—Antero-posterior section of centrum seen in figure four, showing flaring articular funnels such as are found in all the individuals of this series.



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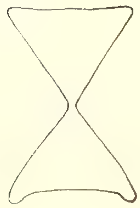

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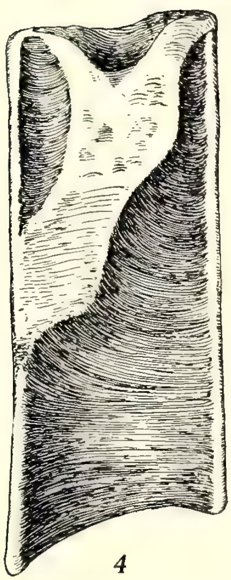

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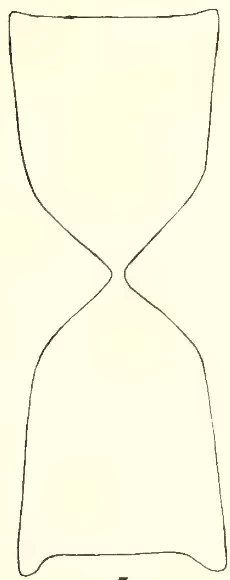

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Bulletin of the Department of Geology

Vol. 3, No. 5, pp. 109-172, Pl. 17. ANDREW C. LAWSON, Editor

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OF THE

JOHN DAY BASIN

BY

FRANK C. CALKINS

BERKELEY
THE UNIVERSITY PRESS
AUGUST, 1902

PRICE 45 CENTS

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A CONTRIBUTION TO THE PETROGRAPHY OF THE JOHN DAY BASIN.

BY

FRANK C. CALKINS.

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INTRODUCTION.

In the summer of 1899 the writer was a member of an expedition led by Dr. John C. Merriam, whose primary object was the collection of vertebrate fossils from the Tertiary deposits of Eastern Oregon. A considerable number of petrographical specimens was collected at that time. Dr. Merriam's subsequent excursions to the region in the summers of 1900 and 1901 gave opportunity to add to the collection, and it may now be considered fairly representative.

The petrography of the region is, as the writer hopes to show, of rather exceptional interest; yet it has been practically untouched by previous writers. The only references found which deal with anything but the broadly general character of the rocks occur in King's report on the Fortieth Parallel Survey. This author compares the John Day beds with his Truckee beds of Nevada, and considers the two formations equivalent. He recognizes the volcanic character of the material of the John Day beds, and having examined them petrographically, classifies them as trachytic tuffs.* The literature bearing on the general geology is summarized in Dr. John C. Merriam's "Contribution to the Geology of the John Day Basin."†

* Geol. and Geogr. Expl. Fortieth Parallel, Vol. I, Systematic Geology, 1870, pp. 423 and 454.

† Bull. Dept. of Geology, Univ. of Cal., Vol. II, No. 9, 1901, p. 275 *et seq.*

A few words may be said here concerning the plan and scope of the present paper. It is divided into three parts. The first contains a brief sketch of the geological features of the region. Although these features have been treated of at greater length by Dr. Merriam, it is believed that a summary account will be useful as a preface to the petrographical descriptions. These, which form the bulk of the paper, are contained in the second part. In conclusion, some discussion of a few questions of broader geological interest is attempted, in the light of the facts gained by petrographical study.

The writer's acknowledgements are due to Dr. Merriam for the collection of a large part of the rock specimens, and for much information in regard to their field occurrence. To Professor Andrew C. Lawson he is obliged for much aid and helpful suggestion in the laboratory investigation.

THE GEOLOGICAL SECTION.

GEOLOGICAL FEATURES OF THE REGION.

Geographical Limits.—The region with which this paper deals is situated in north central Oregon, well to the east of the Cascade Range. It includes all of the area draining into the John Day River above Clarno's Ferry, with the exception of that portion drained by the South Fork. The area thus defined is approximately a right-angled triangle. The westernmost and sharpest angle lies near Antelope, the right angle is about twenty miles to the northeast of Ritter, and the southernmost point a few miles east of Cañon City.

The elevations inclosing this drainage basin have apparently a certain geological unity, and collectively are designated as the Blue Mountain Range. They appear to have a foundation of pre-Tertiary rocks, which in the western ridges are largely mantled over by Eocene and Miocene volcanics. To quote Dr. Merriam's general statement, "The rugged eastern ridges, rising to an elevation of over 6000 feet, are composed largely of pre-Tertiary formations which have been much disturbed. To the west the ranges are made up principally of Tertiary lavas forming regular and frequently flat-topped ridges somewhat lower than those to the east."* To the north and south of Antelope these ridges die out and merge into the great basalt plateau extending to the Des Chutes River.

The John Day Basin itself contains an enormous accumulation of Tertiary sediments, which in post-Tertiary time have been deeply dissected by the John Day River and its tributaries. The area is therefore characterized by hills and plateaus separated by deep cañons or narrow valleys.

The region probably has been defined more or less clearly as a basin of accumulations since the beginning of the Cretaceous period. It has, however, suffered frequent crustal disturbance, as shown by the increasingly disturbed altitudes of the formations observed as we descend the geological scale. In late Tertiary time, the northeastern and southeastern limits of the basin were obliterated, perhaps by volcanic accumulations, to be revealed subsequently by the forces of erosion and by renewed activity on the main lines of crustal movement.

The main characteristics of the geological formations, in order of age, will now be briefly sketched.

Pre-Tertiary Geology.—In its broadly general features, the pre-Tertiary geology of the Blue Mountains has a noteworthy similarity to that of the Sierra Nevada in Northern California. Corresponding to the "sub-jacent series" of the Sierras, they are clay slates and metamorphic sandstones intruded by plutonic rocks of granitoid and of ultrabasic character. Overlying this ancient series are Cretaceous shells, sandstones and conglomerates, corresponding in lithological character to the Knoxville and Chico formations of this State. In the upper Cretaceous are found an abundant fossil fauna which clearly define its age as lower Chico.*

The more ancient rocks were observed in the Blue Mountains south and east of the Basin, and the Cretaceous in the foot-hills of the southern ridge, where the Chico has transgressed across the supposed Knoxville.

The Clarno Eocene.—The Eocene is generally exposed, and probably reached its greatest development in the western end

* *Loc. cit.*, p. 271.

T. W. Stanton, quoted by Merriam, *op. cit.* p. 284.

of the region. The thickness of the formation is several hundred feet. The name "Clarno Formation" was given by Dr. Merriam, from the typical exposures at Clarno's Ferry.

Lithologically, the Clarno is a volcanic formation, in which truly detrital matter plays an unimportant part. The lower portion of the Clarno is composed in greater part of pyroclastic material, while in the upper half lavas, including several different varieties, are abundant.

The vents through which the lava burst up through the lower tuff beds are exposed to observation in great numbers in the region between Currant Creek and Burnt Ranch. The chimneys of the ancient volcanoes have been filled with lava that has assumed on cooling a beautiful columnar structure, and these volcanic necks, denuded of the less resistant tuffs, form bold, steep-sided "buttes" that are imposing features of the scenery, as well as of great geological interest.

The John Day Miocene.—The early Miocene, which overlies the Eocene without marked unconformity, is known as the John Day series and has been noted long as a source of vertebrate fossils. Over a broad area in the east-central part of the basin, it is exposed in magnificent cliff sections, attaining a thickness of about 2000 feet.

The strata of this formation are formed of regularly bedded rocks, red, blue, yellow, and buff in color, generally weathering into typical "bad-land" forms. They are divided by Dr. Merriam on lithological and stratigraphical grounds into three horizons, designated as Upper, Middle and Lower John Day.

We shall show that the principal material in all three divisions is fine-grained tuff. A few thin flows of lava, insignificant in volume, are intercalated with the tuffs in various sections, and water-worn gravels and sands occur near the upper limit of the series.

*The Miocene Basalt.**—After the John Day tuffs had accumulated to a thickness of 2000 feet or more they were subjected to erosion. The inequalities of surface observed by the writer in Turtle Cove at the contact with the next overlying formation

* Columbia lava as defined by Merriam.

reached several hundred feet.* The eroded surface was then flooded with enormous quantities of basaltic lava. Flow after flow followed until their total thickness became, in the limits of the John Day Basin, as much as 1500 feet.

These basalt floods, which seem to have inundated the most or the whole of the Blue Mountain Range,† constitute what is perhaps the greatest lava field extant and what is certainly the most important formation of the plains of eastern Oregon and Washington and western Idaho.

One or more thin flows of basaltic rock are intercalated with the lowest beds of the formation above the main lava series.

The Mascall Formation.—This formation, which overlies the great basalt series without notable unconformity, is preserved within the John Day Basin only in a monoclinal trough extending along the southern end of the basin from Spanish Gulch to Cañon City.

In their general field characters, the Mascall beds show some resemblance to the John Day, though they differ in the more frequent occurrence of fine bedding, and occasionally are cross-bedded. They seem to be mainly composed of tuffs and ashes, but comprise some material of organic origin and probably some sandstone and conglomerate. They are also in general characterized by light colors, gray or cream, in contrast to the variegated tints of the John Day. Dr. Merriam estimates the thickness of the formation at from 800 to 1000 feet, and the age as probably upper Miocene.

The Rattlesnake Formation.—This lies in almost horizontal attitude upon the tilted and truncated Mascall beds in the elongated area mentioned above. Dr. Merriam named this formation and considered it of Pliocene age. It appears to be of fluviatile origin in large part, and comprises a large amount of coarse gravel and sandstone, together with fine material that may be tuffaceous. Somewhere near the middle of the section there occurs a widely spread sheet of light colored pumiceous tuff, overlaid by a glassy gray rhyolite.

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* Angular as well as erosional unconformity is noted by Dr. Merriam, *op. cit.*, p. 299.

† Merriam, *op. cit.*, p. 303.

Quaternary and Recent Deposits.—True stream terraces of rounded gravel are generally well defined along the John Day River and its main branches, and there are also many old alluvial slopes, covered with angular rubble, declining gently from the steep sides of the valley toward the centre, but toward a level much higher than that occupied by the present streams.

Beds of pure white ash are found at many localities interbedded with alluvium of probably post-Quaternary age.

PETROGRAPHICAL DESCRIPTIONS.

PRE-EOCENE ROCKS.

General Classification.—The only granitoid rock in our collection is that from the middle fork of the John Day Basin near Ritter. It is provisionally classified here as granodiorite.* Another acid intrusive, probably of pre-Cretaceous age, was found near Spanish Gulch. Serpentines occur on Beach and Desolation creeks, and also at Spanish Gulch, though no specimens were taken at the last-named locality. At Spanish Gulch and Beach Creek there are coarse-grained pyroxenites which are assigned to the species websterite.

Granodiorite of the Middle Fork.—This is a medium-grained hypidiomorphic granular rock, whose color in mass is a rather light gray. The minerals seen in the hand-specimen by the unaided eye are plagioclase, biotite, hornblende, orthoclase, quartz, and titanite, with an occasional grain of pyrite. Hornblende and biotite, both exhibiting good crystal form, occur in about equal abundance. Small brown crystals of titanite are so numerous as to form a notable feature of the rock. Quartz is an essential constituent, but decidedly subordinate in amount to the feldspars. These may be seen to comprise two varieties; the one, always pure white in color, is striated; the other, which is of a delicate flesh-tint, is without striation. The two differ sharply in their manner of crystallization. The plagioclase is generally in rather small crystals of more or less idiomorphic

* The same rock was referred to in Merriam's paper (*op. cit.* p. 279) as quartz diorite, that name being given by the present writer after a preliminary examination.

form. The orthoclase on the contrary forms a cement inclosing, with the possible exception of quartz, all the other minerals of the rock. The basal reflections, mottled by the inclusions, are continuous over areas about 2 cm. in diameter. These areas are apparently not bounded by crystallographic planes, and the inclusions occur in greater quantity than the inclosing feldspar. In these respects the habit of the orthoclase is different from that of the phenocrysts in typical porphyritic granites.

The microscope reveals the presence of accessory magnetite, apatite, and zircon, which present no unusual characters. A few grains of epidote are seen, which appear to be original.

The hornblende, which is unaltered, is of the deep green pleochroic variety that is usually found in quartziferous rocks. The biotite is generally of a deep greenish brown, though in some cases it has become grass-green on the edges, without notable change in strength of double refraction. Cleavage flakes examined in convergent light show a distinct separation of the optic axes.

The plagioclase feldspar, as optically determined, is mainly andesine-oligoclase, but zonal banding is always present, and the outer shells often belong to acid oligoclase. The alkali-feldspar, which is in somewhat smaller amount than the plagioclase, always occurs interstitially.

The quartz is about equal to the orthoclase in amount. While mainly in the form of allotriomorphic grains, it also occurs in micrographic intergrowth with the plagioclase feldspar.

The period of crystallization for the quartz would thus appear to overlap the final stage in the growth of the plagioclase, and to be anterior to the solidification of the orthoclase, although only one instance of the inclusion of quartz in orthoclase was observed. The order of crystallization is in other respects normal.

The alteration suffered by the minerals has been but slight; it consists of an incipient kaolinization of the feldspars, and the change noted above in the color of the biotite. The rock, however, breaks up readily under the hammer, and the tendency for the grains to break apart causes difficulty in the preparation of slides.

The classification of the rock, without chemical analysis, is perhaps not altogether certain. The term granodiorite is provisionally applied, although the proportion of quartz appears to be somewhat smaller than in the typical granodiorites of the Sierra Nevada. The predominance of plagioclase over orthoclase would seem to preclude the use of the term quartz-monzonite, while the dark constituents are hardly abundant enough to give the rock a dioritic aspect.

A small fragment obtained from a mine at Spanish Gulch appeared to be similar in character to the rock just described, but was too much decomposed to be fit for microscopical study.

Granite-porphyry of Spanish Gulch.—Although this rock possibly has some genetic relationship with that just mentioned, it is of decidely more acid character. The groundmass, which may be seen with the pocket-lens to be a holocrostalline aggregate of quartz and feldspar, carries numerous phenocrysts of quartz, monoclinic, and triclinic feldspar, and a few tablets of biotite. The yellowish brown color of the rock seems due mainly to the dissemination of fine particles of limonite.

By the aid of the microscope the phenocrysts are seen to comprise orthoclase, quartz, and plagioclase in about equal quantity. The groundmass contains the same minerals, with quartz in somewhat larger proportion than among the phenocrysts. The biotite is of the common deep greenish brown variety. Apatite, magnetite and a little zircon occur as accessories. The secondary minerals consist of a little sericite and kaolin in the feldspars, numerous specks of limonite throughout the rock, and specks and veins of a greenish brown micaceous mineral that will be described further in the sequel.

The plagioclase phenocrysts exhibit, in addition to the albite striation, frequent pericline and Carlsbad twinning, while one Baveno twin was observed. A distinct zonal banding is always visible between crossed nicols, and, although there is in general an increase of acidity from centre to periphery there usually have been oscillations during the growth of the crystal, expressed by the fact that the successive shells are alternately more acid and more basic. The maximum extinction angle observed in the zone perpendicular to the brachypinacoid was 12°, in the centre of a crystal whose outermost and most acid zone extinguished at 2°.

These angles correspond respectively to a basic oligoclase near $Ab_2 An_1$ and an acid oligoclase near $Ab_5 An_1$.

The orthoclase, generally twinned on the Carlsbad law, exhibits a faint zonal banding. The extinction angles measured from the basal plane are not high, indicating that the percentage of soda is rather low.

Both kinds of feldspar contain liquid inclusions, and a few of apatite, zircon, and magnetite. Of more interest, however, is the frequent inclosure in the peripheral portions of the phenocrysts of small quartz and feldspar grains similar to those composing the groundmass. This of course demonstrates that the growth of the feldspar phenocrysts continued after the groundmass was at least in part crystallized. The quartz, which occurs with the usual corroded outlines, exhibits no characters of especial interest.

The micaceous secondary mineral above referred to, although somewhat paler, is similar in color to ordinary biotite. It further resembles biotite in having strong pleochroism and strong double refraction. In sections normal to the cleavage, the trace of the cleavage plane is found to be the direction of greatest absorption and the direction of least elasticity. The interference colors are the brilliant mottled greens and reds that are shown by the micas. The secondary character of the mineral, however, is quite evident from its occurrence in small, irregular aggregates and in veinlets that often follow cleavage cracks in the feldspar. Its properties are very similar to those of the mineral which Professor Lawson* has named iddingsite, and it is probably closely related to, if not identical with, that species. In describing other rocks, we shall have frequent occasion to note the presence of similar material.

Pyroxenites of Spanish Gulch and Beach Creek.—The specimens from these two localities are so similar that they may be described best under a single heading. Both rocks are very coarse allotriomorphic granular aggregates of greenish gray pyroxene, which is the only mineral that can be identified macroscopically. The grains often attain a length of one or two inches. The pyroxene always shows one very nearly perfect pinacoidal

* Bull. Dept. Geol. Univ. Cal., Vol. I, 1893, p. 30, *et seq.*

cleavage, at right angles to which is a rather indistinct parting. In one specimen the lustrous cleavage lamellæ show considerable distortion, which is doubtless the result of mountain-making stresses.

Although macroscopically the crystals appear to be homogeneous, they are at once seen, when examined in thin section, to be lamellar intergrowths of orthorhombic and monoclinic pyroxene. The former variety seems in the majority of grains to predominate, but the proportions are in certain cases reversed. A section parallel to the good cleavage of one crystal showed, on examination in convergent polarized light, a single bar traversing a system of colored rings. A second section, perpendicular to the first and parallel to the imperfect parting, showed high interference colors, and an extinction angle, measured from the cleavage, of 39°. Parallel to these cleavage traces narrow stripes were visible in polarized light, being distinguished by their low interference colors and straight extinction. These were sections of lamellae of a rhombic pyroxene, found by examination in convergent light to be cut perpendicular to the bisectrix **a**. More frequently, however, the sections cut parallel to the imperfect parting are found to consist mainly of rhombic pyroxene, in which case the bisectrix **a** is normal to the section. Stripes of the monoclinic mineral are always seen in greater or less amount, and show an extinction angle near 40°. From the facts just stated it is evident that the two minerals form regular intergrowths after the usual plan, having the vertical axis in common, and the orthopinacoidal faces of the monoclinic in composition with the brachypinacoidal faces of the orthorhombic lamellae.

The orthorhombic pyroxene has, in thin section, a very pale greenish brown tint, and a feeble though evident pleochroism. It therefore is probably an enstatite or a bronzite poor in iron. The monoclinic mineral, which appears almost colorless and without pleochroism, has the extinction angle of diallage, and its characteristic lamellar parting; it is therefore referred to that species.

The inclusions, which are not especially abundant, are similar for the two minerals. They consist mainly of opaque rods and grains, arranged in lines parallel to the vertical axis of the host.

Some are very minute, but others of more considerable size are recognizable as magnetite, and these often have the form of prisms with pyramidal terminations. There were observed also a few grains of chromite.

The enstatite of the Beach Creek specimen has undergone some alteration, resulting in the formation of pale green actinolite and a serpentinous substance. The latter occurs in irregular veinlets, usually filling cracks transverse to the prismatic axis of the pyroxene. The actinolite, which has an extinction angle of about 17°, was observed in but one section. It apparently arose from a paramorphic alteration, for the actinolite had its vertical axis in common with the enstatite which it partly surrounded.

Serpentine of Beach Creek.—The mass of this rock consists of dark green serpentine, whose structure is not macroscopically discernable. Distributed rather sparingly in this substance are some lustrous crystals with lamellar cleavage that resemble enstatite. The specimen is also traversed by a few small veins of fibrous chrysotile.

Examined in thin section, it is seen to be derived from a peridotite, whose essential minerals were olivine and a rhombic pyroxene, but both minerals are now completely replaced by their usual alteration products. The greater portion of the section is made up of serpentine that shows in a typical manner the familiar mesh-structure indicating a derivation from olivine. The pyroxene is represented by pseudomorphs of bastite, identified by its low refractive index and weak double refraction as well as by its fibrous structure. Its outlines are always irregular, and it is often seen to inclose well-defined areas of the serpentine with mesh-structure. These facts mean that the olivine crystallized as usual before the pyroxene. The process of serpentinization has been accompanied by the usual separation of magnetite. Another secondary product is zoisite, small grains of which occur in clusters, most commonly included in the bastite.

As an accessory, there occurs a little chromite, while some of the magnetite may be primary.

Serpentine of Desolation Creek.—The rock from this locality differs markedly from that just described, and possesses some unusual characteristics. Macroscopically examined, it is seen to consist mainly of a greenish gray substance of oily lustre, and apparently crystalline. There are a few veins of a substance of similar texture and lustre, but with a yellowish green color similar to that of epidote. The surface of the specimen is dotted with red grains of about 1 mm. in average diameter, sometimes with a hollow centre, their characteı being revealed under the microscope.

On microscopical examination, serpentine of the scaly variety, antigorite, is found to make up the bulk of the rock. The structure, which is best seen in polarized light, gives hardly a clue to the origin of this mineral. It occurs in elongated scales that generally overlap and cross one another in all directions so as to form a kind of feltwork. In certain small areas, however, the scales are rudely parallel, and the thought is suggested that these areas may represent altered pyroxene, while the rest of the serpentine is derived from olivine.

The material of the veins is similar to that forming the bulk of the rock, and has the same felted structure. The serpentine here is more nearly pure, however, and occurs in larger individuals, so that it forms more satisfactory material for study of the optical properties. The mineral is transparent, has a low index of refraction and varies in color from pale olive-green to colorless. In the colored sections there is a distinct pleochroism. Rays vibrating parallel to the elongation are the more absorbed, and are colored a more or less intense olive-green, while the rays vibrating in the perpendicular direction are pale yellowish green. Between crossed nicols the interference colors are low, and do not rise above yellow of the first order. The elongation is positive.

As in other serpentines, magnetite is formed as a secondary product, and the centre of the veins is always marked by a line of magnetite dust. A few grains of chromite were also seen.

The red grains observed in the hand specimen form perhaps the most unusual feature of the rock. They are composed of quartz, as determined by a low refractive index, weak double refraction and uniaxial and positive character. Each of the rounded areas in which it occurs contains a number of interlocking allotriomorphic grains. The red color is due to finely divided ferric oxide, which occurs along the boundaries of the cluster and between the individual grains. This quartz is evidently a secondary filling of cavities, but whether these cavities are original or are formed by differential solution is doubtful.

ROCKS OF THE CLARNO EOCENE.

General Classification.—The Clarno is essentially a volcanic formation. The clastic rocks are tuffs and agglomerates of widely varying texture, and massive lavas also constitute an important part of the series. While the writer is unable to give in detail the succession of the various rock types represented, a general idea may be gained by considering the sections at the localities where these rocks are exposed.

In Hald's Cañon, near the town of Mitchell, the section consists of a considerable thickness of hornblende and pyroxene andesite which seem immediately to overlie the supposed Cretaceous. At Clarno's Ferry the lowest exposed beds are andesite tuffs, containing fragments of both hornblende and pyroxene andesite. Above these tuffs are andesite lava, and the Eocene section is topped by rhyolitic lavas and tuffs, overlaid by the red beds of the John Day Miocene. In the Cherry Creek area, the andesitic tuffs, with leaves similar to those found near the base of the Clarno's Ferry section, are overlaid by pyroxene andesite, quartz basalt, and rhyolite. At Bridge Creek, the leaf beds just beneath the John Day series are underlaid by rhyolite, while quartz-basalt and pyroxene andesite occur lower down the cañon, and, it appears, stratigraphically beneath the rhyolite.

Comparing the various sections, we find the succession to be, speaking generally: (1) Andesite, (2) Quartz-basalt, (3) Rhyolite. To work out the succession in detail would involve more careful field study than Dr. Merriam or the writer has been able to give to the subject. The pyroxene andesites are probably later than the hornblende andesites.

Pyroxene Andesites.—The most representative specimens of this type of lava were collected in Hald's Cañon. The material from various flows, viewed macroscopically, exhibits much variation in structure and color, but a microscopical study proves that these variations are due to differences in conditions of consolidation and degree of weathering, while the rocks are mineralogically, and no doubt chemically, of the same type. These macroscopical variations may be illustrated by describing three typical hand-specimens.

A specimen collected near the foot of the cañon has a compact gray or drab ground-mass, in which are abundant small dull white crystals of striated feldspar, small prisms of black pyroxene, and grains of a soft olive-green mineral. A second specimen, from farther up the cañon, has a ground-mass of olive-green color, with phenocrysts of notably large size. The most prominent are of feldspar, always distinctly striated, and strongly flattened on the brachypinacoid. These often attain dimensions of about 2 mm. x 8 mm. x 10 mm. Of smaller size and prominence are the stout prisms of greenish black pyroxene. The soft olive-green or brownish green substance observed in the first rock occurs here in prisms of very well developed crystal form. Its nature will be discussed in connection with the microscopical characters. A third specimen, from near the head of the cañon, is a dark gray rock having somewhat the appearance of a basalt. The abundant small phenocrysts of striated feldspar are generally glassy, and do not stand out prominently from the ground-mass, but they are sometimes stained a bright red by iron oxide. On close examination, small prisms of pyroxene may be detected, often associated with a soft greenish substance.

The last-described specimen, being the freshest of the three, may serve as a type for microscopical study. Its microscopical characters will therefore be described at some length, and special features observed in other specimens will afterward be noted.

In thin section, it is seen that the phenocrysts are plagioclase and rhombic and monoclinic pyroxene, the two latter minerals being sometimes intergrown. Magnetite also occurs in two generations. All these minerals occur in a holocrystalline groundmass, cemented with a paste of alkali feldspar. Apatite is an accessory. Decomposition has affected the hypersthene, and to a smaller extent, the phenocrystic feldspar.*

* See plate 17, fig. 2.

The feldspar phenocrysts invariably exhibit polysynthetic twinning. Carlsbad twins also occur in a majority of cases, so that Michel Lévy's method of determination may conveniently be applied. In the main central portion of a doubly twinned crystal, the concurrent angles were 19° and 34.5°, corresponding with a composition of about $Ab_3 An_4$. Distinct zonal banding is always present, and the successive shells, while showing a general decrease in basicity, give evidence of the oscillation that seems to be usual in the growth of phenocrysts. The most acid shells have the composition of andesines. The inclusions comprise crystals of augite, magnetite, and apatite, but the most abundant are of glass, usually in the form of negative crystals, each containing one or more bubbles. The feldspar substance is generally fresh, but a certain zone, or the centre of a crystal, is sometimes replaced by a green fibrous or scaly mineral, and red oxide of iron is often deposited along cracks or cleavages.

The augite is of a green variety, very feebly pleochroic, and has an extinction angle of about 45°. The stout prisms, of octagonal cross-section, are in general of sharply idiomorphic outline. Twinning on the orthopinacoid is of frequent occurrence. In contrast with the hypersthene, the augite is entirely unaltered.

Hypersthene is somewhat more abundant than augite. It occurs in well formed octagonal prisms, with greater relative elongation in the direction of the vertical axis than is shown by the monoclinic pyroxene. It is also distinguished by weak double refraction, straight extinction and a marked pleochroism. The axes colors are: $\mathfrak{a}$, pale reddish brown; $\mathfrak{b}$, yellow; $\mathfrak{c}$, pale green, very similar to the color of the augite.

The alteration of the hypersthene is deserving of especial notice. The process of decomposition begins at the surface and, in the transverse cracks, extends most rapidly in the direction of the vertical axis. Almost every crystal has been attacked, and the replacement of the original substance in many cases has been complete. The final product is a pseudomorph composed of fibres that lie nearly parallel to the vertical axis of the hypersthene, so as to extinguish almost uniformly in polarized light. The structure is thus quite analogous to that of bastite, but the fibres differ considerably from bastite in their optical properties. By ordinary transmitted light, the mineral is olive-green. The pleochroism is fairly strong, with the greatest absorption parallel to the length. Between crossed nicols the extinction is seen to be straight, and the elongation positive. The double refraction, which, because of the fibrous structure, could not be measured exactly, is in excess of .020, and gives rise to bright colors of the second order.

Comparing these properties with those of iddingsite, we find in most respects a fairly close resemblance, although the lamellar structure described by Lawson does not appear to be present. It seems highly probable that the mineral is practically identical with iddingsite.

It is worth noting in this connection that iddingsite has always been supposed to originate from the decomposition of olivine. Fibrous pseudomorphs in volcanic rocks, derived from rhombic pyroxene, have been observed by Gregory* and by Bonney†. The double refraction of the mineral described by Bonney is weak, while Gregory does not allude to this point. The writer has found no description that agrees completely with the one given here.

The structure of the groundmass is a feature of great interest. In ordinary light it appears to be of the common andesitic type, being made up of feldspar laths with grains of pyroxene and magnetite in a colorless, transparent base. Between crossed nicols, however, this base is seen at once to be a crystalline substance, in the form of irregular, interlocking grains, each of which incloses poikilitically a dozen or more crystals of the other constituents. Its properties, so far as determined, are as follows: The refractive index, as determined by the Becke method, is higher than that of the balsam, and lower than that of the plagioclase. The double refraction is slightly lower than for the plagioclase. Owing to the small area of the clear spaces, it was impossible to obtain a satisfactory interference figure, and no cleavage was detected. Twinning does not occur. Treatment with hydrochloric acid does not seem to produce any effect. The

*U. S. Geol. Survey, Bull. 165, 1900, p. 170.

†Geol. Mag., 1885, Vol. 22, p. 76.

combination of all these characters appears to identify the mineral beyond reasonable doubt as alkali feldspar. The lath-shaped feldspars, on the contrary, are without exception triclinic. Their composition was determined by Becker's method as about $Ab_1 An_1$. The structure, although on a much smaller scale, is exactly analagous to that exemplified in the dioritic rock of the Middle Fork (see p. 115), and strikingly illustrates the tendency of the alkalies, especially potash, to remain in the mother-liquor until the other bases have crystallized.

Alkali-feldspar in the rôle of a cement has been noted by Washington in the groundmass of certain Italian lavas of the vulsinite family.* In some of those rocks, the alkali feldspar borders, and is oriented upon, the phenocrysts, but in the present case it appears to have crystallized quite independently of the adjacent plagioclase.

A few points of difference in the other pyroxene-andesites of this locality may now be noted. Original hypersthene was not observed in the other specimens, but was always replaced by iddingsite. This material is found to vary in structure and color. The fibres, while they sometimes have the parallel arrangement above described, are often in spherulitic or irregular aggregates. The color may become very pale, or it may change to a reddish brown. The micropoikilitic structure occurs locally in the other specimens, but all the slides show a large amount of glass-base. The feldspar phenocrysts in the most weathered rock have undergone a partial alteration to zeolite, which will be described later in a more typical example.

The apatite in this last-mentioned specimen has a notable peculiarity. The larger crystals, occurring in the groundmass and included in the augite, are charged with a brownish pigment, which in longitudinal sections is seen to be arranged in fine lines parallel to the vertical axis. Rotated over the polarizing nicol, these crystals are found to have a marked pleochroism, with the greater absorption for rays vibrating parallel to the principal axis ($e > o$). The identity of the mineral is proved by its high refractive index, straight extinction, weak negative double

*Journ. Geol. 1896, vol. 4, p. 833.

refraction, the characteristic crystal forms, and by a chemical test with nitric acid and ammonium molybdate.

Pyroxene andesites of the Hald's Cañon type also occur at Fox, on Beach Creek, and in the Cherry Creek region. The Cherry Creek rock also exhibits the micropoikilitic groundmass in almost complete development. In the Beach Creek specimen, the base is glass, which is locally altered to a semi-opaque brownish white mass of uncertain composition. The hypersthene in both cases is only slightly decomposed.

A chemical analysis by the writer of the freshest material from Hald's Cañon is given here:

Analysis of Hypersthene Andesite, Hald's Cañon.

SiO_2	57.49%
Al_2O_3	17.22
Fe_2O_3	4.34
FeO	3.01
MgO	3.38
CaO	6.48
Na_2O	3.90
K_2O	1.30
H_2O at 110°	0.62
H_2O above 110°	1.37
TiO_2	1.12
P_2O_5	0.28
MnO	0.22
BaO	trace
Total	100.73

The rather high percentage of combined water is probably derived mainly from the iddingsite, which probably contains some of the ferric iron, though a larger proportion of the latter is probably in the form of limonite and hematite. The analysis shows no other remarkable features, except perhaps the rather large amount of titanium, which is presumably in the iron ore. The potash, somewhat contrary to the writer's expectations, is present in about the usual amount for this type of rock; it even falls somewhat below the average. Yet when we calculate the corresponding amount of orthoclase, we obtain a percentage of about 7.7, supposing the orthoclase to be free from the albite molecules. This is, however, rarely true, and supposing the alkali feldspar to have the formula Ab_1Or_4, the percentage would increase to 9.6. This appears sufficiently high to agree with the estimate arrived at by a careful microscopical survey. The peculiar structure of the groundmass is thus seen to be merely the necessary result of its slow cooling, without disturbing movement, allowing complete crystallization of the elements in their natural order.

Hornblende Andesite of Hald's Cañon.—This rock shows the usual porphyritic structure. In the hand-specimen may be seen, imbedded in a pink, rough-textured groundmass, abundant phenocrysts of dull white feldspar and black hornblende prisms.

On examination of thin sections, the phenocrysts are found to lie in an altered andesitic groundmass, which contains amygdaloidal cavities filled with a variety of secondary minerals. Apatite and magnetite are rather abundant accessories.

The phenocrystic feldspar always shows albite striation, often combined with pericline and generally with Carlsbad twinning. They are optically determined to be mainly near acid labradorite ($Ab_1 An_1$), though certain shells of the zonally banded crystals are more acid. Glass inclusions are characteristically abundant. Their alteration consists in the formation of minute veins apparently of quartz and zeolites.

The hornblende, which is always sharply idiomorphic, is of a brown variety, rich in iron. The pleochroism is extremely intense. The axes colors are: **a**, clear greenish yellow; **b**, greenish brown; **c**, deep reddish brown. The interference colors are brilliant, and indicate a double refraction in excess of .050. The maximum extinction angle is about 5°. The heavy borders of magnetite are mingled with opaque hematite dust.

The groundmass contains many slender rods of rusty iron ore, which apparently represent a second generation of hornblende entirely resorbed. The feldspars of the second generation are all of plagioclase, determined as basic andesine, and therefore somewhat more acid than the phenocrysts. Filling the interstices between these laths and microlites is a crystalline paste composed in considerable part of zeolites. It is evidently of a secondary character, and perhaps represents an originally glassy base. The groundmass is interspersed with fine particles of hematite which are the cause of the pink color seen macroscopically.

The minerals filling original cavities are granular quartz, spherulitic chalcedony, and a zeolite occurring in a few divergent aggregates imbedded in chalcedony. This zeolite, which was recognized as such by its very low refractive index, has an extinction angle of about 22°, measured between the axis of elongation and the axis of greatest elasticity; in this respect it corresponds to brewsterite.

Hornblende-hypersthene Andesite of Clarno's Ferry. The specimens from the boulders in the tuff beds of Clarno's Ferry are very similar in macroscopical appearance to the hornblende andesite of Hald's Cañon. Microscopical study, however, reveals some characters that entitle these rocks to a separate description.

One of the specimens had originally the same character as the Hald's Cañon rock, and the feldspars and groundmass exhibit a similar alteration. No original hornblende, however, now remains, having been replaced by pseudomorphs of magnetite and opaque red ochre.

The original constituents of a second specimen differed from these in the presence of a rhombic pyroxene, which is now represented only by pseudomorphs. The chief interest of the rock lies in its exemplification of several alteration processes.

In the microscopical section about half the rock is seen to consist of a turbid hyalopilitic groundmass, in which lie phenocrysts of altered feldspar and brown hornblende, with pseudomorphs, of a mineral resembling iddingsite, after a rhombic pyroxene. The accessories are apatite, magnetite, and tridymite, while zeolites occur as a filling of cavities and partially replacing feldspar.

The apatite is of the brown pleochroic variety already described on page 126.

The feldspar phenocrysts are found by the method of Michel Lévy to be acid labradorite, with the approximate composition Ab_1An_1. Their alteration, which is in general far advanced, is of an interesting and unusual character. The writer has observed nothing similar except in the Clarno rocks, and has seen no description in the literature that would apply to the present case. Yet this mode of alteration, most clearly exemplified in this specimen, is the typical one in the feldspar of the Clarno volcanic rocks.

The feldspar substance that remains is perfectly clear and fresh. Every crystal, however, contains areas, irregular and jagged in outline, of a clear and colorless mineral, which by reason of its very low refractive index appears deeply sunken below the surface of the feldspar. The refractive index is found by the Becke method to be much lower than that of balsam. A distinct pinacoidal cleavage is often visible. Between crossed nicols the extinction is found to be parallel to, or nearly parallel to, the cleavage. The interference colors, while in most individuals lower than those exhibited by the feldspars, sometimes reach yellow of the first order, which by the comparative method is found in the slides used to indicate a double refraction near .010.

Similar material also occurs in fairly large irregular patches, in small veins, and occasionally forms a fine lace-work of minute veinlets in the groundmass. While the mineral evidently fills original cavities and small fissures, it seems in some cases to have replaced metasomatically a portion of the groundmass.

Examination of cleavage flakes from the larger masses leads to the discrimination of two different minerals. Heated before the blow-pipe, all the fragments exfoliate, swell, and fuse to a white enamel. Treated with acids, they all dissolve without gelatinization. But when their cleavage flakes are examined in convergent polarized light, they do not all exhibit the same behavior. A certain portion are found to lie parallel to the plane of the optic axes, as in stilbite. The remainder, in which the lamellar cleavage was more nearly perfect, show the emergence of an acute negative bisectrix, and the optic axial angle, even in flakes from the same individual, varies from nearly zero to about 50°. This optical behavior is characteristic of heulandite.

It will be recalled that part of the zeolitic material has a double refraction near .010, and therefore higher than that assigned in the books either to stilbite (.005) or heulandite (.007). But the double refraction is a function of the axial angle, so variable in the case of heulandite, and may be expected to vary considerably in that mineral. The current figure, as determined by Michel Lévy,* was probably not based on the study of a large number of specimens. In view of these considerations, the mineral with the higher double refraction is referred to heulandite.

The hornblende, originally of the same character as that of the Hald's Cañon rock, has been largely transformed in a peculiar manner. The change, beginning on the exterior, produces a green hornblende, whose color is in beautiful contrast to that of the original mineral. The cleavage cracks in all directions are parallel in the two minerals, and twinning, when present in the original, continues without interruption into the paramorphic shell. The pleochroism of the secondary hornblende, in shades of a peculiar grayish green, is about as intense as the pleochroism of ordinary biotite. Between crossed nicols, the interference colors are in contrast to the brown hornblende, only moderately high. The extinction angle is 17°.

The iddingsite pseudomorphs are without magnetite rims, and have the characteristic outlines of idiomorphic crystals of rhombic pyroxene. Although none of the original mineral was found, their derivation from a rhombic pyroxene, probably hypersthene, cannot be doubted. The iddingsite is here of a greenish brown color, with the usual optical characters, and is generally arranged in divergent or spherulitic groups.

Lining the filled-in original cavities of the rock, especially visible in polarized light, there is always an abundance of minute tablets, which, by their hexagonal form, their refraction intermediate between that of balsam and that of the inclosing zeolite, and their weak double refraction, are identified as tridymite.

Andesitic Tuff of Clarno's Ferry.—The material that forms the bluffs of Clarno's Ferry varies greatly in degree of coarseness; it includes, on the one hand, coarse agglomerates with huge andesitic boulders, and, on the other, tuffs of such fine texture as to preserve the most delicate leaf-impressions. Although they show evidence in many places of the strong action of water, these rocks are practically all of volcanic rather

* Les Minéraux des Roches, Paris, 1888, p. 311.

than of detrital origin. This will become evident from the description of a few typical specimens.

One of these, gathered near the base of the cliff at the typical locality, is a greenish blue rock, rather incoherent in texture, made up of unassorted volcanic fragments varying in diameter from half an inch to a minimum. These fragments include bits of lava and crystals, among which glistening splinters of hornblende and angular fragments of feldspar may be discerned.

No representative slides of this rock could be prepared, but the various kinds of fragments were microscopically examined. The lava is found to be a pyroxene andesite of the Hald's Cañon type. It contains phenocysts of green augite and zeolitized labradorite, with pseudomorphs of green and brown iddingsite that presumably represent hypersthene in a highly decomposed groundmass. The hornblende, examined in cleavage fragments under the microscope, is found to be an olive-green variety with a fairly large extinction-angle.

A second specimen, from the lower leaf-bearing horizon, is a fine-grained, compact rock, about as hard as limestone. In color it is lead-gray, obscurely mottled with reddish purple, by which the leaf-impressions and certain of the bedding planes are also tinted. Small fragments of hornblende, with streaks and veins of a soft olive-green mineral, are also visible macroscopically.

The microscopical examination proves that the rock is a tuff, so much decomposed, however, that the original structure is greatly obscured. The original minerals, occurring as angular crystal fragments, are feldspar, hornblende, magnetite, and apatite. The feldspar in abundant small laths shows low extinction angles characteristic of andesine. The hornblende is of an olive-green pleochroic variety, with an extinction-angle near 15°. Apatite often occurs in rather large prisms. A mineral resembling iddingsite occurs in fine-grained spherulite aggregates of oval or irregular form.

The most interesting feature of this rock, however, consists in the presence of an abundant zeolitic cement. This is best observed between the crossed nicols, by whose aid it is seen that the interstices between the other minerals are completely filled with a clear substance having a double refraction near that of quartz. This material extinguished almost uniformly over considerable areas, but, especially in the more open spaces, exhibits a somewhat divergent or radial structure that gives rise to a "zeolitic" extinction. The properties of the mineral, so far as determined, are as follows: The refractive index is decidedly lower than for balsam. The double refraction is about .010. The extinction is parallel, or nearly parallel, to the elongation, which is optically positive. The mineral does not gelatinize with acids, but a test on the rock powder showed it to be soluble, and the acid solution gives strong reactions for alumina, lime and soda. Although the mineral is not specifically identified, it is without doubt a lime-soda zeolite. In another specimen of still finer texture, this cement, when the slide is viewed between crossed nicols, simulates rather strikingly the micropoikilitic structure described in the Hald's Cañon pyroxene andesite.

Andesitic Tuff of Cherry Creek.—The matrix of the leaf beds at Cherry Creek, while similar in origin to the Clarno's Ferry tuffs, shows evidence of more thorough working over by water, resulting in more thorough lamination, and more nearly perfect sorting of the constituent grains. Although associated with coarse agglomerate beds, the leaf-bearing strata vary in texture from coarse sandstone to fine-grained material resembling porcelain. A specimen of medium-grained sandstone may be described as typical.

Macroscopically examined, the rock is seen to consist of rather angular fragments of pink or brown lava, with some feldspar grains. These are cemented to a firm and compact sandstone, colored pale brown by finely divided limonite.

Under the microscope, the main part of the rock is found to consist of the rock fragments which prove to be of altered porphyritic andesite. Their feldspar phenocrysts, which all exhibit to a greater or less extent the zeolitic alteration described on page 130, seem to be all plagioclase. Several were determined as acid labradorites or basic andesines. No ferromagnesian minerals were observed, but there are a few pseudomorphs, mainly composed of limonite, whose forms indicate their derivation from hornblende. The groundmass, though always decomposed, shows the typical andesitic structure, and the feldspar laths have the extinction angles of andesine.

The free feldspar grains, which vary much in size, have the form of laths or of angular fragments of larger crystals. In character they are similar to those of the andesite fragments.

The cementing material which completely fills the interstices, is a zeolite with low double refraction and one perfect pinacoidal cleavage. It is probably stilbite or heulandite, or perhaps both are present. The specks of limonite, scattered through the rock, are especially concentrated in the cement.

The rock thus described is evidently an andesitic tuff, whose materials to some extent were worked over and arranged by flowing water. The character of the material, its homogeneity, and the general angularity of the fragments, are evidence of pyroclastic origin. The lamination and the absence of fragile vesicular fragments are the result of water action.

Quartz Basalts of Cherry Creek.—Of the lavas overlying the leaf-bearing tuffs of the Cherry Creek locality, a pyroxene-andesite of the Hald's Cañon type has already been noted. In this place will be described a lava of somewhat peculiar character, which may be designated as a quartz-bearing hypersthene-basalt.

A typical specimen, viewed macroscopically, is seen to consist mainly of a dead black, perfectly compact and very fine-grained groundmass. In rather sparing quantity, but evenly distributed, lie small crystals of greenish olivine and rounded grains of clear colorless quartz.

Under the microscope, the groundmass is resolved into a typical "feltwork". The main constituent is pyroxene (both rhombic and monoclinic), in slender prisms. Small feldspar laths occur in subordinate amount, and there is a large quantity of pale brown globulitic glass-base. Apatite occurs as an accessory, while magnetite grains are rather abundant.

The two varieties of pyroxene are not readily distinguished except between crossed nicols. If in polarized light a prism is placed parallel to one of the cross-hairs, it is oftenest found to have its central portion in extinction, and bordered by two bright lines, which extinguish in turn at a large angle. Most of the crystals are thus found to be intergrowths of the two pyroxenes after the plan that is usual in volcanic rocks, although separate individuals of both varieties occur. More closely defined, they are a greenish augite, with an extinction angle near 45° and a fairly pleochroic hypersthene. The latter seems to be slightly more abundant. The slender prisms have irregular and splintery ends. Prismatic cleavage is visible, and each crystal is broken by numerous transverse cracks. They are characterized by abundant glass-inclusions of irregular form. A few crystals are distinguished from the groundmass by greater size, and possibly indicate two periods of crystallization for the mineral.

The feldspar, which occurs only in the form of microlites, was determined by the method of Becker, and by extinction angles measured from the $\breve{a}$ axis on both the brachypinacoid and perpendicular to it, as acid labradorite, (Ab_1 An_1.).

The phenocrysts of olivine, though bounded in part by crystal planes, often show evidence of magmatic resorption. While some of the crystals are perfectly fresh, others are almost completely changed over to an olive-green mineral, with the high interference colors characteristic of iddingsite. Here it does not form paramorphs, but rather irregular aggregates.

The quartz is probably the most interesting constituent. The grains occur, with even distribution, at the rate of about a dozen to a slide of ordinary size. Their outlines never show a suggestion of crystal form, but are always the irregular curves produced by magmatic corrosion. Each grain is generally a crystal individual, but in one case two were observed in contact, separated by an irregular line. Fine irregular cracks are rather numerous. The quartz in one specimen is almost entirely without inclusions, —a single prism of apatite was the only one observed.

The modifications produced by magmatic resorption are very similar to those described for similar cases by Iddings,* Diller,† Lacroix,‡ and other writers. Each grain of quartz is surrounded by a zone of brown glass, bordered in turn by a wreath of small prisms of pale green augite. The degree of resorption presents all gradations, and there has often resulted the complete destruction of the quartz, whose place is then marked by a nest of augite prisms.

* Bull. U. S. G. S., No. 66, 1890, p. 20 *et seq.*

† Bull. U. S. G. S., Nos. 79, 1891, and 150, 1897, pl. XXXVII.

‡ Les Enclaves des Roches Volcaniques, 1893, pp. 17–48, fig. 1.

In a slide from a second specimen, there occurs an additional phenomenon of peculiar interest. Although the body of the quartz grains here is free from any inclusions within the range of the highest powers available to the writer, each grain contains, a little within the periphery and parallel to it, a zone of minute, apparently gaseous inclusions. There can be no doubt that their presence is due to the action of the heated magma during the absorption of the grain.

A chemical analysis by the writer is given below, with one of a quartz-basalt from the Lassen Peak district described by Diller, for comparison.

	I.	II.
SiO_2	59.61	57.25
Al_2O_3	15.98	16.45
Fe_2O_3	1.12	1.67
FeO	5.42	4.72
MgO	5.04	6.74
CaO	5.54	7.65
Na_2O	3.68	3.00
K_2O	1.10	1.57
H_2O at 110°	0.20	
H_2O above 110°	1.14	0.40
TiO_2	0.65	0.60
P_2O_5	0.14	0.20
MnO	0.21	0.10
NiO	0.05	
SrO	trace?	trace
BaO	0.04	0.03
Total	99.92	100.38

The more important points of difference are the greater silica content of the Oregon rock, the smaller percentage of lime and magnesia and the higher ratio of soda to potash. Notwithstanding these differences, there is a notable resemblance between the two analyses.

Andesite from Volcanic Neck at Cherry Creek. In the hand-specimen this rock has a somewhat basaltic aspect, being compact, fine-grained and of a dark iron-gray color. The specimen contains a mass, as large as an almond kernel, of milky quartz somewhat discolored by iron oxide.

I. Quartz-basalt, Cherry Creek. Analyst, F. C. Calkins.

II. Quartz-basalt, Cinder Cone, 10 miles N.E. of Lassen Peak. Described by Diller, Bull. U. S. G. S. Nos. 79 and 150. Analyst, W. F. Hillebrand.

Microscopically examined, the groundmass is seen to be similar in structure and composition to that of the quartz-basalt just described. But the phenocrysts of olivine and of limpid quartz are absent, and the rock is mineralogically more allied to the pyroxene andesites. Feldspar is more abundant than in the quartz-basalt, and seems to have crystallized in two generations, though the distinction between phenocrysts and groundmass is not sharp. The feldspars are labradorite, and the pyroxenes are of the same character and from the same undergrowths as in the quartz-basalts. Considerable glass is present.

The quartz noted in the hand-specimen is without doubt an inclusion. In polarized light it resolves itself into a granular aggregate of many individuals. Liquid and gaseous inclusions occur in great abundance, arranged in curving lines that pass without interruption from one individual to another. The effects produced by resorption, namely the zones of glass and augite, are similar to those observed in the quartz-basalt.

An apparent inclusion of hornblende is represented in one of the slides by an opaque mass, mainly of iron oxide, with a hexagonal outline.

Spherulitic Rhyolites of Currant Creek Hill.—The rhyolitic lavas of this locality, while comprising a small amount of glassy material resembling obsidian, are in the main eminently characterized by tbe development of spherultic structures. In this field a wide variation in the size of the spherulites is observed. In certain places their diameters are near that of buckshot, while in others they range from half an inch to nearly a foot. The finer-grained rock is usually fairly coherent, but the coarser material is generally thoroughly disintegrated, so that the spherulites, more resistant to weathering, may be readily picked from the crumbling matrix.

Only from the fine-grained phase could hand specimens be gathered, or slides prepared to illustrate the structure of the rock as a whole. Macroscopically this rock is cream-white to yellowish green in color, and composed of spherulites from one to three millimetres in diameter, imbedded in a fine lithoidal groundmass. The spherulites compose about half the bulk of the rock. When broken, they distinctly show their radiate structure, and spherical cracks, often lined with minute sparkling crystals, are generally present. The rock shows a distinct banded structure, marked by the different size of the spherulites in the different layers.

Under the microscope. a few small phenocrysts of quartz and feldspar become visible, the latter including sanidine and an acid plagioclase. The spherulites, often formed about a phenocryst as a nucleus, appear by transmitted light of the usual cloudy brown tint. The fibres always have a small extinction angle, and their elongation is invariably *positive* when the double refraction is perceptible. A considerable proportion, however, seem practically isotropic. In most described spherulitic rhyolites the fibres are either all negative or partly negative and partly positive. The facts observed in this rock may perhaps be explained by supposing them to be of sanidine and anorthoclase elongated in the direction of the vertical axis, which would be nearly parallel to the axis of elasticity $\mathfrak{b}$. Both feldspars have a small optic axial angle, which means that the difference of elasticity in the directions $\mathfrak{b}$ and $\mathfrak{c}$ is small. Now if such fibres were viewed in the direction of the axis $\mathfrak{a}$ their effect on polarized light, owing to the nearly equal elasticities parallel to $\mathfrak{b}$ and $\mathfrak{c}$, would be small, and, if the fibres were very slender, imperceptible. If, on the other hand, they were viewed in the direction of $\mathfrak{c}$, they would have an apparent double refraction nearly equal to the maximum and the direction of elongation would be optically positive.

Numerous small granophyric intergrowths of quartz and feldspar are included in the spherulites, from which they are distinguished by being quite transparent. The material lining the crescentic cracks is found to be mainly quartz and opal, with occasional crystals of a zeolite which has weak double refraction and a perfect pinacoidal cleavage. The groundmass shows well marked perlitic structure, and is eviently an altered glass, but it is much devitrified, and speckled with minute, weakly birefringent crystal grains.

The large spherulites gathered from the disintegrated rock generally show considerable irregularity of form. They are, first, often formed by the coalescence of several individual spherulites of similar size, while numbers of smaller spherulites often lie imbedded in the surfaces of the larger; second, they are always surrounded by numerous gently rounded annular ridges, which are shown by the microscope to have their planes parallel to the surface of flow.

A microscopical thin section was made through the centre of a spherulite three-fourths of an inch in diameter. The outer portion was found to consist of slender fibres radiating from a central nucleus. This nucleus, with about a third the diameter of the whole, is composed of an aggregate of radiate fibrous groups, very irregular in form. The fibres, as in the specimen above described, always have a small extinction angle and positive elongation. Between these feldspar fibres, there lie numerous minute shreds of a green pleochroic mineral, with straight extinction and moderate double refraction.

Flow structure is indicated in two ways. Numerous small brown trichites, scattered through the feldspar substance, show a linear parallel arrangement, while in the outer portion there are alternating clear and cloudy bands, the cloudy bands dotted with numerous clear circular areas. The cause of this latter phenomenon is problematical, but it may possibly be explained as indicating an incipient spherulitic crystallization at an early period, afterward superseded by crystallization from more widely separated centres. The radial arrangement of the fibres is interrupted in no way by the structures just described. The lines of trichites and the cloudy bands are parallel to the plane of the external rings.

A few crystals of acid feldspar and a few clear granophyric intergrowths of feldspar and quartz are scattered through the fibrous mass.

The spherulites over an inch or so in diameter usually contain irregular central cavities, more or less completely filled with secondary minerals, and afford many specimens of unusual interest and beauty. The mineral species represented are quartz, opal, chalcedony and fluorite, and two zeolites that appear to be new. The description of a few specimens will serve to illustrate their mode of occurrence.

One of the largest is a fine miniature cavern. The roof is covered with botryoidal chalcedony, from which depend slender stalactites of the same mineral. The floor is built up of several variegated layers of chalcedony and opal, and a change of position during its formation is prettily shown by the fact that the upper half of the layers is inclined at an acute angle to the lower layers.

A second geode contains a lining of chalcedony, while the centre is quite filled in with small granular crystals of pale lilac and apple-green tints, of fluorite. The identity of the mineral was proved by its form, its isotropic behavior toward polarized light, and the evolution, on treatment with sulphuric acid, of hydrofluoric acid fumes. The writer has seen no mention of a similar occurrence of fluorite.

In another hollow spherulite, the cavity was first lined with chalcedony and a little milky opal, then almost filled with a snow-white mineral compact near the inclosing wall, but finely fibrous in the centre. Inclosed in the compact portion of this substance, in much smaller amount, are many small lustrous tablets of a bright orange-red color.

The fibrous mineral was found to have the following properties: Heated in the closed tube, it gives off abundant water. Before the blowpipe it fuses at about 3½ to a white enamel. Boiled with strong acids, it dissolves but sparingly, and does not gelatinize. Of the optical properties little could be ascertained, because of the extreme slenderness of the fibres, but it was found that the extinction is straight, the elongation parallel to the axis **a**, and the double refraction weak. The mineral readily dissolves in hydrofluosilicic acid, and the solution deposits, on evaporating, hexagonal crystals of sodium fluosilicate, and amorphous fluosilicate of aluminum. We therefore have, evidently, a soda zeolite, but one with properties differing from those of any described mineral.

The red tablets also appear to be of a zeolite with soda as the base. There is a perfect cleavage parallel to the tabular face, and cleavage flakes examined in convergent polarized light are found to be normal to a positive, probably acute, bisectrix. The red color is due entirely to disseminated particles of ferric oxide. Before the blowpipe, the mineral exfoliates, swells and easily fuses. From the hydrofluosilicate solution, were obtained good sodium crystals and some amorphous matter.

In the decomposed matrix of the large spherulites, opal occurs in abundance. This material is oftenest milky, and of a yellowish or bluish white, but many specimens more transparent exhibit considerable play of color. A probably similar occurrence in another portion of the State has been exploited for precious opal, but was found unprofitable and abandoned.

Rhyolites of Clarno's Ferry.—The specimens of rhyolitic lava and tuff brought from this locality seem to represent two or three chemical types.

One of the massive specimens appears to be a typical liparite, with few characters of especial interest. The phenocrysts are quartz, sanidine, and oligoclase, and lie in a reddish purple groundmass, devitrified and showing in part a spherulitic structure. There are a few inclusions of decomposed hypersthene andesite, which give evidence as to the succession at this locality.

The other lava is of more unusual character. Macroscopically, it shows abundant phenocrysts of fresh glassy feldspar and quartz, in a cream-white, lustreless groundmass. This groundmass has been decomposed locally in a peculiar manner, for the hand-specimen contains several small masses of a soft kaolin-like substance, with imbedded crystals of quartz and glassy feldspar, which can be accounted for only by such a decomposition.

Under the microscope, accessory apatite, magnetite and zircon are noted. The groundmass is partially devitrified; it is seen in polarized light to be specked with minute, doubly refracting grains, and a feebly developed microspherulitic structure may be observed locally on careful examination. The bipyramids of quartz have suffered the inevitable magmatic corrosion. A distinct rhombohedral cleavage was observed in one crystal. The feldspars, which occur in well-formed crystals, comprise both orthoclase and plagioclase, but the latter is decidedly predominant. They inclose apatite, magnetite, and zircon, contrasting with the quartz, which is devoid of mineral inclusions. No ferromagnesian silicates are present in the rock.

The measurement of extinction angles for the determination of the feldspars, which was carried out with some care, led to rather anomalous results. These may be summarized as follows: Basal cleavage flakes gave angles varying from 0° to 3°, with an average of about 1° in a dozen measurements. This average would indicate an acid andesine. The angle on the brachypinacoid measured in two flakes, was 11°, corresponding to a more basic andesine. Five sections nearly perpendicular to the bisectrix **a** were discovered, which gave extinction angles, measured from the trace of $\infty P \breve{\infty}$ toward the obtuse angle oP: $\infty P \breve{\infty}$, of 56° to 66° with an average of 60°. This angle, according to Fouqué,* indicates labradorite. The Michel Lévy method on two doubly twinned crystals gives concurrent angles corresponding to andesine. While the results thus seem to indicate something abnormal in the optical character of the plagioclase, it is evidently of a more basic character than the general appearance of the rock would indicate.

Of the associated tuffs one is a soft cream-colored rock, composed mainly of fine pumice fragments, with their cavities lined with microscopical crystals of secondary origin. A grain or two of quartz was the only original mineral seen.

The second is apparently of a type much richer in iron. The mass of the rock is rather dark green, and composed of fragments evidently of decomposed pumice, with considerable more or less earthy green or greenish brown matter. Numerous bipyramids of quartz are imbedded in this matrix, and less conspicuous crystals of glassy feldspar.

For microscopical study only very imperfect slides could be prepared, but their examination revealed a few interesting facts. The feldspars prove to be mainly oligoclase, with a smaller amount of orthoclase. The quartzes have preserved their crystallographic boundaries in great part, but have generally suffered a slight magmatic corrosion. They usually contain a few large glass inclusions, each with a bubble, and often clouded with crystallites. The material in which these large crystals are imbedded contains, besides small fragments of feldspar, and original quartz, only secondary minerals. The pumice fragments, recognized by their vesicular structure, have been thoroughly devitrified. Secondary quartz is abundant, and a zeolite occurs in

* Bull. Soc. Fr. de Mineralogie, 1894, No. 17, p. 428

small patches with a radiate fibrous structure. The material which gives the rock its green color, and which occurs in abundance, is of apparently micaceous structure. It mostly forms irregular aggregates of deep green to brownish green color, almost opaque in the thick slides. It is seen to have a double refraction higher than that of quartz and to be pleochroic. A single individual seen of perhaps the same mineral was large enough to exhibit the optical properties more clearly. Its outline is oblong and rectangular. The centre is a confused fine-grained aggregate, but a broad peripheral zone behaves optically as a unit, and shows a distinct cleavage parallel to the longer pair of edges. The pleochroism, from deep grass-green to pale yellowish green, is pronounced; the greater absorption is experienced by rays vibrating parallel to the cleavage, to which the extinction between crossed nicols is parallel. The interference colors are bright, indicating a double refraction of at least .020. The mineral thus seems comparable in its optical properties to iddingsite.

ROCKS OF THE JOHN DAY MIOCENE.

General Classification.—It has already been stated that the John Day system, except for a comparatively small proportion of its thickness, is made up of pyroclastic material. The evidences of this fact generally observable in the field are: (1) the low specific gravity of the rocks, due to the porosity of the constituent fragments; (2) the angularity of these fragments, which is recognized by the harsh, gritty texture of the rocks; (3) the general or at least frequent absence of fine lamination, which testifies to a rapid accumulation of the material rather than slow deposition by wind or water. In the coarser-grained specimens, the angular lapilli and fresh feldspar fragments are easily recognized, and the tuffaceous character is clearly evident.

Dr. Merriam's threefold division of the series may be used advantageously in our petrographic description. The lower or "red beds" are found to be trachytic, while the two upper divisions—the "blue" and "buff beds," respectively—are mainly andesitic in character. The lava found near the middle of the series proves to be a rhyolite of peculiar microscopical characters.

Rocks of the Lower John Day.—The lowest division is the one most readily recognized in the field, being strongly characterized by the habit of weathering into softly rounded hills, and even more by the prevailing red colors. Interbedded, however, with the dominant red material are occasional layers of white or yellow.

A close examination of hand specimens affords evidence of their tuffaceous character. Perfectly angular and glassy crystals of feldspar always may be seen in moderate amount. Certain specimens show abundant decomposed lapilli, distinguished by their greenish white color from a fine, earthy red matrix. In contrast to the freshness of the feldspar is the generally advanced decomposition of the unindividualized material. This is made evident by the greasy or clayey "feel" of finer-grained specimens, and even more strikingly by its behavior toward water. When an attempt was made to grind a thin section on a wet plate, the rock showed a strong tendency to crumble and even to slake somewhat after the manner of lime, while rubbing quickly reduced it to a clayey paste. A few rather poor sections were produced by dry grinding.

Under the microscope, the ashy structure becomes apparent in even the compact clayey material. The larger portion seems to consist of decomposed glass-fragments, often highly vesicular, and rendered in great part opaque by the formation of kaolin and impregnation with red oxide of iron. In smaller amount occur fragments of a compact microlitic rock composed of feldspar laths with the extinction angles of oligoclase or andesine, and a little magnetite. A few grains of green augite are found, and a few of quartz. The larger grains of feldspar are always bounded by crystal planes or irregular surfaces of fracture. Rather more than half show albite twinning, and their extinction angles are those of oligoclase. The untwinned crystals seemed to be orthoclase. The determinations in both cases were confirmed by examination of cleavage flakes, and by microchemical tests with hydrofluosilicic acid. Black scales with metallic lustre are rather common, and a number, picked from the hand specimen, seemed unaffected by the magnet. They thus appear to be ilmenite.

These tuffs are provisionally classified, from the acid character of the feldspars, combined with the scarcity of quartz, as trachytic. While this diagnosis may be based on somewhat insufficient grounds, chemical analysis, owing to the decomposed state of our material, would perhaps form an equally uncertain basis of classification.

Rocks of the Middle John Day.—The typical rock of this division, and the one forming most of the lower portion, is a blue or greenish blue tuff, usually heavily bedded, and characterized by the presence of abundant brown calcareous nodules. The top of the Middle John Day in the Turtle Cove exposures may be considered as marked by the thin flow of rhyolitic lava. The upper fifty feet or so, if we adopt this limit, include several strata of white, buff and brownish beds with some intercalated layers of greenish material resembling that of the underlying typical blue beds.

The typical and predominant rock of the middle division is of rather pale bluish green color, in texture usually fine and rather compact, with a surface harsh and gritty to the touch. When the rock is exposed to the weather, the color becomes lighter, and of a more bluish cast, so that the prevalent tint of the bluffs carved from these beds is a sort of "robin's-egg-blue." The only mineral to be recognized macroscopically is the glassy feldspar, and whitish lapilli, often sparkling with minute colorless crystals, are always to be detected in all but the finest material. Decomposition is in general much less advanced than in the red beds, and the preparation of slides is not attended with the difficulties encountered in the case of those rocks. The secondary processes, on the other hand, have effected a recementing of certain small portions to form a moderately hard rock, with smooth surfaces of fracture breaking indifferently across the constituent pumice fragments.

The microscopical characters are best seen in slides from the medium-grained phases. Of original minerals in addition to the feldspar, the microscope reveals a rather small amount of green augite, and accessory iron ore, apatite and zircon. The feldspars usually show both albite and Carlsbad twinning, and are referred by their extinction angles in favorable sections, to the species andesine or labradorite. The few untwinned sections generally give interference figures indicating their approximate parallelism to the brachypinacoid, and none could be proved orthoclase. That feldspar is therefore supposed to be absent.

The fragments that constitute the bulk of the tuff, while comprising a small proportion of compact rock resembling the groundmass of andesite, are in greater part of devitrified pumice. The larger fragments of this material, which always exhibit sharply angular boundaries, are highly vesicular in structure, and the gas cavities, separated by thin partitions, are sometimes of oval or nearly circular outline, sometimes strongly drawn out in one direction. The originally glassy substance of the septa appears, by ordinarily transmitted light, of a pale brownish tint, clouded with whitish dust resembling fine kaolin. Between crossed nicols, the devitrification of the glass becomes evident. Little or none of the original amorphous substance remains; it has been replaced by a microcrystalline aggregate of weakly polarizing minerals. Microspherulitic structure is occasionally to be seen. The gas cavities are more or less filled by the minute, colorless tablets and prismatic crystals thickly implanted in the bounding walls. The small dimensions of these crystals hardly permit of quite satisfactory determination, but two species may be distinguished. The tablets, attached by one edge, are always of hexagonal outline, often approaching to rhombic by the almost complete suppression of one pair of faces. Their limpidity, weak refraction and double refraction correspond to tridymite, and they are confidently referred to that species. The prismatic mineral is in the form of slender rods, squarely terminated at the distal end, and showing a longitudinal cleavage. The refractive index is much below that of balsam, and the double refraction feeble; this mineral is in all probability a zeolite. Needles of similar character, under high-power lenses, may be seen among the devitrification products of the glassy septa. The tridymite is presumably of primary origin.

Between the larger fragments is some finely comminuted material. The green material that gives the rock its characteristic tint occurs as thin shreds in the devitrified glass and among the crystals in the pumice vesicles, but the greater portion is mixed with this interstitial dust. The cloudy masses of this mineral contain no individuals that show its crystallographic, or, with any definiteness, its optical properties. The color is grass-green, and a faint pleochroism may sometimes be detected. Between crossed nicols the mineral generally appears quite dark; the apparent isotropism is due to compensation, for locally there may be observed a feeble double refraction. This material is presumably of the nature of chlorite or glauconite; probably both substances are present. Calcite occurs in the typical blue rock in but small amount.

These rocks were not analyzed chemically, but the silica percentage was determined in a typical sample, as 60%. Thus the silica content and the mineralogical character of the rocks would both tend to place them in the family of andesites.

The brown nodules so characteristic of the Middle John Day vary in diameter from a few inches to a foot or more. Their forms are generally spheroidal or ovoid. The material is compact and fairly hard, and its calcareous nature is shown by effervescence on the application of weak acids.

Under the microscope the structure, so far as its original features are concerned. is found to be identical with that of the blue tuffs just described. But the pumice fragments have become thoroughly impregnated with calcite, which lines the larger and fills the smaller cavities. The scattered grains of feldspar have narrow borders of the same mineral, In polarized light, the calcite generally shows the "zeolitic" extinction that indicates a radiate-fibrous structure. In addition to the abundant calcite, a few patches of some unidentified zeolite are found, and numerous small oval areas of brown iddingsite. The general effect, between crossed nicols, of the intricate patterns traced in brilliantly polarizing calcite, varied by the deeper interference colors of iddingsite, is that of an illuminated arabesque.

The light-colored layers occurring near the top of the Turtle Cove section show the same structural characters. and the same secondary alteration of the pumice becomes evident under the microscope. Augite was not found in this material. The feldspars, which were rare and not thoroughly studied, apparently include a little orthoclase. The green chloritic substance is absent, but ragged patches of iddingsite and of calcite are rather abundant. These rocks are probably more acid than the blue tuffs, and may be classified as either trachytic or rhyolitic tuffs.

Rocks of the Upper John Day.—These, so far as the main and lower portion is concerned, are very similar to the rocks of the Middle John Day. They consist of fine-grained tuffs which, although they comprise a small proportion of green strata, are prevailingly of a light buff or light greenish brown color. In the uppermost portion, however, there are at certain localities about 300 to 400 feet of sands and gravels, pointing to conditions of accumulation in contrast to those that controlled the deposition of the underlying portion of the John Day series. There are also in certain exposures of the lower part of this division red beds resembling those of the Lower John Day. A peculiar modification of the tuff-beds by intrusive basalt, consisting in the formation of slender columns perpendicular to the walls of the dykes, has been described by Dr. Merriam.* The heat of the basalt flows poured out upon the uppermost beds has also changed their color to brick-red by oxidation of the ferrous iron.

The material forming the main part of the Upper John Day, because of its general resemblance to the blue tuff described in detail, will not require extended description. Its macroscopical characters, except usually color, are essentially the same as those of the rocks of the middle division. Under the microscope also it shows the same ashy structure. The original constituents, in order of abundance, are angular and often vesicular glass fragments with a relatively small amount of microlitic hypocrystalline rock, plagioclase usually of the andesine or labradorite groups, green augite and accessory iron ore, apatite and zircon. A few grains of apparently original quartz were seen in some slides. The material is generally a little less decomposed than the blue tuff described above, and the secondary filling of the pumice vesicles has taken place to a smaller extent. The secondary materials comprise a little quartz and calcite and some indeterminate zeolites, but the most important is perhaps the substance which imparts to the rock its usual color. This

* *Op. cit.*, p. 304.

mineral, occurring in the same manner as the supposed chlorite or glauconite of the blue tuff, appears to be iddingsite; it shows, when seen in sufficently large units, the high double refraction, strong pleochroism and micaceous form of that mineral, and is reddish brown to greenish brown in color.

The silica percentage of a typical specimen was determined to be 58.3%. The tuffs of the Upper, as well as of the Middle John Day, are believed to be mainly andesitic.

The matrix of the plant-remains collected near Lone Rock is a light green rock of fine, even, and compact texture. Examined microscopically in their section it shows the "ashy" structure in a highly typical manner. The constituent particles are mainly of delicate pumiceous glass, with cuspate or ragged outlines, a fact which indicates that the material was deposited quietly, without being rolled by wind or water currents. The coloring matter is identical with that of the typical, Middle John Day rocks. The vesicles of the pumice grains and the interstices between them are filled with a colorless substance generally isotropic but occasionally showing a feeble double refraction, which may be analcite.

In the beds immediately overlaid by the basalt flows, the heat of the molten lava has often produced a deep red color. Specimens of the rock thus altered, when examined under the microscope, appear to be strongly impregnated with ferric oxide. This appears to have been derived by the destruction of the iron-bearing silicates that color the green and buff tuffs, for these minerals are not found in the baked red rocks. A considerable quantity of secondary quartz and analcite is sometimes present.

The slender columns found in the Upper John Day where it is cut by the Davis dikes in Turtle Cove are described by Dr. Merriam* as extending about fifteen feet on either side of the basalt in a direction about normal to the plane of the dyke, while single columns are often at least ten feet in length. The diameters of these long columns average about two inches; in a lenticular mass of tuff included in the dyke the diameters of the columns are about five inches. As Dr. Merriam points out, the

* *Loc. cit.* Instances of similar development of columns in sandstone and coal are cited by Rosenbusch, Gesteinslehre, p. 26.

diameters evidently increase in proportion as the original temperature was high and the rate of cooling slow, a rule which appears to hold generally in the development of columnar structure in lavas.

The short fragments of these columns brought to the laboratory are of hexagonal or pentagonal cross-section, the prism faces of each column being generally in part slightly concave, in part slightly convex; in one pentagonal column, for example, two adjacent faces are convex, and the other three concave. When a column is broken transversely at any point, a peculiar phenomenon is observed; one of the surfaces of fracture always has in the centre a circular, button-like protuberance, the other, of course, a corresponding saucer-like depression. The direction of convexity is always the same in a given column, but its relation to the dyke was not noted. This phenomenon is significantly analagous to the transverse "ball and socket" jointing often developed in the columns of basalt.

The material of these tuff-columns is somewhat harder and more compact than the rock of the same beds beyond the zone of contact-modification. Under the microscope, however, no considerable modification of the internal structure is to be observed.

From the sandy and gravelly beds locally found near the top of the John Day section two types of rock are represented in our collection.

One is a fine-grained conglomerate, composed of well rounded bits of compact buff tuff like that most characteristic of the Upper John Day.

The other is a sandstone varying in texture from coarse to moderately fine, and of a deep green color. The grains macroscopically may be seen to be mainly feldspar, but small fragments of rock are also visible. The color is due to the abundant cement, which consists mainly of a compact deep green substance, though the bright cleavage faces of a zeolite are occasionally seen.

Under the microscope the grains are found to be sub-angular in form. The feldspars, when determinable, are found to be plagioclase with the average composition of andesine; although orthoclase may be present its presence was not demonstrated.

There is a considerable amount of deep green augite, of the variety found in the John Day tuffs. Only a few grains of quartz were seen. The rock fragments are mainly of lava, and similar to those found in the tuffs. A few fragments of some cherty material were also found. The cement proves to be a mixture of zeolitic material with a glauconitic (?) substance, apparently identical with that so characteristic of the "Blue Beds."

It is evident that this sandstone has been produced by the working-over of the underlying tuffs. The fragile lapilli so abundant in those rocks are entirely absent from the sandstone. They were probably reduced in the process of corrosion and of rolling along the ancient river bottom, to a state of fine division. The feldspathic sandstone is the result of a mechanical concentration by running water of the more resistant and denser constituents of the tuffs. A small amount of foreign material has been introduced perhaps, but it is insignificant in amount.

Lavas of the John Day Series.—The few thin sheets of lava found in various sections, intercalated with the John Day tuffs, fall into four distinct petrographical types, which will be described separately.

At Bridge Creek a thin flow of lava occurs, whose horizon was determined by Dr. Merriam to be near the base of the Middle John Day. A single specimen from near the upper surface was examined by the writer.

Macroscopically, this rock is compact and of a light reddish brown color and dull lustre. A few small crystals of the feldspar are the only minerals distinguished by the unaided eye. The structure is that of a flow-breccia, formed by the breaking up of the first formed surface crust, whose fragments became mixed with the still fluid and moving paste beneath.

Under the microscope, a few grains of green augite are found, and accessory magnetite and apatite. The feldspars are very scarce and usually of irregular outline, so that their determination was not accomplished in a very satisfactory manner. The grains practically all show polysynthetic twinning, and the highest extinction angle observed in the zone was about perpendicular to $\{010\}$.

The glassy groundmass shows the contorted lamination usually produced by viscous flow. It is for the most part rendered nearly opaque by a finely divided ochreous pigment. Small portions, however, are transparent with a rich brownish red color. These transparent portions, between crossed nicols, exhibit weak double refraction; dark brushes parallel to the cross-hairs of the microscope radiate from numerous points on the boundaries of these areas. This phenomenon will be discussed later, in connection with some rocks which exemplify it more clearly.

No chemical investigation of this rock was attempted. Its mineralogical character, however, combined with the evidently rather high percentage of iron, leads the writer to the belief that this is a glassy acid andesite, corresponding approximately in chemical character to the tuffs composing most of the John Day beds.

Another thin flow, with brecciated and vesicular surface, was seen in the valley north of Antelope. The color is deep red, owing doubtless to secondary oxidation of the iron content. The rock contains only a few small grains of feldspar, which could not be satisfactorily determined, and of quartz, which is probably all secondary. It is impossible to classify this rock with precision, but it appears to be of andesitic character.

Immediately overlying this lava in Antelope Valley, and seen by Dr. Merriam in the hills to the west, are two or three flows of rhyolite. The petrographical character of this rhyolite, as will be shown in the description, is well marked and peculiar. In Turtle Cove, about sixty miles from Antelope, a thin lava flow of considerable extent occurs near the horizon that divides the Upper from the Middle John Day. It is a remarkable fact that the petrographical character of this rock, including even the microscopical structure, is practically identical with that of the Antelope rhyolite. The resemblance is so striking that the rocks from the two occurrences can best be described together as a single type.

Macroscopically, the rocks are seen to be of a drab, or of light gray or buff color, and to consist mainly of fine-grained material with lithoidal and compact texture. Sparingly distributed in this groundmass lie phenocrysts of glassy feldspar rarely more than two millimetres in diameter. There are generally no other minerals recognizable by the unaided eye. With a lens, however, it may be seen that the rock usually contains numerous lenticular openings lined with quartz. Larger cavities lined with milky opal are occasionally present. Certain phases are characteristically marked by wavy and more or less parallel lines of brownish red color. These are the traces on the broken surface of contorted laminae impregnated with ferric oxide.

In the thin section on the stage of the microscope, we find magnetite in a few large grains and zircon and apatite as stout prisms in the groundmass or small crystals included in feldspar, all being in rather small amount. Original quartz is also found, but it is confined to the groundmass, and is usually inconspicuous.

The feldspar phenocrysts are usually sharply idiomorphic. The average relative development in the direction of the crystallographic axes may be roughly indicated by the proportion $a:b:c::4:2:3$. The feldspar is always perfectly fresh, and carries but few inclusions of zircon, apatite and glass. Between crossed nicols they are seen to be without zonal structure. Both albite and pericline striations seem to be present in a majority of the crystals, while Carlsbad twins occur occasionally in a small proportion of the crystals. By optical methods of investigation, the feldspars were found to be sanidine and anorthoclase. The latter is decidedly predominant. As sanidine only a single crystal was certainly proved; this crystal, which showed no twinning, was cut nearly normal to the bisectrix $\mathfrak{a}$, and its optic axial angle was almost zero. There are, however, a sufficient number of untwinned sections to warrant a presumption that more orthoclase occurs. In the triclinic feldspar the striae are usually narrow and always very indistinctly defined. In sections cut nearly perpendicular to $\mathfrak{a}$, that axis is found to bisect a very acute optic axial angle, so that the black hyperbolae of the interference figure, when that is well centered, never pass out of the field during a complete revolution of the stage. The extinction angle in these sections could not be sharply determined, and the extinction angle in the section perpendicular to $\mathfrak{c}$ could not be determined accurately. A crystal giving a slightly eccentric obtuse bisectrix-figure extinguished 8° from the basal cleavage, to which the obscure pericline striation was slightly inclined. The indistinctness of the twin lamellae is highly characteristic of anorthoclase, and the small value of the angle V is a character distinguishing that species from all other triclinic feldspars. There is no doubt, therefore, that the dominant feldspar of these rhyolites is anorthoclase.

The structure of the groundmass is in some ways so unusual that it will require a rather extended description. Two slightly different varieties may be recognized, and will be considered separately.

In one of these the groundmass, by ordinary light, has an appearance similar to that of some glassy rhyolites with well defined flow-structures. Separated by a subordinate amount of cloudy substance are clear brown, sinuous areas, sometimes branching, which have a general tendency to extend themselves in a common direction and curve about the phenocyrsts like lines of flow, which they doubtless represent. But on close examination, and especially in polarized light, each of these streaks is seen to be made up of two rows, separated by a sharp central line of short fibres standing normal to the edges. The small size of these fibres is an obstacle to optical investigation, but they are found to have a weak double refraction and apparently a rather large angle of extinction. The material between the fibrous streaks is generally cloudy and cryptocrystalline, appearing brightly speckled between crossed nicols. Sometimes, however, there is a little apparently amorphous, clear, light brown material, which shows between crossed nicols cloudy brushes parallel to the cross wires. A more typical exemplification of this phenomenon is found in a rock soon to be described, and it will not be discussed at present. Grains of quartz large enough to be determined as such are sprinkled rather abundantly through the groundmass, always lying between and not in the sinuous, fibrous bands.

Occurring locally are almond-shaped bodies, sometimes several millimetres in length, often distinguishable from the groundmass macroscopically by their lighter gray color. They are found to be made up of rather large fibres, grouped in slightly divergent bundles, suggesting a half-open fan. The fibres are colorless and fairly clear, and have the refractive index and double refraction of feldspar, but a remarkably large extinction angle, attaining a maximum of about 40°. If, as there seems no reason to doubt, they are composed of acid feldspar, their elongation can not be parallel either to the vertical or the front-and-back axis.

As secondary constituents there occur opal and quartz lining numerous minute amygdaloidal cavities, and a mineral with very high double refraction disseminated in particles too minute to permit of determination, but supposed to be calcite. Its amount is insignificant. The cloudy substance that clouds a great portion of the groundmass is perhaps kaolin.

The second structural variety of these rhyolites shows no flow structure. About three-fifths of its groundmass is cloudy by transmitted light and dirty white or gray by reflected light. The remainder, which is fairly transparent, forms irregular, cuspate or roughly oval areas, joining one another to form a sort of web. The cloudy portion, in polarized light, is seen to be composed mainly of weakly bi-refringent fibres, whose arrangement is for the most part confused. On the borders of the clearer areas, however, they often form more or less nearly perfect spherulites. In these structures, the fibres can be shown to have a low extinction angle and positive elongation; they are thus analogous to those of the spherulites in the Eocene rhyolites, and are believed to be of sanidine and anorthoclase, or the latter alone. The more transparent areas, however, are formed of stout fibres, or, more properly, rods, in parallel or diverging groups, with the characteristically high extinction angle and other properties of the mineral forming the peculiar almond-shaped bodies in the variety of this rock first described. The boundaries between the clear and cloudy spaces are not very definite and the transparent rods often seem to form extensions of, or to be interdigitated with, the fibres of the dusky spherulites. In such cases, it is generally noticeable that the two varieties do not extinguish together. A portion of the edge of a more than usually large transparent space is sketched in plate 17, fig. 4. The quartz is remarkably inconspicuous, and apparently much less abundant than in the facies described first.

The amygdaloidal cavities with their secondary lining are much less abundant here than the other variety, which presumably belongs to the more superficial portions of the flows, though field data in regard to this point are lacking.

The chemical composition of a typical specimen from Antelope, with the second type of groundmass, is shown in the following analysis made by the writer:

Analysis of Rhyolite, Antelope Valley.

SiO_2	75.40
Al_2O_3	13.56
Fe_2O_3	0.21
*FeO	0.61
MgO	0.07
CaO	0.38
Na_2O	4.64
K_2O	4.40
H_2O at 110°	0.44
H_2O above 110°	0.94
TiO_2	0.04
P_2O_5	0.09
MnO	trace
Total	100.78

The rock is a decidedly acid rhyolite, with soda slightly preponderating over potash, and with iron, lime and magnesia in insignificant amount. Completely crystallized, this magma would form a rock essentially of the following mineralogical composition:

Albite,	40.3
Orthoclase,	26.7
Anorthite,	1.4
Quartz,	31.6

In view of the large excess of silica, the absence of quartz phenocrysts is remarkable. The amount of quartz in the ground mass apparently falls so far short of 30 per cent. that it would seem that there must be a more considerable amount of siliceous glass base than is apparent, or that quartz fibres enter into the composition of the spherulites.

In the central part of Turtle Cove, overlapping the edge of the rhyolite whose petrographical characters we have been describing, is a flow eight or ten feet in thickness of a glassy lava of a different aspect.

* FeO probably too high.

The contraction parting of this rock, as observed by the writer in the field, is rather curious. It may be characterized as a sort of perlitic structure on a large scale. Blocks of all sizes, from that of a sugar barrel down, bounded by intersecting, curved surfaces, are strewn on the slope beneath the crumbling edge of the flow. Each block is subdivided and re-subdivided by smaller and smaller systems of perlitic cracks, whose distinctness generally decreases with their size. Under the blows of the hammer, the rock breaks down so readily that it is impossible to obtain trimmed hand-specimens of the usual form. The broader surfaces of contraction parting are often coated with a thin film of milky opal, decorated with delicate moss-like figures in black, which are probably formed of oxide of manganese.

The rock, macroscopically examined, appears of a rather dark pearl-gray color. It is essentially composed of glass. A smooth surface examined with the aid of a lens, exhibits a fine eutaxitic structure, the wavy streaks being alternately gray and opaque and dark and transparent.

Under the microscope accessory magnetite, apatite and zircon were also noted, and a very few small phenocrysts of orthorhombic pyroxene of rather deep green color.

The feldspar phenocrysts, as in the lithoidal rhyolite, are mainly anorthoclase, recognized by the characteristic shadowy striation and the small angle of the optic axes. In addition there may be orthoclase,—though none was proved,—and one crystal with distinct and continuous twin lamellae was seen, which is probably an acid plagioclase.

The flow-structure of the groundmass is beautifully shown in thin section, the alternating wavy bands appearing by ordinary transmitted light to be cloudy gray and pale transparent brown.

The lines of flow curve around the phenocrysts and a few angular fragments, evidently derived by the breaking up of a thin temporary crust formed on the fluid lava.

The transparent laminae exemplify typically a phenomenon briefly noted in two of the other John Day lavas. This supposed glass, carefully examined between crossed nicols, is found to be not entirely isotropic. Radiating from numerous points on the edges of the laminae into the clear substance are obscure dark brushes lying like the arms of the dark cross of a spherulite, parallel to the cross-hairs of the microscope. If a gypsum plate giving the sensitive red of the first order is introduced in the usual manner, it is always found that the bright sectors, lying between the dark brushes, which are bisected by the **a** axis of the plate, raise its polarization color to purple. while the other sectors throw that color down to orange. The effect is the same as if we were dealing with imperfect spherulites of positive fibres. But the most careful scrutiny, with high-power lenses, fails to reveal any fibrous structure. It therefore seems probable that the phenomenon described is due to molecular strains in the glass produced in the process of cooling and contraction, rather than by spherulitic crystallization.

The position of this rock in the scheme of classification, even in the absence of chemical analysis, is pretty clearly indicated by the petrographical characters. The predominance among the feldspars of anorthoclase, the uniformly vitreous structure of the groundmass, and the scarcity of ferromagnesian constituents, indicate that it is a rhyolite. It is presumably not very different in chemical composition from the Antelope rock and the flow immediately underlying the gray rhyolite itself.

The contrast between the glassy groundmass of this rock and the fibrous groundmass of the flow just beneath it is striking and not easy of explanation. Two hypotheses seem worthy of consideration. First, the lithoidal rhyolite may be much older than the glassy rhyolite, and its devitrification may be due to secondary agencies acting for a long interval between the extravasation between the two flows. There are two objections to this hypothesis. There is no field evidence of any considerable difference of age. The fibrous structure, independent of any system of cracks or joints, and developed to a comparatively uniform degree throughout the rock, has no appearance of being secondary. The alternative hypothesis assumes that this fibrous structure is original, and due to some conditions of eruption not active in the case of the glassy flow. In this connection, an idea is suggested by the fact that the numerous small cavities are present in the lithoidal and absent from the glassy lava. It is submitted that watery vapor may have been abundantly occluded in the earlier flow and prevented from escaping immediately, when the lava was poured out by viscosity of the acid magma. The presence of superheated vapor is well known to be a potent aid to crystallization, and is supposed to have here determined the formation of the feldspar fibres. In the later flow the water is presumed to have been present in too small quantity to produce such an effect.

THE MIOCENE BASALTS.

Field Characters and Classification.—The great basalt series above the John Day is mainly built up of heavy lava flows, the interbedded tuffs being relatively of insignificant volume. These tuffs, as far as observed by Dr. Merriam or the writer, are also basaltic. Penetrating the John Day beds at several localities and connected with the overlying lavas are numerous basalt dykes, whose occurrence, combined with the predominance of massive lavas over tuffs, seems to give evidence that the prevailing mode of extravasation was by quiet up-welling from fissures rather than by explosive eruption from craters.

The structural features of the basalts as observed in the field are not especially remarkable. The development of columnar structure in both dykes and flows is general, the size and perfection of the columns increasing with the thickness of the mass in which they occur. The upper portion of the flows have the usual vesicular character, and the slaggy and ropy surfaces have been especially well preserved in certain cases when the overlying layer has been of tuff rather than of lava.

Laboratory investigation has shown that the mineralogical constitution of these basalts is remarkably constant. They are without exception normal olivine basalts of probably the most common type. This uniformity of character is not confined to the limited region discussed in the present paper, but holds good for specimens collected by the writer at various points in Northern Oregon and Central Washington*.

The basic lavas occurring in small volume interstratified with the lowest beds of the Mascall formation are of another type,

* Through the courtesy of Dr. George Otis Smith of the United States Geological Survey, the writer has been enabled to examine sections, prepared in the Survey's laboratory, of basalts collected in the Ellensburg, Washington, quadrangle.

distinguished by the absence of olivine. They will be described, for the sake of ready comparison, in this section, but under a separate heading.

Olivine Basalts.—The differences to be observed in the various specimens of the olivine basalts are chiefly structural. Differences in conditions of cooling have naturally given rise to the various degrees of crystallization, so that we have, on the one hand, intersertal basalts with a large proportion of glassy base, and, on the other, holocrystalline rocks with typical ophitic or granulitic structure. Between these extremes we may trace complete gradations. In view of their mineralogical likeness and structural diversity, the most convenient method of describing this group of rocks will be to consider first the characters of the constituent minerals, and afterward the structural variations.

The primary minerals, in the usual order of abundance, are basic plagioclase, augite, olivine, iron ore, and apatite. All of these may be considered essential except the last, which is an accessory occurring in variable amount. Glass forms an essential part of a large majority of specimens. The secondary minerals are the serpentinoid alteration products of olivine, and analcite and natrolite occurring in amygdaloidal cavities.

The feldspars in every specimen examined seem divisible into two classes on the basis of size; yet, although this distinction has always forced itself upon the observation of the writer, there is usually no such contrast, either in size or form, as exists between the phenocrysts and the groundmass laths of a typical andesite or trachyte. The large feldspars of these basalts are greatly elongated in the direction of the brachyaxis, and more or less flattened on the brachypinacoid. The average relative development in the direction of the three principal axes may be roughly expressed by the proportion $a : b : c :: 6 : 1 : 2$. They are distinguished from the smaller crystals by greater regularity of outline. The feldspars of the small size are generally characterized by skeleton forms and intricate outlines. As inclusions in all the feldspars there are negative crystals of glass clouded with magnetite dust. Less common are magnetite crystals and rounded grains of augite; these occur in the large feldspars, in which they have commonly a zonal arrangement. In polarized light, the albite striation is always visible; Carlsbad twins are extremely common; pericline striation is somewhat rare. The zonal banding is rarely discernible in the smaller laths, but is always developed to a slight extent in the large crystals. By measurement of concurrent extinction angles in Carlsbad twins cut normal to the brachypinacoid, it is found that the plagioclases are all labradorites, ranging from one extreme to the other of that group. The average composition seems to correspond very nearly to the formula $Ab_3\ An_4$; the main portion of the large crystals is usually more basic, and the smaller may be as acid as $Ab_1\ An_1$.

The augite is most frequently of the common pale brown variety. A faint tinge of green is occasionally noticeable. In the more highly crystalline phases of the basalt, the pyroxene is not uncommonly a pale violet brown, titaniferous augite. The fact that this variety is confined to the more crystalline and therefore in general more deeply seated rocks is perhaps significant of some differentiation within the heavy flows. In the hypocrystalline basalts the augite occurs in two generations. The phenocrysts vary in quality of form; a sharp development is commoner in the faces of the prismatic zone than in the terminal faces. Twinning on the brachypinacoid is not infrequent. The common inclusions, besides feldspar and iron ore, are irregular inclusions of glass. The groundmass of the hypocrystalline contains augite generally in the form of minute grains or rods. A peculiar manner of growth for the augite is revealed in certain hypocrystalline basalts, and it will be described in the sequel.

Olivine occurs in somewhat variable quantity, but is always distinctly subordinate to augite. The crystals are generally inferior in size to the larger feldspars, and never large enough to be macroscopically prominent. In form they may be either sharply idiomorphic or somewhat rounded. Inclusions appear to be generally absent. The olivine is never entirely fresh, and is often entirely replaced by secondary material which will be described a short distance below. As a rule, the olivine of the hypocrystalline specimens tends to associate itself with augite.

Iron is always abundant, and may sometimes exceed the olivine in amount. In the glassy basalts it occurs as dust, crystal grains or fern-like skeleton crystals. In the more crystalline basalts it seems to be in rod-like forms, giving lath-shaped sections. The iron ore is believed to be generally or always magnetite, more or less titaniferous. The characteristic form and cleavage of ilmenite were nowhere observed.

The apatite has the usual form of slender hexagonal prisms, often greatly extended in the direction of the vertical axis. Its prominence varies widely in the different specimens owing to the fact, whose demonstration may be more logically presented in the discussion of structure, that apatite is in these rocks one of the later secretions from the magma.

The secondary material, which to a great extent replaces olivine, all seems to belong to the species iddingsite, but presents a wide range of variation in structure and color. The color ranges from reddish brown to deep grass-green. The double refraction appears to be somewhat lower for the latter variety. The iddingsite occurs in these three ways: as pseudomorphs after olivine, as a filling in cavities, and in minute vein-like streaks. The replacement of olivine begins on the outer surface and along the cracks of the original mineral and works inward. The final result of the process carried to its completion may be a pseudomorph of felted scales or fibres, often showing a mesh-structure like that of true serpentine in altered peridotites. On the other hand, the iddingsite may form a true paramorph, behaving optically as a unit, as it does in the typical occurrence described by Professor Lawson.* When this mineral occurs as a filling of cavities, the first layer is generally made up of fibres perpendicular to the walls of the cavity, while the centre is filled in with a fine, irregular, felted aggregate.

In certain vesicular facies of the basalt, good specimens of the zeolites, natrolite and analcite are found. The former occurs in the usual radiate-acicular structure, often forming spherulitic masses an inch in diameter. The analcite occurs as a filling in small cavities, but in many larger cavities it takes the form of beautiful clear trapezohedral crystals implanted in the walls.

We now turn to the consideration of the structural variations

* *Loc. cit.*

of the olivine basalts. It is found that the greater number of specimens may be ranged, on the basis of structure, in a graded series. It would perhaps be possible to obtain in the field specimens of almost undifferentiated glass, but none of those represented in our collection have more than 40 per cent. of glass. The highest term of this series, on the other hand, is represented by a number of holocrystalline, ophitic specimens. In the more crystalline facies, the tendency to develop that type of structure generally is well declared, but in exceptional cases, probably owing to movement in the magma near its period of final consolidation, a typical intersertal structure has been produced.

It will be the endeavor of the writer in the following paragraphs to trace the gradual development of holocrystalline structure. This may perhaps be done most clearly by describing four arbitrarily chosen stages in the development of the ophitic structure, and separately noticing in brief the intersertal variety. The logical order of description is that of increasing crystallization.

A specimen from near the wall of the Davis dyke is perhaps the most glassy of our collection. The characters to be observed in the hand-specimen are the high specific gravity, grayish black color, and fine, compact texture. Abundant minute laths of feldspar may be recognized by the lustre of their basal cleavage-faces; owing to their transparency, they are not distinguished by any difference of color.

Under the microscope the feldspar and augite appear to belong to two generations. The larger crystals of feldspar, generally well formed, are often grouped with large grains of augite, in which case either the boundaries between the minerals are irregular, or the augite appears to have asserted its crystal form against the feldspar. Augite grains are often included in the outer portion of these large crystals. The smaller feldspars exhibit a great variety of splintery, indented and ruin-like forms. The elongated sections often are composed of a number of narrow strips either parallel or sometimes only approximately so, connected by narrow bridges. Cross-sections often show a lining banded parallel to the walls, of a deep green, translucent substance which is apparently isotropic.

The method of growth in the augite seems to be indicated by the following observations: In areas of the cloudy groundmass adjacent to the augite grains, there is seen between crossed nicols an obscure polarization of light. These areas, when the stage is revolved, extinguish as units, generally at the same time with the augite. It appears therefore that most of the augite crystals are surrounded by a sort of delicate sponge of the same mineral, oriented on the parent grain.

In the third stage of crystallization, the structure might be designated as semi-ophitic. The augite and feldspar, and occasionally olivine, may all be distinguished on fresh fractures by the unaided eye, and occasional phenocrysts of feldspar attain a diameter of several millimetres.

The microscopical structure of a specimen of this type is illustrated in Plate 17, fig. 5. Between large plates of augite, in which abundant feldspar laths lie without any rule of orientation, are inclosed angular or irregular areas of hypocrystalline structure, composed of cloudy glass with crystals of feldspar, olivine, and iron ore. In this case olivine is entirely replaced by iddingsite, which also fills macrolitic cavities into which the feldspar crystals project. Apatite needles are abundant in the groundmass, but rarely penetrate the edges of certain augite or feldspar areas.

In a fourth specimen, the holocrystalline character is evident in the hand-specimen, where the surfaces of fracture are entirely determined by the rough black crystal grains of augite, with their included strips of bright feldspar. A few large phenocrysts of yellowish feldspar may be seen, as in the type last described.

Under the microscope, the typical ophitic structure is seen in complete development. The small lath-shaped feldspars and the olivine are idiomorphic against the iron ore, which is in turn idiomorphic against augite. The apatite needles are usually concentrated in certain areas, either of augite or even oftener of feldspar with more or less granular structure, which appear to have been one of the last portions of the rock to crystallize from the groundmass.

The typical intersertal structure is exemplified in a few specimens. Microscopically, these are seen to be composed of feldspar laths without regular orientation, between which lie more or less rounded grains of augite and olivine, iron ore which is in this type characterized by isometric rather than rod-like forms, and a small amount of glass base containing needles of apatite.

From the description given above, we may gather that the general order of crystallizatiou is as follows: Plagioclase, olivine, iron ore, augite, apatite, but an exception seems to occur in the case of some of the feldspar, which is noted in the last paragraph but one. The large crystals of feldspar also have certainly not been formed entirely in a distinct "intratelluric" period; on the contrary, their frequent inclosure of augite shows that they have continued their growth after many of the smaller laths had completed theirs. Evidence in the same direction is the fact that the largest and most distinctly phenocrystic feldspars occur in the most crystalline facies of the basalt.

Olivine-free Basalts in the Lower Mascall.—This is a rock composed essentially of plagioclase and augite, with magnetite as an abundant accessory. Both feldspar and augite occur in two generations, but the feldspar only is recognized macroscopically, imbedded in a grayish black aphanitic groundmass.

The sharply idiomorphic feldspar phenocrysts in the thin sections are found to be almost invariably twinned on the Carlsbad law, and each half of the twin is generally marked by not more than three or four narrow striae on the albite plan. Zonal structure of a peculiar kind is always seen. A large kernel bounded by crystallographic planes, is sharply distinguishable from a peripheral zone, which has a distinctly lower refractive index. In one crystal cut perpendicular to the brachypinacoid, the concurrent angles in the two halves of the Carlsbad twin indicated that the kernel was bytownite and the shell labradorite. Granules of augite are often included in the outer portion of the feldspar phenocrysts. It is possible that the basic kernels of the feldspars are truly intratelluric, and the shells are additions made during the final period of consolidation. The augite, which is pale brownish green, occurs in a few ill-formed phenocrysts often grouped with those of feldspar when the irregular boundaries between the two minerals apparently indicate that they mutually interfered in crystallizing.

The structure of the groundmass is typically intersertal. Between the plagioclase laths lie rounded granules of augite, crystals of magnetite, and a very small amount of brown glass. There are a certain proportion of laths distinguished by their greater size, and these are characteristically interspersed with augite inclusions generally in a row in the centre of the crystal.

The minerals are all perfectly fresh and there is no secondary material to indicate the prior presence of olivine. The rock, however, is classed as a basalt because of the basicity of the feldspars and the important part played by the augite.

ROCKS OF THE MASCALL FORMATION.

General Classification.—The Mascall Formation near its base contains beds probably of organic origin, containing the imprints of leaves. At one locality the section is partly made up of well rounded gravels. But the dominant material resembles the John Day tuffs in texture, in general mode of weathering, and in part in the heavy character of the bedding, though fine lamination and even crossbedding are not uncommon. The material after laboratory examination is believed to be in greater part of pyroclastic origin.

Cañon City Leaf Beds.—The matrix of the leaves at this locality is a white, fine-grained chalky substance, so light that it floats on water. Examined under the microscope, the powder, although it consists largely of fine particles of indeterminate character, contains some bodies that are apparently of organic nature. These include slender rods and, more characteristically, little tubes of circular cross-section, with transverse partitions like stems of bamboo.

Tuffs.—The material in which the fossils are imbedded is usually light-colored, fine-grained and of harsh texture. It is not sufficiently coherent to be cut into macroscopical sections. The rock powder is found to consist in large part of angular glass fragments, with much indeterminate opaque dust and a few glassy and angular grains of feldspar. There is no doubt that these rocks are acid tuffs.

Near the base of the Mascall section at Belshaw's Ranch occurs a somewhat coarser and fresher material. This is a gray friable tuff composed essentially of angular, sometimes vesicular, fragments of clear glass. The only other constituent is feldspar, but the crystals are too rare to afford sufficient material for determination. Following is a chemical analysis of the rock:

	I	II
SiO_2	68.22	74.22
Al_2O_3	12.41	13.50
Fe_2O_3	1.00	1.09
FeO	1.36	1.49
MgO	0.18	0.19
CaO	0.95	1.03
Na_2O	3.38	3.69
K_2O	3.97	4.33
H_2O at 110°	3.42	
H_2O above 110°	4.82	
TiO_2	0.34	0.35
P_2O_5	0.11	0.11
MnO	not det.	
Total	100.16	100.00

I. Rhyolitic tuff, Belshaw's Ranch, Analyst F. C. Calkins.

II. Analysis recalculated on a water-free basis to 100 per cent.

The remarkably high percentage of both hygroscopical and combined water somewhat masks the true character of the rock, by proportionately reducing the apparent percentages of the other oxides. The recalculated analysis shows that the rock is a rhyolite, with potash slightly in excess of soda.

ROCKS OF THE RATTLESNAKE BEDS.

Besides sandstone and conglomerate, the Rattlesnake beds comprise considerable material similar to the common Mascall tuff. It is perhaps in part worked over by water. This will receive but this passing mention.

The coarse tuff occurring near the middle of the section is a porous, light gray rock, composed of angular lapilli with rather numerous grains of feldspar, and comparatively few of quartz and green augite. The feldspar is mostly of an acid triclinic variety, showing fine shadowy striations on the basal cleavage flakes. A few also appear to be sanidine.

The lava which usually underlies this tuff is evidently of the same chemical character. We may abridge its description by referring back to the gray glass rhyolite of the Turtle Cove, to which this rock bears a striking similarity in general appearance, structure of groundmass, and character of phenocrysts. These last are mainly anorthoclase, as proved by the shadowy twin striation, small axial angle, and the characteristic extinction angle measured in several sections normal to the obtuse bisectrix. One nearly uniaxial sanidine crystal was found. An occasional corroded phenocryst of quartz is seen. The groundmass is not clouded as in the Cove rhyolite, but the glass, appearing clear and homogeneous in ordinary light, shows the same shadowy brushes when between crossed nicols.

ROCKS OF RECENT FORMATION.

This material is friable and very fine-grained and of a cream-white color. All but a very small portion is made up of glass fragments which are angular and often filled with vesicles that are usually strongly drawn out in one direction. The remainder consists of crystal grains. These, owing to their having higher specific gravity than the glass fragment, were collected in considerable quantity by mechanical concentration with water. They consist of feldspar, hornblende, hypersthene, and a little augite and magnetite. The large majority of the feldspars are triclinic, as shown by the striation of basal cleavage flakes, and the zonal structure of those lying on the brachypinacoid. In composition they range from labradorite to oligoclase. Some orthoclase is also present, as shown by the presence of basal flakes with straight extinction, and unzoned clinopinocoidal flakes extinguishing at an angle of about 5° from the base. These crystals are often in the form of tablets elongated in the direction of the clino-axis and twinned according to the Carlsbad law by simple juxtaposition of the clinopinacoids. The hypersthene is in well formed prisms; it shows strong pleochroism in shades of green and brown, and straight extinction. The hornblende is also well formed, is greenish brown and pleochroic, and has an extinction angle of 17°.

A chemical analysis by the writer is presented here:

Analysis of Recent Ash, John Day Basin.

SiO_2	66.64
Al_2O_3	13.93
Fe_2O_3	0.95
FeO	1.46
MgO	1.14
CaO	2.61
Na_2O	5.66
K_2O	2.64
H_2O at 110°	1.19
H_2O above 110°	3.81
TiO_2	0.18
P_2O_5	0.12
MnO	not det.
Total	100.33

The analysis has some curiously anomalous features. The ratio of the alkalies is such as commonly obtains in andesites, but the percentage of alkalies is too high, and lime, magnesia and iron too low to agree with any typical andesite. It is suggested that this ash may have come from an andesitic magma, as the crystals would indicate, and that it contains a more than normal proportion of the light pumice grains, the heavier ferromagnesian minerals having mostly fallen closer to the source of eruption.

CONCLUSION.

GENERAL PETROLOGY.

The John Day region, considered as a petrographical province or a part of one, is characterized to a certain extent by the fact that its rocks are all derived from what Rosenbusch calls the gabbro-peridotite and granito-diorite magmas. Rocks allied to nepheline syenite are quite unrepresented. The preponderance of soda molecules over potash in all the rocks analyzed is also a significant fact, and the recurrence of anorthoclase-bearing rhyolites of similar type in Eocene. Miocene and Pliocene times is significant of a certain persistency of petrographical character of the region.

Any comprehensive study of a great series of volcanic rocks should include some attempt to discover whether the succession of chemical types obeyed any definite law. With this end in view, we have tabulated here the succession in the John Day Basin. While in certain details it may be defective or doubtful, it probably gives the main facts with substantial accuracy.

Clarno Eocene	Hornblende-andesite. Pyroxene-andesite, basic. Quartz Basalt. Rhyolite.
John Day Miocene	Trachyte (?) tuff. Andesite tuff. Rhyolite and rhyolite tuff (in small amount). Andesite tuff.
	Basalt, thickness over 2000 feet.
Mascall Miocene	Rhyolite tuff at base. Basalt, interbedded with basal beds. Rhyolite tuffs (probably).
Rattlesnake Pliocene	Rhyolite and rhyolite tuff.

The general order seems to afford a fairly strong confirmation of Iddings's theory that the normal succession is from intermediate to more basic and more acid types.

In the Eocene we seem to have a complete cycle in accordance with this theory. The period extending from the base of the John Day to the top of the Rattlesnake formation may be considered as a second cycle, though the presence of rhyolite, apparently balanced by no corresponding basic eruption, in the middle of the John Day andesite tuffs, indicates an apparent failure of the rule. Since, however, such a basic member was not especially looked for, a failure to observe it does not prove its absence.

The recent ash may represent the first term of a third cycle.

CONDITIONS OF ACCUMULATION OF THE TERTIARY DEPOSITS.

The supposition that the fossil beds of the John Day region were of lacustrine origin seems to have been generally accepted by early writers, perhaps tacitly and without critical examination. Of late, however, this view has been subjected to criticism, and in the writer's opinion shown to be absolutely untenable in connection with the greater part of the deposits in question.

Dr. Merriam* and W. D. Matthew† have discussed the

* *Op. cit.*, p. 299.

† Am. Naturalist, May, 1899, vol. 33,

question and have brought out clearly the fact that the fossils of these beds are terrestrial, to the total exclusion of aquatic forms. Matthew, who advocates the theory of æolian origin for the White River Beds, emphasizes the absence of lamination in those rocks, and the failure of shore features at their contact with older formations. Let us consider what light our petrographic study has thrown upon this problem.

The fact of the great preponderance of pyroclastic material in the tertiary beds of Eastern Oregon, recognized to a certain degree in the field, has been demonstrated by laboratory study. This very fact throws a burden of proof upon any advocate of the lacustrine hypothesis. If the material is not detrital there is no presumption in favor of the supposition that it was laid down by water unless it is shown to have the structural characters of water-laid deposits.

They do not, in the opinion of the writer, possess those characteristics. In materials like the John Day tuff, comprising fragments so different in density as augite crystals and highly vesicular pumices, descending through any considerable depth of water, a sorting action would be exerted and produce lamination. The upper portion of a stratum deposited in a single shower would be composed mainly of the lighter fragments and the base mainly of the heavier fragments. No such lamination was observed. Where a layer of tuff is distinguished by difference of color or hardness from those immediately above and below, it is found to be homogeneous from top to bottom. It appears to the writer that the regularity of the strata on a large scale would be characteristic of material falling from widely spreading clouds of volcanic ash.

The "red beds" of the Lower John Day deserve a paragraph of special comment. The deep brick color of these rocks is due to their impregnation with ferric oxide. The peroxidation of this iron must have been a secondary process which must necessarily have taken place before the material was deeply buried beyond contact with atmospheric influences, and which could not have been accomplished under water. It is believed, then, that the early John Day was a period when thin showers of ash were falling with intervals generally long enough to allow of oxidation *pari passu* with their accumulation. The climate was presumably hot and arid, for the iron seems to be in a condition of low hydration. The rarity of similar red beds in the higher strata may be accounted for by the supposition that they accumulated more rapidly.

The writer of course excepts from the foregoing discussion those laminated beds in the Clarno, Upper John Day, Mascall, and Rattlesnake. These are believed to represent local or temporary variations from the ordinary condition of accumulation. The contrast of their structure with that of the predominant pyroclastic material is an exemplification of the proverbial saying that the exception proves the rule.

EXPLANATION OF PLATE 17.

Fig. 1.—Hornblende-hypersthene Andesite, Clarno's Ferry, showing altered hornblende and feldspar, iddingsite pseudomorphs, and cavities filled with zeolite.

Fig. 2.—Pyroxene Andesite, showing replacement of hypersthene by iddingsite. The groundmass in the field shown is composed of a dozen interlocking crystal grains of alkali feldspar, thickly interspersed with plagioclase microlites and magnetite grains.

Fig. 3.—Green Tuff, Middle John Day, Turtle Cove, showing altered pumice, a fragment of lava, feldspar, and augite.

Fig. 4.—Detail of groundmass of John Day Rhyolite, Antelope.

Fig. 5.—Semi-ophitic Basalt, with plagioclase, olivine (replaced by iddingsite), iron ore and augite in order of crystallization, cloudy glass base, and microlitic cavities filled with iddingsite.

Fig. 6.—Glassy Basalt, The Dalles. Large feldspars partly inclosing augite, which incloses small feldspars. The groundmass is glass charged with magnetite dust and augite-particles, and contains slender prisms of apatite.

University of California,

June, 1902.

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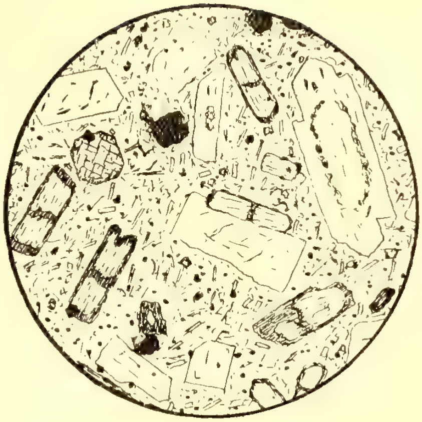

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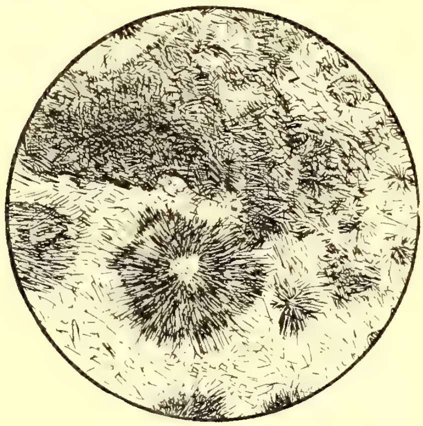

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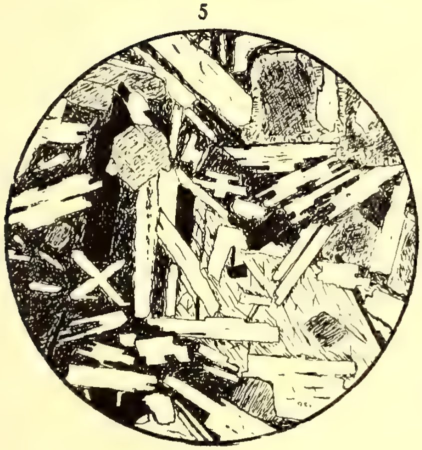

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UNIVERSITY OF CALIFORNIA PUBLICATIONS
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THE IGNEOUS ROCKS

NEAR

PAJARO

BY

JOHN A. REID

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THE IGNEOUS ROCKS NEAR PAJARO.

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JOHN A. REID.

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INTRODUCTORY NOTE.

These notes are offered as a small contribution to the knowledge of the granitic rocks of the Coast Ranges of California. No attempts at the correlation of these rocks have yet been made, and the following notes are presented in the hope that they may be a start in the right direction, and of service to other workers. Several interesting and important questions have arisen, chiefly on the nomenclature of intermediate rock types of basic composition, and it is the aim of this paper to call attention to them.*

*My acknowledgments are due Professor A. C. Lawson, under whose care and advice this work was completed.

OCCURRENCE.

The rock which forms the subject of these notes is exposed at the quarry of the Granite Rock Company on the Pajaro River, about seven miles east of Pajaro station on the line of the Southern Pacific Railroad. It forms the axis of a ridge running approximately N. 35° W., through which the river has cut a gorge five hundred feet deep, the walls on both sides being composed largely of the rock under discussion. Southward along the ridge the rock can be traced on the east flank, by exposures in the gullies, for a mile; further south the overlying sedimentaries cover it completely. To the north of the river cañon no good outcrops have been found, the only indications consisting of surface wash, which contains fragments of the rock, on the west flank of the ridge. In the cañon the north wall, while presenting a few jutting outcrops, is too overgrown with heavy brush or covered with soil to allow much investigation. It is only on the south, where the quarry faces are being worked, that the rock can be well seen.

GEOLOGICAL RELATIONS.

The ridge of which this rock forms the axis is one of a series of parallel ridges composing this portion of the Coast Ranges. From the Pajaro River at the quarry, for three miles south the altitude of the hills is comparatively low, midway between the Santa Cruz Mountains on the north and the Gavilan Range on the south. For lack of a better arbitrary line dividing these two units of the California Coast Ranges, and because the igneous rock to be discussed is probably genetically connected with the granite of the Gavilan Mountains, the Pajaro River will be taken as dividing line, and all south as a portion of the Gavilan Range.

At the point of best exposure of the rock, the San Juan valley lies to the southeast, and the upper Pajaro valley to the west. The Pajaro River approaches from the southeast and flows for half a mile along the line of contact between the plutonic rock and the overlying sedimentaries. It turns then nearly at right angles directly across the ridge, and flows southwestward toward the ocean. A very sharp elbow is thus formed.

The ridge has the nature of a simple fold, with the plutonic rock in the anticlinal axis. On either side are overlying sedimentary rocks, to the west dipping gradually under the valley soil, and to the east buckled into another similar fold. The fold next to the east, however, is exposed only as far south as the river; south of that lies the San Juan valley.

It is at the elbow of the river above mentioned, and at the railroad bridge a quarter of a mile southeast, that the nature of the overlying sedimentary rocks is best seen.

At a point a few yards east of the railroad bridge is found the synclinal axis separating the ridge mentioned from the one to the east. From this point to the elbow of the river these sedimentaries dip at angles varying from from nearly 90° to 40° to the east. They are of soft white shales, with some medium-grained yellowish sandstoue near the bottom, all rather thinly bedded. On the west flank of the ridge near the quarry are found the same series, but nearly all removed by erosion. The sandstone near the base is well exposed, however, dipping 40° to the west. To the north of the quarry, on the west flank of the ridge, the transverse cañons all through the anticlinal axis and beyond the syncline already mentioned, show a well developed sequence of coarse, rather thickly bedded yellowish sandstone below, and white shales, thinly bedded, above. Three miles south of the quarry, on the road from Watsonville to San Juan, the same coarse, heavy-bedded, yellowish sandstones appear on the summit of the ridge. The road here passes through what appears to be the old worn channel of a fairly large stream, being bounded on both sides by water-worn cliffs of sandstone.

No fossils were found in this series of sandstones and shales, hence its age is somewhat uncertain. In lithological characters, however, it corresponds well with the rocks of the lower Monterey. Future research will probably show its close relation to the rocks of this series.

At the quarry, on the west slope of the ridge, is found a later overlying series of friable sandstones, non-coherent sands, and heavily bedded shales. These rocks lie across the truncated edges of the first named series and upon the worn surface of the igneous rock. The sandstone and loose sands, showing the characteristic cross bedding of beach sands, lie lowest, and are covered by a bed of white sandy shale in a single stratum from four to ten feet in thickness. This series of rocks dips at an angle of 15° to the west. The crest of the ridge above the quarry is bare of overlying sedimentary rocks for a hundred yards back from the cañon.

The age of this second series of sandstones and shales is also uncertain, due to lack of sufficient fossils. What shells were found, however, taken in connection with the stratigraphic relations, would make the age probably late Pliocene.

The plutonic rock itself is broken and shattered in all directions, showing the great stresses and movements to which it has been subjected.

PETROGRAPHICAL TYPES.

The plutonic rock, as a mass, is of constant character, but contains both acid and basic modifications in the form of dykes and inclusions. The basic phase, consisting of a darker, finer-grained variety than the main mass, is the oldest portion of the whole, and contains intrusions of all the other phases. The acid variety occurs only in dykes, from the fraction of an inch up to a foot in width, and cuts both the other phases of the rock. However, the basic phase appears to occur chiefly in the west of the exposure, while the acid dykes are more numerous in the east. The dykes are both pegmatitic and aplitic. These four types of the rock will each be taken up in turn and discussed.

THE MAIN MASS.

Macroscopical Characters.—In a hand specimen this rock is seen to consist of black hornblende and a glassy feldspar, of about equal proportions. The hornblende shows a well developed prismatic cleavage, and a slight tendency toward idiomorphic forms. Some of the crystals are 12 mm. in length, but average about 5 mm. The feldspar is in more or less irregular grains, averaging 4 mm. in size. A few of these show cleavage faces. Besides these essential minerals there occur some small flakes, 1.5 mm. in size, of lustrous brown biotite, scattered very sparingly throughout the rock. Wherever the biotite occurs, the surrounding minerals are stained greenish, from the slight alteration of biotite to chlorite. Original pyrite also occurs in small grains.

Microscopical Characters.—Under the microscope the rock is seen to be composed essentially of light and dark green hornblende and a clear vitreous plagioclase, with a little more feldspar than amphibole. Both minerals are in smaller crystals than appears in the hand specimen, each seeming crystal being composed of several distinct smaller ones. The accessory minerals are magnetite, apatite, biotite, and pyrite, in order of relative abundance. The magnetite is in rather large amount, conspicuous under the microscope. Lastly, a little quartz occurs interstitially. The secondary minerals are chlorite, epidote, and a little limonite.

. The hornblende occurs in the usual prismatic form with the faces (110) and (010) developed. The crystals average in length 3.97 mm. with a maximum cross section of .9 mm. Terminal planes are entirely lacking. There are two varieties of the minerals: a dark green, and a light green to nearly colorless. Basal sections show besides the traces of prismatic cleavage, a distinct parting parallel to (100). Longitudinal sections cut parallel or nearly parallel to (010) show also a very distinct parting on $(\bar{h}\ o\ l)$. This parting is developed best in the lighter colored hornblende. The minimum angle observed between this parting plane and the vertical crystallographic axis was 68° 54′, which would make $h = l = 1$ or the cleavage plane $(\bar{1}01)$. The pleochroism is $\mathfrak{c}$ = bluish green; $\mathfrak{b}$ = olive green; $\mathfrak{a}$ = yellow. The absorbtion scheme is $\mathfrak{c} > \mathfrak{b} > \mathfrak{a}$. The two varieties differ in color, intensity of pleochroism, and absorbtion, and the double refraction is a little stronger in the light than in the dark variety. The angle of extinction is the same for both, averaging 16°, and the direction of extinction being nearly at right angles to the transverse parting on $(\bar{1}01)$. Twinning is frequent on (100), the two main divisions of a twin often showing three or four twinned lamellae between them. In sections cut parallel to (010), this twinning causes with the parting on $(\bar{1}01)$ a faint "herring bone" structure similar to that shown by augite.

The two varieties of hornblende are crystallized in perfect continuity with each other. Sometimes the dark mineral is the center of a crystal; sometimes the light forms the neucleus. In general it may be said, however, that the dark green variety is the older and probably the more basic form, as in the majority of cases the light mineral is moulded around it.

The minerals included in the hornblende are magnetite in irregular grains and well-formed crystals, and apatite in small prisms. Some secondary epidote, with its very high birefringence, has been formed, as well as some chlorite. The epidote is often interlocked with fibers of undecomposed hornblende in an intricate manner.

The feldspars under the microscope are very clear, and in most cases free from secondary products. What appears to be single crystals to the unaided eye are found to consist of a number of smaller individuals, with a few traces of idiomorphic boundaries. In size the crystals range from 3.09 mm. at a maximum to less than 1 mm., averaging 1.10 mm. Cleavages parallel to base and brachypinacoid are developed sparingly. The twinning most commonly observed is that on the albite law; often pericline lamellae are seen, and more rarely carlsbad twins. The measurement of the maximum symmetrical extinction angles on the albite lamellae indicate that the feldspars range from andesine, with an extinction angle of 20°, to a medium basic labradorite, with an extinction angle of 41°. However, most of the feldspar corresponds to an acid labradorite, with an extinction angle of 35°. This determination of the feldspars was checked by specific gravity tests, using Klein's solution. A small amount of feldspar came down at 2.64, and a somewhat larger amount at 2.65. The major portion, a little over half, came down at from 2.66 to 2.68, while the remainder did not fall until a specific gravity of 2.70 was reached. Thus the plagioclase is mostly an acid labradorite, with some basic labradorite and considerable andesine.

Zonal structure is common, the zones being usually divided by sharp lines. The most basic feldspar is at the center, and shows a greater number of twinning lamellae than the more acid border. In a few cases the change from basic to acid is a gradual one, a progessive wave of extinction crossing the crystals as the stage of the microscope is revolved. These zonal crystals show the best approach to idiomorphism, except in the cases where quartz is in contact with the feldspar. Inclusions are few, being limited to magnetite and apatite, and secondary products are practically absent.

The biotite shows its usual characteristics. It is red-brown in basal sections, with strong pleochroism in sections perpendicular to the base, showing colors from yellow to deep brown.

The magnetite is a striking constituent of the rock, occurring in large irregular grains up to 1.01 mm. in size. Also it shows well developed crystal form in octahedra. Many of the crystals show striations which may be traces of cleavage, and a brilliantly reflecting surface of a crystal was observed in one slide. The percentage of magnetite in the rock, as extracted by the magnet, is 2.05 per cent. The apatite, in prisms .19 mm. by .045 mm. in diameter, and grains of pyrite in all sizes up to 1 mm. occur in the usual manner and need no detailed description.

The last material to crystallize is some interstitial quartz, sometimes in relatively large grain 2 mm. in size. It is not abundant, and when found, has the usual characteristics of granitic quartz. The minerals in contact with it often exhibit well developed crystal faces.

In structure the rock cames nearest to the granitic, or hypidiomorphic granular, although showing traces of porphyritic. The order of crystallization is, from first to last, magnetite, apatite, hornblende, feldspar, and quartz.

THE BASIC PHASE.

In the hand this rock appears made up of black hornblende and glassy feldspar, of a grain equal to that of a medium fine grained sandstone, the crystals being .5 mm. to 1 mm. in size The dark mineral appears in slight excess, causing the rock to show a very dark color. In the field this variety occurs in inclusions in the main mass from an inch in diameter to large irregular lens-shaped bodies many feet in diameter. These larger occurrences stand nearly vertical and are invaded by small intrusions of the main mass. Some show what appears at first glance to be a flow structure, in fine white lines of feldspar.

Under the microscope the rock is found to consist of green hornblende and plagioclase, with accessory magnetite and apatite. No quartz is present. The two essential minerals are about equal in amount, though variations occur in which horn blende clearly predominates. The grain is fine, the hornblende averaging .31 mm in size of crystals, and the feldspar .25 mm. Very few crystal faces are developed, the rock presenting a good hypidiomorphic granular structure. That which in the hand specimen looks like flow structure is composed of rough lines of feldspar crystals somewhat larger than the average. The hornblende crystals often have a rough approximation to an allignment parallel to these feldspar bands. This would indicate that the rock was subjected to pressure when in a more or less plastic condition. The roughly lens-shaped masses of the rock would seem to indicate the same. In some portions of these bodies the rock has been fractured in parallel lines, which have become filled with secondary epidote.

In those portions of the rock which show no traces of parallel arrangement of the crystals, no decomposition products occur; in that which shows effect of pressure a little hornblende has changed to epidote and the feldspars are clouded.

The hornblende has the same characteristics as that of the main mass. The two varieties, light and dark colored, appear in the same manner. The differences are: first, a much greater tendency to twinning on (100); second, the parting on ($\bar{1}01$) is shown only in a few of the larger crystals; and lastly, no traces of a parting on (100) can be found.

The feldspars occur in crystals elongated parallel to the albite twinning lamellae. Only traces of cleavage are present. Zonal structure is found, but not well developed. The range in composition of these plagioclases is from andesine. with a maximum extinction angle of 20°, to acid labradorite, with a maximum angle of 35°. They thus correspond with the feldspar of the main mass, but are a trifle more acid. All characters are the same. The magnetite is in small grains in size up to .1 mm, scattered throughout. It often shows well developed octahedral form. In this rock phase it also shows undoubted cleavage parallel to the octahedral faces. In some of the larger grains the grinding of the rock slide has caused the appearance of a series of parallel cleavage faces, which show high metallic luster. The biotite and apatite occur in relatively small amount and do not differ from that already commented on.

THE ACID DYKES.

The two rocks already described are cut by a network of small dykes, the rocks composing which range from a fine grained aplitic type to a very coarse grained pegmatite. Intermediate types are also found, as will be discussed later.

Aplite.—In the hand this type is of fine grain, showing clear quartz, a white or pinkish cloudy feldspar, and a small amount lustrous muscovite. The quartz and feldspars appear to be in grains .7 mm. in size, and some of the muscovite flakes are 2 mm. in diameter. The mica, while normally of small amount, in some cases increases so as to make up practically all the rock. Under the microscope the rock is seen to be composed of quartz, orthoclase, microcline, plagioclase, and muscovite, with a very few ragged crystals of hornblende. A few grains of pyrrhotite occur, usually much altered to hematite. Epidote and chlorite occur secondarily derived from the hornblende.

The quartz occurs in irregular grains molded around the other constituents, and is clear and free from inclusions. It makes up about 25 per cent. of the rock. In size of grain it averages .36 mm., with a maximum of 1.46 mm. The orthoclase occurs in slightly larger crystals, elongated parallel to the clino-axis and exhibiting some very good cleavages on the base (001) and (010). The size of the crystals averages .75 mm., with a maximum of 2.95 mm. It is much decomposed, zonal structure being often well developed in the alteration. Kaolin is the chief product of decomposition, though some sericite is formed, the crystals altering from the center outward. The orthoclase often contains inclusions of flakes of muscovite, seemingly parallel to the crystallographic directions (001) and ($\bar{1}$01). Wavy extinction is frequent. The orthoclase makes up between 40 and 50 per cent. of the whole. A small amount of microcline is found, usually in smaller grains than the orthoclase, recognized by its characteristic cross-hatched structure. It crystallized out before the quartz, coincident with the orthoclase. It makes up about 5 per cent. of the rock.

The plagioclase occurs in irregular crystals, of the same size as the potash feldspar. It is twinned only on the albite law.

The maximum extinction angle measured on the albite lamellae, is 9°, which indicate that it is oligoclase. It shows less decomposition than the orthoclase, and no good cleavage. It makes up about 20 per cent. of the rock. Some traces of poikilitic structure were observed, the plagioclase being included in the orthoclase. The muscovite occurs in flakes, averaging .58 mm. in diameter, with well defined basal terminations and ragged edges. It shows the usual high interference tints and strong absorption. A little biotite sometimes occurs, in crystallographic continuity with the colorless mica. The mica makes up about 5 per cent of the rock.

The hornblende, when it occurs, is in small ragged crystals, averaging .25 mm. in size, and of the usual characteristics. It is often altered to chlorite and epidote. A few grains of magnetite are found with the hornblendes. The normal order of crystallization holds, save that the microcline crystallized before the quartz.

Pegmatite.—The other type of dyke rock is a coarse grained pegmatite, consisting, as seen in a hand specimen, of clear quartz, cloudy feldspar, and biotite. The quartz and feldspar are intimately mixed, the individual crystals of each averaging 1 cm. or a little larger, in size. The feldspars, to the naked eye, appear to be of two varieties, one being more cloudy and showing better cleavage than the other. The biotite recurs in large flakes, arranged in all directions through the rock mass. These flakes are often 5 cm. to 7 cm. in diameter. In all of this phase of the rock, taken from the zone of weathering, the biotite was almost completely altered to green chlorite, traces of the original lustrous brown mica remaining in the centers of the largest. There is often an approach to graphic structure with the quartz and the feldspar.

The type of coarse grained pegmatite passes by gradations into the fine grained aplite. The grain becomes finer, muscovite appears in small flakes, and with the disappearance of the biotite the aplitic phase is reached. A phase illustrating very well the intermediate type was found: a normal fine grained granite, with both micas well developed. Also, some varieties of the dyke rocks were found consisting of biotite and muscovite almost entirely, the whole stained green by secondary chlorite.

Under the microscope the quartz and the feldspar are seen to be intricately crystallized in interlocking grains. As with all the other rock types discussed, the grain is finer than appears in a hand specimen.

The quartz is the last mineral to separate out, occurring in large irregular crystals molded on and around the other constituents, It shows undulatory extinction and also a peculiar faint irregularly lined structure between crossed nicols that looks somewhat like an incipient cross-hatched structure of microline. This structure is no doubt due to strains in the rock. Inclusions in the quartz are few. It makes up from 30 per cent. to 50 per cent. of the rock, varying in different parts. The feldspars are orthoclase, microcline and plagioclase. These are associated in a rather complex manner, the relative proportions of each varying in different portions. The orthoclase, however, averages less than in the aplite. It shows no twinning, but cleavages on (001) and (010) are very well developed, that on the base being the better. It is somewhat decomposed into cloudy kaolin, but most of its opaque appearance is due to a great number of inclusions. These are small flakes of muscovite, with many liquid inclusions, and smaller ones that cannot be definitely determined. The orthoclase makes up about 20 per cent. of the rock. The plagioclase shows the usual albite twinning, with a few pericline lamellae. The usual optical methods show it to be oligoclase, as in the aplite. It shows less inclusions and products of decomposition than the orthoclase, with much poorer cleavage. A little calcite is formed secondarily. Checks on the determination of the feldspars were made by specific gravity tests. By Klein's solution the orthoclase, with good cleavage and very cloudy appearance, came down at 2.57, and the clearer plagioclase, with poor cleavage, at 2.63. Also microcline, with its usual characteristics is present sparingly. It appears to have crystallized before the quartz, at the same time as the orthoclase.

The biotite is almost all altered to chlorite in the freshest rock to be obtained. At a later date, when the fresh rock is exposed in the quarry face, further study may be profitable. Hornblende occurs very sparingly as an accessory in small irregular grains much altered to epidote. Its characteristics are the same as in the main mass. Some few grains of highly refractive sphene are also seen.

RHYOLITE.

On the top of the hill above the quarry were found small scattered boulders of disintegration of a rock totally different from any seen in place in the vicinity. The occurrence was limited entirely to a few scattered pieces of the rock, which appear to be remnants of a lava which once mantled a portion of the region. There is no connection between these fragments and the plutonic rocks above described. To the unaided eye the rock is seen to be composed of phenocrysts of clear quartz, a clear feldspar, cloudy feldspar, and biotite, in a trachytic-appearing ground mass of a yellowish gray color. Under the microscope the phenocrysts, in order of relative abundance, are oligoclase, sanidine, quartz, and biotite.

The oligoclase, recognized by its small angles of extinction on on the albite lamellae, makes up about 15 per cent. of the rock. It is in well formed crystals averaging 3 mm. in size, which sometimes show a zonal structure. The sanidine occurs in larger phenocrysts sometimes 6 mm. in size. It is very glassy, and exhibits a rather poor cleavage, which distinguishes it from the quartz. It makes up about 10 per cent. of the rock. The quartz occurs rather sparingly in more or less rounded grains, averaging 2 mm. in diameter. It is free from inclusions, and makes up about 5 per cent. of the whole.

The ground mass is too finely crystalline to be resolved under the microscope into its constituents. It appears almost purely feldspathic, however. Chemical analysis, to determine the silica content, was relied upon to settle the classification of the rock. As given in the table following, the percentage of silica is 74.12. It is therefore a rhyolite.

CHEMICAL CHARACTERISTICS.

Following is a table containing complete and partial analyses of the rocks described in these notes, with a number of similar ones for purposes of comparison:

TABLE I.

	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII
SiO_2	49.26	46.23	53.00	48.90	52.00	55.80	56.52	49.15	45.11	46.85	74.95	74.44	74.12
TiO_2	trace	trace	.57	.26	—	.88	.25	.18	.21	.30	—	—	—
Al_2O_3	16.88	18.29	17.19	16.03	15.75	17.44	16.31	21.90	19.67	20.02	—	—	—
Fe_2O_3	6.49	* 6.55	4.78	12.52	3.55	2.59	4.28	6.60	4.32	2.30	—	—	—
FeO	6.94	* 7.07	5.05	1.12	12.84	4.67	5.92	4.54	8.57	4.60	—	—	—
CaO	7.58	9.99	8.08	8.22	7.39	7.13	6.94	8.22	10.45	13.84	—	—	—
MgO	4.80	7.04	4.66	6.24	3.42	3.59	4.32	3.03	5.65	10.16	—	—	—
MnO	.61	.12	trace	.04	—	.11	.14	—	—	trace	—	—	—
$NiO+CoO$	.05	trace	—	—	—	—	—	—	—	—	—	—	—
Na_2O	3.41	* 3.07	2.92	3.87	3.37	3.67	3.43	3.83	3.87	1.32	—	—	—
K_2O	.72	* .79	1.49	1.17	1.24	2.26	1.44	1.61	.64	trace	—	—	—
SrO	trace	trace	—	—	—	.09	—	—	—	—	—	—	—
ZrO	none	—	—	—	—	—	—	—	—	—	—	—	—
BaO	none	—	—	—	—	trace	—	—	—	—	—	—	—
P_2O_5	.34	* .21	.37	—	1.06	.33	.40	.33	.25	trace	—	—	—
H_2O—110°	.41	.05	1.35	1.66	.35	1.13	1.03	1.92	.83	.88	—	—	—
H_2O+110°	2.90	1.02									—	—	—
S	trace	trace	—	—	—	—	—	—	—	—	—	—	—
CO_2	undet.	—	—	—	.11	—	—	—	—	—	—	—	—
Total	100.39	*100.43	99.46	100.03	100.02	99.88	100.98	101.31	100.07	100.27	—	—	—
Sp. Gr.	2.95	2.98	2.856	2.95					2.865				

* Approx. not checked.

I. Diorite, with some quartz. Pajaro. Reid analyst.
II. Diorite, fine grained. " " "
III. Diorite, Schwarzenberg, Rosenbusch "Gesteinslehre."
IV. Diorite, " hornblende-rich. "
V. Augite diorite, Duluth, A. Streng and J. H. Kloos, "Crystalline Rocks of Minnesota," Neues Jahrbuch, 1877.
VI. Average of analyses of diorites, Pirsson, "Geol. of Little Belt Mts." U. S. G. S. 20th An. Report.
VII. Average of 14 analyses of diorites, Brögger, "Schrifter u.i Vid i. Christ." 1895.
VIII. Hornblende-gabbro, Duluth, A. Streng and J. H. Kloos, "Crystalline Rocks of Minnesota," Neues Jahrbuch, 1877.
IX. Hornblende-gabbro, Lindenfels, Odenwald, Rosenbusch, "Gesteinslehre."
X. Gabbro-diorite. Maryland. G. H. Williams.
XI. Pegmatite. Pajaro. Reid anal.
XII. Aplite. " " "
XIII. Rhyolite. " " "

In Table I, column I gives the analysis of the rock which constitutes the main mass at Pajaro. It is lower in silica and higher in iron than the average diorites. Column II gives the analysis of the finer grained, more basic phase at Pajaro. It is still lower in silica, and higher in iron, lime, and magnesia than the typical diorites. The alkalies show but little change, too small to be of importance. Columns XI, XII, and XIII give the silica contents of the pegmatite, aplite, and rhyolite, respectively. The great difference between the acidity of the dyke rocks and their inclosing rocks is at once apparent. The other columns give analyses of similar rocks taken for purposes of comparison in the discussion of nomenclature.

The following Table II gives the calculated mineral composition of analyses 1 and 2 above. The feldspars are calculated as Ab_1An_1.

TABLE II.

	I	II
Hornblende	55.59	58.80
Plagioclase	39.96	38.82
Magnetite	2.65	2.40
Apatite	1.14	.58
Quartz	.66	none
Total	100.00	100.00

NOMENCLATURE.

General Discussion.—In regard to the nomenclature of these rocks the question of their exact classification naturally arises. Unfortunately, it is yet impossible to assign the igneous rocks to their proper place on but one basis; there is still a clash between the purely mineralogical basis of classification and the purely chemical.

Chemically, the two principal rocks discussed in these notes may be either diorites or gabbros; and II is much nearer a typical gabbro in composition. In Table I is given an average analysis of diorites by Pirsson, column VI, and another by Brögger, in column VII. That of Brögger comes nearest representing a typical diorite. In comparison, it is seen that in VII the silica is considerably higher, while the iron, lime, and magnesia, are lower, than in I and II, II being decidedly more basic. The soda is approximately the same, but the potash is higher in VII, due to some orthoclase being present. Most of the potash belongs with the ferro-magnesian minerals, however. Columns VIII and IX give two anylyses of hornblende-gabbros. Of these, the silica is lower, and the lime and magnesia higher, than in the diorites already cited, VI and VII. The alumina is also higher in the hornblende-gabbros, and the alkalies are about the same. These two rocks are, therefore, decidedly more basic than the diorites. Column X, the gabbro-diorite of Williams, may be taken as a gabroitic rock. On comparing it with II, the more basic of the Pajaro rocks, the main differences are the higher silica, alumina, lime and magnesia, and the lower iron and alkalies; II, therefore, is a little more acid than X. Comparing II with VIII and IX again, it may be seen that II has a lower alumina content, yet on the whole is more basic. As regards I, it is more acid than these gabroitic rocks cited, but corresponds well with analysis IV, a hornblende rich diorite cited by Rosenbusch. Both I and IV are more basic than the typical diorites. Chemically, therefore, I stands intermediate between the diorites and gabbros, while II takes its place with the gabbros.

Mineralogically, the Pajaro rocks, I and II, are unequivocally diorites, being composed of hornblende and a medium basic plagioclase. By all the tests this plagioclase is found to be an acid labradorite or basic andesine. I, while chemically more acid than II, is slightly more basic mineralogically, as it contains a small amount of basic labradorite. The conflict is apparent.

Rock I may be classified without much hesitation as a basic diorite, poor in feldspar, rich in hornblende, and with a very little quartz. This corresponds to the nomenclature of Rosenbusch, as cited in analysis IV. Rock II cannot be so easily disposed of, however, although so similar to I. Such names as hornblende-gabbro, gabbro-diorite, or diorite-gabbro naturally suggest themselves. But in the two cases cited, the term hornblende-gabbro is used to denote rocks containing hornblende as a primary constituent, with augite or diallage and a basic labradorite. Irving* uses the same term to denote a rock with basaltic hornblende, augite, diallage, labradorite essentially, and some accessory biotite, oligoclase, and quartz. This use of the term seems well taken; it should be limited to such rocks. The term gabbro-diorite, as used by Williams, analysis X, denotes a gabbro in which the original pyroxene has been changed to amphibole. In this case the term diorite-gabbro would appear to be better. Brögger has suggested the terms diorite-gabbro and gabbro-diorite for these rocks of intermediate type, but inclines more to the purely chemical differences.

Chemically II could be well placed as a diorite-gabbro, in the use of which term the latter part denotes the type nearest to which the rock approaches. Mineralogically, however, as no trace of a pyroxene exists, the hornblende being all undoubtedly primary and the feldspar an acid labradorite, the use of such a term as diorite-gabbro is not justified. Nor would gabbro-diorite be fully applicable. These two terms should be limited in use to rocks of intermediate mineralogical composition as well as chemical, else no approach to uniformity can ever be reached. Rock II has differentiated on a line not yet covered by proper names. Hence it will also be designated by the simple term diorite, as I, and of very basic composition.

Graphic Representation.—All the analyses of dioritic rocks of Table I, except V, have been plotted in the figure, Plate 18.†

* "Copper-bearing Rocks of Lake Superior." U. S. Geol. Surv. Monograph V.

† Suggested by Dr. A. C. Lawson.

In this triangulation method an equilateral triangle is divided each way into one hundred parts, each division being thus taken as a graphical representation of one per cent. The triangle is not shown in its entirety, as all the plots fall in the lower right-hand corner. The SiO_2 is set off first from the left leg of the triangle and marked on the right leg, making the apex of a new triangle whose altitude is a measure of the acidity or basicity of the rock. The second part of the plot is located by the use of the alumina and total iron percentages, as follows: The alumina content is set off to the right from the left leg of the new triangle, and the total iron is set off from the right leg to the left. The intersection of these two lines gives the second point of the plot. By connecting the two points found by a line the first segment of the plot is found. The second and third points are found in a similar manner, using the lime-magnesia and soda-potassa percentages, respectively. By joining these points by straight lines the plot is completed.

From each point found as above a triangle may be drawn, whose altitude is a measure of the content of the oxides whose lines fall within it. For instance, from the silica point a triangle may be drawn whose altitude measures the total content of the oxide in the rock, and inversely measures the acidity. From the second, the alumina-iron point, a triangle may be drawn whose altitude expresses the content of the lime, magnesia, soda, and potash, and a comparison of this with the first altitude gives the relative proportion of alumina and iron to silica. Similarly the other points serve as the apices of triangles whose altitudes express relative proportions of the different oxides. Also the length of the different segments is a similar measure, and the direction of each indicates the relative abundance of the two oxides whose content determine it.

Each plot thus consists of four points and three segments, which may or may not be calculated on a water-free basis. For the series of igneous rocks, or better, rock magmas, the plots of the basic occupy the left or center of the triangle, while the acid occupy the right. The method is yet not all to be desired, nor fully worked out in all its possibilities, still the plots serve well to bring out the likenesses and differences of the rocks cited.

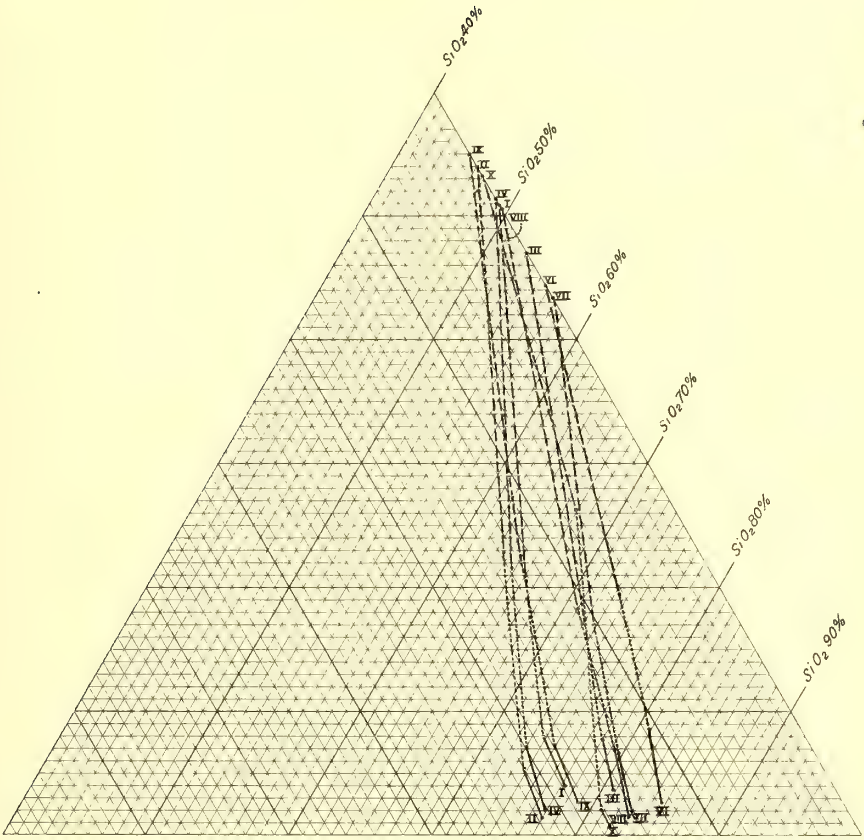
From a comparison of the nine plots, numbered in accordance with Table I, it is seen, first, that the normal diorites are more acid than the two main rocks of these notes. This is shown by the plots of the diorites being farthest to the right, their shorter Al-Fe line, Ca-Mg line, and little longer Na-K line. Second, the rocks I and II show undoubted similarity to the hornblende-gabbros, the Al-Fe line only being a trifle shorter, and to the diorite IV of Rosenbusch, a rock rich in hornblende. Thirdly, the gabbro (gabbro-diorite of Williams), analysis X, shows more basic than all, although poorer in iron. Therefore, from these plots, it appears that from the point of view of composition of igneous magmas, the Pajaro rocks are nearer the gabbros than the diorites.

CONCLUSION.

The igneous rocks at Pajaro represent a good example of the differentiation of igneous magmas. The oldest phase, the fine grained diorite, is the most basic—an ultra-basic diorite. The next in point of age is the main mass of the rock, also a basic diorite. In this phase, the change from the crystallization of the basic minerals to the acid was sudden, as is attested by the sharply zoned feldspars and little interstitial quartz. Through these two rocks were later intruded acid dykes of pegmatite and aplite, high in silica and the alkalies, often containing 50 per cent. orthoclase.

The dioritic rocks had best be called basic diorites, the great balance of their characteristics falling on that side. Their actual nomenclature has, however, disclosed the lack of conformity in rock classification, and it is to be hoped that these notes may be of some small service in calling more careful attention to the general question of the nomenclature of the more basic igneous plutonic rocks.

University of California,
May, 1902.



DIAGRAMATIC COMPARISON OF ANALYSES

Spaces. = 1 per cent.

Al_2O_3 — $FeO + Fe_2O_3$ ————

CaO — MgO ....

Na_2O — K_2O ————

Percentage of SiO_2 indicated by position of initial point of curve on right side of triangle.

LITH BRITTON & REY, S.F.

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MINERALS
FROM
LEONA HEIGHTS
ALAMEDA CO., CALIFORNIA

BY

WALDEMAR T. SCHALLER

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THE BULLETIN OF THE DEPARTMENT OF GEOLOGY OF THE UNIVERSITY OF CALIFORNIA is issued at irregular intervals in the form of separate papers or memoirs, each embodying the results of research by some competent investigator in geological science. It is designed to have these made up into volumes of from 400 to 500 pages. The price per volume is placed at $3.50, including postage. The papers composing the volumes will be sent to subscribers in separate covers as soon as issued. The separate numbers may be purchased at the following prices from the University Librarian, J. C. Rowell, to whom remittances should be addressed:—

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MINERALS FROM LEONA HEIGHTS, ALAMEDA CO., CALIFORNIA

BY

WALDEMAR T. SCHALLER

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INTRODUCTION.

A small body of pyrite occurs near Leona Heights, Alameda Co., Cal., containing some chalcopyrite, and the ore has been mined for a number of years for the manufacture of sulphuric acid. In consequence of the oxidation of the sulphides, several secondary sulphates of iron and copper have been formed in and about the mine, and specimens of these secondary minerals have been collected and studied by the writer. These natural vitriols occur in such good crystals that an interesting crystallographic study can be made of them. Our present crystallographic knowledge of these sulphates has been largely dependent on the study of artificial crystals.

All of the minerals found at this locality, with one exception, were identified with known species. These are Pyrite, Chalcopyrite, Copper, Melanterite, Pisanite, Chalcanthite, Copiapite, Epsomite, Hematite, Limonite and Alunogen (?). Besides these, a copper sulphate with seven parts of water, Boothite, to be described later, was also observed. Of these pyrite, melanterite, pisanite, chalcanthite and boothite occur in good measurable crystals. Copiapite occurs, to some extent, in crystals, but they are all microscopic.

The crystals were measured with the two-circle goniometer, except a very few fragments, which were broken in such a manner as to render their setting up in true polar position impossible. The forms on these fragments were, consequently, determined from measurement of the interfacial angles. While many of the faces gave excellent reflections, the ratios obtained from the two-circle readings were, with one exception, not considered as more accurate than those previously obtained. The one exception is pisanite, for which elements were calculated from the readings. These, it is thought, approximate more closely to the true elements than those which heretofore have been accepted for pisanite.

In the chemical analyses the iron was determined by titration with potassium permanganate, with occasional checks by weighing the iron as ferric oxide. The copper was determined by iodometric titration. The water was weighed directly in a calcium chloride tube, fractional water determinations being usually made. It was found, by experiment, that all of the water of these sulphates was given off below 300° C.

PYRITE.

General Description.—The ore of the Alma Mine consists chiefly of massive pyrite intermixed with some chalcopyrite and usually carrying small values of gold and silver. Crystals of pyrite occur scattered through the rock, which is rhyolite, often largely decomposed to clay. The crystals described here, were collected some years ago at the opening of the mine by Mr. Fritz Böhmer, of Alameda, who kindly placed them at the disposal of the writer.

Crystallographic Characters.—On examination with the lens, the crystals, ranging up to 3 mm. in diameter, and even occasionally somewhat larger, were found to consist principally of the pyritohedron {120}, with occasionally the cube and the octohedron. The cube faces are invariably narrow and the octahedral faces triangular in shape, the latter varying in size up to about one-third the size of the pyritohedron {120}.

All of the larger crystals are more or less rounded and the faces uneven and often dented, always giving a large number of reflections. The ten forms below were definitely established and a few more possibly are present, but on account of the lack of sharpness of the signals, their identification is somewhat uncertain.

Letter.	Symbol.		Letter.	Symbol.	
	Gdt.	Miller.		Gdt.	Miller.
a	0∞	100	*o*	1	111
d	∞	110	*ω*	$1\frac{5}{2}$	252
δ	$\infty\frac{4}{3}$	340	*n*	12	121
e	$\infty 2$	120	*t*	24	241
h	$\infty 4$	140	*s*	23	231

The forms {100}, {110}, {340} and {140} occur as narrow and rounded faces. Of the other forms only {120} and {111} were well developed. The remainder were all small and the complete number of faces belonging to each form was not always present.

The following table shows the measurements together with the calculated angles for these forms.

No.	Letter.	Symbol.		Measured.		Calculated.	
		Gdt.	Miller.	ϕ	ρ	ϕ	ρ
1	*a*	0∞	100	0°00′	90°00′	0°00′	90°00′
2	*d*	∞	110	44 54	"	45 00	"
3	δ	$\infty\frac{4}{3}$	340	37 01	"	36 52	"
4	*e*	$\infty 2$	120	26 30	"	26 34	"
5	*h*	$\infty 4$	140	14 12	"	14 02	"
6	*o*	1	111	45 12	54 45	45 00	54 44
7	ω	$1\frac{5}{2}$	252	46 36	29 31	"	29 30
				20 46	71 24	21 48	69 37
8	*n*	12	121	44 45	33 46	45 00	35 16
				26 28	66 10	26 34	65 54
9	*t*	24	241	14 20	64 52	14 02	64 07
				26 15	77 06	26 34	77 23
10	*s*	23	231	23 45	37 18	26 34	36 42
				18 38	57 44	18 26	57 41
				33 46	75 29	33 41	74 30

The combinations of forms on the measured crystals are shown in the following table:

Cryst. No.	*a*	*d*	δ	*e*	*h*	*o*	ω	*n*	*t*	*s*
1	*a*	—	—	*e*	—	*o*	—	*n*	—	—
2	*a*	—	—	*e*	*h*	*o*	—	*n*	—	*s*
3	*a*	*d*	δ	*e*	*h*	*o*	ω	*n*	*t*	*s*
4	*a*	—	—	*e*	—	*o*	ω	*n*	*t*	*s*
5	*a*	*d*	δ	*e*	—	*o*	ω	*n*	—	*s*

Chemical Properties.—Chemical tests showed that the crystals of pyrite contained no copper. The massive ore, however, gave a reaction for copper, which probably comes from the admixed chalcopyrite. Other elements, such as arsenic or thallium were not tested for.

CHALCOPYRITE.

Some portions of the massive ore show a sulphide having the color of chalcopyrite and affording a qualitative test for copper. No crystals of chalcopyrite were met with; neither were any large masses of pure chalcopyrite found.

COPPER.

Native copper occurs very sparingly in a shaft sunk some distance above the Alma Mine, as small arborescent groups consisting of irregularly grouped, distorted crystals, possibly octahedrons.

MELANTERITE.

General Description. — The ferrous sulphate, melanterite, occurs rather widely distributed as an efflorescence, but only in small quantities. In the mine it occurs as small prismatic crystals, up to 2 mm. in size. A pale green mineral, probably melanterite, occurs with a deposit of copiapite near the mine.

Crystallographic Characters.—One specimen of loose crystals of various minerals, collected in the mine, shows a few minute well-formed crystals of melanterite, elongated in the direction of the vertical axis and giving an extinction angle, with the direction of elongation, of about 20°. The crystals measured average in size about 2 mm. in length and $\frac{1}{5}$ mm. in thickness. Some of the crystals are well developed, the faces, especially the prism {110} and the base {001}, giving perfect reflections.

Fifteen forms, besides a few vicinal ones, were observed on the nine crystals measured. Of these seven are new. These forms are quoted below in two columns, those in the second column being the new forms:

Letter.	Symbol.		Letter.	Symbol.	
	Gdt.	Miller.		Gdt.	Miller.
c	0	001	*l*	$\infty 2$	120
b	0∞	010	*d*	$+\frac{1}{2}0$	102
m	∞	110	*k*	$+\frac{2}{3}0$	203
w	$+\frac{1}{3}0$	103	*x*	$+\frac{3}{2}0$	302
v	$+10$	101	*q*	$+20$	201
o	01	011	*j*	$+\frac{9}{4}0$	904
r	$+1$	111	*B*	$+\frac{3}{2}$	332
σ	-12	$\bar{1}21$			

The measured and calculated angles are given in the table below for the forms observed on these crystals.

No.	Letter.	Symbol.		Measured.		Calculated.	
		Gdt.	Miller.	ϕ	ρ	ϕ	ρ
1	c	0	001	89° 59′	14° 14′	90° 00′	14° 16′
2	b	0∞	010	0 00	90 00	0 00	90 00
3	m	∞	110	41 06	"	41 06	"
4	l	∞2	120	24 11	"	23 34	"
5	w	$+\frac{1}{3}0$	103	89 59	35 01	90 00	35 06
6	d	$+\frac{1}{2}0$	102	90 15	42 27	"	42 50
7	k	$+\frac{2}{3}0$	203	"	48 44	"	49 02
8	v	+10	101	89 49	58 22	"	58 00
9	x	$+\frac{3}{2}0$	302	90 15	66 18	"	66 15
10	q	+20	201	"	71 28	"	71 22
11	j	$+\frac{9}{4}0$	904	"	73 00	"	73 03
12	o	01	011	9 22	57 18	9 21	57 24
13	σ	—12	$\bar{1}21$	19 43	73 26	19 29	73 00

For the two forms $r = \{111\}$ and $B = \{332\}$, in the zone $c\ m$, the following interfacial angles were measured and calculated:

	Measured.	Calculated.
$c:r = (001) : (111) =$	55° 55′	55° 59′
$c:B = (001) : (332) =$	63° 13′	63° 13′

Of the seven new forms, five were positive orthodomes, occurring on one crystal. Each form gave a distinct signal so that the faces did not insensibly grade into one another.

$l = \infty 2 = \{120\}$. This new prism was present on two crystals as a fairly large form. The reflections, in both cases, were but fair.

$d = +\frac{1}{2}0 = \{102\}$. This dome was relatively a large face, about equal in size to $w = \{103\}$. The reflection was fair.

$k = +\frac{2}{3}0 = \{203\}$. This form was not quite as broad as the preceding dome.

$x = +\frac{3}{2}0 = \{302\}$. Two occurrences of this dome were noted, on crystal No. 5, as a very narrow face, and on crystal No. 8, as a broader face.

$q = +20 = \{201\}$. This form was a very narrow dome.

$j = +\frac{9}{4}0 = \{904\}$. This dome was also very narrow. The crystal on which these domes occurred was somewhat bruised below this form, so that it is possible that another dome, large and triangular in shape, possibly $\{301\}$, was originally present.

$B = +\frac{3}{2} = \{332\}$. This pyramid was observed on two fragments. It gave good reflections.

Figs. 1–3, Plate 19, show some of the combinations observed on these crystals.

Besides these forms, given above, a few vicinal ones were observed on crystal No. 6, of which the symbols calculated from the measurements and the probable true symbols, are given below.

Calculated symbols.	Probable symbols.
$\{5.1.12\}$	$\{102\}$
$\{7.14.2\}$	$\{120\}$
$\{\bar{6}.12.5\}$	$\{\bar{1}21\}$

The habit of the crystals is prismatic with the unit prism and the base the predominating forms.

The following table shows the combinations of the forms on the crystals:

Cryst. No.	c	b	m	l	w	d	k	v	x	q	j	o	r	B	σ
1	c	—	m	—	—	—	—	—	—	—	—	—	—	—	—
2	c	—	m	—	—	—	—	—	—	—	—	—	r	B	—
3	c	b	m	—	—	—	—	—	—	—	—	o	—	—	—
4	c	—	m	—	—	—	—	—	—	—	—	—	—	—	—
5	c	—	m	—	w	d	k	v	x	q	j	—	—	—	—
6	c	b	m	l	w	—	—	—	—	—	—	—	—	—	σ
7	—	—	m	—	w	—	—	v	—	—	—	—	—	—	—
8	c	b	m	l	—	—	—	—	x	—	—	—	—	—	—
9	c	—	m	—	—	—	—	—	—	—	—	—	r	B	—

The axial ratio, $a : b : c = 1.1823 : 1 : 1.5421$; $\beta = 104° \ 14'$, was calculated from the three following measurements of interfacial angles, in preference to a calculation from the averages of p'_0, q'_0 and e', since the polar adjustment was not perfect.

$$c : m = (001) : (110) = 80° \ 42'$$
$$c : o = (001) : (011) = 56° \ 13'$$
$$m : m' = (110) : (1\bar{1}0) = 97° \ 47'$$

This ratio agrees very closely with the one obtained by Zepharovich,* which is

$$a : b : c = 1.1828 : 1 : 1.5427; \ \beta = 104° \ 15\tfrac{1}{2}'.$$

* Zeitschr. Krys. 1880, 4, 107.

A calculation of the seven new forms to correspond to Goldschmidt's Winkeltabellen is given in the following table, based on the elements derived by Zepharovich:

Number.	Letter.	Gdt.	Miller.	ϕ	ρ	ξ_0	η_0	ξ	η	x' (Prism) $(x:y)$	y'	$d' = \text{tg}\,\rho$
1	*l*	$\infty 2$	120	23° 34′	90° 00′	90° 00′	90° 00′	23° 34′	66° 26′	0.4363	∞	∞
2	*d*	$+\frac{1}{2}0$	102	90 00	42 50	42 50	0 00	42 50	0 00	0.9271	0	0.9271
3	*k*	$+\frac{2}{3}0$	203	"	49 02	49 02	"	49 02	"	1.1515	"	1.1515
4	*x*	$+\frac{3}{2}0$	302	"	66 15	66 15	"	66 15	"	2.2732	"	2.2732
5	*q*	$+20$	201	"	71 22	71 22	"	71 22	"	2.9666	"	2.9666
6	*j*	$+\frac{9}{4}0$	904	"	73 03·	73 03·	"	73 03·	"	3.2828	"	3.2828
7	*B*	$+\frac{3}{2}$	332	44 29·	72 52	66 15	66 38	42 02·	42 58·	2.2732	2.3141	3.2438

Physical Properties. — The determination of the optical properties gave results agreeing with those already determined. A cleavage piece (parallel to the base) showed, with convergent light, a biaxial interference figure, with a large angle. The trace of the axial plane was parallel to the trace of the clinopinacoid. Tests with the quartz wedge showed that this section was normal to an axis of maximum elasticity, that is, it gave a negative sign. As, however, the obtuse bisectrix emerges on the base, the mineral is positive with $Bx_a = \mathfrak{c}$, nearly parallel to the clino-axis.

The cleavage is basal, perfect. The mineral is colorless to very pale green. In its pyrognostic characters, it agrees well with those already ascribed to melanterite.

Chemical Properties.—Only a very small quantity of material could be collected for an analysis, which, in consequence, is only approximate and serves but to identify the mineral. It is worth noting that no magnesia could be detected. The analysis gave:

	Analysis.	Calc. for Melanterite.
FeO	28.1	25.9
SO_3	31.2	28.8
H_2O	42.0	45.3
CuO, MgO	none	
	101.3	100.0

This gives the formula, $FeSO_4+7\ H_2O$.

According to fractional water determinations, $\frac{6}{7}$ of the water is given off at a temperature of about 110°, while a temperature above 200° is necessary to drive off the remaining molecule. It would thus seem as if the last molecule might be considered as constitutional, only six molecules being water of crystallization. Following the suggestion of Prof. Remsen,* the structural formula for melanterite may be written,

$$OS\left\langle\begin{array}{l}\left.\begin{array}{l}O\\O\end{array}\right>Fe\\ \left.\begin{array}{l}O\\O\end{array}\right>H_2\end{array}\right. + 6\ H_2O.$$

PISANITE.

General Description.—The most abundant secondary mineral occurring in the mine is pisanite. Long prisms of this mineral are seen almost everywhere and large magnificent specimens are rather abundant, especially near the mouth of the northern tunnel. Unfortunately, on the slightest jarring most of the crystals readily detach themselves from the rock. Many of the crystals seem to have formed directly on the rock and were lying loose; unattached. Others again were feebly united to the rock, especially at one end of the prisms and these hung downward in large groups. No radial or other regular grouping of the crystals was observed. The specimens are quite free from other minerals, the conditions, at the time of formation of the crystals, seeming to have been just right for pisanite and not right for any other mineral.

The mineral probably crystallized out from a solution of iron and copper sulphates. Zonal structure, though common in the artificial crystals, was not observed in the natural ones. Inclusions of pyrite are not uncommon and drusy pyrite frequently covers the crystals to a large extent.

Crystallographic Characters.—The crystals average about 5 mm. in length and about 1 mm. in thickness. Many are much longer and the thickest one measured 3 mm. by 4 mm. on the base. Certain crystals of pisanite had been partially dissolved, the re-solution going on with a remarkable difference in

* Inorganic Chemistry, by Ira Remsen, 5th edition, 1898, pp, 218, 709.

rapidity in different directions. Many of the crystals are hollow, the inside being entirely dissolved away. Occasionally portions of the prism faces are also dissolved, leaving merely shells.

Hitherto, our knowledge of the crystallography of pisanite has been limited to the results obtained by Des Cloizeaux, who derived his elements from three interfacial angles. The method of measurement, with the two-circle goniometer is peculiarly well adapted for the determination of the axial elements since all of the readings can be used. From the average values of p'_0, q'_0 and e', and the readings on the prism faces, the following axial ratio was obtained by the writer:

$$a:b:c = 1.1670 : 1 : 1.5195;\ \beta = 105^\circ\ 11'.$$

The ratio does not vary much from that obtained by Des Cloizeaux, namely: $a:b:c = 1.1609:1:1.5110$; $\beta = 105^\circ\ 22'$, but is believed to be nearer the true one. The crystals were readily adjusted in true polar position, as usually all four of the prism faces were present and all gave excellent reflections.

In all, seventeen forms were observed, of which ten are new. These forms are given below in two columns, those in the second column being the new ones.

Letter.	Symbol. Gdt.	Symbol. Miller.	Letter.	Symbol. Gdt.	Symbol. Miller.
c	0	001	a	$\infty 0$	100
b	0∞	010	h	2∞	210
m	∞	110	f	$\frac{3}{2}\infty$	320
w	$+\frac{1}{3}0$	103	l	$\infty 2$	120
t	-10	$\bar{1}01$	v	$+10$	101
o	01	011	g	$-\frac{2}{5}0$	$\bar{2}05$
π	$-\frac{1}{2}$	$\bar{1}12$	r	$+1$	111
			E	$-\frac{3}{5}$	$\bar{3}35$
			D	-2	$\bar{2}21$
			σ	-12	$\bar{1}21$

The angles measured, together with those calculated from the elements obtained by the writer, for the forms, are given in the table below.

Number.	Letter.	Symbol.		Measured.		Calculated.	
		Gdt.	Miller.	ϕ	ρ	ϕ	ρ
1	*c*	0	001	90° 00′	15° 11′	90° 00′	15° 11′
2	*b*	0 ∞	010	0 02	90 00	0 00	90 00
3	*a*	∞ 0	100	89 32	"	90 00	"
4	*h*	2∞	210	60 25	"	60 37	"
5	*f*	$\frac{3}{2}$∞	320	53 26	"	53 06	"
6	*m*	∞	110	41 36	"	41 36	"
7	*l*	∞ 2	120	23 45	"	23 56	"
8	*w*	+$\frac{1}{3}$0	103	90 00	36 00	90 00	35 48
9	*v*	+10	101	90 02	58 12	"	58 19
10	*g*	−$\frac{2}{5}$0	$\bar{2}05$	90 03	15 00	"	15 01
11	*t*	−10	$\bar{1}01$	90 02	47 13	"	47 09
12	*o*	01	011	10 28	57 03	10 07	57 04
13	*r*	+1	111	46 43	65 35	46 50	65 46
14	*π*	−$\frac{1}{2}$	$\bar{1}12$	27 22	40 21	27 57	40 42
15	*E*	−$\frac{3}{5}$	$\bar{3}35$	30 28	46 28	30 33	46 38
16	*D*	−2	$\bar{2}21$	39 04	75 25	38 37	75 35
17	*σ*	−12	$\bar{1}21$	19 40	72 25	19 32	72 46

The following are the new forms, briefly described:

a = ∞0 = {100}. The orthopinacoid was noted twice, once as a broad face and once as a narrow face.

h = 2∞ = {210}. This prism was noted on three crystals, as rather large faces.

f = $\frac{3}{2}$∞ = {320}. On crystal No. 1 was noted a small face in the prism zone, the measurement of which agrees well with the calculated value, though the reflection was very poor.

l = ∞2 = {120}. This prism always occurred with *h*, and was about equal to it in size. Crystal No. 15 showed the three new forms, *a*, *h* and *l*, in the prism zone.

v = +10 = {101}. Only once was this form noticed, as a small face with a poor reflection.

g = −$\frac{2}{5}$0 = {$\bar{2}05$}. This dome also occurred but once as a rather large face. It gave a good reflection.

r = +1 = {111}. The unit pyramid was represented by a long narrow face, giving a good reflection.

$E = -\frac{3}{5} = \{\bar{3}35\}$. This form was noted but once as a long narrow face. The face is in the zone *c m*.

$D = -2 = \{\bar{2}21\}$. This form occurs on two crystals. The reflections in both cases were fair.

$\sigma = -12 = \{\bar{1}21\}$. A small face represents this form.

The base and the unit prism are the predominating forms, the other forms being subordinate in size. The common habit is long prismatic. Most of the crystals show only the two forms *c* and *m*. The crystals measured and shown in Figures 4–7, Plate 19, are not so long, and consequently deviate slightly from the common long prismatic habit.

Seventeen crystals were measured, of which two showed only the unit prism faces, both ends being broken off. Many more were examined with a lens, but no other forms were seen. The combinations seen on these crystals are shown in the following table:

Cryst. No.	*c*	*b*	*a*	*h*	*f*	*m*	*l*	*w*	*v*	*g*	*t*	*o*	*r*	π	*E*	*D*	σ
1	*c*	—	—	—	*f*	*m*	—	—	—	—	—	*o*	—	π	—	*D*	—
2	*c*	—	—	—	—	*m*	—	—	—	*g*	—	—	—	—	—	—	—
3	*c*	—	—	*h*	—	*m*	*l*	—	—	—	*t*	—	*r*	—	—	—	—
4	*c*	—	—	—	—	*m*	—	—	—	—	*t*	—	—	—	*E*	—	—
5	*c*	*b*	—	—	—	*m*	—	*w*	—	—	—	*o*	—	π	—	—	—
6	*c*	—	—	—	—	*m*	—	—	—	—	*t*	*o*	—	—	—	—	—
7	*c*	—	—	—	—	*m*	—	*w*	—	—	—	—	—	—	—	—	—
8	*c*	—	—	—	—	*m*	—	—	—	—	*t*	—	—	—	—	—	—
9	*c*	*b*	—	—	—	*m*	—	—	—	—	—	*o*	—	π	—	*D*	—
10	—	—	—	—	—	*m*	—	—	—	—	—	—	—	—	—	—	—
11	*c*	*b*	—	—	—	*m*	—	—	—	—	—	—	—	—	—	—	—
12	—	—	—	—	—	*m*	—	—	—	—	—	—	—	—	—	—	—
13	*c*	*b*	—	—	—	*m*	—	—	—	—	—	—	—	—	—	—	—
14	—	*b*	—	*h*	—	*m*	*l*	—	—	—	—	—	—	—	—	—	—
15	*c*	—	*a*	*h*	—	*m*	*l*	—	—	—	—	—	—	—	—	—	σ
16	—	—	—	—	—	*m*	—	—	—	—	*t*	*o*	—	—	—	—	—
17	*c*	—	*a*	—	—	*m*	—	—	*v*	—	—	—	—	—	—	—	—

All of the forms observed by Des Cloizeaux were noted on these crystals, except $-\frac{8}{9} = \{\bar{8}89\}$ and $-\frac{5}{22} = \{\bar{5}.5.22\}$, which are probably vicinal.

In the following table the values are derived from the measurements by the writer, and show a slight difference from those given by Goldschmidt:

$a = 1.1670$	$\lg a = 0.06707$	$\lg a_0 = 9.88537$	$\lg p_0 = 0.11464$	$a_0 = 0.7680$	$p_0 = 1.3021$
$c = 1.5195$	$\lg c = 0.18170$	$\lg b_0 = 9.81830$	$\lg q_0 = 0.16628$	$b_0 = 0.6581$	$q_0 = 1.4665$
$\left.\begin{matrix}\mu = \\ 180 - \beta\end{matrix}\right\}$ 74° 49′	$\left.\begin{matrix}\lg h = \\ \lg \sin \mu\end{matrix}\right\}$ 9.98457	$\left.\begin{matrix}\lg e = \\ \lg \cos \mu\end{matrix}\right\}$ 9.41814	$\lg \frac{p_0}{q_0} = 9.94836$	$h = 0.9651$	$e = 0.2619$

Number.	Letter.	Gdt.	Miller.	ϕ	ρ	ξ_0	η_0	ξ	η	x' (Prism) $(x:y)$	y'	$d' = \operatorname{tg}\rho$
1	*c*	0	001	90° 00′	15° 11	15° 11′	0° 00′	15° 11′	0° 00′	0.2714	0	0.2714
2	*b*	0 ∞	010	0 00	90 00	0 00	90 00	0 00	90 00	0	∞	∞
3	*a*	∞0	100	90 00	"	90 00	0 00	90 00	0 00	∞	0	"
4	*h*	2 ∞	210	60 37	"	"	90 00	60 37	29 23	1.7758	∞	"
5	*f*	$\frac{3}{2}$ ∞	320	53 06	"	"	"	53 06	36 54	1.3319	"	"
6	*m*	∞	110	41 36	"	"	"	41 36	48 24	0.8879	"	"
7	*l*	∞2	120	23 56	"	"	"	23 56	66 04	0.4440	"	"
8	*w*	+$\frac{1}{3}$0	103	90 00	35 48	35 48	0 00	35 48	0 00	0.7211	0	0.7211
9	*v*	+10	101	"	58 19	58 19	"	58 19	"	1.6206	"	1.6206
10	*g*	−$\frac{2}{5}$0	$\overline{2}05$	$\overline{90}$ 00	15 01	$\overline{15}$ 01	"	$\overline{15}$ 01	"	$\overline{0}.2683$	"	0.2683
11	*t*	−10	$\overline{1}01$	"	47 09	$\overline{47}$ 09	"	$\overline{47}$ 09	"	$\overline{1}.0778$	"	1.0778
12	*o*	01	011	10 07·	57 04	15 11	56 39	8 29	55 42·	0.2714	1.5196	1.5436
13	*r*	+1	111	46 50·	65 46	58 19	"	41 42	38 35	1.6206	1.5196	2.2215
14	*π*	−$\frac{1}{2}$	$\overline{1}12$	$\overline{27}$ 57·	40 42	$\overline{21}$ 58	37 13·	$\overline{17}$ 48	35 10	$\overline{0}.4032$	0.7598	0.8602
15	*E*	−$\frac{3}{5}$	$\overline{3}35$	$\overline{30}$ 33	46 38	$\overline{28}$ 17	42 21·	$\overline{21}$ 41	38 45·	$\overline{0}.5381$	0.9117	1.0587
16	*D*	−2	$\overline{2}21$	$\overline{38}$ 37	75 35	$\overline{67}$ 36·	71 47	$\overline{37}$ 11	49 11	$\overline{2}.4270$	3.0392	3.8890
17	*σ*	−12	$\overline{1}21$	$\overline{19}$ 32	72 46	$\overline{47}$ 09	"	$\overline{18}$ 37	64 11	1.0778	"	3.2245

Physical Properties.—The plane of symmetry is also the plane of the optic axes. A section of the mineral cut approximately parallel to the clinopinacoid showed that the axis of elasticity nearly parallel to the clino-axis was the axis of minimum elasticity. A section cut normal to this axis of elasticity, showed, in convergent light, a biaxial interference figure with a large angle. This figure also showed its positive character. A cleavage piece (parallel to the base) also showed a figure nearly equal in size to the first one seen but perhaps a trifle larger. This latter figure gave a negative sign, with the quartz wedge. The mineral is therefore positive with the obtuse bisectrix emerging nearly normal to the basal pinacoid. The mineral agrees, therefore, in its optical properties with pisanite.

The mineral does not occur massive but only in crystals. Concretionary and stalactitic forms were not met with. The mineral is blue in color, vitreous and transparent when free from any coating of pyrite. It is very brittle and shows a good basal cleavage. The crystals, which have lain in trays, exposed to the air for almost a year, have not become ocherous externally. Exposed to the sunlight, however, they become white and opaque.

Cold water readily dissolves the crystals, from which solution ferric hydrate is copiously precipitated on heating. Its pyrognostic characters are similar to those of melanterite, except that it readily gives a reaction for copper. Heated in a closed tube, it readily melts in its water of crystallization and on stronger ignition is reduced to a black, magnetic mass. Its hardness is about 2.5 and its specific gravity is close to 1.8–1.9.

Chemical Properties.—It was not possible to pick out enough material for an analysis, without including a good deal of pyrite. The abundance of the mineral, however, allowed of several analyses of different specimens, the average of which analyses is seen in the table below.

	Average Analysis.	Same with Insol. deducted.	Molecular Ratio.	Calculated.
CuO	13.39	15.73	1.11	14.11
FeO	10.48	12.31	.97	12.75
SO_3	24.02	28.21	2.00	28.40
H_2O	38.44	45.14	14.23	44.74
Insol.	14.85	....	......	....
	101.18	101.39		100.00

The last column is the calculated percentage for the formula $CuO.\ FeO.\ 2SO_3 + 14\ H_2O$.

Water was given off at the temperatures stated in the following proportions:

		Ratio.
H_2O (110°)	33.58	6.11
H_2O (above 200°)	4.86	.89

Practically no water is given off between 110° and 200°. It would thus seem as if $\frac{6}{7}$ of the water content of pisanite is given off at a low temperature and that nearly twice that temperature is necessary to expel the last molecule of water, a fact which suggests that, structurally, the six molecules play a different *rôle* from the seventh. The six molecules are water of crystallization while the seventh is constitutional water.

As with melanterite, the formula for pisanite may be written,

$$OS \left\langle \begin{matrix} O \\ O \end{matrix} \!>\! R \atop \begin{matrix} O \\ O \end{matrix} \!>\! H_2 \right. + 6\ H_2O$$

where R represents (Fe,Cu) in the ratio of 1:1. Pisanite may then be regarded as a salt of tetrahydroxyl sulphuric acid, OS $(OH)_4$, in which half of the hydrogen is replaced by iron and copper in equal proportions.

Just what the temperature is, at which all of the six molecules of water of crystallization are driven off, is difficult to say. It is probably not far from 100°–110°. A temperature of about 250° will probably expel all of the water of the mineral.

A partial analysis of a specimen of pisanite, with a larger amount of insoluble matter, gave:

		Ratio.
CuO	8.60	.99
FeO	7.61	.97
SO_3	17.53	2.00

We thus have good evidence that the pure crystals of pisanite have the definite formula $FeO.CuO.2SO_3.2H_2O+12\ H_2O$.

The original analysis of pisanite, by Pisani,* gives a ratio agreeing quite well with this formula. His analysis, together with the ratios calculated therefrom, is:

		Ratio.
CuO	15.56	1.04
FeO	10.98	.82
SO_3	29.90	2.00
H_2O	43.56 (by diff.?)	12.95
	100.00	

Analyses of other specimens show that this ratio is not necessarily constant. The material is much poorer and is not in good crystals, like the pisanite already described. An analysis of the specimen collected by Mr. Booth is given in the table below. In the last column is given the composition calculated from the formula $2FeO.CuO.\ 3SO_3+21\ H_2O$.

* Comptes Rendus, 1859, 48, 807

	Analysis.	Insol. deducted.	Ratio.	Calculated.
CuO	8.13	9.22	.95	9.45
FeO	14.53	16.47	1.88	17.08
SO_3	25.74	29.18	3.00	28.53
H_2O	40.34	45.74	20.88	44.94
Insol.	11.80	....	....	....
	100.54	100.61		100.00

Water was given off at the temperatures stated in the following proportions:

		Ratio.	
H_2O (102°)	34.68	17.96 or	5.99
H_2O (above 102°)	5.66	2.92	.97

Crystallographically and optically the properties of the two substances are identical. Some of the material was dissolved in water, the gangue filtered off and the filtrate slowly evaporated. A little sulphuric acid was added to prevent the precipitation of the iron as a basic salt. Crystals were obtained, isomorphous with pisanite, and having a definite ratio of FeO to CuO of 2:1. A mixture of artificial sulphate of copper and iron in the proper proportion was dissolved in water and allowed to evaporate. Crystals were obtained, having the definite composition expressed by the formula, $2FeO.CuO.3SO_3+21H_2O$. The crystals are isomorphous with pisanite, and showed the forms, $\{001\}$, $\{110\}$, $\{103\}$, $\{101\}$, $\{011\}$ and $\{\bar{1}21\}$. The axial ratio calculated from a few poor readings is:

$$a:b:c=1.1739:1:1.5218;\ \beta=104°\ 30'$$

The artificial salt corresponding to this formula has been described by von Hauer and the crystals measured by Brezina,* who made them triclinic. It is interesting to note that the crystals of pisanite, described by Hintze† and of which a partial analysis is given, also correspond fairly well with this formula. His analysis gives only determinations of CuO and SO_3. Assuming that no gangue was present in his material, his analysis becomes:

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* Pogg: Annalen 1865, p. 635.

† Zeitsch. Krys. 1878, 2, 309.

		Calc. for formula.
FeO	(16.15)	17.08
CuO	10.07	9.45
SO_3	28.84	28.53
H_2O	(44.94)	44.94
	100.00	100.00

Still a third specimen of pisanite shows a variation from either of the two specimens described. The most noticeable difference is the presence of about three per cent. of magnesia. The material is somewhat impure and not in good crystals. In the last column, below, is the calculated percentage for the formula $3CuO.FeO.MgO.5SO_3.5H_2O + 30H_2O$. The analysis gave:

	Analysis.	Insol. deducted.	Ratio.	Calculated.
CuO	16.40	17.95	3.09	17.28
FeO	4.99	5.46	.99	5.21
MgO	2.58	2.82	.99	2.92
SO_3	26.72	29.25	5.00	28.97
H_2O (110°)	31.28	34.25	26.00	39.10
H_2O (above 110°)	10.01	10.96	8.32	6.52
Insol.	8.67	......	....	....
	100.65	100.69		100.00

Though the fractional water determination is not very good, it would seem as if the formula of this mineral might be written

$$OS\left\langle\begin{matrix}O\\O\end{matrix}>R \atop \begin{matrix}O\\O\end{matrix}>H_2\right. + 6H_2O\text{, where } R = (Cu,Fe,Mg) \text{ in the ratio of } 3:1:1.$$

If we consider the magnesia as replacing part of the iron, the formula becomes $3CuO.2FeO.5SO_3+35H_2O$, which is not far from pisanite, taken two and a half times, $2\frac{1}{2}CuO.2\frac{1}{2}\ FeO.5SO_3+35H_2O$.

The mineral, described and named *salvadorite* by W. Herz,* is of especial interest as differing somewhat from normal pisanite. It is probably a variety of pisanite, in which the copper predominates, approximating the formula $2CuO.FeO.3SO_3+21H_2O$.

BOOTHITE.

General Description.—One of the secondary minerals occurring in the Alma mine proves on investigation to be a new copper

* Zeitschr. Kryst. 1896, 26, 16.

sulphate crystallizing with seven parts of water instead of five, as is the case with chalcanthite.

The mineral occurs massive, with a crystalline structure, and also as fibrous fragments, differing somewhat in physical properties from the massive variety. Chalcanthite is intimately associated with the massive variety.

Crystallographic Characters.—Two incomplete crystals of boothite were obtained which showed, with one or two exceptions, only one face of each of the forms present.

The crystals are monoclinic and have the following eight forms:

Letter.	Symbol. Gdt.	Miller.
c	0	001
a	∞0	100
m	∞	110
t	—10	$\bar{1}01$
z	—30	$\bar{3}01$
π	—½	$\bar{1}12$
e	—1	$\bar{1}11$
σ	—12	$\bar{1}21$

The angle β was measured directly and is probably fairly accurate. From the average of several calculations of p'_0 and q'_0, together with β, an axial ratio was calculated which is to be considered as approximate. The calculations gave:

$$a:b:c = 1.1622:1:1.5000,\ \beta = 105^\circ\ 36'.$$

The angles measured, together with those calculated for these forms, from the axial ratio just given, are quoted below:

Number.	Letter.	Symbol. Gdt.	Miller.	Measured. ϕ	ρ	Calculated. ϕ	ρ
1	c	0	001	90° 00′	15° 36′	90° 00′	15° 36′
2	a	∞0	100	"	90 00	"	90 00
3	m	∞	110	41 10	"	41 47	"
4	t	—10	$\bar{1}01$	90 01	46 20	90 00	45 37
5	z	—30	$\bar{3}01$	89 54	74 39	"	74 29
6	π	—½	$\bar{1}12$	27 29	41 17	27 31	40 13
7	e	—1	$\bar{1}11$	34 35	61 25	35 16	61 26
8	σ	—12	$\bar{1}21$	19 46	72 49	19 28	72 33

The combinations of the forms on the two crystals (Figs. 8 and 9, Pl. 19) are shown in the following table:

Cryst. No.	c	a	m	t	z	π	e	σ
1	c	a	m	—	—	π	e	—
2	—	a	m	t	z	π	—	σ

$c = 0 = \{001\}$. The base occurred only on one crystal. The reflections were excellent from both faces.

$a = \infty 0 = \{100\}$. The orthopinacoid was present on both crystals but gave only a good reflection on the one crystal.

$m = \infty = \{110\}$. The prism faces were small and very poorly developed. The reflections were poor.

$t = -10 = \{\bar{1}01\}$. This dome occurred as a large face. The reflection was fair.

$z = -30 = \{\bar{3}01\}$. This form occurred as a face not so large as t, the reflection being but fair.

$\pi = -\frac{1}{2} = \{\bar{1}12\}$. This pyramid was noted on both crystals.

$e = -1 = \{\bar{1}11\}$. This pyramid and the preceding one occurred on one crystal, the unit pyramid being rather large. The faces lay in the zone cm.

$\sigma = -12 = \{\bar{1}21\}$. This form occurred as two large faces, the reflections being, however, poor.

The following table gives the calculation of the forms observed:

$a = 1.1622$	$\lg a = 0.06528$	$\lg a_0 = 9.88919$	$\lg p_0 = 0.11079$	$a_0 = 0.7747$	$p_0 = 1.2906$
$c = 1.5000$	$\lg c = 0.17609$	$\lg b_0 = 9.82391$	$\lg q_0 = 0.15978$	$b_0 = 0.6667$	$q_0 = 1.4447$
$\left.\begin{matrix}\mu = \\ 180-\beta\end{matrix}\right\}74^\circ 24'$	$\left.\begin{matrix}\lg h = \\ \lg \sin\mu\end{matrix}\right\}9.98370$	$\left.\begin{matrix}\lg e = \\ \lg \cos\mu\end{matrix}\right\}9.42962$	$\lg \frac{p_0}{q_0} = 9.95101$	$h = 0.9632$	$e = 0.2689$

Number.	Letter.	Gdt.	Miller.	ϕ	ρ	ξ_0	η_0	ξ	η	x' (Prism) $(x:y)$	y'	$d' = \operatorname{tg}\rho$
1	c	0	001	90° 00′	15° 36′	15° 36′	0° 00′	15° 36′	0° 00′	0.2792	0	0.2792
2	a	$\infty 0$	100	"	90 00	90 00	"	90 00	"	∞	0	∞
3	m	∞	110	41 47	"	"	90 00	41 47	48 13	0.8933	∞	"
4	t	—10	$\bar{1}01$	$\overline{90}$ 00	45 37	$\overline{45}$ 37	0 00	$\overline{45}$ 37	0 00	$\bar{1}.0217$	0	1.0217
5	z	—30	$\bar{3}01$	"	74 29	$\overline{74}$ 29	"	$\overline{74}$ 29	"	$\bar{3}.6030$	"	3.6030
6	π	$-\frac{1}{2}$	$\bar{1}12$	$\overline{27}$ 31	40 13	$\overline{21}$ 21	36 52	$\overline{17}$ 22	34 56	$\bar{0}.3908$	0.7500	0.8457
7	e	—1	$\bar{1}11$	$\overline{35}$ 16	61 26·	$\overline{46}$ 41	56 18·	$\overline{30}$ 28	45 49	$\bar{1}.0608$	1.5000	1.8372
8	σ	—12	$\bar{1}21$	$\overline{19}$ 28·	72 33	"	71 34	$\overline{18}$ 32·	64 05	"	3.0000	3.1820

Physical Properties.—An examination of the crushed massive material on the stage of the microscope showed several roughly square cleavage plates (parallel to the base) which, with convergent light, showed a biaxial interference figure with a large angle. From a study of this figure the following facts were ascertained. The optic axial plane is parallel to the clinopinacoid. The bisectrix emerging nearly normal to the base is an axis of maximum elasticity. The mineral boothite agrees thus with melanterite and pisanite and like them is probably positive, the obtuse bisectrix emerging on the base.

The cleavage is basal, imperfect. Several of the long fibrous fragments show numerous cracks parallel to the base and transverse to the direction of elongation. The hardness of the mineral is 2 to 2.5, and the specific gravity about 2.1. The color is blue, like chalcanthite, except perhaps a little paler blue. Many of the specimens have whitened on exposure to the air, showing that the mineral is probably unstable in dry air. In the fibrous pieces the luster is decidedly silky or pearly, while in the more massive variety it is vitreous.

Chemical Properties.—The mineral is readily soluble in cold water, and in its pyrognostic characters behaves like chalcanthite. It does not fuse in a closed tube, but whitens, and finally, upon strong ignition, becomes black.

Two analyses of fresh material were made, one of the fibrous fragments and one of the more massive material. Both lead to the same formula. The water was weighed direct in a calcium tube, and the copper determined in the usual volumetric way. The mean analysis of the fibrous fragments gave:

	Analysis.	Insol. deducted.	Ratio.	Calculated.
CuO	26.80	27.83	1.00	27.85
FeO, MgO	trace	trace	....	......
SO_3	27.32	28.37	1.00	28.02
H_2O (105°)	35.29	36.64	5.80	37.83
H_2O (above 105°)	7.14	7.42	1.19	6.30
Insol.	3.70	....	....	....
	100.25	100.26		100.00

The analysis of the massive mineral gave the following results:

	Analysis.	Insol. deducted.	Ratio.	Calculated.
CuO	27.52	28.53	1.00	27.85
FeO	0.27	0.28	......	....
MgO	trace	trace	......	.....
SO_3	27.63	28.65	1.00	28.02
H_2O	42.21	43.76	6.78	44.13
Insol.	3.54	......	....	......
	101.17	101.22		100.00

The ratio of $CuO:SO_3:H_2O$ in both is 1:1:7; $\frac{6}{7}$ of the water or 6 molecules being given off at 105°. This mineral may then also be considered as a salt of tetrahydroxyl sulphuric acid. The formula for boothite then becomes $CuSO_4.H_2O+6H_2O$, or, writing it structurally,

$$OS\left\langle\begin{array}{l}\left.\begin{array}{l}O\\O\end{array}\right>Cu\\\left.\begin{array}{l}O\\O\end{array}\right>H_2\end{array}\right. + 6\ H_2O.$$

As has been shown for manganese sulphates,* the amount of water of crystallization depends on the temperature at which crystallization takes place. The same law doubtless holds good for copper sulphate. It is probably due to this fact that we have a copper sulphate crystallizing with seven parts of water instead of five. The temperature at which this septahydrate of copper forms is probably near 0° C., a temperature which must often be reached in the Alma mine.

The name *boothite* is proposed for this new sulphate of copper, in honor of Mr. Edward Booth of the Department of Chemistry, University of California, who was the first to direct the writer's attention to this deposit of sulphates.

The three minerals, melanterite, pisanite and boothite, form an isomorphous series whose general formula may be written, $RSO_4.H_2O+6H_2O$. They are all monoclinic and their axial ratios vary but little.

	a	c	β
Melanterite	1.1828	1.5427	104° 16′
Pisanite	1.1670	1.5195	104 30
Boothite	1.1622	1.5000	105 36

* Dr. F. G. Cottrell, Journ. of Phys. Chem., Vol. IV, p. 637, 1900.

CHALCANTHITE.

General Description.—Chalcanthite is, next to pisanite, the most abundant secondary mineral in the mine. It occurs as drusy coatings on the massive ore and on the timbers of the mine, and as loose crystals. The loose crystals are of a dark blue color, while the drusy coatings vary in color from a light blue to a pale green.

Crystallographic Characters.—The crystals vary in size, the drusy crystals being very small, while the loose dark blue crystals average about $1 \times 3 \times 5$ mm. Many, however, are very much larger, the largest one found measuring $4 \times 10 \times 35$ mm. Most of the crystals are not rich in forms, but occasionally a crystal was found which showed quite a rich combination. The following fourteen forms were observed on the seven crystals measured, two of which, $l = \{120\}$ and $g = \{1\bar{4}1\}$, are new:

Letter.	Symbol. Gdt.	Symbol. Miller.	Letter.	Symbol. Gdt.	Symbol. Miller.
c	0	001	*v*	01	011
b	0∞	010	*q*	$0\bar{2}$	$0\bar{2}1$
a	$\infty 0$	100	*w*	$0\bar{3}$	$0\bar{3}1$
m	∞	110	*p*	$\bar{1}0$	$\bar{1}01$
l	$\infty 2$	120	*s*	$\bar{1}1$	$\bar{1}11$
M	$\infty\overline{\infty}$	$1\bar{1}0$	*z*	$\bar{1}3$	$\bar{1}31$
h	$\infty\bar{2}$	$1\bar{2}0$	*g*	$1\bar{4}$	$1\bar{4}1$

The measurements, with the calculated values, taken from Goldschmidt's Winkeltabellen, are given in the following table:

Number.	Letter.	Symbol. Gdt.	Symbol. Miller.	Measured. ϕ	Measured. ρ	Calculated. ϕ	Calculated. ρ
1	*c*	0	001	31° 57′	29° 59′	31° 54′	29° 46′
2	*b*	0∞	010	0 00	90 00	0 00	90 00
3	*a*	$\infty 0$	100	79 16	"	79 19	"
4	*m*	∞	110	53 03·	"	53 03	"
5	*l*	$\infty 2$	120	37 10	"	37 14	"
6	*M*	$\infty\overline{\infty}$	$1\bar{1}0$	110 34	"	110 33	"
7	*h*	$\infty\bar{2}$	$1\bar{2}0$	133 11	"	133 11	"
8	*v*	01	011	16 45	47 55	15 56	47 45
9	*q*	$0\bar{2}$	$0\bar{2}1$	154 48	35 24	155 24	35 59
10	*w*	$0\bar{3}$	$0\bar{3}1$	165 52	51 25	166 13·	51 47
11	*p*	$\bar{1}0$	$\bar{1}01$	$\overline{67}$ 02	37 30	$\overline{67}$ 39	37 41·
12	*s*	$\bar{1}1$	$\bar{1}11$	$\overline{39}$ 08	48 46	$\overline{39}$ 30	48 19·
13	*z*	$\bar{1}3$	$\bar{1}31$	$\overline{153}$ 27	56 29	$\overline{153}$ 22·	57 54
14	*g*	$1\bar{4}$	$1\bar{4}1$	140 36	64 32	140 45	64 23

$l = \infty 2 = \{120\}$. This new prism was observed but once, as an extremely narrow face, giving, however, a fairly good reflection.

$g = 1\bar{4} = \{1\bar{4}1\}$. This new pyramid was observed on only one crystal, though both faces of the form are present, one face giving a good reflection and the other face a poor one. The form lies in the zone *M w*.

The crystals show two habits. In one the form $p = \{\bar{1}01\}$ is very large, and the crystals are tabular parallel to this form and sometimes extremely thin. In the second habit the prism zone is well developed, and the faces elongated somewhat in the direction of the vertical axis, giving a prismatic habit to the crystals. Other forms are abundant on crystals of this latter habit, notably the domes, $p = \{\bar{1}01\}$, $q = \{0\bar{2}1\}$ and $w = \{0\bar{3}1\}$. Figs. 10, 11, Plate 19, show the two habits.

The combinations occurring are given in the following table:

Cryst. No.	*c*	*b*	*a*	*m*	*l*	*M*	*h*	*v*	*q*	*w*	*p*	*s*	*z*	*g*
1	—	—	*a*	*m*	—	*M*	—	—	—	—	*p*	—	—	—
2	—	*b*	*a*	*m*	—	*M*	—	—	*q*	—	*p*	—	—	—
3	—	*b*	*a*	*m*	—	*M*	*h*	—	*q*	*w*	*p*	—	*z*	*g*
4	—	—	*a*	*m*	—	*M*	—	—	*q*	*w*	*p*	—	—	—
5	*c*	*b*	*a*	*m*	—	*M*	*h*	—	—	—	*p*	*s*	—	—
6	*c*	*b*	*a*	*m*	*l*	*M*	*h*	*v*	*q*	*w*	*p*	*s*	—	—
7	—	*b*	*a*	*m*	—	*M*	*h*	—	*q*	—	*p*	—	*z*	—

The following table gives a calculation of the two new forms, $l = \{120\}$ and $g = \{1\bar{4}1\}$:

Number.	Letter.	Gdt.	Miller.	ϕ	ρ	ξ_0	η_0	ξ	η	x' (Prism) $(x:y)$	y'	$d' = \mathrm{tg}\,\rho$
1	*l*	$\infty 2$	120	37° 14′	90° 00′	90 00′	90° 00′	37° 14′	52° 46′	0.7601	∞	∞
2	*g*	$1\bar{4}$	$1\bar{4}1$	140 45	64 23	52 50	$\overline{58}$ 14	34 47	$\overline{44}$ 17	1.3193	$\bar{1}$.6147	2.0851

Chemical Properties.—All of the analyses showed merely a trace of magnesia, and no iron. The crystals represent, therefore, a rather pure copper sulphate. The average of the analyses gave:

	Analysis.	Ratio.	
CuO	31.14	.97	
FeO	none		
MgO	trace		
SO_3	32.06	1.00	
H_2O (110°)	28.20	3.91	4.95
H_2O (above 110°)	7.50	1.04	
Insol.	.81		
	99.71		

Considering, as before, that the water given off at 110° is water of crystallization, while the remaining molecule is constitutional water, we may write the formula of chalcanthite, $CuSO_4.H_2O+4H_2O$, or structurally,

$$\mathrm{OS}\left\langle\begin{matrix}\begin{matrix}\mathrm{O}\\ \mathrm{O}\end{matrix}>\mathrm{Cu}\\ \begin{matrix}\mathrm{O}\\ \mathrm{O}\end{matrix}>\mathrm{H_2}\end{matrix}\right. +4H_2O.$$

This formula differs from that of boothite only in the fact that it has four molecules of water of crystallization, instead of six.

COPIAPITE.

General Description.—A yellow ferric sulphate is quite abundant, both at the mine and in the immediate neighborhood, which agrees well in its various properties with copiapite. Some distance from the mine, on what is probably an old prospecting dump, a thick layer of copiapite occurs which was selected for the analyses. Some distinct, though microscopic crystals, occur associated with pisanite, but the entire amount of this material is too small for a chemical analysis.

Under the microscope, with the highest power, the minute crystals are seen to be six-sided tabular crystals, nearly colorless and nonpleochroic if thin, but somewhat pleochroic if rather thick. The pleochroism is colorless to pale yellow. Cleavage is perfect parallel to the plates, which are probably copiapite crystals tabular to the clinopinacoid. They are too small to show the emergence of a bisectrix.

Chemical Properties.—Under the microscope the material analysed was seen to consist of a granular mass with no distinct crystals, with which a few colorless prisms were intermixed. Some of these prisms give parallel extinction and are probably epsomite while others give varying angles of extinction up to about 20° and were possibly melanterite. The amounts of ferrous iron, magnesia and alumina varied somewhat in different samples. The average of several analyses of this material gave the following results:

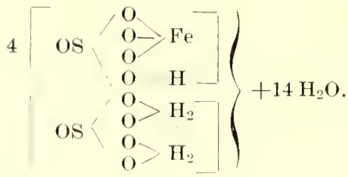
	Analysis.	Ratio.	
Fe_2O_3	25.04	15.65	
Al_2O_3	0.31	0.30	= 2.0
FeO	0.44	0.61	
MgO	0.29	0.73	
SO_3	38.36	47.95	= 5.5
H_2O	29.71	165.06	= 19.1
Insol.	5.43		
	99.58		

A fractional determination of the water gave:

H_2O (at 110°)	20.25
" (at 150°)	3.10
" (at 200°)	2.26
" (at 260°)	1.77
" (above 260°)	2.33
	29.71

These water determinations were not carried out very accurately but they show that about two-thirds of the water is given off at 110°. To assume that exactly two-thirds or 12 molecules of the water are given off at 110°, which is probably water of crystallization, would give us, for the formula of copiapite, $2Fe_2O_3.5SO_3.6H_2O+12H_2O$. If, now to obtain the acid of which copiapite is the ferric salt, we substitute for Fe''' its equivalence 3H, we obtain $2(3H)_2O_3.5SO_3.6H_2O+12H_2O$. Neglecting the twelve molecules of water of crystallization, and reducing the first part of the formula, we obtain $6H_2O.5SO_3$ $6H_2O=5H_2SO_4.7H_2O$ as the acid from which copiapite is derived —a very improbable acid.

If, however, we assume that fourteen molecules of the water, instead of twelve, are water of crystallization, we then have $2Fe_2O_3.5SO_3.4H_2O+14H_2O$. as a formula for copiapite. Again substituting 3H for Fe''', this becomes $6H_2O.5SO_3.4H_2O+14H_2O$., or, neglecting the fourteen molecules of water, $2H_2O.SO_3 = H_2SO_4.H_2O$, which latter is tetrahydroxyl sulphuric acid, as the acid of which copiapite is the ferric salt. This formula would require that 24.2 per cent. of water be given off at the first temperature, about 110°. Structurally, the formula for copiapite would then become,



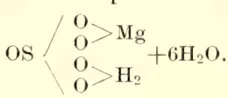
EPSOMITE.

General Description.—Epsomite occurs in the mine, and was also frequently observed in the immediate vicinity, as an efflorescence. It occurs as bent and curved fibrous prisms, showing, however, no crystal surfaces. Under the microscope the prisms give straight extinction.

Chemical Properties.—The analysis served merely to identify the mineral.

	Analysis.	Insol. deducted.	Calculated.
MgO	12.4	14.8	16.3
SO_3	26.5	31.7	32.5
H_2O (110°)	34.1	40.8	51.2
H_2O (above 110°)	10.2	12.2	
Insol.	16.3	......	
Al_2O_3	trace	trace	
FeO, CuO	none		
	99.5	99.5	100.0

The formula for epsomite may be written, like that of melanterite,



ALUNOGEN.

A coating of white powder, intimately associated with pieces of copper sulphate, covers the bunkers in front of the mine. The powder is readily soluble in cold water, which solution gave tests for copper from the admixed copper sulphate, aluminum, sulphuric acid and water, with traces of ferrous iron and magnesia. Under the microscope the mass consists of a granular aggregate of a white mineral, only partially transparent. The mineral agrees, so far as can be determined, with alunogen, and is tentatively referred to that species.

Besides the efflorescences of epsomite in the neighborhood, an occasional specimen was met with which, besides giving a test for magnesia, showed also the presence of aluminum in fairly large quantities. It is probably a mixture of alunogen and epsomite. All of the specimens were, however, impure and dehydrated to some extent, so that no analysis was made of any of these aluminium sulphates.

HEMATITE AND LIMONITE.

The alteration of pyrite is usually accompanied by the formation of oxides of iron, and both hematite and limonite occur at the mine. The hematite is in the form of a compact red ochre. A specimen gave 10 per cent. of water, which may have been occluded, or the mineral may be classed as turgite. The limonite occurs mostly as yellow ochre, although occasionally it is in compact brown masses.

SUMMARY.

By the study of the sulphate crystals formed by the oxidation of the pyrite ore, ten new forms are established for pisanite, seven for melanterite and two for chalcanthite. A new sulphate of copper containing seven molecules of water, instead of five, occurs as one of the secondary minerals, to which the writer gives the name *boothite*. The three minerals,, pisanite, melanterite and boothite form an isomorphous series.

The theory is advanced that all of these hydrous sulphates may be regarded as salts of tetrahydroxyl sulphuric acid, since they apparently contain one molecule of constitutional water.

In conclusion, the writer wishes to express his thanks to Dr. Arthur S. Eakle, under whose guidance the investigations were carried out. Also to Dr. W. C. Blasdale and Mr. Booth of the Chemical Department, and to Mr. Storch, the superintendent of the pyrite mine, grateful acknowledgements are due, for much assistance.

University of California,
April, 1903.

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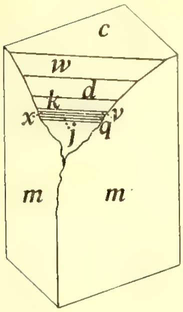

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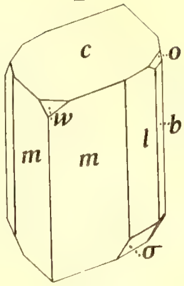

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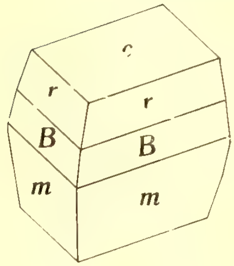

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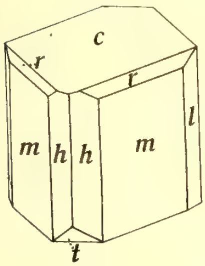

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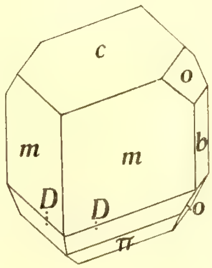

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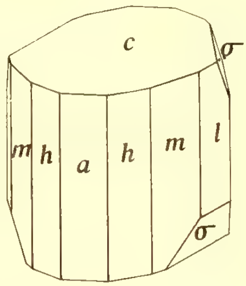

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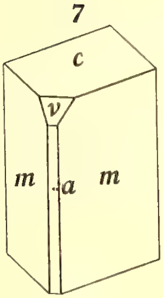

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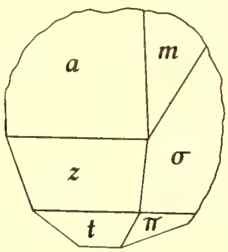

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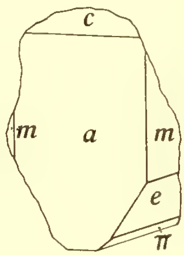

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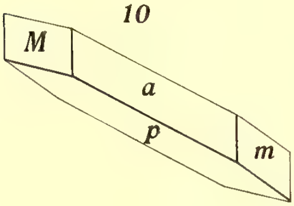

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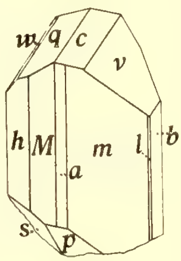

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Bulletin of the Department of Geology

Vol. 3, No. 8, pp. 219-229. ANDREW C. LAWSON, Editor

PLUMASITE

AN OLIGOCLASE-CORUNDUM ROCK

NEAR SPANISH PEAK, CALIFORNIA

BY

ANDREW C. LAWSON

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APRIL, 1903

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UNIVERSITY OF CALIFORNIA PUBLICATIONS
Bulletin of the Department of Geology
Vol. 3, No. 8, pp. 219-229. ANDREW C. LAWSON, Editor

PLUMASITE

AN OLIGOCLASE-CORUNDUM ROCK

NEAR

SPANISH PEAK, CALIFORNIA

BY

ANDREW C. LAWSON.

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Recent Recognition of Corundiferous Rocks.—One of the notable features of petrographic research during the past few years has been the discovery in several widely separated portions of the earth's surface of rocks in which the mineral corundum plays the rôle of a normal constituent. The mineral has long been known as an interesting accessory in certain granite rocks and as a not uncommon occurrence in certain metamorphic schists and crystalline limestones. But the interest attaching to these occurrences has been almost purely mineralogical, and they have contributed but little to petrological science. Even in the latest text-books corundiferous igneous rocks are not discussed. In the last edition of Iddings' translation of Rosenbusch's "Mikroskopische Physiographie," 1898, it is asserted that "corundum never occurs as an essential constituent of rocks, with the exception of emery, which, together with iron oxides, forms independent bodies in the crystalline schists. It appears only as an accessory constituent in granites, gneisses, granular limestones and dolomites, and is constantly accompanied by spinel, rutile and sillimanite."

In Rosenbusch's last book, "Elemente der Gesteinslehre," 1898, rocks of this interesting character are not recognized. These facts are not mentioned by way of criticism of the text-books, but simply to emphasize the recency and practical simultaneity of the various discoveries referred to. These discoveries have, moreover, been supplemented, and, indeed, in a large measure anticipated, by the brilliant synthetic studies of Morozewicz.*

In contrast to the state of knowledge at the date of the text-books above referred to we have to-day a considerable body of information on the occurrence and character of corundiferous igneous rocks. In India Holland† has described a corundum syenite. In Russia Morozewicz has described corundum syenite and corundum pegmatite from the Urals‡ as well as a more basic type consisting of anorthite and corundum together with some biotite with accessory spinel, apatite and zircon, to which he gives the name Kyschtymite. In Eastern Ontario, Canada, there have been discovered areas of corundiferous syenites, nepheline-syenites and anorthosites which are the most extensive and important occurrences of corundiferous igneous rocks at present known, whether they be regarded from a petrological standpoint or as a source of supply for the best quality of abrasive material. These rocks have been described by Professor W. E. Miller§ and others. The occurrences of corundiferous rocks in the United States has recently been reviewed by J. H. Pratt.|| The most noteworthy occurrences are those of Montana,

* Experimentelle Untersuchungen über die Bildung der Minerale im Magma, Tschermak's M.u.P.M. N.F. Band XVIII, 1899.

† Manual of the Geology of India, Economic Geology, Pt. 1, 1898. Memoirs, Geological Survey of India, Vol. XXX, Pt. 3, 1901.

‡ Op. cit.

§ Rpt. Bureau of Mines, Vol. VIII, 2nd pt., 1899, Toronto.

|| U.S.G.S. Bull. 180, 1901.

where corundum is found as an original constituent of certain lamprophyre dykes in Yogo Gulch described by Pirsson,* who refers its origin to endomorphism of the magma by absorption of the adjacent shales. A corundiferous mica-augite-andesite at Ruby Bar, Montana, is described by Kuntz,† and Pratt has noted a corundiferous augite-mica-syenite from the same or a neighboring locality, as well as a corundiferous biotite-syenite from Gallatin county, Montana.‡ The important occurrences of corundum associated with peridotites in the Appalachian belt described by Pratt appear to be concentration products on the contacts of the peridotite, and may therefore be secondary rather than pyrogenic, although Pratt regards them as differentiation products of the same magma which gave rise to the peridotite.

In addition to these occurrences it has been long known that corundum exists as an accessory in a variety of volcanic rocks, notably in the volcanic districts of the Rhine, but these have usually been looked upon as inclusions picked up by the magma and foreign to it. It seems probable, in view of the establishment of the pyrogenic origin of corundum in the cases above referred to, that many of these supposed exotic occurrences of that mineral will be recognized as products of the crystallization of magmas.

The Discovery.—It is the purpose of the present paper to offer a contribution to this growing body of information regarding corundiferous igneous rocks. The writer first became aware of the existence of the rock which forms the subject of the paper by seeing a fragment of it in the lapidary shop of Mr. Kinrade of San Francisco. He secured the specimen, and on inquiry ascertained that it had been brought there by Mr. J. A. Edman of the Diadem Mine, Plumas Co., Cal. He thereupon communicated with Mr. Edman and subsequently visited him, and was by him conducted to the locality where the rock outcrops. The credit of the discovery of this new and interesting rock, therefore, belongs to Mr. Edman, although it is the writer's privilege

* U.S.G.S. 20th An. Rpt., Pt. III, p. 554 et seq.

† Am. Jour. Sci., 4th Ser., Vol. IV, 1897, p. 418.

‡ Op. cit., pp. 30, 31.

to call the attention of petrographers to its character and mode of occurrence, in so far as these can at present be ascertained.

The locality lies in a region of peculiar geological interest, occupying the northeast corner of the Bidwell Bar quadrangle as mapped by H. W. Turner of the U. S. Geological Survey. It is on the lower flank of Spanish Peak about two miles due east of the summit, near the southwest margin of a broad belt of peridotite. It is thus near the line of faulting to which the bold eastern scarp of Spanish Peak owes its origin.

The lower flanks of the mountain are traversed by numerous small creeks which cut up the surface into a succession of alternating ridges and gulches. The corundiferous rock occurs on one of these minor ridges, and the corundum was first discovered by Mr. Edman as float in the adjoining gulch, and by him traced to its source.

The Peridotite Cut by Corundiferous Dyke.—The corundiferous rock at this locality occurs in the form of a white feldspathic dyke cutting a rock which is referred to in several of Turner's publications on the geology of the Sierra Nevada. In the 14th annual report of the U.S.G.S. he says; "The largest single dyke of serpentine which is known to have been originally a peridotite or pyroxenite occurs in the northern end of the range in Sierra and Plumas counties. . . . This serpentine dyke has a width, where it is crossed by the middle fork of the Feather River, of more than 3 miles." In the 17th annual report he gives the following petrographical note concerning this rock: "Locality: one and one-half miles west of Spanish Ranch post-office. Microscopically this is an apparently fine-grained purplish and green rock, evidently in part serpentine. Microscopically, the structure is coarse granular, and the rock is largely olivine, in rather large anhedrons, intersected by a network of cracks, which cross at all angles, and along these cracks serpentine is forming. Fibrous serpentine and tremolite occur between the olivines evidently as alteration products. Associated chiefly with the serpentine are black streaks of magnetite in aggregates of minute grains. Chromite or picotite may be present but was not observed." In a later publication* he modifies this descrip

*The Bidwell Bar Folio, 1898.

tion as regards the tremolite by saying: "The colorless amphibole was at first supposed to be tremolite, which is a lime-magnesia amphibole. Chemical analyses and microscopic examinations, however, show that there are two colorless amphiboles present, one monoclinic probably edenite, and the other orthorhombic probably gedrite." The samples of rocks collected by the present writer at the place where the corundiferous dyke cuts it agree fairly well with Turner's description except as to minor details. Here the rock may be found both in a fairly fresh condition and also largely serpentized. The fresh rock has a well marked but rude schistosity. On fractures transverse to this schistosity it is of a dull greenish gray color and compact texture, relieved by long narrow blades of a light colored, cleavable mineral, and showing irregular partings in the plane of schistosity. On the cleavage surfaces the rock presents a silvery gray spangled appearance as a ground-mass, with numerous cleavage blades of the same light colored material. These blades lie with their axes of elongation rudely parallel to the schistosity but in all orientations in that plane. They are about 5×1 mm. in size.

Examined in thin section the rock is seen to be made up of but two primary minerals. The more abundant of the two agrees with olivine in its optical properties. It forms a mosaic of rather angular or occasionally subrounded anhedrons, which have an average size of .25 mm. Occasionally these show a tendency to elongation, so that one diameter may be twice the other, but for the most part they are approximately equidimensional in cross section. The olivine is not only a mosaic aggregate of anhedrons in this section, but many of these anhedrons have a polysomatic structure. The anhedrons, whether simple or polysomatic, are traversed with irregular sharp cracks, and along these cracks incipient serpentinization may be observed as noted by Turner. Occasionally this process has proceeded so far as to give rise to distinct patches of serpentine. Lying in this mosaic are elongated prisms of a colorless mineral having the optical characters of tremolite. This makes up about 20 per cent. of the rock. In the zone of the vertical axis it has idiomorphic boundaries, but the ends of the prisms are splintered out. This is undoubtedly the mineral which Turner first identified as tremolite and afterwards referred partly to edenite and partly to gedrite. It is a colorless monoclinic amphibole with extinction angles not exceeding 18°, showing the oblique emergence of an optic axis on (100). Turner does not give the chemical and optical reactions which induced him to change his identification. The only other mineral present is magnetite, and this is secondary, being found only in shreds in the serpentine areas of the sections.

Chemical Composition of Peridotite.—The rock when digested in a pulverized condition with strong acids fails to dissolve and yield gelatinous silica, and on this account a doubt arose as to the character of the mineral which on optical grounds had been determined as olivine. To resolve this doubt, and also to obtain information as to the chemical character of the colorless amphibole, the rock was chemically analyzed by Dr. W. C. Blasdale, to whom the writer desires to express his obligations. Dr. Blasdale's analysis is as follows:

SiO_2	41.49
Al_2O_3	2.22
Fe_2O_3	1.07
FeO	7.11
MgO	39.63
CaO	1.89
Loss on ig.	5.56
	98.97

From this analysis the mineralogical composition of the rock has been computed to be as follows:

Olivine	$2(MgO,FeO),SiO_2$	44.97 per cent.
Serpentine	$2H_2O,3MgO,2SiO_2$	33.12 " "
Magnetite	$Fe_2O_3.FeO$	1.39 " "
Edenite	$2H_2O,CaO,3MgO, 4SiO_2$	15.36 " "
	MgO,Al_2O_3,SiO_2	4.24 " "
		99.08 " "

The analysis thus leaves no doubt of the peridotitic character of the rock notwithstanding its failure to yield gelatinous silica on digestion with acids. It reveals, moreover, the presence of an aluminous molecule which is supposed, in accordance with Turner's observations, to be combined with the tremolite molecule to form edenite. The degree of serpentinization is greater than would be inferred from an inspection of the thin slides.

Original Edenite.—Turner regards the amphibole in the rock described by him as secondary, but in the rock with which we are here concerned it appears to be as much an original mineral as the olivine. It is in part intergrown with the olivine in parallel intergrowth and its idiomorphic form, contrasting with the allotriomorphic character of the olivine abutting upon it, shows that for the most part it antedated in crystallization the latter mineral. It appears then clearly that the country rock in which the conundiferous dyke occurs is a peridotite and may for convemence be designated an amphibole-peridotite.

In the more altered facies of this rock taken from the same locality and the same mass, serpentine is the predominating mineral and there are only residuals of the olivine and pseudomorphs of the edenite. There is naturally much more secondary magnetite, and a notable amount of calcite or dolomite in ragged patches occurs mixed with the serpentine.

Extent of the Corundiferous Dyke.—The dyke of corundiferous rock which cuts this amphibole-peridotite is of quite limited extent so far as the writer's observation goes. The strike of the dyke is about N.N.W. or transverse to the axis of the ridge upon which it is found. There are but three exposures and these do not extend for more than 125 feet along the strike. The width of the dyke is about 15 feet, but its dip is difficult to determine, owing to the imperfection of the exposures. The slope is mantled with soil and with fragments arising from the disintegration of the amphibole-peridotite and the exposures of the dyke project through this covering of loose material. The rock of the dyke is composed chiefly of feldspar and is white in color, being thus in marked contrast to the darker rock mass which it cuts.

The Corundiferous Facies.—From a petrographical point of view the rock of the dyke is far from uniform. In the middle exposure, where a pit had been sunk by Mr. Edman at the time of the writer's visit, it consists of a coarse allotriomorphic granular aggregate of white feldspar in which are imbedded crystals of corundum. The feldspar is but slightly decomposed and in thin section is seen to be finely striated due to twinning on the albite law. The symmetrical extinction angles of these albite lamellae do not exceed the low values characteristic of oligoclase. The specific gravity as determined on three selected fragments was found with the Westphal balance to be 2.630, 2.634 and 2.636, the average being 2.633. An analysis of the feldspar, which was kindly made by Mr. J. Newfield, of the Chemical Department of the University of California, gave the following results:

SiO_2	61.36
Al_2O_3	22.97
CaO	5.38
Na_2O	8.08
H_2O	1.72
	99.51

This calculated to a water free basis gives the following molecular ratios:

SiO_2	1.045
Al_2O_3	.230
CaO	.098
Na_2O	.134

These ratios correspond to those of an oligoclase of the formula Ab_5 An_2 with 2.7 per cent. of SiO_2 to spare.

The Corundum.—The corundum is in crystals ranging in size from a few millimeters to over five centimeters in length. These are of a pale violet blue color. In most cases they are imperfectly formed but many were observed with well defined crystal forms, showing sharply hexagonal cross-sections. The faces of these crystals are rough and do not lend themselves to measurement with the reflecting goniometer. There is apparently but one habit represented and this is due to an acute rhombohedron without prismatic faces. The angle between two of these rhombohedra, measured over the basal edge with a contact goniometer, was found to be 164° and between the same two faces over the polar edge 120°. These values agree with those given for the form θ $(8.8.\overline{16}.3)$. There is occasionally observed a parting in these crystals parallel to the base. The specific gravity of the corundum varies from 3.9 to 4.2 with an average value of about 4.0.

When the corundum crystals are broken off the fracture surfaces show not uncommonly scaly films of a lustrous silvery white, or pearly mineral of micaceous habit. The scales are brittle, and when examined on the stage of the microscope they have the characters of a biaxial mineral with small optic angle, rather low double refraction and negative character. They are, therefore, identified as margarite. There occurs through the feldspathic part of the rock a similarly appearing secondary mineral in the form of small veinlets and patches. In this case, however, the luster is more waxy and the color somewhat greenish. The mineral is foliated, and the scales when examined on the stage of the microscope show it to be unaxial and positive and to have a feeble double refraction. Its specific gravity is 2.74. These data are insufficient for identification with any known mineral, but they agree most closely with the characters of a light colored chlorite. It appears to occur in the rock along minor breaks and dislocations.

Chemical Composition of the Rock.—Representative hand specimens of the rock composed practically of only oligoclase and corundum were taken to determine the proportion in which these two minerals are present in the rock. The specific gravity of the rock was found from a series of four samples, weighing 165 to 442 grms., to be 2.789. Knowing this and the specific gravity of both constituent minerals, as given above, the proportion was found to be oligoclase 83.64 per cent., corundum 16.36 per cent. Taking the round numbers 84 and 16 as the respective percentages of the two minerals, the bulk analysis of the rock is found to be as follows:

SiO_2	51.80
Al_2O_3	35.39
CaO	4.54
Na_2O	6.82
H_2O	1.45
	100.00

The Rock Type Defined.—It appears from the foregoing description that this interesting rock has resulted from the consolidation of a magma having approximately the composition of oligoclase with an excess of alumina. This particular type of rock magma does not appear to have been as yet recognized among the known occurrences of rocks, and it is, therefore, proposed to name it, for convenience in reference, *Plumasite*, from Plumas county, in which it occurs. For purposes of reference to this type plumasite may be defined as a rock resulting from the consolidation of a magma having the composition of a medium acid plagioclase with an excess of alumina. The extent to which the alumina is in excess is not material to the definition. It is characteristically a coarse allotromorphic granular aggregate of acid plagioclase with idiomorphic crystals of corundum, but on its chilled margins may have a fine-grained porphyritic structure with phenocrysts of plagioclase in a plagioclase groundmass.

Other Facies of the Dyke.—At the exposure 100 feet northwest of that just described the dyke has an exposed width of 15 feet. About two-thirds of the exposure on the southwest side consists of a very coarse-textured white feldspar rock the same as that above described, but without corundum so far as could be discovered. Scattered sporadically through this coarse feldspar rock there are occasional nests of a greenish gray mineral having a fibrous radial habit which proves on microscopic examination to have the characters of a colorless monoclinic amphibole. These are apparently secondary and not original products of the crystallization of the magma. The remaining third of the dyke on the northwest side is much finer grained and is porphyritic in structure, though apparently consisting wholly of white feldspar. It appears to be the chilled selvage of the dyke, but, owing to the unsatisfactory character of the outcrop, its relations to the coarse-grained portion of the dyke could not be determined.

The only other exposure of the dyke is about 25 feet to the southeast of the first outcrop described. Here the rock is again fine grained to microcrystalline and porphyritic. The porphyritic crystals range up to 5 millimeters in size, and usually show polysynthetic twin striations on the cleavage faces. Optical reactions show that these porphyritic plagioclases are andesine. The groundmass in which these phenocrysts are involved is a very fine microgranitic aggregate of feldspar whose composition is undetermined. There is no corundum discoverable in this facies of the dyke.

Correlation.—Turner has given us an account* of an extended series of white feldspathic dykes distributed throughout the gold belt of the Sierra Nevada, several of which occur in the vicinity of Meadow Valley to the east of Spanish Peak. These rocks are classed by Turner under the soda syenites, and as the feldspar in those cases investigated by him consist almost wholly of albite, he calls them *albitites.* The dyke with which we are concerned in this paper evidently belongs to this series, although even in the non-corundiferous facies it cannot be called an albitite. These dykes according to the writer's observations vary considerably in their mineralogical composition, some being rich in quartz and others quite devoid of it, so that, although having a distinct consanguinity, they would fall into a number of petrographically different classes. Plumasite is the first of these in which corundum has been found, but others having this character will doubtless be found when the field is better known.

* Notice of some Syenitic Rocks of California. Am. Geol., Vol. XVII, June, 1896, p. 375 et seq.

University of California,

April, 1903.

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PALACHEITE

BY

ARTHUR S. EAKLE

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THE BULLETIN OF THE DEPARTMENT OF GEOLOGY OF THE UNIVERSITY OF CALIFORNIA is issued at irregular intervals in the form of separate papers or memoirs, each embodying the results of research by some competent investigator in geological science. It is designed to have these made up into volumes of from 400 to 500 pages. The price per volume is placed at $3.50, including postage. The papers composing the volumes will be sent to subscribers in separate covers as soon as issued. The separate numbers may be purchased at the following prices from the University Librarian, J. C. Rowell, to whom remittances should be addressed:—

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PALACHEITE

BY

ARTHUR S. EAKLE

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INTRODUCTION.

Name of Mineral.—A mineral occurring in bright red crystals was found, about a year ago, in the Redington mercury mine, Knoxville, California, in considerable quantity. It proves to be a new hydrous basic sulphate of iron and magnesium, for which the author proposes the name *palacheite*, in honor of Dr. Charles Palache of Harvard University.

Occurrence.—The specimens are loosely coherent aggregates of minute crystals, which readily crumble on the slightest pressure into smaller aggregates or bunches of crystals. There is no cementing matrix whatever, the specimens being merely intergrown crystals; even the smallest crystal seems to be an intergrowth, more or less parallel, of smaller individuals. The superintendent of the mine, Mr. J. B. Mason, who found the mineral and has kindly sent specimens to the writer, reports that the red sulphate was found by cross-cutting through an old stope which had been filled about forty years ago, the mineral having formed in this stope with newly formed cinnabar and much sulphur. The heat developed from the decomposition of the marcasite was so intense where the mineral occurred, that the old timbers of the stope had become converted into solid charcoal. The specimens sent to the writer had much yellow sulphate associated with them, which is probably copiapite, although this has not yet been definitely proved.

This mine is quite noted for the variety of sulphates formed from the decomposition of the sulphides, epsomite, knoxvillite and redingtonite,* and coquimbite† having previously been described from there.

CRYSTALLOGRAPHIC CHARACTERS.

Measurements.—The crystals were measured principally by the two-circle method, although a few interfacial angles were also determined. The larger crystals, owing to their composite structure, give poor measurements, the prism faces being striated and often interrupted, and the bases wavy; but some of the smallest crystals, about 1 mm. in size, gave very exact readings, and these were chosen for the calculations.

System and Habit.—The crystals are monoclinic and have but one habit, namely, short prisms terminated by the two basal planes. The prismatic zone and the base are in almost equal development, and the crystals in consequence resemble rhombohedrons.

Polar Elements and Axial Ratio.—The average values of p'_0, q'_0 and e' determined from the coördinates x' and y', for the prisms, clino-domes and bases, were as follows:

$$p'_0 = 0.6852 \ ; \ q'_0 = 0.3996 \ ; \ e' = 0.5128.$$

* Melville and Lindgren, U. S. Geol. Surv. Bull. 61, 1890.

† A. S. Eakle, Mineralogical Notes, Bull. Dept. Geol., Univ. Cal., Vol. 2, 315–326, 1901.

From these values the elements and axial ratio for the monoclinic crystals become

$$p_0 = 0.6097 \; ; \; q_0 = 0.3556 \; ; \; e = 0.4563 \; ; \; \mu = 62^\circ 51'.$$
$$a : b : c = 0.6554 : 1 : 0.3996 \; ; \; \beta = 117^\circ 9'.$$

Forms.—The forms occurring on the crystals are as follows:

$c = 0 = \{001\}$	$b = 0\infty = \{010\}$	$d = -20 = \{\bar{2}01\}$
$m = \infty = \{110\}$	$a = \infty 0 = \{100\}$	$p = -1 = \{\bar{1}11\}$
$l = \infty 2 = \{120\}$	$n = 01 = \{011\}$	$s = -12 = \{\bar{1}21\}$
$t = \infty\frac{5}{4} = \{450\}$	$o = 02 = \{021\}$	

The base {001}, unit prism {110} and clino-prism {120} are the predominating forms. The prism faces are invariably vertically striated. The pinacoid {010} is usually narrow, but always perfect, without striations. The other forms occur rarely and are always very narrow, sometimes mere line faces, on the edges between the main forms. Figure 1, Pl. 20, shows the habit and usual combination; Fig. 2 shows, in addition to the main forms, some of the rarer ones, in their relative development. Fig. 3 is an orthographic projection of the forms on the basal plane.

Calculated Table.—The following table gives the calculations for the eleven forms, arranged to correspond to Goldschmidt's Winkeltabellen:

$a = 0.6654$	$\lg a = 9.816506$	$\lg a_0 = 0.214881$	$\lg p_0 = 9.785116$	$a_0 = 1.6411$	$p_0 = 0.6097$
$c = 0.3996$	$\lg c = 9.601625$	$\lg b_0 = 0.398375$	$\lg q_0 = 9.550962$	$b_0 = 2.5025$	$q_0 = 0.3556$
$\left.\begin{matrix}\mu - \\ 180 - \beta\end{matrix}\right\} 62^\circ 51'$	$\left.\begin{matrix}\lg h = \\ \lg \sin \mu\end{matrix}\right\} 9.949300$	$\left.\begin{matrix}\lg e = \\ \lg \cos \mu\end{matrix}\right\} 9.659271$	$\lg \frac{p_0}{q_0} = 0.234154$	$h = 0.8898$	$e = 0.4563$

Number.	Letter.	Gdt.	Miller.	ϕ	ρ	ξ_0	η_0	ξ	η	x' (Prism) $\frac{x}{y}$	y'	$d' = \operatorname{tg} \rho$
1	c	0	001	90° 00′	27° 09′	27° 09′	0° 00′	27° 09′	0° 00′	0.5128	0	0.5128
2	b	0∞	010	0 00	90 00	0 00	90 00	0 00	90 00	0	∞	∞
3	a	$\infty 0$	100	90 00	"	90 00	0 00	90 00	0 00	∞	0	"
4	m	∞	110	59 45	"	"	90 00	59 45	30 15	1.7147	∞	"
5	l	$\infty 2$	120	40 36·	"	"	"	40 36·	49 23·	0.8573	"	"
6	t	$\infty\frac{5}{4}$	450	53 54·	"	"	"	53 54·	36 05·	1.3716	"	"
7	d	—20	$\bar{2}01$	$\overline{90}$ 00	40 37	40 37	0 00	40 37	0 00	$\bar{0}.8576$	0	0.8576
8	n	01	011	52 04	33 02	27 09	21 47	25 28	19 34·	0.5128	0.3996·	0.6501
9	o	02	021	32 41	43 31	"	38 38	21 50	35 25	"	0.7992	0.9496
10	p	—1	$\bar{1}11$	23 20	23 31	9 47	21 47	9 06	21 30	$\bar{0}.1724$	0.3996	0.4352
11	s	—12	$\bar{1}21$	12 10	39 16	"	38 38	7 40	38 13·	"	0.7992	0.8177

Interfacial Angles.—The calculated, and some of the measured, interfacial angles are as follows:

	Calculated.	Measured.
(110) : $(1\bar{1}0)$	60° 30′	60° 30′
(010) : (120)	40 36	40 36
(010) : (450)	53 54	53 52
(001) : (110)	60 47	60 40
(001) : (011)	19 34	19 31
(010) : (021)	54 35	53 40
(001) : $(\bar{2}01)$	68 06	67 45
(001) : $(\bar{1}11)$	41 57	....
(001) : $(\bar{1}21)$	51 06	....

PHYSICAL PROPERTIES.

General Characters.—The crystals are transparent and have a deep brick red color, vitreous luster and pale yellow streak. They are very brittle, have a hardness of 1.5 to 2, and a specific gravity of 2.075, determined with the Thoulet solution. Cleavage is very perfect parallel to the clino-pinacoid $\{010\}$ and distinct parallel to the unit prism $\{110\}$.

Optical Characters.—The plane of the optic axis lies normal to the clino-pinacoid. The mineral is optically positive, and the acute bisectrix $\mathfrak{c}$ makes an angle of about 12° with the vertical axis in the acute angle β. Sections cut almost normal to the vertical axis show a good biaxial interference figure. The indices of refraction were determined approximately on thin sections by the Duc de Chaulnes' method, and gave for sodium light

$$\alpha = 1.544 \ ; \ \beta = 1.548 \ ; \ \gamma = 1.572.$$

The double refraction from this would be high = .028. The optic angle calculated from the indices gives

$$2V_{na} = 40° \ 54'.$$

A measurement of the optic angle of a section mounted in Canada balsam, the latter having about the same index as β, gave:

$$2H_{na} = 40°.$$

The dispersion is $\rho < v$.

The crystals are strongly pleochroic; $\mathfrak{c}$, deep orange red; $\mathfrak{b}$, pale red; $\mathfrak{a}$, bright yellow. In thin sections the colors are much paler, $\mathfrak{b}$ and $\mathfrak{a}$ becoming almost colorless, while $\mathfrak{c}$ becomes orange yellow.

CHEMICAL PROPERTIES.

Pyrognostics.—The mineral strongly exfoliates, like stilbite, before the blowpipe, and is converted into an infusible brownish black, magnetic mass. Much water is given off in a closed tube, which does not react acid unless the heat is high enough to decompose the sulphate. It is difficultly soluble in cold water, but when the solution is heated it becomes decomposed with the separation of a bulky, yellowish red precipitate of ferric hydroxide. The mineral is easily and completely soluble in dilute acids. It is perfectly tasteless.

Composition.—The average of several analyses of the mineral gave for its composition

			Molecular Ratio.	Approx. Ratio.
Fe_2O_3	19.51		.122	1
MgO	9.35		.239	2
SO_3	38.37		.480	4
H_2O at 100° C	19.53	32.28	1.793	15
H_2O above 100° C	12.75			
	99.51			

The formula, therefore, is $Fe_2O_3.2MgO.4SO_3+15H_2O$, and this requires the following percentages, which correspond very well with the analysis:

Fe_2O_3	19.28
MgO	9.64
SO_3	38.55
H_2O	32.53
	100

A fractional water determination was as follows:

At	100° C	19.53
	160	6.12
	220	3.52
	270	1.34
Above	280	1.77
		32.28

All of the water could be driven off without decomposing the sulphate. About nine molecules were lost at 100° C, thirteen at about 270°, and the remaining two probably near 300°. Twenty per cent. of the water driven off at 270° was reabsorbed over night by exposure to the air, and enough moisture was absorbed after several days to render the powder a pasty mass.

RUBRITE.

In the year 1890 Darapsky* published an analysis of an impure red sulphate, from Chili, which he named rubrite from its color, and later, in 1898,† he gave another analysis under the same name, although there is very little in common between the two analyses, and his derived formulas were quite different. This later analysis corresponds fairly well to that of palacheite, although he makes the formula for his mineral $Fe_2O_3.2MgO.4SO_3+18H_2O$. From the size of his crystals it would seem as though something more than the mere chemical composition could have been determined for his mineral. His description simply states that they were bright-red, long, orthorhombic or monoclinic crystals. In view of his meager description and the fact that palacheite bears no resemblance to the original material to which the name rubrite was given, the writer has no hesitancy in giving a name to the Knoxville sulphate.

* Neues Jahrbuch, Min. 1890, 1, 65.

† Ibid, 1898, 1, 163.

University of California,
April, 1903.

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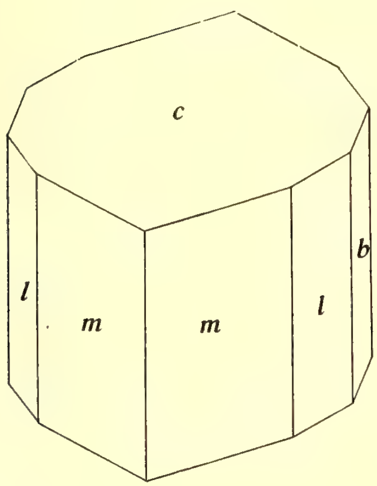

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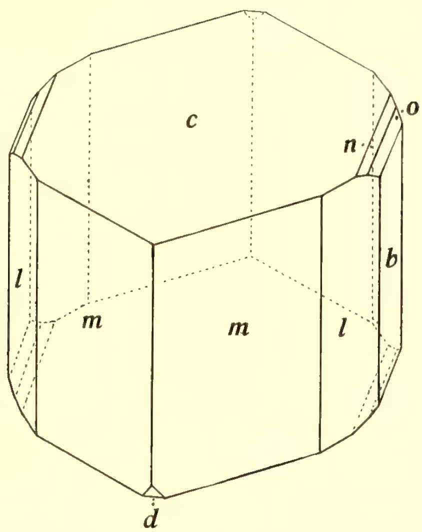

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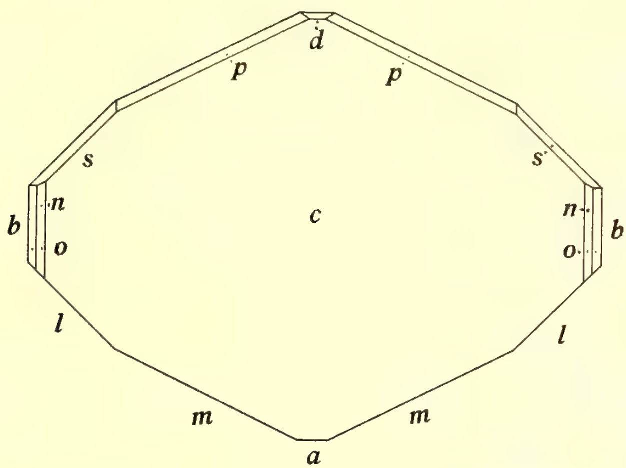

UNIVERSITY OF CALIFORNIA PUBLICATIONS
Bulletin of the Department of Geology
Vol. 3, No. 10, pp. 237-241, No. 11, pp. 243-248 ANDREW C. LAWSON, Editor

TWO NEW SPECIES OF FOSSIL TURTLES FROM OREGON

BY

O. P. HAY

A NEW TORTOISE FROM THE AURIFEROUS GRAVELS OF CALIFORNIA

BY

W. J. SINCLAIR

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Vol. 3, No. 10, pp. 237-241. ANDREW C. LAWSON, Editor

TWO NEW SPECIES OF FOSSIL TURTLES FROM OREGON.

BY

O. P. Hay.

The testudinate remains here described were collected by parties under the charge of Dr. John C. Merriam during the years 1899 and 1900, in the course of geological explorations in the John Day basin of Oregon. The materials are quite fragmentary, and there is some question regarding the horizon from which some of them were derived. Nevertheless, it seems to the writer that the bones afford characters which will enable future investigators, obtaining haply better materials, to identify their finds. Of the remains sent me there are four lots, with numbers indicating localities where collected and their place in the record of the museum of the University of California, as follows:

Museum No. 2219, locality No. 909, Rattlesnake beds, Rattlesnake Creek.

Museum Nos. 2179, 2180, locality No. 815, Mascall or Rattlesnake beds, Rattlesnake Creek.

Museum No. 552, locality No. 887, Mascall or Rattlesnake beds, Rattlesnake Creek.

Museum No. 2192, locality No. 896, Mascall beds, Beaver Creek, near Crooked River.

The lots about which there is doubt are those bearing the museum numbers 552, 2179, and 2180. The nature of the doubt is explained in the following extract from Dr. Merriam's report on the geology of the John Day basin (Univ. Cal. Bull. Dept. of Geol., ii, p. 311, 1901):

"The Rattlesnake gravels contain many vertebrate remains, most of which have hitherto been listed with the Mascall fauna. The Rattlesnake fossils, when weathered out, are frequently to be found resting upon the Mascall beds below, and as most of the material from both Rattlesnake and Mascall is found detached from the matrix, the difficulties in the way of separating the faunas are considerable."

The bones sent me are hard and thoroughly fossilized, and the color and the character of the fossilization appears to be identical in the two cases. For reasons given below I regard provisionally the questionable materials as having been derived from the Rattlesnake beds.

According to Dr. Merriam's report, the the Mascall beds belong to the upper Miocene, the Rattlesnake deposits to the Pliocene.

CLEMMYS HESPERIA sp. nov.

I take as the type of this species the bone bearing the number 2219 of the Palæontological Department of the University of California. This is the left hyoplastron, having the outer posterior portion, which enters into the bridge, missing. Figure 1 represents it the natural size and as viewed from below. The sutural edges are present which met the hyoplastron of the opposite side, the postero-lateral border of the entoplastron, the hinder extremity of the epiplastron, and the front of the hypoplastron. As will be observed, the humero-pectoral sulcus, represented by a dotted band, crosses the entoplastron, while the pectoro-abdominal sulcus is well back on the hyoplastron. The structure of these parts is identical with that of the genus Clemmys, represented to-day on the Pacific Coast by *Clemmys marmorata*. The free border of the bone between the humeral buttress and the epi-hyo-plastral suture is acute.

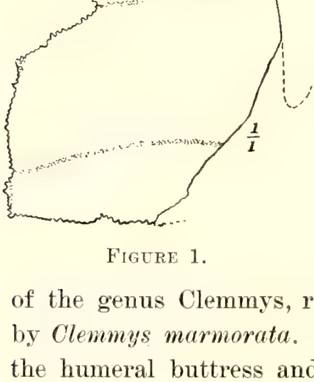

Figure 1.

The bone thickens until it reaches a thickness of 7 mm. where the suture just named meets the entoplastron. At the inner posterior angle the bone is only 3 mm. thick.

In lot No. 2179 there is a portion of a left hyoplastron which lacks the free border, but which in the portions represented is identical with the specimen above described. I regard it, therefore, as belonging to the same species and to the same formation. In this lot are included also a portion of the right epiplastron (Fig. 2), the first right peripheral bone (Fig. 3), a right peripheral, apparently the eighth or ninth, and some other fragments. The epiplastron has the border which joined its fellow of the other side missing, so that it is impossible to determine accurately the width of the anterior lip of the plastron. However, this bone has been used in making the restoration of the front of the plastron, as seen in figure 1. Figure 2 shows this bone as seen from below. It resembles closely the same bone in *C. guttata*, except that its upper side was not so deeply excavated as in the latter species. According to the restoration the lip had a breadth of about 34 mm.

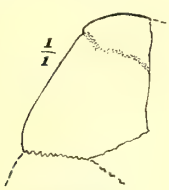

FIGURE 2.

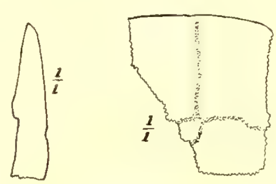

FIGURE 3.

The free borders of the epiplastron are subacute. Seen from the side, this border runs forward to the gulo-humeral sulcus and then turns rather abruptly downward, forward and inward. From the acute edge the bone thickens rapidly, until a thickness of 7 mm. is attained. The gulo-humeral sulcus has probably continued backward on the entoplastron.

A piece of the thickened border of the xiphiplastron of this specimen is present. It extends from the junction with the hyoplastron to just behind the femoro-anal sulcus. Most of the free edge is broken away, but enough remains to show that it was acute. It thickens gradually until, at the inner border of the surface above which was covered with horny skin, the thickness is 6 mm. The femoro-anal sulcus comes to the free edge 19 mm. behind the anterior end of the bone.

Figure 3 presents a view of the first right peripheral both from above and from the right-hand edge, which joined the second peripheral. The left-hand border joined the nuchal. The first peripheral resembles closely that of *C. guttata*. It will be observed that the outer anterior angle of the first vertebral scute extends outward on the bone here described and comes into contact with the second marginal scute. We have the same arrangement here that we find in *C. leprosa*, as shown by figure 30, page 102, of Boulenger's Catalogue of Chelonians. This indicates that the first vertebral scute was broader than it is in *C. guttata*. The peripheral mentioned above, probably the ninth of the right side, resembles somewhat that represented by figure 4; but it is shorter antero-posteriorly and higher, the fore and aft dimension being 15 mm., the height 19 mm. The longitudinal sulcus runs closer to the upper border than in figure 4. The figure just referred to presents a view of the left ninth peripheral of an individual somewhat larger than the one just described. It is part of a lot numbered 552. Figure 4 shows the upper surface and the anterior end of the bone. Accompanying this bone there is the hinder outer angle of the hypoplastron, extending from the suture with the xiphiplastron to the inguinal buttress. A view of a section of the bone near the xiphiplastral surface is shown in figure 5. It is of course possible that this lot was derived from the Mascall beds and do not belong to this species.

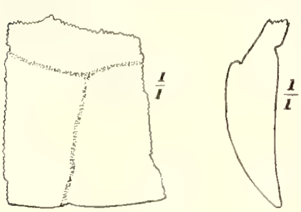

Figure 4.

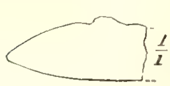

Figure 5.

From a comparison of the bones above described with the corresponding parts of *C. guttata* it appears that the carapace of *C. hesperia* attained a length of five or six inches. Unfortunately, I have not been able to compare the fossil species with *C. marmorata* of the Pacific Coast.

From the Rattlesnake beds, Rattlesnake Creek, Oregon.

CLEMMYS SAXEA sp. nov.

This species is founded on rather meagre materials, being represented by two bones, the pygal marginal, and a posterior peripheral. These bear the number 2192 of the museum of the University of California. They were collected from the Mascall beds, on Beaver Creek, near Crooked River, Oregon.

The marginal pygal, taken as the type of the species, is represented by figure 6. This presents a view of the bone seen from above and also as seen from the sutural edge; and therefore both the size and the thickness of the bone are indicated. It has an antero-posterior length of 18 mm. and a width of 22 mm. at the anterior end and of about 10 mm. at the posterior end. The greatest thickness is 6 mm. On the superior surface the bone is convex; on the inferior suaface it is concave. The sulci bounding the dermal shields are deeply impressed. The one between the last vertebral scute and the supracaudal scute lies well down on the bone, as in *C. guttata*. In *C. leprosa*, according to Dr. Boulenger's figure, this sulcus lies on the penultimate pygal bone. This bone is of rather peculiar form and will doubtless be easily recognized when additional materials have been discovered.

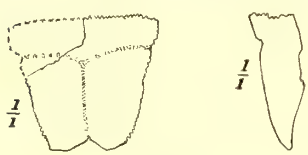

FIGURE 6.

The peripheral accompanying this pygal, the tenth of the left side, resembles the one represented by figure 4, but is smaller, and the horizontal sulcus has evidently run very close to the upper border, as it does in the corresponding bone of *C. leprosa*. Near the hinder end of the upper edge of the bone is a deep pit for the end of a rib.

UNIVERSITY OF CALIFORNIA PUBLICATIONS
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A NEW TORTOISE FROM THE AURIFEROUS GRAVELS OF CALIFORNIA.

BY

W. J. Sinclair.

So few vertebrate remains are known from the auriferous gravels of the Sierra Nevada, that the discovery of any well preserved material helps considerably in the attempt to make an exact determination of the age of these deposits. Testudinates from the gravels are unknown in palaeontological literature, but accounts of the finding of "turtles" in the placer mines are still remembered in the mining region. Particular interest attaches to the specimen here described not only on account of its superior state of preservation, but because its relation to the gravels has been determined by a careful examination of the locality where it was found. This tortoise is from gravels of the rhyolitic epoch, about two miles below Vallecito, Calaveras County, on the Parrott's Ferry road. It was discovered by Messrs. Sloan and Rudorf, the proprietors of the "Old Stiff" gravel mine, on Balaklava Hill. The gravel in which the specimen was found contains small fragments of rhyolite tuff, but no pebbles of the later volcanic rocks of the Sierra Nevada. The gravels are overlain by a white rhyolite tuff, exposed at the top of the high bank above the mine pit. The tuffs are overlain by a gravel containing abundant andesite pebbles, and the section is capped by a sheet of augite-latite, a part of the Tuolumne Table Mountain flow described by Dr. Ransome.* The remains of the animal were found in a stratum of gravel mixed with sand and fine tuff particles, lying from ten to fifteen feet above the bedrock of the

* Some lava flows of the western slope of the Sierra Nevada, California. U. S. G. S. Bulletin No. 89.

mine. When received at the museum of the University of California, the specimen was imbedded in a coherent mass of tuff and gravel particles. This investing matrix has since been removed, exposing the greater part of the carapace and plastron.

The preservation of the specimen is largely due to the interest of Mr. Jenkins and Mr. J. M. Stephens, of Murphys, by whom it was forwarded to Berkeley. The writer is indebted to Dr. O. P. Hay for suggestions regarding the systematic position and relationships of the species.

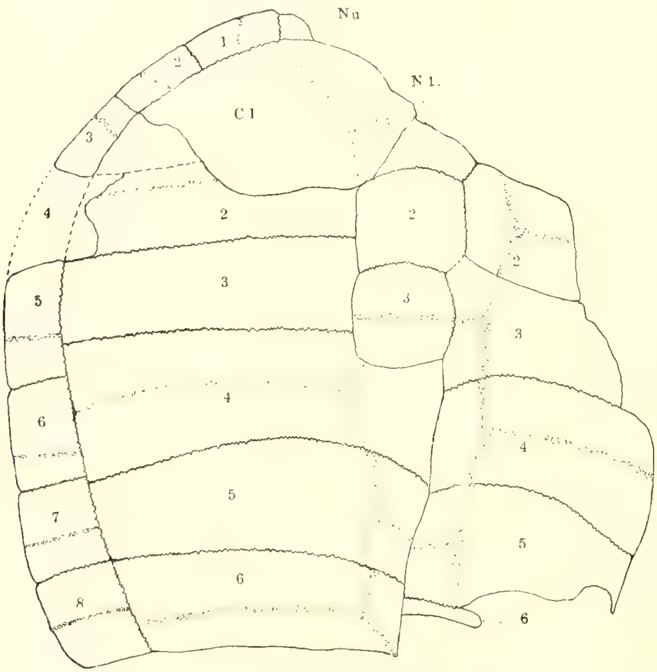

FIG. 1. *Stylemys calaverensis* n.sp. Carapace, dorsal view. × ¼.

The carapace (Fig. 1) has been considerably crushed, and the relations of the various elements obscured by the slipping of one part over the other. The first costal on the left side overlaps the first neural. The second and third costals on the right side are in their natural position with reference to the neurals, while those on the left side are overlapped by the neurals, as is shown by the displacement of the trace of the dorsal scutum on the third neural and fourth left costal. The sixth left costal has been thrust slightly toward the right, as compared with the fifth. The relative position of the marginals has remained practically unchanged.

Parts of the nuchal plate and of the first neural are represented. The second and third neurals are preserved almost entire. Six costals and eight marginals are also represented. The relation of the neurals to the costals on the left side cannot be determined exactly owing to the displacements already mentioned. The first neural is represented by its posterior portion. The second approaches a hexagonal outline, with convex anterior and concave posterior border. The third neural is also hexagonal in outline with convex anterior border. The second costal plate is in contact with the first and second neurals; the third, with the second and third neurals. Three marginal plates oppose the first costal plate. The fifth marginal opposes the third costal, while parts of the fifth and seventh as well as the entire sixth marginal are in contact with the fourth costal. The fifth and sixth costals support one marginal each. The costal plates are alternately wider and narrower at their dorsal and marginal borders.

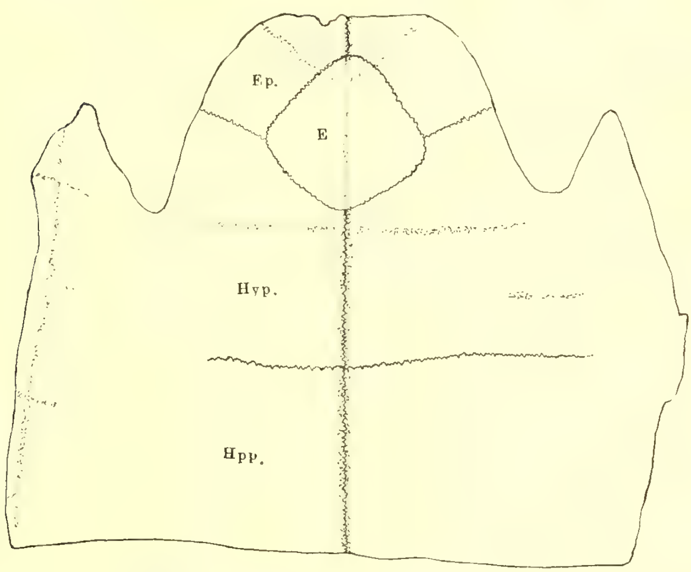

FIG. 2. *Stylemys calaverensis* n.sp. Plastron, ventral view. × ¼.

The plates of the plastron (Fig. 2) are less easily distinguished than those of the dorsal shield. The anterior border of the epiplastron has been broken. The entoplastron is entire. In shape it is almost quadrilateral. The hyoplastron is entire, but its lateral boundaries are not clear. The hypoplastron is incomplete posteriorly. Sutural contact between carapace and plastron begins with the third marginal plate.

The boundaries of the epidermal shields cannot be completely followed on either carapace or plastron. On the carapace, alternate costals are marked by the traces of the margins of the lateral shields. The dorsal shields appear to have been long in proportion to their width. In outline, they were hexagonal. The first, second, and third dorsal shields may be traced more or less completely. The first dorsal shield completely overlapped the second neural and the adjacent halves of the first and third neurals. The second appears to have had an equal extent, and to have involved in a similar manner the fourth neural, and parts of the third and fifth. Each marginal bears the traces of an epidermal shield. So far as the traces of the shields can be followed on the plastron, they agree with the usual arrangement of these elements in *Stylemys*. The anterior border of the pectoral shield terminates at the base of the axillary notch.

MEASUREMENTS.

Second neural, anteroposterior diameter (approximate)	50 mm.
Second neural, transverse diameter	55
Third neural, anteroposterior diameter	56
Third neural, transverse diameter	51
Third costal, length (approximate)	182 +
Third costal, width at dorsal extremity	68
Third costal, width at marginal extremity	42
Fourth costal, length	181
Fourth costal, width at dorsal extremity	55
Fourth costal, width at marginal extremity	67
Fifth costal, length	168
Fifth costal, width at dorsal extremity	52
Fifth costal, width at marginal extremity	37
Sixth costal, length (approximate)	138
Sixth costal, width at dorsal extremity (approximate)	38
Sixth costal, width at marginal extremity (approximate)	51

First marginal, length	44
First marginal, width at costal margin	51
First marginal, width at free margin (approximate)	67
Third marginal, length	58
Third marginal, width at costal margin	42
Third marginal, width at free margin	51
Sixth marginal, length	65
Sixth marginal, width at costal margin	50
Sixth marginal, width at free margin	50
Eighth marginal, length	61
Eighth marginal, width at costal margin	49
Eighth marginal, width at free margin (approximate)	52
Epiplastron, greatest width	151
Entoplastron, antersposterior diameter	81
transverse	88
Hyoplastron, length along median suture	83

The remains described belong to a tortoise or land turtle referable to *Stylemys*, a genus which is represented by large forms in the White River and John Day beds. It is specifically distinct from *Stylemys nebrascensis* and near *Stylemys oregonensis* from the John Day. The name *Stylemys calaverensis* is proposed for this new Californian species.

The strongest points of difference between *Stylemys nebrascensis* and the new form are found in the relation of the second costal to the first two neural plates. A considerable amount of individual variation is observable in this respect in the figured specimens of *Stylemys nebrascensis*.* The second costal may be in contact either with the second neural alone or with the second and third neurals; the third costal, with the third and fourth neurals, or with the second, third, and fourth. The Californian species has the second costal in contact with the first two neurals. The third costal may have a small contact with the missing fourth neural, but this can not be definitely ascertained owing to the worn condition of the bones.

In addition to the specimen described, remains of tortoises are known from several other localities in the Sierra Nevada region, from gravels of the same age. Some fragments of marginal plates

* Leidy, Smithsonian Contrib. to Knowledge. Vol. VI. "The Ancient Fauna of Nebraska." Pl, XIX–XXIV, pp. 101–111.

of a large tortoise were found by the writer in a stratum of fine gravel about ten feet above the bedrock in an abandoned placer mine near Cave City, Calaveras county. The gravels are inter-rhyolitic like those at Balaklava Hill. These specimens could not be preserved. In the Johnson mine near San Andreas, the impression of a tortoise is said to have been found, some years ago, in the leaf-bearing rhyolite tuffs. It is not known what became of this specimen. In the University collection there is a very fragmentary specimen labeled "from cement near Todd's Valley." A single marginal plate of a second individual from the rhyolitic gravels on Balaklava Hill was forwarded to the University museum by Mr. Stephens.

University of California,
May, 1903.

UNIVERSITY OF CALIFORNIA PUBLICATIONS
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NEW ICHTHYOSAURIA

FROM THE

UPPER TRIASSIC OF CALIFORNIA

BY

JOHN C. MERRIAM

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MAY, 1903

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NEW ICHTHYOSAURIA
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JOHN C. MERRIAM.

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INTRODUCTION.

In a large collection of Upper Triassic saurian material which has recently been presented to the University of California by Miss A. M. Alexander there are two Ichthyosaurian species differing considerably from any that have been described. Though we are as yet only partially acquainted with their structure, they seem to be generically distinct from all of the known forms. Both specimens were obtained from exposures of the Trachyceras horizon of the Hosselkus limestone occurring a few miles northeast of Winthrop, Shasta County, California.

RELATIONSHIPS AND SYSTEMATIC POSITION.

The Ichthyosauria previously described from the Upper Triassic fauna of California comprise six species placed in the genus *Shastasaurus*. So far as the extremities are known, these species are characterized by extreme shortness of the limb elements. The humerus, radius and ulna are wider than long, while the phalanges are circular in outline and ordinarily without lateral notching. The coracoid is antero-posteriorly constricted or pedunculate, the ribs of the middle dorsal region have but one head, and excepting one form (*S. perrini*) the vertebral centra are distinguished by their shortness.

Of the two new types, one (Pls. 21, 22 and 23) is characterized by its elongated limb elements, tridactyle manus, notched or constricted phalanges, shield-shaped coracoid, and long vertebral centra. For this form the new generic and specific name *Leptocheirus zitteli* is proposed.

The second form (Pl. 24) has also the elongated type of vertebral centrum and the slender tridactyle limbs but differs from the other species, so far as known, in possessing dorsal ribs with widely forked heads. Its limbs differ from those of the other new type in that the posterior extremities are larger than the anterior instead of being much smaller. This form has been given the name *Toretocnemus californicus*.

Both *Leptocheirus* and *Toretocnemus* are sharply separated from *Shastasaurus* by their limb structure. The slender propodial, epipodial, and phalangeal elements are wholly different from the greatly abbreviated forms known in *Shastasaurus*. From each other *Leptocheirus* and *Toretocnemus* are distinguished by the character of the rib articulation in the dorsal region and by the difference in the relative size of the limbs.

Both of the new genera, as also *Shastasaurus*, differ considerably from the European *Mixosaurus*.* In that genus the limbs have elongated propodial and epipodial segments but are distinguished by being pentadactyle, by having four elements in the first row of the mesopodial segment, and by the articulation of two or

* See E. Repossi. Il Mixosauro degli strati triasici di Besano in Lombardia. atti della soc. ital. di scien. natur. Vol. XLI, Fasc. 3, p. 361–372, Tav. VII, IX, Nov., 1902.

more distal carpals on the intermedium. The arches, vertebræ, and dentition are also, as far as known, different from the corresponding structures in the Californian forms. From *Ichthyosaurus* the new genera differ in the form of their pectoral and pelvic arches, the elongation of their epipodial segments, and the constant notching with frequent double notching or shafting of their phalanges.

Including the forms here described, six distinctly separated groups of Ichthyosaurians designated as genera are now known. These groups may be characterized as follows:

Mixosaurus. Dorsal ribs mainly single-headed. Coracoid pedunculate or with anterior and posterior emargination. Scapula, ischium, and pubis much expanded distally. Interclavicle triangular, with concave borders. Limbs pentadactyle, propodial and epipodial segments elongated. Elements of epipodial segments separated by a wide cleft. Phalanges notched, sometimes with double notching or shafting. Four elements in the proximal row of mesopodial region. Intermedium supporting at least two elements distally. Dentition differentiated.

Leptocheirus. Dorsal ribs, so far as known, single-headed. Coracoid elliptical, without emargination; scapula expanded distally; clavicle broad; interclavicle probably broadly triangular. Limbs tridactyle with a very rudimentary fourth digit. Propodial and epipodial segments elongated. Elements of epipodial segments separated by a wide cleft. Phalanges notched on one or both sides. Three bones in the proximal row of mesopodial segments. Carpus and tarsus with linear arrangement, the intermedium supporting a single element distally.

Shastasaurus. Ribs of dorsal region mainly single-headed. Caudal hypocentra uniting to form long chevron bones. Coracoid pedunculate; scapula, ischium, and pubis much expanded distally. Pubis with deep obturator notch. Elements of pro- and epipodial segments greatly shortened. Radius and ulna separated by a cleft. Ulna considerably smaller than radius.

Cymbospondylus (?) As yet, too imperfectly known for satisfactory generic description.

Toretocnemus. Ribs of the middle or posterior dorsal region with widely forking heads. Caudal hypocentra uniting to form cheveron bones. Ischium and pubis much expanded distally. Pubis with obturator foramen. Limbs tridactyle with rudimentary fourth digit, structure in general as in *Leptocheirus*. Posterior limbs larger than anterior.

Ichthyosaurus. Ribs of dorsal region double-headed excepting a few of the most posterior. Coracoid generally pedunculate or with emargination. Scapula, ischium, and pubis narrow. Bones of the epipodial segments greatly shortened, generally in contact along their inner borders. Notching present on only a few phalanges on the anterior border of limb. Number of digits varying from three with a rudimentary fourth to ten. Dentition isodont.

Baptanodon, *Opthalmosaurus*. Propodial elements articulating distally with three greatly shortened epipodial bones. Dentition considerably reduced.

The subdivision of the order Ichthyosauria into families was attempted by Baur,* who set up a family for each of the genera known at that time, *viz.*, Mixosauridæ, Ichthyosauridæ, and Baptanodontidæ. To these three the writer has suggested the addition of the Shastasauridæ† as a group sharply distinguished from the others. Repossi's recent paper shows *Mixosaurus* to be much more like *Shastasaurus* than was indicated by previous descriptions. The two genera are, however, distinctly separated, the types of limbs particularly being widely different. Of the two new genera here described *Leptocheirus* is nearer to *Mixosaurus* than to any other of the genera but has throughout a different type of extremity and pectoral arch, while the dentition shows no signs of differentiation. *Toretocnemus* is like *Leptocheirus* in its type of limb, like *Shastasaurus* in the form of its pelvic arch and chevrons, and like *Ichthyosaurus* in the forking of its dorsal ribs.

The question as to how the genera in the order Ichthyosauria should be grouped was one which did not seem difficult to solve when only *Ichthyosaurus*, *Baptanodon*, and *Shastasaurus* were fairly well known and but a small part of the skeleton of *Mixosaurus* had been described. Now that *Mixosaurus* has been

* G. Baur, Ueber den Ursprung der Extremitaten der Ichthyopterygia, Ber. d. XX Versam. d. Oberhein. Geol. Ver. Vol. XX, p. 3.

* Bull. Dept. Geol. Univ. Calif., Vol. 3, p. 87.

carefully described and additional forms have been obtained from the Triassic of California, it becomes a much more difficult matter. To settle it satisfactorily involves a discussion of the primitive characters and the course of evolution of the Ichthyosauria. This is deferred to a study of the subject to appear in a later paper.

DETAILED DESCRIPTION OF NEW GENERA AND SPECIES.

Leptocheirus. New Genus.

Caudal vertebræ elongated. Dorsal ribs single-headed. Coracoid shield-shaped, much elongated antero-posteriorly, without anterior or posterior emargination. Extremities with three slender digits and rudiment of a fourth. Anterior limb much larger than posterior. Elements of the propodial and epipodial segments of anterior and posterior limbs much longer than broad. Epipodial bones separated by a wide cleft. Bones of first and third rows of the mesopopial, metapodial, and phalangeal regions all notched on one or both sides. Carpus and tarsus with linear arrangement, three elements each in the in the proximal and distal rows, intermedium articulating distally with but a single bone. Dentition isodont, conical teeth set in open grooves.

Leptocheirus zitteli n. sp.

PLS. 21, 22, AND 23.

The type specimen (No. M 8099, University of California Palæontological Museum) is represented by the lower half of a skull with a part of the dentition, the complete pectoral girdle, both anterior limbs, and numerous fragmentary ribs, vertebræ, and abdominal ribs. It was discovered by Miss A. M. Alexander in the Trachyceras zone of the upper Triassic limestones at the Cove near Madison's Ranch on Squaw Creek, Shasta Co.

Vertebræ and ribs.—The only well-preserved vertebra present is an anterior caudal (Pl. 23. fig. 4) with the following dimensions: length 14 mm., height 22 mm., greatest width 24 mm. The end faces are very deeply concave, sloping sharply from the periphery and almost meeting in the center. The diapophyses are small but have considerable lateral projection. The articular surfaces for the reception of the lower arches are situated on rather prominent apophyses. The centrum is hexagonal in cross-section, the inferior surface and the lateral areas above and below the diapophyses being flat or slightly concave.

The *ribs* are very imperfectly preserved and only one specimen was found in which the form of the head and shaft can be seen distinctly. The single head is twisted backward and both sides of the shaft are grooved, the posterior more deeply than the anterior. The form of this rib is similar to that in the dorsal region of *Shastasaurus perrini*. A great many of the *abdominal ribs* are present in their original positions. They are in five linear series like those of *Ichthyosaurus*.

Anterior arch.—Excepting the clavicles and the inter-clavicle, which had slipped forward a short distance, the bones of the pectoral girdle were all in their natural positions, with the limbs in place on each side. The *coracoids* (Pl. 21, fig. 2) are very much expanded antero-posteriorly. Their diameter measured in this direction is twice the length of that taken transversely. Their form is roughly elliptical. The anterior and posterior ends are gently-rounded and there is no trace of an anterior or posterior emargination. There is no pedunculation of the portion articulating with the humerus and scapula as in *Shastasaurus* and *Mixosaurus*, though the proximal portion is considerably thickened. The portion next the median line is considerably thickened by a high ridge running obliquely forward. The *scapulæ* (Pl. 21, fig. 2) are short and broad, having the general form seen in *Shastasaurus*. The articular surface is curved so as to form two fairly distinct facets for the coracoid and humerus. The anterior hook is shorter and the notch below it not so well marked as in *Shastasaurus osmonti* or *alexandræ*. As the posterior angle of the upper margin is very thin, it probably did not extend far beyond the limits given in the figure and was therefore shorter than in *S. osmonti*.

The *clavicles* (Pl. 21, fig. 1) are represented by two heavy, broad bars meeting, or possibly overlapping, on the median line in front of the coracoids. The ends next the scapulæ are broken away so that the total length of these elements can not be determined. The ends next the median line are considerably broadened and are concave on the posterior side. As far as can be determined the clavicles are much like those of *Shastasaurus alexandræ* and *osmonti*.

An elongated, triangular bar, shaped somewhat like a boomerang, stretches across the median line below the contact of the clavicles and possibly represents the *interclavicle* (Pl. 21, fig. 1, Ic and Ic′). One-half of the triangle is perfectly preserved. The angle on the other side has been broken away, but had probably a form similar to the part present. The obtuse angle on the convex side of the bone may represent the median stem of the interclavicle in *Ichthyosaurus*. If this element is entire the posterior angle or median stem is much more reduced than in any other known Ichthyosaurian.

MEASUREMENTS.

Coracoid	
Antero-posterior diameter	72 mm.
Transverse diameter	35
Greatest thickness at proximal end	12.5
Greatest thickness on distal margin	15
Scapula	
Length	40
Thickness at proximal end	11
Width at proximal end	*19
Clavicle	
Width at end next median line	16
Width in middle of shaft	11

Anterior limbs (Pl. 22, fig. 1).—In agreement with the generally elongated type of the limb, the *humerus* is considerably longer than broad. The distal end is wider than the proximal, having a transverse diameter equalling two-thirds the length of the bone. The trend of the anterior border is nearly at right angles to that of the distal margin, while the posterior border slopes backward. This means that the posterior side of the limb would receive a little less power than the anterior side, a fact that might have some influence in determining the location of reduction in the phalangial portion of the limb. In the middle of the anterior margin is a sharply cut notch which is opposite the deepest part of a much broader indentation of the posterior side. This constriction of the middle of the humerus clearly represents the original shaft of the bone. Its presence here

*Approximate.

helps to explain the occurrence of a similar constriction in the more specialized humerus of *Shastasaurus*. A prominent ridge on the upper side of the proximal end is opposite a much larger elevation corresponding to the pectoral ridge on the inferior side. Both prominences extend to about the middle length of the humerus. A narrow ridge on the posterior distal angle of the upper side is opposite a similar elevation on the ulna. The radial and ulnar borders are both sharply concave as in *Ichthyosaurus*.

The *radius* has exactly one-half the length of the humerus. The anterior border is nearly straight, showing only a faint indentation near the middle. The posterior border is deeply concave. The surface of contact with the radiale takes up nearly the whole of the distal end. The contact with the intermedium is only along the posterior angle.

The *ulna* has a deeply concave anterior border, and as in *Mixosaurus* shows no emargination on the posterior side. The facets for the intermedium and the ulnare are of nearly the same length. A low triangular ridge is present near the posterior proximal angle.

The *carpus* and *metacarpus* consist of three linear series of three bones each. The radiale is a little wider proximally than the ulnare, and in consequence the intermedium articulates principally with the ulna. The intermedium and the other two ossicles of the middle linear series have entire margins. All the elements of the two outer series are notched on the margins next the lateral borders of the limb. In both right and left limbs the metacarpal of digit one is deeply notched on both sides.

The *phalangeal* region consists of three well developed digits and the merest vestige of a fourth. There are seven phalanges in digits one and three, and eight in the middle finger. The terminal phalanges are exceedingly small and simple and it is not probable that more than one or two have been lost from this specimen.

What may be considered as a rudimentary or perhaps as an incipient digit four is represented in both right and left limbs by two very small ossicles. These elements are opposite the first phalanx in one limb and opposite the first and second in the other. One or two additional ossicles may have been present in this row but a careful search has failed to reveal them.

Excepting phalanx one of digit two and two very minute rounded ossicles at the distal end of the paddle, all of the phalanges are sharply notched. Half of the phalanges in digits one and three are notched on both sides; the remaining ones are cut in on the outer border only. In digit two the notching is, for some unknown reason, always on the posterior side of the phalanges. The presence of the double notching on many of the phalanges, occurring as it does with greater axial length than is found in these elements in the later groups of the Ichthyosauria, can hardly be interpreted otherwise than as an indication that the phalanges were originally even longer than we find them here and that their middle or shaft portions were considerably constricted as in the normal phalanx of a shore or land reptile.

MEASUREMENTS.

Humerus	
Length	61 mm.
Width at proximal end	34
Width at distal end	41
Width at notch	22
Thickness through pectoral ridge	20
Radius	
Greatest length	31
Width, proximal and distal	20
Width, median	16.5
Ulna	
Greatest length	31
Width, proximal and distal	20.5
Width, median	18
Radiale	
Length	15
Width	14.5
Distal carpal one, length	11.5
Metacarpal one, length	10

Posterior limbs (Pl. 22, fig. 2).—The posterior limb is much smaller than the anterior, the parts present indicating that its total length was about one-third shorter. This paddle is also of the tridactyle type but the fourth digit is a little larger than that indicated in the anterior limb. The femur is much smaller than the humerus and has a much more slender median or shaft region. The tibia and fibula were both considerably longer than broad and each shows a marked median constriction, the notches being very deep on the inner side. The tibia is somewhat broader than the fibula.

The tibiale is imperfectly preserved. The anterior margin is not shown and it is not possible to determine whether it was notched. The intermedium is imperfect as is also the fibulare. It is not possible to state whether the latter was notched on the posterior side. Distal tarsal two is well preserved and has entire margins. Distal tarsal three is deeply notched posteriorly. In the metapodial region numbers two and three are preserved. Like the corresponding element of the anterior limb, number two has entire margins. Number three shows a deep median constriction like that in number one of the correspoding region of the anterior limb.

In the phalangeal region, the arrangement and form of the elements is much the same as in the anterior limb. The rudimentary fourth digit is represented by four small ossicles situated immediately behind the mesopodial and metapodial regions.

MEASUREMENTS.

Femur	
Width of distal end	*30
Width of narrowest portion of shaft	18
Tibia	
Length	19
Width	16
Distal tarsal three	
Length	9
Width	7
Metatarsal three	
Length	7
Width	5.5

Skull (Pl. 23, figs. 1, 2, and 3.)—Of the cranial portion only the maxillary, jugal, lachrymal, and postorbital are preserved in such form that they can be satisfactorily studied. The relations of these elements are not markedly different from those in *Ichthyosaurus*. In a cross-section of the middle portion of the skull as it appears on this specimen there are two palatal bones, probably the palatines and a median element having the appearance of the vomer. In each orbit there is a large portion of a sclerotic ring composed of plates of considerable size.

*Approximate.

The mandible is constructed much like that of *Ichthyosaurus*, with the exception that the supra-angular is somewhat larger, taking up nearly the whole of the outer side back of the middle of the orbit. The angular is visible on the outer side of the jaw only as a very narrow strip near the posterior end. A cross section of the mandible taken below the anterior end of the lachrymal (Pl. 23, fig. 3) shows a very large spenial extending below the supra-angular, and a saddle-like section of the dentary resting upon the supra-angular and overlapping it on the outside.

In a section at the posterior end of the mandible (Pl. 23, fig. 2) there are shown the supra-angular, angular, and a large element (*ar*) which can hardly represent anything other than the articular. This seems to be an elongated bone of considerable size. In addition to these there is possibly a fourth element (x), which resembles somewhat a bone doubtfully determined as corresponding to the coronoid in *Shastasaurus alexandræ*. This element is very indistinct and may not be separate from the angular.

Dentition.—Though many scattered teeth supposed to belong to Ichthyosaurians have been found in the Californian Triassic, this is the first specimen to show the dentition in place in the jaws. As is shown in Plate 23, figure 1, the slender conical teeth are very numerous and closely crowded. As in *Ichthyosaurus*, they are inserted in rather shallow, open grooves (Pl. 23, fig. 3). There is no evidence that bony partitions separate the teeth transversely as in *Mixosaurus*. As the maxillary teeth are conical the dentition is evidently isodont. What appear to be short and broad teeth near the posterior end of the series in Plate 23, figure 1, are individuals which could be only partly exposed in preparation, owing to their turning inward. As the teeth are softer than the matrix it has not been possible to expose their surfaces satisfactorily, and the structure could be studied only in cross-section. So far as can be seen, they are not materially different from the teeth of *Ichthyosaurus*.

Toretocnemus, New Genus.

Vertebral centra elongated. Neural arches with lateral ridge, not greatly thickened. Middle dorsal ribs with widely forking heads articulating on small and widely separated diapophyses and parapophyses. Caudal vertebræ with single-headed ribs and Y-shaped lower arches. Limbs tridactyle, with a rudimentary fourth digit. Propodial and epipodial segments elongated. Elements of epipodial segments separated by a wide cleft. Posterior limbs equaling or excelling the anterior in size. Ilium long and slender. Pubis very broad, with obturator foramen.

Toretocnemus californicus, n. sp.

Pl. 24.

This species is represented by a specimen (No. M 8100 University of California Palæontological Museum) embedded in a slab which had been weathered in such a manner that a large portion of the skeleton was carried away. There remain nearly all of the ribs, the middle and posterior dorsal and the anterior caudal vertebræ, the pelvic arch, both hind limbs, and the right anterior limb. The type specimen was discovered by Miss A. M. Alexander in the Upper Triassic limestones at Bear Cove, three miles north of Brock's Ranch, on Pitt River, Shasta County.

Vertebræ and ribs.—About thirty *vertebræ* are present, two-thirds of the number being behind the pelvic arch. The centra are all deeply biconcave and have a length equal to about half their height. On the most posterior vertebræ the upper arches are about a third higher than the centra and have rather thin, sharply recurved spines. The zygapophyses are here represented by notches. The diapophyses on these vertebræ are a trifle below the middle of the centrum. Immediately behind the pelvis the upper arches become higher, broader, and more nearly erect and the zygapophyses are better developed. In this region the diapophyses are low down on the sides of the centra and are considerably elongated vertically by swinging downward and forward to the anterior margin. Below the contact of two of the caudal centra there is a V-shaped lower arch like those known in *Shastasaurus perrini*.

Near the middle of the dorsal region the diapophyses are small and round and lie above the middle of the side of the centrum, while prominent parapophyses with backwardly directed facets are present low down and nearer the anterior margin (Pl. 24, fig. 4).

MEASUREMENTS.

Middle dorsal centrum, length			11 mm.
"	"	" height	*14.5
Anterior caudal centrum, length			10
"	"	" height	13

The *ribs* associated with the dorsal vertebræ described above have broadly forked heads, the two articular surfaces being separated by a strong notch (Pl. 24, fig. 4). A prominent ridge begins behind the point of separation of the two heads and runs along the upper portion of the anterior side of the shaft as in *Shastasaurus*. A little farther back in the column the two heads are still distinctly separated, but the notch between them is much shallower. Numerous cross-sections of ribs show both the circular section such as is obtained near the end and the constricted section obtained in the doubly grooved middle or proximal portion of the shaft in *Shastasaurus*.

Posterior arch (Pl. 24, fig. 3).—The entire pelvic arch lay below the vertebral column, immediately in front of what are recognized as the anterior caudal vertebræ. Although the girdle is moved from its normal position with relation to the vertebral column, the elements are in very nearly their natural positions with relation to each other. The ilia are considerably longer than the ischia and pubes, and are much more slender and longer than in *Shastasaurus perrini*. The ischia are also narrower than in *S. perrini*. In the extremely broad pubes the obturator notch of *Shastasaurus* is represented by an obturator foramen.

MEASUREMENTS.

Ilium	
Length to broken distal end	29 mm.
Ischium	
Greatest length	22
Greatest width	14.5
Pubis	
Greatest length	23.5
Greatest width	22

Posterior limbs (Pl. 24, fig. 1).—Both of the posterior extremities lie near the pelvic arch. The proximal portion of each limb had been beautifully exposed by weathering, but unfortunately the phalanges are missing.

*Approximate.

The shaft of the *femur* is constricted and twisted in the middle, and the expanded ends are turned so as to cut each other at an angle of about seventy-five degrees. The main projection of the twisted proximal end beyond the plane of the distal end seems to be toward the upper side, forming a great trochanteric ridge. The tibial and fibular borders are both markedly concave.

The tibia and fibula have about half the length of the femur, and both are longer than wide. The *tibia* differs from the fibula in having the anterior and posterior borders of about the same length. The proximal end is gently rounded, corresponding to the concave articular surface of the femur. The articular facet for the tibiale is long and is normal to the long axis of the bone. The facet for the intermedium is small and oblique. The middle or shaft portion is considerably constricted, the indentation of the anterior margin being less than that on the posterior border.

The *fibula* is somewhat narrower than the tibia. The straight posterior border is much longer than the deeply emarginate anterior side. The proximal margin is much more oblique to the axis than in the case of the tibia. The articular facets for the intermedium and the fibulare are of about equal length and are both oblique.

In the *tarsus* the tibiale and distal tarsal one have a quadrate form and are deeply notched in the middle of the anterior border. The pentagonal intermedium, the square distal tarsal two immediately below it, and the similarly formed metatarsal two show no emargination. The fibulare possesses a small notch on the outer border. On its distal side there is a large facet for distal tarsal three and a smaller, oblique one on which there probably rested an ossicle belonging to a fourth digit. Similarly there are two facets on the distal end of distal tarsal three, one for metatarsal three and an oblique outer facet of the same size for a metatarsal four. Distal tarsal three has no emargination on the outer or posterior border such as occurs in *Leptocheirus* on the outer side of the carpals along the borders of the paddles. This is evidently due to the fact that the lateral border was here partially or entirely covered by a series of elements belonging to a rudimentary fourth digit.

MEASUREMENTS.

Femur	
Length	32.5 mm.
Width of proximal end	16
Width of distal end	24
Thickness at twist, parallel with plane of distal end	8
Thickness of proximal end	11
Tibia	
Length	15
Width, proximal	13
" notch to notch	8
" distal	12
Fibula	
Greatest length	18
Width, median	9.5
" distal	12
Fibulare	
Length	8
Width	7.5
Distal tarsal one	
Length	6
Width	7

Anterior limbs (Pl. 24, fig. 2).—The anterior limb has unfortunately been weathered on one side so that the proximal and posterior portions of the humerus and the part of the manus behind the second digit are gone. So much of the limb as is present resembles considerably the type of anterior extremity found in *Leptocheirus*. The width of the radius appears to be slightly greater, its anterior notch deeper, and the notching of the metapodal and phalangeal bones seems to be carried farther than in *Leptocheirus zitteli*. In digit one the metacarpal and all of the phalanges are notched on both anterior and posterior sides. In digit two phalanx one has a deep posterior notch, while two and three are notched on both sides.

MEASUREMENTS.

Radius	
Greatest length	15 mm.
Width, proximal and distal	12
" between notches	9
Radiale	
Length	8
Width, proximal	8.5
" at notch	6.5
" distal	7.5

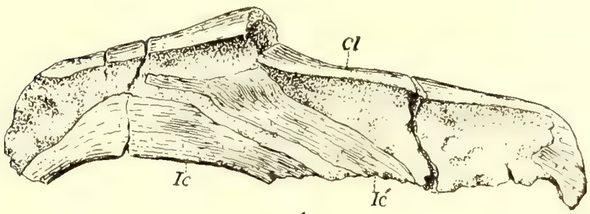
EXPLANATION OF PLATE 21.

Leptocheirus zitteli n. gen. and sp.

Figures reproduced natural size from the type specimen.

Fig. 1.—Clavicles (cl) and probable interclavicle (Ic and Ic′). The interclavicle has been separated into two fragments by a crack in the matrix.

Fig. 2.—Inner side of the coracoids and the left scapula.



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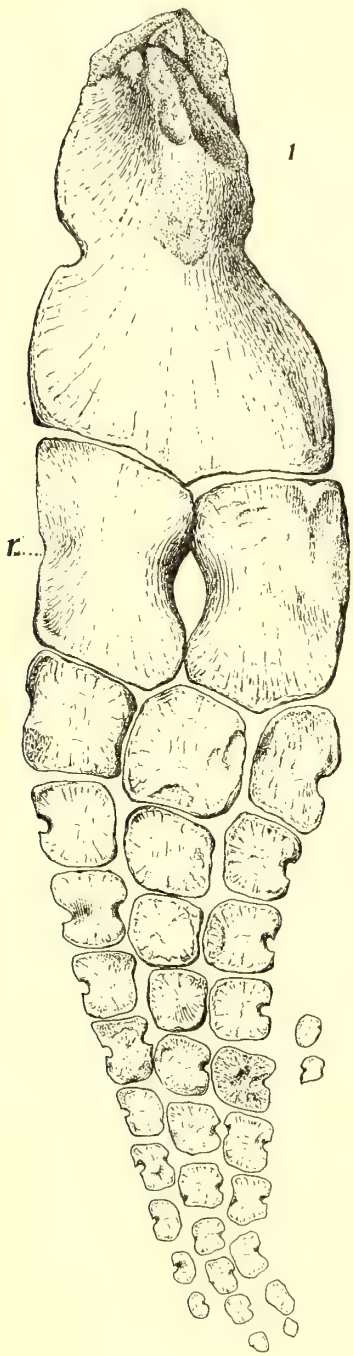
EXPLANATION OF PLATE 22.

Leptocheirus zitteli n. gen. and sp.

Figures reproduced natural size from the type specimen.

Fig. 1.—Superior side of left anterior limb. *r*, radius.

Fig. 2.—Posterior limb. *t*, tibia.



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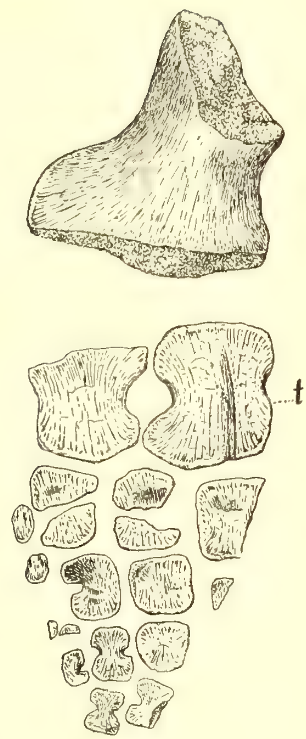

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EXPLANATION OF PLATE 23.

Leptocheirus zitteli n. gen. and sp.

Figures reproduced natural size from the type specimen.

Fig. 1.—Right side of skull.

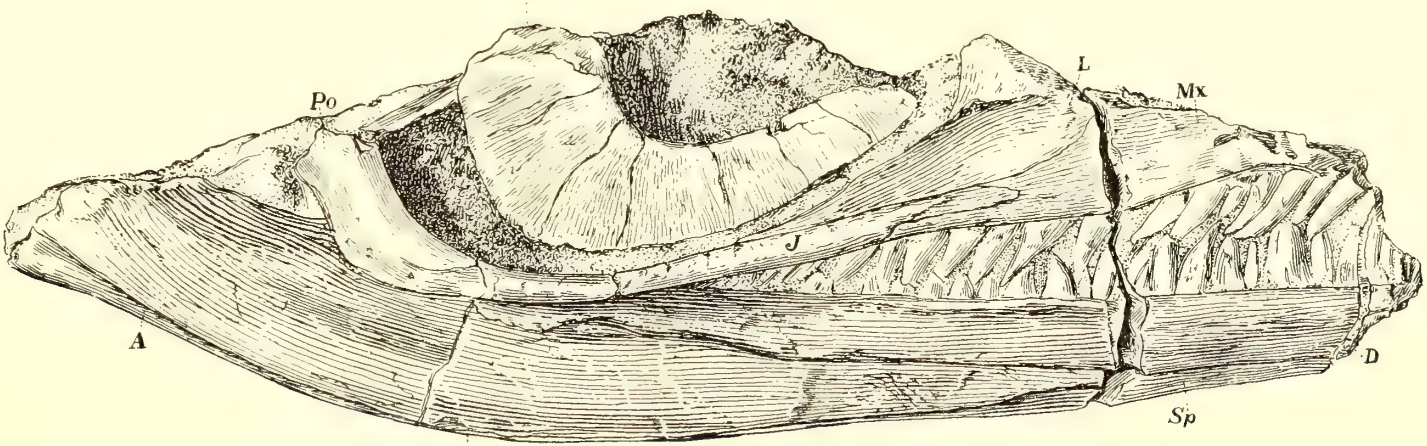
Fig. 2.—Cross-section of posterior portion of the lower jaw, taken above the point marked *A* on the lateral view of the skull.

Fig. 3.—Cross-section of the upper and lower jaws, taken at the break immediately behind the point marked *Sp* on the lateral view of the skull.

Fig. 4.—Lateral view of an anterior caudal centrum.

Legend for Figures 1, 2, and 3.

L, lachrymal.	Sc, sclerotic ring.	A, angular.
Mx, maxillary.	D, dentary.	Ar, articular.
J, jugal.	Sp, spenial.	X, doubtful element.
Po, postorbital.	Sa, supra-angular.	T, cross-section of tooth.



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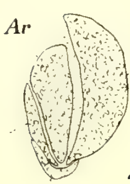

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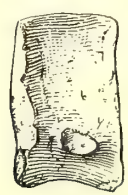

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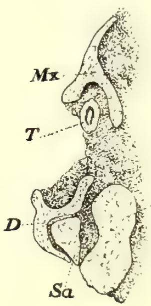

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EXPLANATION OF PLATE 24.

Toretocnemus californicus n. gen. and sp.

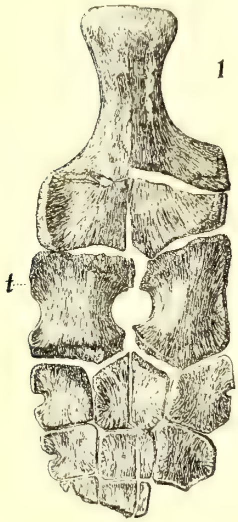
Figures reproduced natural size from the type specimen.

Fig. 1.—Inferior side of right posterior limb. *t*, tibia.

Fig. 2.—Right anterior limb. *r*, radius.

Fig. 3.—Pelvic arch.

Fig. 4.—Middle dorsal vertebræ and a rib from the same region.



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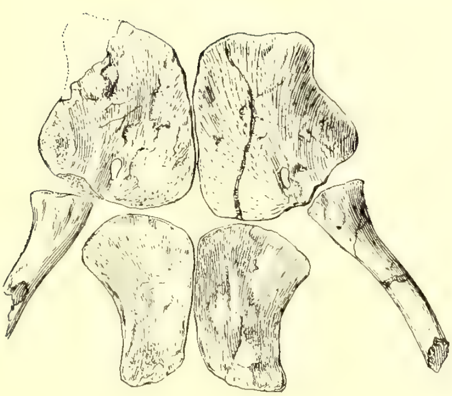

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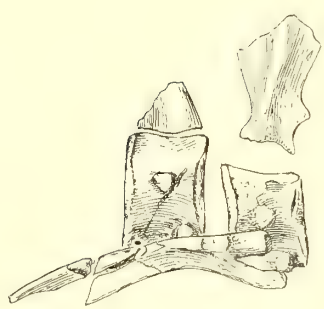

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UNIVERSITY OF CALIFORNIA PUBLICATIONS

Bulletin of the Department of Geology

Vol. 3, No. 13, pp. 265-275, Pls. 25-27. ANDREW C. LAWSON, Editor

SPODUMENE

FROM

SAN DIEGO CO., CALIFORNIA

BY

WALDEMAR T. SCHALLER

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SPODUMENE

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WALDEMAR T. SCHALLER

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OCCURRENCE.

Localities.—Beautiful transparent spodumene of deep amethystine purple, rose and magenta colors, has so far been found in two localities in southern California. The one from which most specimens have been obtained is situated about two miles north of Pala, San Diego Co., and this locality was visited by the writer during the past summer. The other place of occurrence is somewhere in the San Jacinto mountains, probably not far from Cuahuilla, Riverside Co., which is about twenty-five miles from Pala. It is probable that with further exploration other localities will be found in the Smith mountains, San Diego Co. and also in the San Jacinto mountains, Riverside Co.

Mode of Occurrence.—The formation in which these fine crystals are found at the Pala locality consists of a pegmatite dike, dipping westerly at a low angle, perhaps 20°. It is more or less broken, and, as a whole, seems to form the surface of much of the slope of the hill, on which it occurs. The dike is rather broad, but irregular in its present shape, and has a thickness of probably not more than thirty feet. Plate 25 is a photograph of the locality, looking north-west.

So far as the mining developments have shown, only a small portion of the dike is rich in lithia minerals. Ordinarily, the dike is a coarse muscovite granite, the orthoclase and quartz predominating, containing many rounded prisms of black tourmaline, with broken ends. Lepidolite occasionally seems to replace the muscovite and when it does, red, blue and green tourmalines replace the black variety. It is with these gem tourmalines that the spodumene occurs. While the tourmaline and lepidolite are frequently inclosed in the quartz and feldspar, no such inclusions of spodumene have been found. The latter mineral always occurs associated with the other minerals, but never penetrating them or penetrated by them. It occurs in pockets and these facts seem to indicate that the formation of the spodumene is later and not coincident, in time of formation, with the tourmalines and with the dike.

The dike cuts across the large intrusion of dark rock occuring at Pala and briefly mentioned by Dr. H. W. Fairbanks* This large body of dark rock, several miles across is surrounded on all sides by granite. It is in this same body of rock and hardly a mile from the spodumene locality that the well known lepidolite mine is situated from which so many specimens of the fine-grained white lepidolite with the radiating groups of rubellite have been obtained. This large body of lepidolite occurs in a similar pegmatite, having the same general strike and dip as the dike carrying the spodumene, which mineral has not as yet been found in the lepidolite mine.

The dark rock forming the footwall of the dike in which the spodumene occurs, is a diorite, consisting of hornblende, a plagioclase, and (subordinate) orthoclase with accessory magnetite and apatite.

---

* Ninth Report State Mineralogist (California.)

The hornblende is common green hornblende, with usually ragged outline, and possesses normal optical properties. $b = \mathfrak{b}$, $c \wedge \mathfrak{c} = 16°$. The pleochroism is $\mathfrak{a}$ = light yellow to light olive green, $\mathfrak{b}$ = dark olive green, $\mathfrak{c}$ = sea green to blue green. The absorbtion is $\mathfrak{c} > \mathfrak{b} > \mathfrak{a}$.

The triclinic feldspar predominates as is shown by the albite twinning lamellae present. Symmetrical extinction angles gave values from 30° to 35°, making this feldspar labradorite.

The orthoclase occurs sparingly in nearly square sections and is distinguished from the labradorite by its lower relief and birefringence.

From its structure and mineral contents the rock is evidently a basicdiorite containing some orthoclase.

From a description of the other locality, the mode of occurrence of the spodumene there, seems to be similar to that at Pala, being a dike in "blue granite" (the name locally given to the diorite).

DESCRIPTION OF CRYSTALS

Forms.—Only the prismatic zone is well defined on the specimens seen by the writer; both ends of the crystals are rounded off, and any forms occuring there are practically undeterminable. On one of the smaller crystals, the two forms $s = \{121\}$ and $p = \{\bar{1}12\}$ may possibly be present.* The

Dana		Gdt.
p q	=	$-\left(\frac{p}{2}+1\right) \cdot \frac{q}{2}$
$-2(p+1).2q$	=	p q

measurement of these two forms, with the two circle goniometer, gave the following results:

	Measured.		Calculated.	
	ϕ	ρ	ϕ	ρ
$s = 12 = \{121\}$	37° 14′	73° 33′	38° 46′	72° 56′
$p = -\frac{1}{2} = \{\bar{1}12\}$	21 05	31 57	20 05	34 04

The forms in the prism zone, however, can easily be determined. They are

$b = 0\infty = \{010\}$	$n = \infty 3 = \{130\}$
$a = \infty 0 = \{100\}$	$A = \infty\frac{5}{3} = \{350\}$
$m = \infty = \{110\}$	$l = \frac{3}{2}\infty = \{320\}$

* The orientation of the crystals in this paper corresponds to the one given in Goldschmidt's Winkeltabellen. To change the indices to those given in Dana's System, the following transformation symbols (Gdt. Index 3) are used.

The measurement of the angles of these forms with those calculated, are given in the following table.

	Measured. ϕ	Measured. ρ	Calculated. ϕ	Calculated. ρ
$b = 0\infty = \{010\}$	0° 06′	90° 00′	0° 00′	90° 00′
$a = \infty 0 = \{100\}$	90 00	"	90 00	"
$m = \infty = \{110\}$	43 30	"	43 30	"
$n = \infty 3 = \{130\}$	17 06	"	17 33	"
$A = \infty\frac{5}{3} = \{350\}$	29 50	"	29 39	"
$l = \frac{3}{2}\infty = \{320\}$	55 01	"	54 54	"

The form $A = \infty\frac{5}{3} = \{350\}$ is new for spodumene and occurs but once, as a small face.

The form $n = \infty 3 = \{130\}$ was measured by means of a wax impression, as the crystal on which it occurs is too large for measurement with the reflection goniometer.

The unit prism is always present, and measurements of ten faces gave the following values:

ϕ angle on $m = \infty = \{110\}$

43° 30′	43 31
43 29	43 28
43 36	43 26
43 24	43 33
43 33	43 30

Av. = 43° 30′

This value agrees with the one given by Dana in his System, but varies somewhat from the angle obtained by Brush and Dana* on cleavage faces of the Branchville, Conn., spodumene, their results giving 43° 36.5′.

The interfacial angles on the large crystals were measured with a hand goniometer and the averages of these measurements are shown in the following table.

	Measured.	Calculated.
$(110):(1\bar{1}0)$	93° 18′	93° 00′
$(110):(\bar{1}10)$	87 24	87 00
$(1\bar{1}0):(0\bar{1}0)$	44 00	43 30
$(110):(100)$	46 36	46 30
$(100):(0\bar{1}0)$	89 30	90 00

The unit prism, while always present is not always equally developed in its four faces, two parallel faces being frequently

* Amer. Journ. Science, 1880 (3), **20**, 257.

much larger than the other two. The crystal thus presents a tabular appearance.

The orthopinacoid is rather frequently present, though occasionally it is very narrow and rounded to such an extent as to render it difficult to definitely decide if it be present or not. Then again, it may be very broad making the crystal tabular. A marked feature of the orthopinacoid is that it is always deeply furrowed vertically.

The clinopinacoid is not of frequent occurrence, though it has been noted a number of times, from a narrow face, less than a millimeter wide to one almost a centimeter in width. Fig. 2, Plate 26, shows the crystal having the broadest clinopinacoid. From left to right the faces in the prism zone, on this crystal, are $(\bar{1}30)$ (very narrow), $(0\bar{1}0)$, $(1\bar{1}0)$, (100) (furrowed). The orthopinacoidal faces are the only ones striated.

Habit.—Three habits are noticed in these crystals, depending on the relative size of the faces in the prismatic zone.

The most common habit and the one that is more or less confined to the smaller crystals, is a tabular form resulting from the inequality in size of the prism faces. Other faces, such as the pinacoids are usually absent from crystals of this type.

The second most frequent type is where the orthopinacoid is very large and the crystals become tabular parallel to this form. This habit seems to be restricted to the larger crystals.

In the third habit, all three forms, the prism and the two pinacoids are equally developed and the crystal becomes octagonal in shape. This habit is of rare occurence.

Plate 26 is a photograph of seven crystals. Crystal 6 has the first habit, crystals 4 and 7 have the second habit, and crystal 2 has the third habit.

ETCH FIGURES.

On the Unit Prism.—A very marked feature of these crystals is the profusion of natural etch figures which thickly crowd all of the natural faces of the crystals, except the orthopinacoid. Even cleavage (prismatic) pieces frequently show them.

On the faces of the unit prism they are especially thick as can be seen in Fig. 6, Plate 26, which is a crystal tabular to a prism face. The etch figures are usually triangular in shape and vary in size from a maximum length of about three millimeters and width of one millimeter to ones of miscroscopic size. Not infrequently there will be several smaller ones in the base of a larger one.

Occasionally a long string of the figures will run across a prism face, in an approximately horizontal direction.

The orientation of these triangular pits with reference to the crystallographic directions, varies somewhat but, in general, is fairly constant and is shown in Fig. 1. The position of these

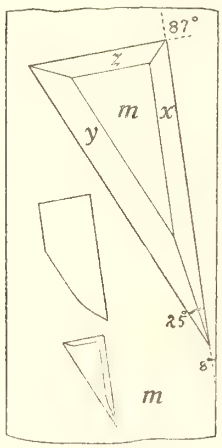


Fig. 1. Showing position of etch figures on unit prism face (110).

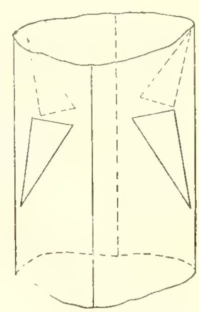


Fig. 2. Showing position of etch figures on the four unit prism faces.

figures on the four prism faces is shown in Fig. 2. It is noticed that they always point away from the orthopinacoid and the angle nearly 90° is nearest the clinopinacoid. Rarely the triangle passes into a trapezium by the addition of a fourth side, as is shown in the middle figure of Fig. 1; very few of the edges are perfectly straight, being more or less rounded, but they are mostly all drawn straight.

Fig. 1, Plate 27, shows a photomicrograph of the common appearance of these etch figures — a large number of imperfect ones closely crowded together. Fig. 2 shows a view of the best group of etch figures that could be found on any of the crystals.

It represents the face (110) while the one to the left of it represents the face ($1\bar{1}0$).

A detailed study of these etch figures shows that they consist of four faces: three side faces and a base. Fig. 1 gives in detail a view of one of these pits. The bottom or the face lettered m is parallel to the unit prism. The face x corresponds to the prism $\{320\}$, the face y to $\{8.14.3\}$ or $\{351\}$, and the face z to $\{\bar{1}\bar{1}.10.3\}$. The measurements on which these determinations are based, are as follows:

	Measured.		Calculated.	
	ϕ	ρ	ϕ	ρ
$m = \infty = \{110\}$	43° 24′	90° 00′	43° 30′	90° 00′
$x = \frac{3}{2}\infty = \{320\}$	55 49	"	54 54	"
	55 40			
	56 09			
av.	55 53			
y $= \frac{8}{3}\frac{14}{3} = \{8.14.3\}$	34 33	81 44	34 20	82 04
	34 44	82 19		
	32 33	82 04		
av.	33 57	82 02		
y $= 35 = \{351\}$	"	"	35 01	82 39
$z = -\frac{11}{3}\frac{10}{3} = \{\bar{1}\bar{1}.10.3\}$	40 44	80 20	40 15	79 47
	40 29	79 25		
	41 06	80 06		
	40 23	79 22		
av.	40 41	79 48		

For the face y the measurements are approximate for the two symbols $\{8.14.3\}$ and $\{351\}$ and the simpler one may therefore be chosen.

Quite frequently the faces m and x grade insensibly into one another or the face m may be entirely lacking. All of the faces are usually very much rounded, making it difficult to obtain any accurate measurements.

The symbols obtained for the faces of the etch figures do not at all agree with those determined by Dana* on Hiddenite.

* Amer. Journ. Science, 1881 (3), **22**, 179.

The form $z = \{\bar{1}\bar{1}.10.3\}$ approximates the form $g = \{\bar{4}41\} = \{681\}$ (Dana).

Measured.			Calculated.	
ϕ	ρ		ϕ	ρ
40 41	79 48	$\{\bar{1}\bar{1}.10.3\}$	40 15	79 47
		$\{\bar{4}41\}$	38 07	81 12

The forms determined by him compared with those obtained by the writer, given in Goldschmidt's and Dana's orientations respectively, are:

Schaller.			Dana.	
Gdt.		Dana.	Gdt.	Dana.
$\{320\}$	=	$\{320\}$	$\{650\} = $	$\{650\}$
$\{351\}$ or $\{8.14.3\}$		$\{\bar{8}.10.1\}$ or $\{\bar{2}\bar{2}.28.3\}$	$\{781\}$	$\{\bar{1}\bar{6}.16.1\}$
$\{\bar{1}\bar{1}.10.3\}$		$\{16.20.3\}$	$\{\bar{4}41\}$	$\{681\}$

On the Clinopinacoid.—The etch figures occurring on the clinopinacoid are rhombic in shape and sometimes modified by another plane, as is shown in the upper figure in Fig. 3, which also shows the position of the etch figures with reference to the crystal. A few of the etch figures run over on the clino prism $(\bar{1}30)$, the clinopinacoid here shown being the negative one. Strings of the etch figures also occur pitching in a direction opposite to that of the clino-axis.

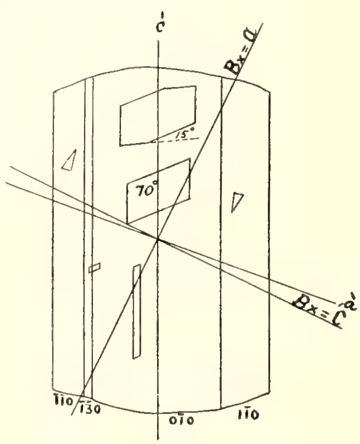


Fig. 3. Showing the position of etch figures on the clinopinacoid $(0\bar{1}0)$ and the optical orientation of the crystal.

Figures 3 and 4, Plate 27, show photomicrographs of the clinopinacoidal etch figures. It will be noticed that there are two prominent varieties, the rhombic, nearly equal in the two directions, and then a long narrow form such as is shown in Fig. 3. They are all identical, as the long narrow ones are simply distorted in one direction.

The prism $\{320\}$ occurs on the clinopinacoidal etch figures and is the only form determinable. A remarkable fact is that on one crystal, the etch figures penetrate the crystal, emerging on the opposite clinopinacoid. These cavities are usually partially choked up by a limonitic earthy substance.

Etch figures also cover the rounded ends of the crystals, but their relation to the structure of the crystal cannot be determined owing to the lack of definite terminal faces.

PHYSICAL PROPERTIES.

General Properties.— In its physical properties, with the exception of the color the mineral does not vary from normal spodumene. The color although rare is not new as it has been noted on some of the spodumene from Branchville, Conn., described by Brush and Dana.* To quote a few words from their paper (p. 258)—"The unaltered spodumene, of a fine amethystine color, . . . In the better specimens the spodumene is perfectly transparent, sometimes colorless, and again of a beautiful rose-pink or amethystine-purple color." This description fits admirably with the San Diego spodumene. One specimen is colorless while the others are of a rose-pink, magenta or amethystine-purple color.

The cleavage parallel to the unit prism is highly perfect. No parting parallel to the orthopinacoid was noticed on any of the crystals. All of the crystals are transparent and show no trace of alteration, being remarkably fresh and thus differing materially from the New England spodumene. The hardness of the mineral lies between that of quartz and beryl. An interesting observation may be mentioned here. On cutting a crystal with a carborundum saw, the mineral became strongly luminous.

The clearest transparent piece was taken for analysis and the specific gravity of it taken by suspension in water. The piece weighed about 10 grams. The specific gravity was determined as 3.189. This agrees very well with the result obtained on the pink Branchville, Conn. spodumene by Brush and Dana, namely, 3.193.

The mineral fuses easily to a clear glass coloring the flame an intense red.

Optical Properties.—The pleochroism is a very striking property of the mineral. The colors are $\mathfrak{a}$ = magenta or amethyst-

* Loc. cit.

ine-purple, $\mathfrak{b}$ = pale pink or amethyst, $\mathfrak{c}$ = colorless. The $\mathfrak{c}$ ray is absolutely colorless no matter how thick the crystal is.

The average of a number of determinations of the inclination of the acute bisectrix to the vertical axis, gave, for sodium light, $Bx_a \wedge c = +25° 24'$. That is, the acute bisectrix lies in the obtuse angle β and is nearly normal to the basal pinacoid (Dana's orientation).

The indices of refraction, α and γ were determined by the method of Duc de Chaulnes on a crystal about a centimeter in thickness. The values obtained, the average of a number of readings, are only approximate, though they agree remarkably well with the determinations of Des Cloizeaux. The results obtained by the writer for sodium light, are:

$$\alpha = 1.652$$
$$\gamma = 1.679$$

This gives, as the strength of the double refraction, $\gamma - \alpha = .027$. The results of Des Cloizeaux are:

$$\text{Na} \quad \alpha = 1.651$$
$$\gamma = 1.677$$

Many attempts were made to prepare a section of the mineral normal to the acute bisectrix but it invariably went to pieces, owing to the highly perfect prismatic cleavage.

CHEMICAL COMPOSITION.

The average of several analysis of the mineral afforded the writer the results shown in column I. In the second column is given an analysis of the pink spodumene from Branchville, Conn., analyzed by Professor S. L. Penfield.* Unfortunately

	I.	II.
SiO_2	= 64.42	64.25
Al_2O_3	= 27.32	27.20
Mn_2O_3	= 0.15	——
Li_2O	= 7.20	7.62
Na_2O	= 0.39	0.39
K_2O	= 0.03	trace
Fe_2O_3	= none	0.20
CaO	= none	——
MgO	= none	——
Ign.	= no loss	0.24
	99.51	99.90

* Loc. cit.

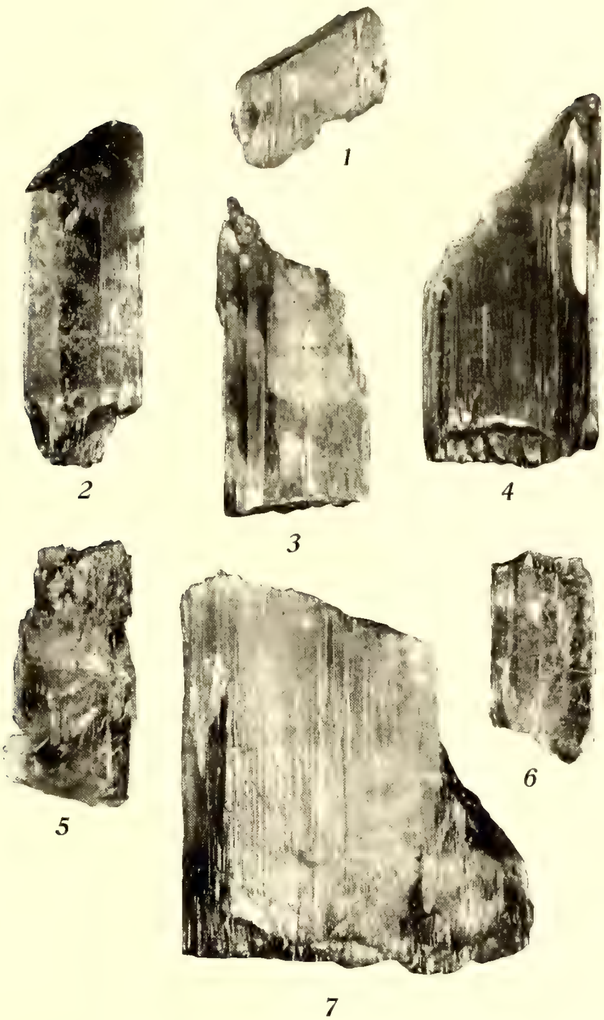
Penfield does not mention the absence or presence of manganese. Otherwise the analysis agree very closely. The results for lithium obtained by the writer are probably a little low. Lithium was separated from the other alkalies by amyl alcohol. The soda fusion had a deep blue-green color and the solution of it in hydrochloric acid had a very decided pinkish cast, affording good qualitative tests for the presence of manganese. Its state of oxidation in the mineral is not known but the absence of any dyads makes it appear more reasonable to consider the manganese as present as Mn_2O_3, replacing the alumina. Iron is entirely absent, the alumina precipitate being, after ignition, pure white. Neither calcium nor magnesium could be detected. There was no loss on ignition either at a low red heat or at a more intense heat.

NOTE.—Since the above was written, short notices of this spodumene have appeared in *Science* for August 28 and September 4, and the gem has been named Kunzite. No detailed description of the mineral is given: only a few of the physical properties being mentioned. In both notes twinning structure is mentioned as characteristic of themineral. A careful study of the position of the etch figures has convinced the writer that the specimens which form the subject of this study are untwinned.

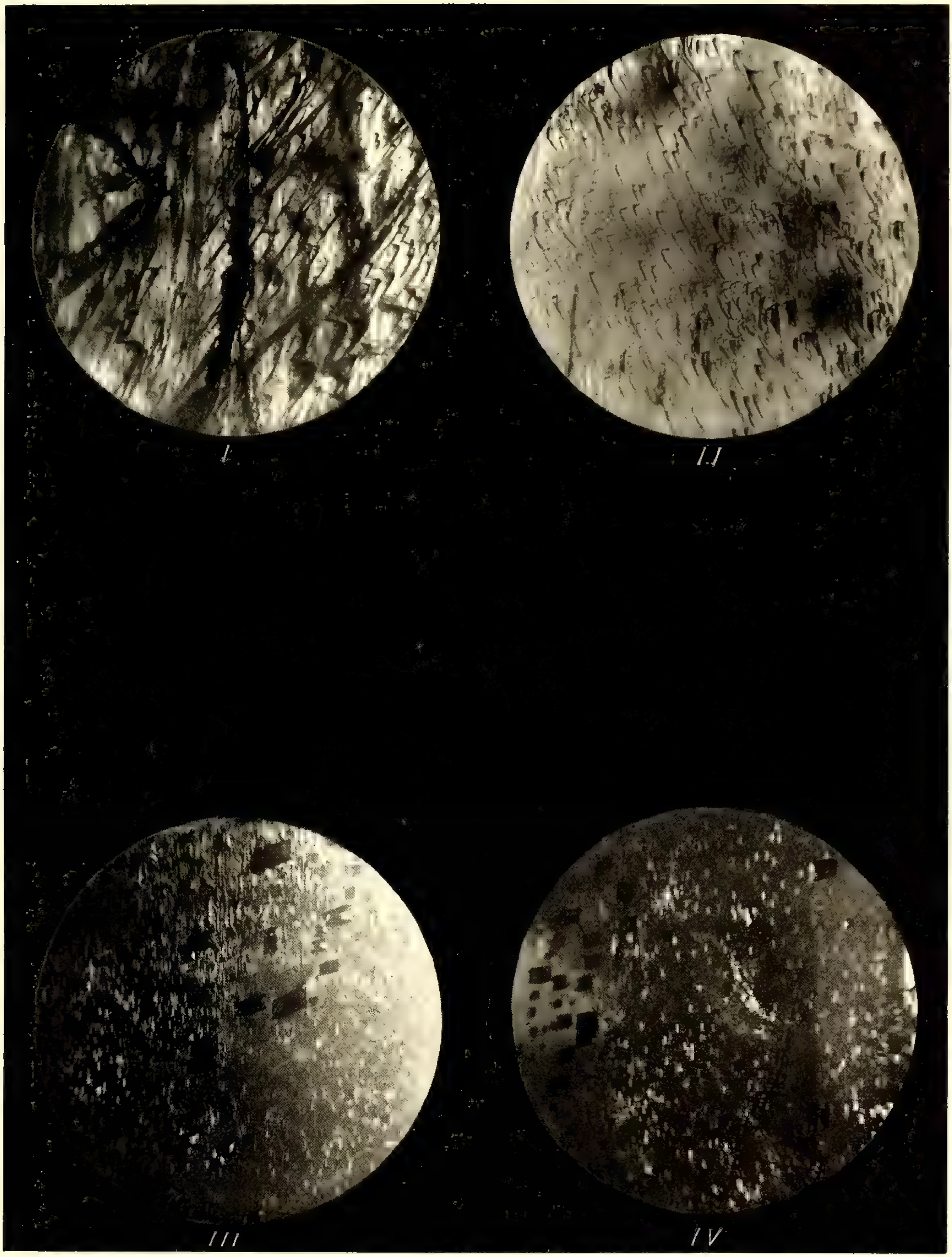
The green spodumene, hiddenite, also occurs in this locality. The writer has recently received from there a small, pale green crystal, about 26 mm. long, 8 mm. broad and 7 mm. thick. The etch-figures on the prismatic faces show that this crystal is twinned, as some of the etch-figures are in reversed position to the others.

University of California,
September, 1903.

View of the Gem Mine near Pala in which the Spodumene is found. Looking north.
From a photograph by A. C. Lawson.



Characteristic forms of the Pala Spodumene. Two-thirds natural size.



Natural etch figures on the Pala Spodumene. I. On the prism $1\bar{1}0$. II. On the prism 110. III and IV. On the clinopinacoid $0\bar{1}0$.

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THE

PLIOCENE AND QUATERNARY CANIDAE

OF THE

GREAT VALLEY OF CALIFORNIA

BY

JOHN C. MERRIAM

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THE BULLETIN OF THE DEPARTMENT OF GEOLOGY OF THE UNIVERSITY OF CALIFORNIA is issued at irregular intervals in the form of separate papers or memoirs, each embodying the results of research by some competent investigator in geological science. It is designed to have these made up into volumes of from 400 to 500 pages. The price per volume is placed at $3.50, including postage. The papers composing the volumes will be sent to subscribers in separate covers as soon as issued. The separate numbers may be purchased at the following prices from the University Librarian, J. C. Rowell, to whom remittances should be addressed:—

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THE PLIOCENE AND QUATERNARY CANIDAE OF THE GREAT VALLEY OF CALIFORNIA.

BY
JOHN C. MERRIAM.

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INTRODUCTION.

Up to the present time only two representatives of the Canidae have been known to occur in the Tertiary and Quaternary formations of California. One of these is supposed to have been found in Quaternary gravels at Murphys, Calaveras County, and has been referred by Leidy to an existing coyote, *Canis latrans* Say. The second species was obtained from loose gravels near Livermore Valley, Alameda County. It was represented by a lower jaw which Leidy identified as *Canis indianensis*, a form described by him previously from remains discovered in the Ohio Valley. Unfortunately, the Californian type has disappeared and we have only Leidy's figure for comparison.

Of the three specimens described in this paper, two were presented to the University of California some years ago. Shortly after they were received, the descriptions and figures published here were prepared by the writer. They were withheld from publication as the specimens were found to represent new and very peculiar types, a thorough understanding of which would necessitate the acquisition of additional material. During the eight years that have passed since these specimens were first studied, extended investigations of the gravels have been made but no new material has been discovered. As yet no very productive beds have been discovered in the fresh water Tertiary and Quaternary of California and the number of mammalian specimens found is small. It is to be hoped that somewhere in the extensive areas covered by these deposits in this state specimens may yet be discovered which will show other portions of the skeletons of these peculiar forms.

A third specimen discussed here is referred to Leidy's *Canis indianensis*, already described from this state. It is, however, of considerable importance. Since the loss of the jaw from Alameda County, it is the sole representative of the species known from this region. This specimen is in the museum of the California Academy of Sciences. Through the kindness of Mr. L. M. Loomis, director of the museum, and of Mr. F. M. Anderson, in charge of the palaeontological collections, the writer has been accorded the privilege of describing and figuring it here.

HYAENOGNATHUS PACHYODON n. gen. and sp.

Pl. 28, Figs. 1 and 2.

Generic characters.—Mandible short and massive. Alveolar margins greatly flared below $P_{\overline{3}}$ and $P_{\overline{4}}$. Dentition $\overline{3}$, $\overline{1}$, $\overline{3}$, $\overline{3}$. $P_{\overline{2}}$ and $P_{\overline{3}}$ small. $P_{\overline{3}}$ molariform. $P_{\overline{4}}$ very large, conical, without accessory tubercles. $M_{\overline{1}}$ massive; protoconid and paraconid forming a heavy shear, metaconid absent; heel short, with reduced hypoconid and entoconid. $M_{\overline{2}}$ and $M_{\overline{3}}$ small.

Occurrence.—The type specimen of this species consists of a mandible (No. M8139, Univ. Calif. Palaeont. Mus.) found at Asphalto, Kern County, close to the foot of the Temblor Range. It was presented to the University by Mr. Bernard Bienenfeld of San Francisco.

The excavations at the locality where the jaw was found seem to have been in beds ranging from late Miocene to Quaternary, but principally in the latest formation. A jaw of a large species of *Smilodon* associated with the *Hyaenognathus* mandible indicates that it was probably obtained from a Quaternary bed, or possibly from the late Pliocene.

Mandible.—The lower jaw is short and heavy, having a strong resemblance to that of the hyaena. Below the molars its height and thickness are about equal to that in the hyaena, but the anterior portion below the premolars is somewhat higher and heavier. As in the hyaena, the inferior border of the mandible is strongly convex below the posterior end of the molar series.

Owing to the extreme shortness of the jaw, the alveolar margins are strongly flared below the carnassial and the last two premolars. The extent of this spreading possibly exceeded that in the hyaenas.

Dentition.—The dentition contains a most remarkable mixture of primitive characters with some extreme specializations. The formula $\overline{3}$, $\overline{1}$, $\overline{3}$, $\overline{3}$, shows the loss of but a single tooth, $P_{\overline{1}}$, while the efficient portion of the dentition may be said to consist of but three teeth, a fairly developed canine, a powerful $P_{\overline{4}}$ and a still heavier $M_{\overline{1}}$.

The incisors are missing from both rami but the clearly defined alveoli show that they were small and crowded. $I_{\overline{1}}$ and $I_{\overline{2}}$ were near the size of the corresponding teeth in the hyaena but $I_{\overline{3}}$ was much more reduced.

The lower canines are short and stout and appear a little weaker than in the hyaenas.

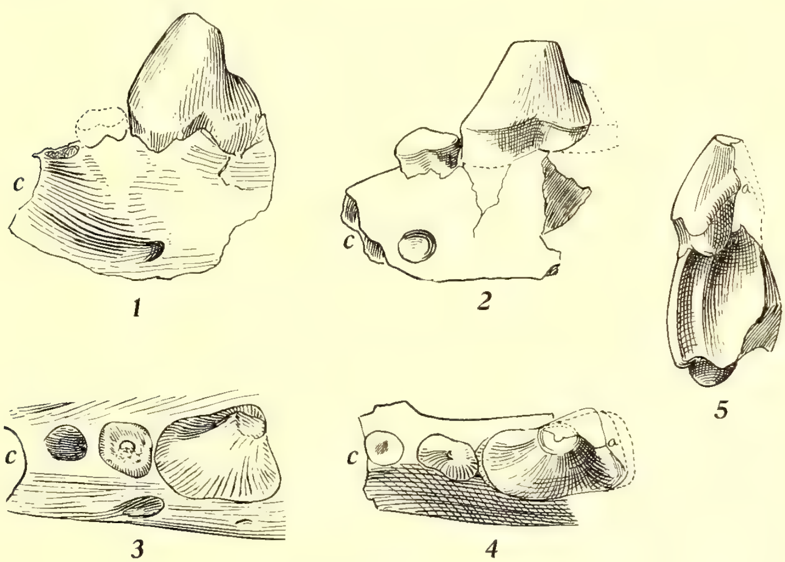
Of the three premolars, $P_{\overline{2}}$ has been lost but its alveolus shows it to have been a thick, single-rooted tooth somewhat smaller than the one behind it. The root of $P_{\overline{3}}$ exhibits a deep groove near the top and was probably divided toward the lower end. The molariform crown seems to be somewhat worn but the button-like base is very thick, with a transverse diameter almost equalling the longitudinal. $P_{\overline{4}}$ has nearly two and one half times the antero-posterior extent of $P_{\overline{3}}$. The simple cone of the crown has no anterior or posterior accessory tubercles, although there is a shelf on the cingulum at the posterior inner angle. On both rami the crown of this tooth is bent backward slightly and is very close to the anterior blade of the carnassial.

In the molar series, $M_{\overline{1}}$ is exceedingly massive and with $P_{\overline{4}}$ has done practically all of the work falling to the cheek teeth. The protoconid and paraconid are both greatly developed. No trace of a metaconid is discovered, although the postero-internal ridge of the protocone is prominent. The small talonid supports an external and an internal tubercle, both of which are very small and low. The crown of $M_{\overline{2}}$ bears an anterior and a posterior tubercle, of which that representing the talonid is much the smaller. $M_{\overline{3}}$ is represented by a small alveolus on each ramus.

Affinities.—The dentition of *Hyaenognathus* has a striking resemblance to so much as is known of the problematical genus *Borophagus*, described from a jaw fragment found in the Blanco beds of Texas. For comparison Cope's figures* of the type specimen are reproduced here together with outlines of the corresponding portion of the *Hyaenognathus* jaw (figs. 1, 2, 3, 4, 5). The only other specimens referred to *Borophagus* are an inferior premolar with a conic basal cusp and a single blade of a sectorial, which were thought by Cope to belong here. If the premolar with a conic basal cusp belongs to *Borophagus*, the Californian form could not be closely related to this genus. If this is eliminated as doubtful and a comparison made with the type, we find the two forms possessing a combination of characters not found elsewhere. Both have the reduced $P_{\overline{2}}$, depressed $P_{\overline{3}}$, and the greatly enlarged, simple $P_{\overline{4}}$. Cope's restorations of $P_{\overline{4}}$ in fig. 2 and fig. 4 show the posterior basal lobe of this tooth considerably extended. According to his view of the tooth in fig. 5, this

* Geol. Surv. Texas, 4th Ann. Rep., 1892. Vert. Palaeont. Llano Estac. p. 52, Pl. XIII, figs. 4, 4*a*, 4*b*.

restoration is not justified, as the outer portion of the heel was unbroken. On fig. 4 the writer has indicated in an unbroken line a third suggestion as to probable form, beginning the restoration at the point *a* where the break in the heel occurs. This shows the tooth to have a form somewhat similar to that of $P_{\overline{4}}$ in *Hyaenognathus*, although not so broad. Cope classified *Borophagus* on the assumption that it had four inferior premolars, though he suggests doubt of this at one point in his description. This is, however, improbable, as the presence of a $P_{\overline{4}}$ corresponding in size to what he considered as the large $P_{\overline{3}}$ and accompanied by a heavy sectorial would mean the elimination of $P_{\overline{1}}$, just as has occurred in *Hyaenognathus* and in the hyaenas.



Figs. 1 and 3. *Hyaenognathus pachyodon*, $\times \frac{3}{4}$. *c*, alveolus of canine. Figs. 2, 4 and 5. *Borophagus diversidens* Cope, $\times \frac{3}{4}$. *c*, alveolus of canine. *a*, point on $P_{\overline{4}}$ where fracture begins. (After Cope.)

Hyaenognathus is evidently allied to *Borophagus* and it is not impossible that future investigation may show generic identity. The differences in the minor details of form in the premolars indicate, however, that the types are specifically quite widely separated, *Hyaenognathus* being the more specialized. Several facts suggest that, while we may show that the two forms are clearly related, we are not in a position to demonstrate generic identity. The Californian specimen represents a more extreme form coming probably from Quaternary beds, while *Borophagus* is Pliocene; the two occur at localities geographically distant from each other; and we do not know the most essential parts of the structure of *Borophagus*.

The genus *Borophagus* was referred provisionally to the Hyaenidae by Cope, and the general form of the mandible in *Hyaenognathus* reminds one very much of that family. The dentition of *Hyaenognathus* has, however, no real structural resemblance to that of the hyaenas, though its functions were evidently similar. This genus represents a type analogous to the hyaenas, but is derived from a different source and worked out on a very different type of tooth structure. It represents the extreme of known specialization of the dog family in one direction.

The genus differs so far from any known form that its affinities are not clearly shown. It resembles the Amphicyonine canids in the heavy jaw and simple premolars, but differs greatly in the characters of the tubercular molars and of the heel of $M_{\overline{1}}$. Also, $P_{\overline{4}}$, although simple, does not correspond to any form found in the Amphicyonines. The genus *Cephalogale*, a somewhat primitive form referred by Zittel to the Simocyoninae, presents many points of resemblance, though it is separated by differences of the same nature as those just mentioned. A similarity to the Mustelines of the *Gulo* group is presumably only superficial.

Professor Cope evidently judged *Borophagus* to be derived from the peculiar aberrant Aelurodons of America. They resemble *Hyaenognathus* in possessing heavy jaws and heavy premolars, in the reduction of the tubercular molars, and in the reduced talon and metaconid of $M_{\overline{1}}$. There are, however, four premolars in *Aelurodon*, three of these having accessory cusps, and the degree of modification required to produce from them a premolar dentition like that of *Hyaenognathus* would be very considerable.

The true affinities of this form can be determined with satisfaction only when we know more of the dentition and when we have some acquaintance with the limb structure. Some of the characters suggest a distant relationship to the Amphicyonines, though this is indistinct and a very wide gap must be filled before we can prove that the actual ancestors are to be found in that group. We can feel assured that in whatever division it is finally shown to belong, its place will be near the outer border of the group.

MEASUREMENTS.

Length of mandible from anterior end of symphysis to posterior end of $M_{\overline{2}}$	112 mm.
Height of jaw below protoconid of $M_{\overline{1}}$	38
Greatest thickness of ramus below protoconid of $M_{\overline{1}}$	20
Length of premolar series	41
" " molar series	48
Greatest diameter of base of canine	16
Antero-posterior diameter of $P_{\overline{3}}$	10
" " " " $P_{\overline{4}}$	22
" " " " $M_{\overline{1}}$	30.5
" " " " $M_{\overline{2}}$	10
Transverse diameter of $P_{\overline{3}}$	8.5
" " " $P_{\overline{4}}$	17
" " " $M_{\overline{1}}$	16
" " " $M_{\overline{2}}$	8.5

HYAENOGNATHUS? (PORTHOCYON n. gen.?) DUBIUS n. sp.

PL. 29 AND PL. 30, FIG. 1.

Distinctive characters.—Muzzle short, forehead and sagittal crest high. Brain case small and narrow, outer walls sloping sharply from the crest. Wings of the premaxillaries reaching back to the blunt anterior ends of the frontals. Palate very broad, with two pairs of large posterior palatine foramina. Posterior nasal openings not reaching forward to the end of the molar series. Dentition $\frac{3?}{}$, $\frac{1}{}$, $\frac{4}{}$, $\frac{2}{}$. $I^{\underline{3}}$ very large. Premolars crowded. Sectorial massive, without deuterocone. Metacone and heel of $M^{\underline{1}}$ small. $M^{\underline{2}}$ reduced.

Occurrence.—This form is represented by a single specimen consisting of the greater portion of a cranium with the essential parts of the dentition (No. M8138, Univ. Calif. Palaeont. Mus.). It was found in a quarry about two miles southeast of

Cornwall, Contra Costa County, California, and was presented to the University by Mr. Bromley of Oakland.

At the request of the writer, the beds in which the cranium was found have been examined by Mr. V. C. Osmont, with a view to determining their age. The formation was found to consist mainly of rather loose gravel beds with some sand and clay. As a whole, it resembles the Quaternary near Suisun Bay just north of this exposure. The beds rest upon the San Pablo formation and dip 10°–20° to the north. Mr. Osmont believes that this formation is cut by Quaternary terraces and that, owing to the terracing and deformation which it has suffered, it may be necessary to refer it to a late Pliocene epoch rather than to the Quaternary.

Cranium.—The cranium is that of an animal between a large wolf and a hyaena in size and resembling the latter in possessing a greatly abbreviated facial region. The results of this shortening are most noticeable in the inferior view (Pl. 30, fig. 1) where the diameter of the palate between the blades of the carnassials is seen to equal the length from the canine to the posterior end of $M^{\underline{2}}$. In the lateral view (Pl. 29) the forehead appears very high and full, although the head shows no indications of deformation by crushing. The brain case is very narrow and the walls slope abruptly from what has evidently been a high and sharp crest. Unfortunately the whole of the upper portion of the skull is gone and the exact form of the crest can not be determined.

The nasal region exhibits a characteristic structure. The posterior ends of the nasals and the anterior ends of the frontals enclosing them are broad and blunt, while the posterior wings of the premaxillaries extend backward almost to the posterior ends of the nasals and meet the frontals.

The anterior end of the jugal did not extend to the lachrymal foramen as in *Canis*, but ends considerably below it as in the hyaena.

In the palatine region there is again a resemblance to the hyaena, in that the posterior nasal opening does not reach forward to the end of the molar series.

In the foramina of the skull a distinctive mark is found in the presence of the two pairs of large posterior palatine foramina.

Dentition.—The dentition is essentially canid. $I^{\underline{1}}$ and $I^{\underline{2}}$

have been lost but were evidently quite small, as there is but little space for them between I^{3} and the median premaxillary suture. I^{3} is very large and in this respect resembles the hyaenas and some of the Aelurodons. The canines are not large. They tend rather to be smaller than is common in the Canidae. P^{1}, ^{2} & ^{3} have been lost but the alveoli show them to have been closely crowded. They were evidently small, though P^{2} and P^{3} were two-rooted. The carnassial is wide and heavy. The protocone blade is situated rather far forward. The deuterocone has disappeared, though the inner root is present. On M^{1}, the metacone is noticeably reduced, the heel and the whole inner lobe are small and the tubercles very low. The anterior inner angle is extended forward from the protocone forming a characteristic shoulder. M^{2} is very considerably reduced.

Affinities.—The relation of this form to that represented by the type of the genus *Hyaenognathus* is a particularly interesting one. Each is represented by a single specimen and they are found in beds not differing widely in age. Both represent short-muzzled, broad-palated types of canids with dentitions which are specialized but still not greatly reduced numerically. Unfortunately we have no corresponding parts for comparison, so that the true relationships between the two can not be determined with absolute certainty. Some of the features of the dentition would seem at first to show that they are very different. In the superior dentition of *Porthocyon*, P^{3}, which opposed the anterior side of inferior $P_{\overline{4}}$, is a small tooth not corresponding in size to the large $P_{\overline{4}}$ of *Hyaenognathus*. Also, the greatest width across the mandible of *Hyaenognathus* is across $P_{\overline{4}}$, or some distance in front of the carnassial, while in *Porthocyon* the width of the palate is greatly decreased immediately in front of the carnassial. On the other hand, we find that in the hyaena, in which somewhat similar structures occur, the large $P_{\overline{3}}$ standing at the point of extreme flare of the mandible is opposite the point where contraction of the palate begins and strikes either against or outside the posterior portion of a small P^{2}. In *Porthocyon* P^{3} is moved so far inward that it stands in front of the inner root of the carnassial, and it may have had much the same relation to $P_{\overline{4}}$ in occlusion that we find between P^{2} and $P_{\overline{3}}$ in the hyaena.

This relation occurs at about the same point in the jaw as in the hyaena, but is farther forward in the dentition, owing to the greater antero-posterior extension of the premolars in the hyaena after the reduction of the molars.

In a comparison of the molar series with that of the mandible of *Hyaenognathus*, we find the reduced crushing surface of M^{1} corresponding fairly well to the small low tubercles on the short tolonid of the lower sectorial. The presence of a prominent antero-internal angle on the first upper molar may be due to anterior extension following loss of the metaconid on the inferior sectorial. The reduction of the metacone can be accounted for by the median position of the single anterior tubercle of $M_{\overline{2}}$. Finally, the more than ordinarily sharp upward twist of the posterior molar is suggestive of correspondence to the similar curve in the inferior molar series of *Hyaenognathus*.

The resemblances just mentioned, coupled with the fact that the two specimens represent individuals not far from the same size, suggest that we are dealing with forms closely related, if not identical. This identity may not be specific, as the two probably do not belong to the same epoch and show a certain degree of difference in dimensions. The writer inclines to the belief that the two forms are generically identical. He doubts, however, whether it is possible to prove identity in the absence of corresponding parts, as characters might exist in either form without finding expression in the general correspondence discussed above. This specimen is therefore given a provisional generic name by which it may be known until the discovery of associated upper and lower jaws gives definite evidence of its affinities.

As in the case of the mandible of *Hyaenognathus*, the form represented by this specimen is so different from any known type that its broader relationships are not clear. While it is recognized as a typical canid, it has no close affinities with any well defined group. As in *Hyaenognathus*, any resemblance to the Amphicyons which appears in the premolars is practically invalidated by the extreme reduction of the molars. There is here, again, some resemblance to certain of the Aelurodons (*A. saevus* and *A. wheelerianus*) in the form of I^{3}, and to a certain extent in the outlines of the upper molars. Among the noticeable characters separating it from this group is the absence of the most distinctive feature of the upper dentition of *Aelurodon*, viz.: of the protostyle of $P^{\underline{4}}$.

Some of the closest general similarities to any other group that this form shows are its resemblances to certain of the species of *Palaeocyon (Speothos)* described by Lund* from the Brasilian cave fauna. *Palaeocyon* was a short-nosed, broad-palated dog with simple, crowded premolars and a very greatly reduced $M^{\underline{2}}$. $M^{\underline{1}}$ was also small and the superior sectorial had no deuterocone. This genus is distinguished from the Californian form by its relatively small I^{3}; minute $M^{\underline{2}}$; narrower and structurally different crushing lobe of $M^{\underline{1}}$; more slender facial region; and the absence of the peculiar characters of the nasal region, jugal, and posterior palatine foraminia found in *H.(?) dubius*. The two types are quite distinct and they may simply represent evolution in the same direction along two different lines. *Palaeocyon* is evidently a member of the Icticyon group in which extreme reduction has taken place at the posterior end of the upper and lower molar series before great crowding or elimination occurred in the premolar series. In the Californian form we have probably an older species. It shows less of the special kind of molar reduction than we see in the Icticyons, but is in many ways more highly specialized. If we consider the *Hyaenognathus* mandible as representing the same group as *H.(?) dubius*, we discover a farther resemblance to the Icticyons in the absence of the metaconid from $M_{\overline{1}}$. On the other hand the presence of three molars, the peculiar reduction of the premolars and the presence of two low tubercles on the heel of the sectorial show it to be distantly removed from *Palaeocyon*.

For the present we can not do more than consider this specimen as representing a very aberrant type of dog, considerably removed from any known group. As it belongs to a comparatively late epoch, we may hope to establish its relationship to one of the older and better known groups when we learn more of the Canidae of the West American Pliocene.

Should this form prove to be identical with *Hyaenognathus*, as has been suggested, we shall have made but little advance in

* P. W. Lund. Blik paa Brasiliens Dyreverden, 1841–45.

the determination of the true affinities of that genus beyond what was suggested by the type specimen. The characters of the cranium and superior dentition seem to point out the same general position with relation to the other types of canids. This we may consider as evidence that the two specimens really represent the same group. It will be necessary to know something of the limb structure, as also something of the history of the group, before we shall have thoroughly satisfactory evidence concerning its true relationships.

MEASUREMENTS.

Width of cranium between the most anterior points of orbits	65 mm.
Length of premolar series	55
” ” molar series	23.5
Antero-posterior diameter of upper canine at alveolar margin of enamel	16
Antero-posterior diameter of alveolus of P^2	7
” ” ” ” ” ” P^3	10
” ” ” ” P^4	28
” ” ” ” M^1	16
” ” ” ” M^2	9
Greatest transverse diameter of P^4	16
” ” ” ” shear of P^4	13
” ” ” ” M^1	22
” ” ” ” M^2	13

CANIS INDIANENSIS Leidy.

PL. 30, FIG. 2.

Canis primaevus LEIDY. Proc. Philad. Acad. Nat. Sc. 1854, p. 200: Jour. Philad. Acad. Nat. Sc. 1856, III, p. 167, Pl. XVII, figs. 11–12; Pl. XXI, figs. 14–16.

Canis indianensis LEIDY. Jour. Philad. Acad. Nat. Sc. 1869, p. 368.

Canis indianensis LEIDY. Geo. Surv. Terrs. Vol. I, Foss. Vert. 1873, p. 23, Pl. XXXI, fig. 2.

Canis lupus. COPE AND WORTMAN. Indiana Geol. and Nat. Hist. Surv. 14th Annl. Rep. 1884, Part II, p. 9.

Canis indianensis. COPE. Jour. Philad. Acad. Nat. Sc., Ser. 2, Vol. IX, p. 453, Pl. XXI, figs. 14–16.

Occurrence.—The specimen referred to this species includes a part of an atlas and the anterior portion of the left ramus of a mandible with the canine, the sectorial, and the last premolar.

It is embedded in coarse sand and gravel cemented by asphaltum. Associated with it is the anterior portion of a *Mylodon* skull containing the roots of the molars. The character of the matrix and the presence of *Mylodon* indicate the Quaternary age of the beds in which it was found.

The locality given for the jaw is Oil Springs, Oil Cañon, Tulare County. The writer has not been able to obtain any definite information concerning this place. There is an Oil Cañon a few miles north of Asphalto, Kern County, and an Oil Springs, Tar Cañon, in the western part of Kings County.

Relationships.—The dimensions of the jaw from Oil Springs are nearly the same as those of the mandible from near Livermore Valley referred to this species by Leidy. The form of the teeth can not be distinguished from that of Leidy's specimen. The jaw appears slightly heavier below the sectorial but the difference may be due to distortion of the fragmentary anterior portion. In both specimens $M_{\overline{1}}$ has a well developed metaconid and the hypoconid is slightly compressed laterally.

This form is, so far as can be seen, a typical dog. It is considerably larger than any existing American wolf and has a more massive jaw and a heavier sectorial. The specific identity of the Californian form with Leidy's type from the Ohio Valley might possibly be called in question, as we do not know corresponding portions of the skeleton from the two regions. The discovery by Cope of a very large wolf similar to *C. indianensis* in collections from the Quaternary of Texas shows that the eastern species ranged well out toward California, and makes it easier to believe that the form from this state is really to be classed with it.

MEASUREMENTS.

Height of jaw below protoconid of $M_{\overline{1}}$	42 mm.
" " " " anterior end of $P_{\overline{2}}$	35
Thickness of lower border of jaw below $M_{\overline{1}}$	16.5
Length from posterior side of $M_{\overline{1}}$ to anterior side of canine	120
Antero-posterior diameter of $M_{\overline{1}}$	35
" " " " $P_{\overline{4}}$	17.5
" " " " canine	13

CANIS LATRANS Say. (?)

Canis latrans. Determined by Leidy. J. D. Whitney. Aurif. Grav. of Sierr. Nev. of Calif., Mem. Mus. Comp. Zool. Harvard, Vol. VI, No. 1, Part 1, p. 246.

A tibia probably obtained from Quaternary gravels at Murphys, California was referred to this species by Leidy. Some doubt exists as to the locality. On the basis of more modern classification of the coyotes, the specific determination might also be questioned.

University of California,
November, 1903.

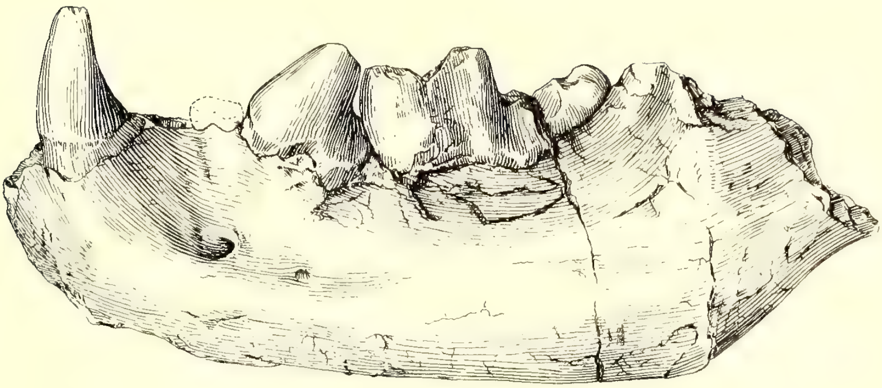
EXPLANATION OF PLATE 28.

Hyaenognathus pachyodon n. gen. and sp.

Figures reproduced three-fourths natural size.

Fig. 1.—Left ramus of mandible, outer side.

Fig. 2.—Mandible from above.



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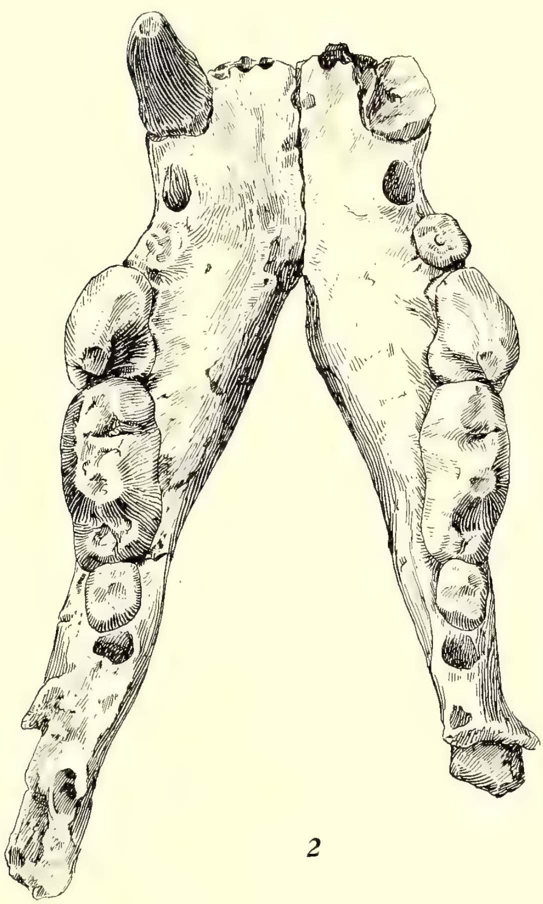

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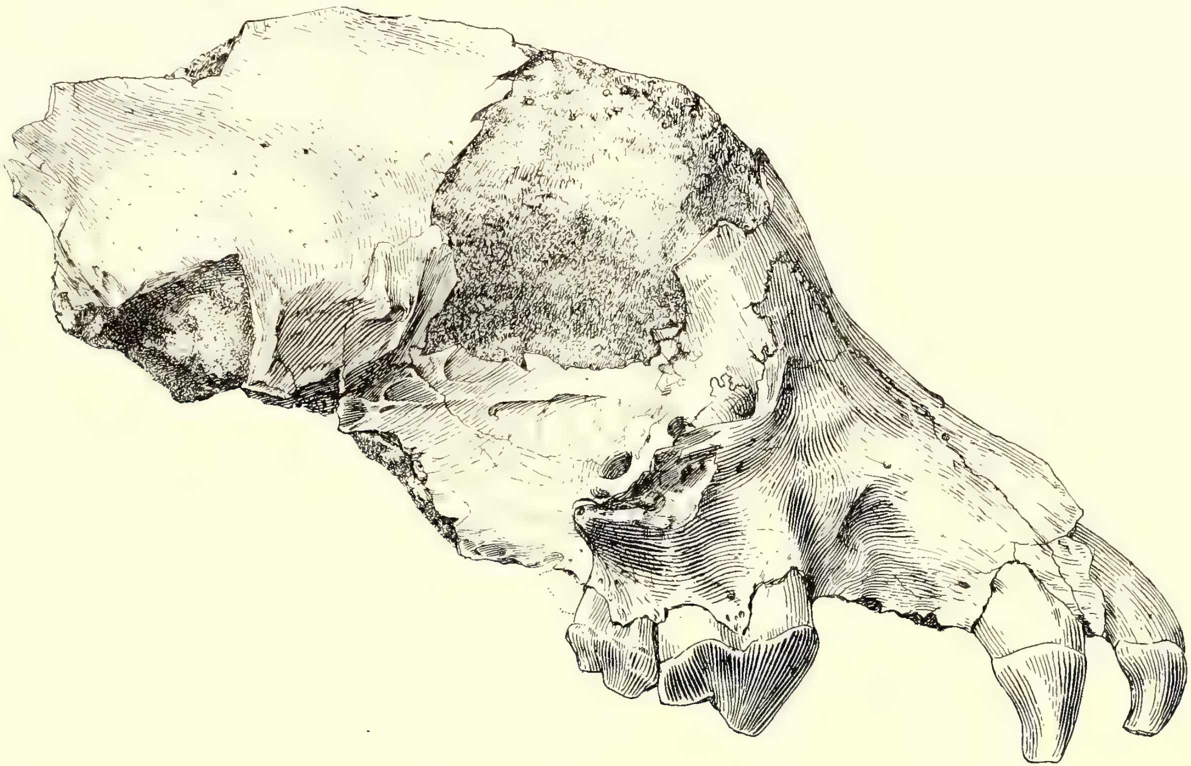
EXPLANATION OF PLATE 29.

Hyaenognathus? (Porthocyon n. gen.?) **dubius** n. sp.

Figure reproduced three-fourths natural size.

The cranium from the right side. The outline of M^2 is shown by a dotted line.

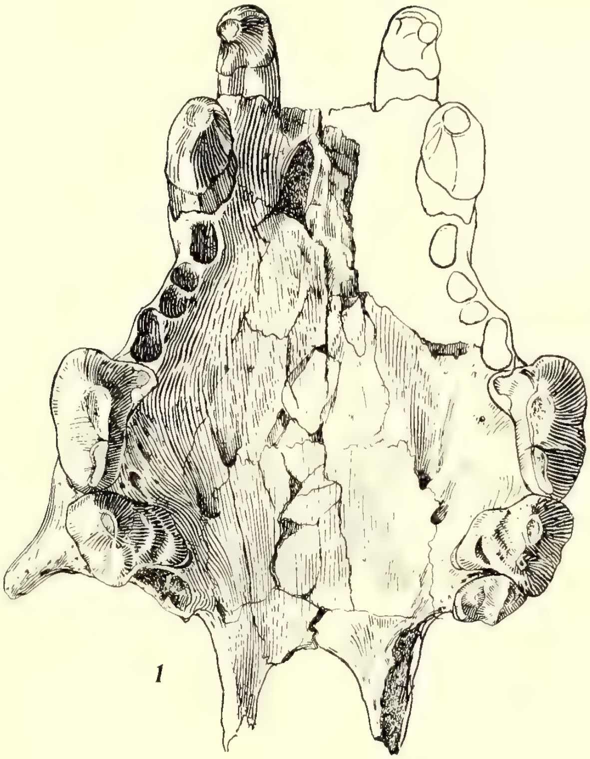


EXPLANATION OF PLATE 30.

Figures reproduced three-fourths natural size.

Fig. 1.—**Hyaenognathus? (Porthocyon** n. gen.?) **dubius** n. sp. Inferior side of the cranium.

Fig. 2.—**Canis indianensis** Leidy. Inner side of the left ramus of the mandible. The partial outlines of $P_{\overline{2}}$ and $P_{\overline{3}}$ are drawn from impressions in the matrix. The length of the jaw is slightly exaggerated.



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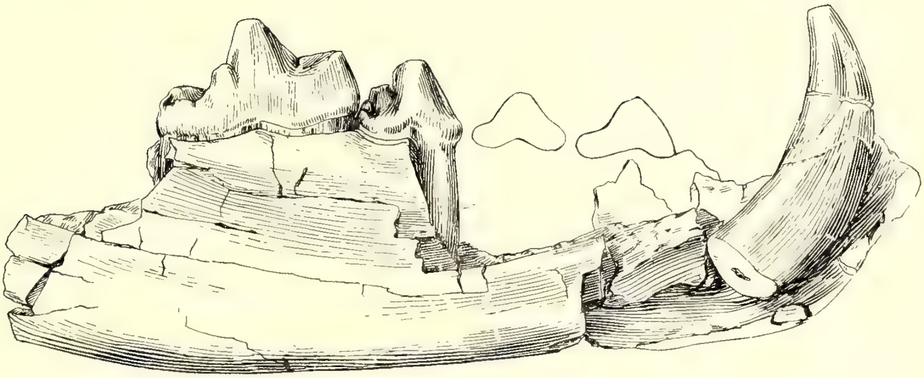

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UNIVERSITY OF CALIFORNIA PUBLICATIONS
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THE GEOMORPHOGENY OF THE UPPER KERN BASIN

BY

ANDREW C. LAWSON

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THE GEOMORPHOGENY OF THE UPPER KERN BASIN

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ANDREW C. LAWSON.

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INTRODUCTION.

During the past season the Sierra Club held its annual outing in the basin of the Upper Kern River. In the large party of enthusiastic mountaineers who participated in the excursion were two geologists. One of these was Mr. G. K. Gilbert and the other was the writer of this paper. Both were attracted by the opportunities which were afforded by the Club's program for exploring, from a geological point of view, this little known but highly interesting portion of the Sierra Nevada, and at the same time indulging in a few weeks of exhilarating recreation.

The observations, upon which the present sketch of some of the geological features of the region is based, were made to a large extent by both Mr. Gilbert and the writer while travelling together over the mountain trails and climbing the peaks that served as vantage points, from which we looked down upon and viewed, as a map spread at our feet, the country through which we passed. The interpretation of these observations was a common theme of conversation both at the time they were made and in camp. Under these circumstances it is evident that a large share of whatever merit this sketch possesses belongs to Mr. Gilbert. In so far as it is desirable that the common observations should be made a matter of record, it would have been better for geological science had the writing of this paper been undertaken by Mr. Gilbert; but he, pleading pressure of more important work, has generously waived the rights of authorship in this field, and so imposed upon the writer the task of narrating and discussing the observations made upon the trip as best he may. But while gratefully acknowledging Mr. Gilbert's cooperation in the field the writer has, thereby, no intention of throwing upon him the onus for the shortcomings of this discussion. That responsibility rests with the writer.

It is needless to say that neither the record nor the discussion pretend to exhaust the geology of the Upper Kern Basin. The region is replete with geological interest and only some of the more salient problems are taken up; and even these suffer from the partial character of the exploration of the region.

The basin of the Upper Kern presents features of exceptional interest to geomorphologists, and the purpose of the paper, as its title implies, is to outline these features and discuss their genesis. While the paper professes to deal primarily with the basin of the Upper Kern, certain features of the region immediately adjoining it are incidentally referred to by way of supplementing the account of the basin itself. A brief description of the rocks of the region, in which petrographic technicalities are dispensed with as far as possible, is given at the outset of the paper as a necessary introduction to the subject matter. The conclusions to which the discussion leads have a general bearing upon the historical geology of the Sierra Nevada, and this bearing is indicated at the close of the paper. The illustrations, when not otherwise indicated, are from photographs by the writer. The map is based on the blue print compilation by Professor J. N. LeConte. All new altitudes are based on barometric measurements made by Professors J. N. LeConte and A. G. McAdie.

PETROGRAPHIC AND STRUCTURAL FEATURES.

Rocks and Geomorphy.—Fundamental to the understanding of the geology of any region is a knowledge of the rocks which underlie it. Especially is this the case when the problems with which we have to deal are those of geomorphogeny such as concern us very largely in the discussion of this region. It will, therefore, be appropriate to first state briefly the general petrographic characteristics of the basin and of such portions of the neighboring territory as may be conveniently discussed in connection with it.

The rocks which underlie the hydrographic basin of the Upper Kern are almost wholly granitic in character. This is a fact of prime importance for the study of the geomorphic evolution of the region. The relief as determined by general atmospheric, stream, and glacial erosion has been controlled by the uniformity of the materials subject to sculpture by these agencies. It has been uninfluenced by that marked differentiation of structure and of resistance to erosion which characterizes the stratified rocks whether they be detrital or volcanic, unaltered or metamorphic, horizontal or folded. There are no belts of soft rocks which might have been sought out by enterprising head-water streams, and by these exploited till they became the dominant drainage lines of the region; no belts of hard rocks which might have been left as dominant ridges; no superposition of hard rocks upon soft which might have yielded mesas and serried escarpments. Yet the region is one of the boldest possible relief. The altitudes within the basin have a range of over 8000 feet. There are very striking contrasts in the slopes of the basin. There is a pronounced system in the drainage lines; and the master stream of the basin, the Kern itself, has a course as straight as an arrow for nearly its entire length. These facts indicate clearly that, notwithstanding the nearly uniformly granitic character of the region, there has been a certain directive control of its sculpture due in part to the character of the rocks.

If, with this conclusion in mind, we turn again to the rocky floor of the basin and attempt to characterize it more precisely we find facts which to some extent, at least, justify it.

Granitic Rocks.—In the first place it may be stated that even where the rocks are granitic, even in the strict sense of the term, this granite presents considerable variation in character. In the middle of the basin, along the cañon of the Kern, the rock is prevailingly a light-colored, coarse, very quartzose biotite-granite. This rock has frequently a porphyritic appearance owing to the exceptional size of the orthoclase crystals, but the latter are as a rule imperfectly formed and the structure would on the whole be classed as hypidiomorphic granular. This granite grades through varieties, in which hornblende replaces part of the biotite, into hornblende-granite with much less quartz. From these there appear to be gradations into quartz-diorite and diorite in which plagioclase can be recognized easily in hand specimens. These more basic facies, however, appear to be quite subordinate in extent as compared with the common biotite-granite. In this type of granite, dykes or veins of pegmatite are rare; but on the cañon walls above the meadows there are numerous small dykes of a reddish, or flesh tinted, fine-grained granite, with but very little admixture of ferro-magnesian minerals. The rock may be perhaps conveniently classed with the aplites, although its structure, as judged by hand specimens, appears frequently to be granular. These dykes were observed in several instances to be from three to five feet wide, but the width of most of them probably does not exceed one foot. They appear to have had little or no influence in giving direction to differential erosion.

The biotite-granite of this portion of the basin, together with its dioritic facies, is characterized by the presence of a great abundance of angular, sub-angular and rounded inclusions of a darker gray, finer grained, porphyritic rock. These appear usually to be slightly more resistant to disintegration than the granite which holds them. In some instances, where such inclusions are particularly abundant, it was estimated that there might be one cubic foot of inclusion for every cubic yard of granite. On the average, however, where these inclusions occur, there is probably not more than one cubic foot of inclusion to every four or five yards of granite. In size the inclusions range from a few inches to several feet in diameter and probably average about one foot.

In this biotite-granite there are, also, in the cañon of the Kern comparatively small areas of coarse-grained gabbro-like rock, in which, however, the proportions of feldspar and ferro-magnesian silicate vary. This gabbro may be assumed, in the light of current doctrines on magma differentiation, to be genetically connected with the granite; but the transitions from the gabbro to the granite, so far as they were observed, are abrupt, and more suggestive of an intrusive relationship than of a gradual transition of one rock into the other. These gabbro areas are devoid of the inclusions which abound in the adjacent granite. The gabbro, where exposed to the weather, shows the etching of the feldspar and the relief of the pyroxene.

Dykes.—In addition to these more intrinsic characters of the granitic rocks in the vicinity of the cañon of the Kern, it may be stated that near the Kern Lakes and for some little distance above Coyote creek the granite is cut rather frequently by small dykes of black, fine grained lamprophyre. These are rarely more than a few feet, sometimes only a few inches, in width, and have all attitudes from nearly horizontal to quite vertical. Some of them are multiple dykes. These dykes appear to be particularly abundant on the east side of Kern Cañon below Lower Lake, on a scar formed by a great rock-slide, where they dip northeasterly at low angles. The dykes above the mouth of Coyote Creek strike E.N.E. and dip southerly at an angle of 70° from the horizon. A multiple dyke of three members was here observed. The most northerly is from four to five feet wide; the next parallel dyke to the south, 10 feet distant, is about two and a half feet wide; and the next, about 10 feet farther south, is six inches wide. The rock is here a dark gray, porphyritic rock with phenocrysts of feldspar and hornblende, the latter predominating. The groundmass is fine grained but apparently holocrystalline. The texture on the chilled edges against the granite is finer than in the middle of the dykes. A little to the south of this multiple group another dyke of the same rock was observed with a strike at right angles to that above recorded. These dykes are somewhat more resistant to the weather than the granite which they cut, and are, therefore, somewhat prominent as a shoulder on the steep mountain slope. They break down into angular blocks, while the granite on disintegration crumbles to a coarse sand.

Such dykes, though locally abundant in the southern part of the basin, in the Kern Cañon, do not appear to be at all common throughout the basin and cannot be said, even where they abound, to have exercised an important influence upon the general morphogenic process, by determining lines of either maximum or minimum erosion; unless we assume that the association of an exceptional number of such dykes with the large rock-slide below the Kern Lakes is more than a coincidence, an assumption which the writer does not feel warranted in making.

Except for the occurrence of the gabbros and the lamprophyric dykes, the summary account given above of the granitic rocks of Kern Cañon would apply fairly well to all the granite country lying to the west of Kern River in so far as it came under the writer's observation. In the high country to the east of Kern River, however, particularly in approaching the summit crest, the granite has quite a different facies. The rock here is uniformly a light colored biotite-granite with a splendidly developed porphyritic structure. The porphyritic crystals are huge orthoclases with perfect crystal boundaries. These are quite frequently three inches in length and average two inches over wide areas. They usually contain inclusions of biotite and hornblende, disposed in rude rectangular zones parallel to the planes of growth of the crystal. In this granite there appear to be no local basic facies, and the inclusions which are so abundant in the granite of the Kern and the country to the west are almost or wholly absent. Dykes of coarse pegmatite are fairly common; and dykes, often of large size, of gray and pinkish aplite are in places very abundant.

Disintegration.—These purely petrographical differences in the prevailing rock of the region are mentioned for the purpose of indicating possibilities in differential resistance to erosion and so aiding us in coming to an understanding of the inequalities of the relief. That such differential resistance to the attack of atmospheric agencies actually does characterize the granite, even where no petrographical distinction can be drawn, is amply witnessed by the heavy mantle of disintegration products which occurs upon many of the unglaciated slopes, sometimes as a coarse, loose sand into which one sinks deeply in climbing, and sometimes as an encumbrance of loose blocks of large dimensions. The disintegration which yields the coarse granitic sand is well exemplified on the trail between Farewell Gap and Coyote Pass, on the upper waters of Coyote and Volcano Creeks, and along the trail between Mt. Guyot and Crab-tree Meadows. On the steep upper slopes of Sawtooth Peak and Mt. Whitney this sand is very abundant, but is in such situations admixed with angular blocks of comparatively fresh granite. The summits of the high peaks, whether flat topped as in the case of Mt. Whitney, or acutely pointed as in the case of Sawtooth, are characteristically encumbered with large angular blocks of granite almost or quite free from finer fragments or sand. These larger blocks present the appearance of having been detached from the underlying surface of granite by a process of decrepitation without the intervention of any appreciable rock decay. It is a process of denudation which has been operative very generally on the high summits of the Sierra Nevada and, indeed, on similar peaks in various parts of the world, as, for instance, Pike's Peak in Colorado, and Ben Nevis in Scotland. But while the encumbrance of angular blocks of fresh granite is characteristic of the high summits and is without doubt due to certain peculiar conditions which obtain there, the tendency to secular decay, which yields the granite sand, is by no means uniform. Large areas of the unglaciated surfaces, even when these are of gentle slope favorable for the accumulation of such sand, show but little of it; while other areas of the same rock, even where the surface is so steep that the sand lies at the angle of repose of loose material, are deeply buried by such waste products. We have in this fact an indication of differential resistance to atmospheric erosion which does not appear to be suggested by the usual petrographic characterization of the terrane, although doubtless the causes for the difference of behavior under the weather could be revealed by sufficiently thorough petrographic investigation.

Kaweah Peaks and the Mineral King Belt.—It must be noted, also, that certain limited portions of the Upper Kern Basin are not composed of granite, and that at least one notable feature of the relief is due in no small measure to this exceptional character of the rocks. The bold group of the Kaweahs (Plate 33B), which extends southeasterly into the basin from its western rim, has a certain individuality and character which distinguishes it from all the other mountain peaks, either in the basin or on its rim. The rocks of this group appear to be metamorphic sediments judging from the similarity of their appearance to such rocks in the Mineral King metamorphic belt, in which occur various crystalline schists, clay slates, quartzites, and limestones.

These rocks are for the most part distinguished from the granite, even at a distance of many miles, by the rusty, reddish brown color which they assume under the weather, and by their smoother and more conical profiles.

Isolated areas of such metamorphic rocks appear to be by no means infrequent in the granites of the southern Sierra Nevada, and, as our knowledge of them is but scant, it may be well to here say a word about the occurrence at Mineral King. This belt has a width from east to west at Mineral King of about four miles. Its western limit against the granite is observable on the cañon walls of the East Fork of the Kaweah a mile or less below Mineral King. Its eastern limit is splendidly exposed in the fine glacial cirques which lie to the southwest, west, and northwest of Sawtooth (Plate 43, A and B). These contacts show clearly that the granite is intrusive in the sedimentary rocks. The metamorphism of the latter is referable to their contact with the granite. On both sides of the belt which lies within these limits, the contact plane is in general nearly vertical, but in some places on the eastern edge of the belt it dips to the east so that the granite is resting upon the sedimentary rocks. This contact is observable again to the east of Mt. Florence and on the mountain slopes to the east of Bullion Flat on the Little Kern. From this point the belt may be followed down the cañon of the Little Kern, on the west side, for about four or five miles, but appears to be very much narrower than at Mineral King and eventually tapers out. In its northern extension the belt may be followed over Timber Gap and across Cliff Creek, but does not cross the main stream of the Middle Fork of the Kaweah. Beyond Cliff Creek it must either pinch out rapidly or swing around to the northeast, cross the Great Western Divide, and connect with the similar rocks of the Kaweah Peaks, in the basin of the Upper Kern. Whether this connection now exists was not positively determined. It seems not improbable, however, that the rocks of the Mineral King belt and those of the Kaweah Peaks are parts of the same belt of strata. In the Mineral King belt, at least, we have a remnant of a once extensive pre-granite sedimentary terrane, which, in a sharply plicated and appressed condition, sank deeply into the granite at the time of the invasion of the crust by the latter in a magmatic condition; a remnant in other words of the roof of a vast batholith.

The influence of this belt of stratified rocks upon the character of the stream topography is very apparent. The strata are inclined at high angles to the W.S.W. The cañon of the east fork of the Kaweah, above Mineral King, and that of the Little Kern, flowing S.S.E. from Farewell Gap, follow the general strike of the strata and are good illustrations of well controlled subsequent drainage, modified, as will be seen later, by glaciation. This subsequent topography is in contrast with the drainage features within the basin of the Upper Kern, where no such control of stratiform structure exists.

The limestones of this bed of metamorphic rocks afford the necessary conditions for the formation of underground channels of dissolution. On the west wall of the east fork of the Kaweah, a little above Mineral King, at an elevation of a few hundred feet above the bottom of the cañon, a large stream issues from such a channel and falls as a beautiful cascade over a bank of travertine deposited from its waters. There are also extensive travertine deposits immediately below Mineral King, large enough to modify, in detail, the geomorphic profile of the valley and to deflect the course of the drainage.

Quaternary Lavas.—There remains to be mentioned, in this review of the rocks of the region, certain volcanic rocks which have a quite limited distribution in its southwestern and southern part. These are the small volcanoes and lava streams of Toowa Valley, and the lava sheets to the south of Trout Meadows and elsewhere near the confluence of the Kern and Little Kern. These are basaltic in character. The volcanoes of Toowa Valley are of very recent date. The geomorphic evolution of the region had reached its present stage long before the volcanic vents opened. Their contribution to the general morphogenic history is confined to the addition of a few small cones to the relief, and to the obstruction by these, and by the lava streams that flowed from them, of the drainage of Toowa Valley (Plates 35 A and B, 36 A).

The lava sheets of the country at the confluence of the Kern and Little Kern are of less recent date, and yet they rest as a veneer upon plateau surfaces which represent a comparatively late stage in the evolution of the geomorphy of the region. In the later stages of that evolution they have suffered the same dissection as the plateaux, and appear now only as remnants. Where they remain, however, they greatly accentuate the flatness of the plateau, and this is their chief contribution to the general morphogenic process.

From the foregoing statement of the petrographic characteristics of the terranes which underlie the basin of the Upper Kern, it will be evident that there are certain diversities in the rocks of the region which account in some measure at least for the inequalities of the relief in so far as these are due to *atmospheric* erosion. When, however, we ask what part these varying petrographic characteristics have played in determining the drainage scheme of the basin, there is no answer forthcoming. Nothing in the petrography of the terranes affords us any clue, for example, to the arrow-like course and meridional trend of the master stream of the basin, and much less does it afford an explanation of the remarkable contrasts in the slopes of the basin.

The Roof of the Granite.—It has been stated in the foregoing discussion that, in various parts of the granitic region of the southern Sierra Nevada, there are outlying areas of pre-granitic stratified terranes, remnants of formations which formed the outer crust of the earth in this region, at the time of its invasion by the vast Sierran batholith or batholiths. These formations may be safely assumed to have originally arched over this batholith as a covering shell. The surface of contact between the granite and the overlying rocks was clearly a very uneven one. This is shown, not only by the relation of these remnants to the granite, but also by the spacial relations of the granite and the rocks invaded by it in the northern Sierra Nevada, where the relative areas of the two classes of rocks are reversed and the granite appears as inliers in the stratified, though often highly metamorphosed terranes. It has been made clear farther that, in the Mineral King belt of sedimentary rocks, which lies immediately to the west of the Upper Kern Basin, we have such a remnant of the roof of the batholith which has been sunk deeply into the granitic magma, and that in the Kaweah Peaks we have probably another such area, or, possibly, an extension of the Mineral King belt. The Kaweah Peaks area, however, appears rather to be sessile upon the granite than sunk down into it, although this is questionable.

These facts suggest that over the granitic terrane of the Upper Kern Basin the original upper surface of the batholith may not be very far above the present actual surface, and that the two may, in places, be even coincident, the present surface being in such a case merely the original upper surface of the batholith stripped of its covering by the usual processes of denudation. Such a contact plane between a batholith and its roof would constitute a structural feature of no mean importance in the degradation of the region; and the possibilities of this control are considered in a subsequent portion of the paper.

Jointage.—In many parts of the Upper Kern Basin the granite of the region exhibits a pronounced jointage. This structure is best displayed in the walls of the glacial cirques in the higher parts of the mountains, and is less abundantly developed in the walls of the deeper cañons. In cases where horizontal jointage prevails there may often be seen distinct and striking differences in the spacing of the joint planes in a vertical range of a few hundred feet, on a cliff face. Near the top of the cliff the joint planes are close together and the joint blocks thin, while lower down they are more widely separated and the blocks thick. Similar differences in the spacing of joint planes have been observed by the writer in other parts of the Sierra Nevada, as for example in the walls of Yosemite. Such horizontal jointages are usually traversed by others approximately vertical, breaking the rock into more or less rectangular prisms or slabs. In other cases the granite has a sheeted or lamellar structure, due to the dominance of a single system of nearly vertical jointage. This is finely exemplified in the cirques about Mt. Whitney, where the sheets are thin and remarkably even from the top of the cirque walls to the bottom. But the direction of this vertically sheeted jointage is not constant over wide areas. In the cirque southwest of Mt. Whitney its strike is roughly east and west, while in the cirque northwest of Mt. Whitney its direction is northwest and southeast. The horizontal and vertical jointages are the most regular and persistent, but there are many parts of the region where the joint planes have all attitudes except vertical and horizontal. In such cases they intersect without apparent system and are often distinctly curved; and the intensity of this jointing is, also, characteristically much more marked in the upper part of cliff faces than in the lower. Some interesting divergencies of joint planes were observed in the case of sharp crests between opposing cirques, in which the jointage in each cirque was parallel to the slope of its walls. In general no definite and persistent system of jointage can be said to characterize the region, the directions of all but the horizontal jointage varying greatly, and even that is only called horizontal by courtesy, for it is not uncommonly inclined at as much as 10° or more to the horizon. But there appears to be a more or less definite relationship between the intensity or frequency of jointage, particularly horizontal, oblique and curved jointage, and proximity to the high surfaces of the region, and a similarly close relation between the oblique or curved jointage and the form of the surface. If this general proposition be true, and it certainly has an observational basis, then the jointage would appear to have been developed in part, at least, *pari passu* with progress of erosion, and to be, in a sense, dependent upon it. If this be the case, then jointage in these granites cannot be a structural feature altogether antecedent to the geomorphic evolution and so controlling the latter. They cannot, therefore, be supposed to be due to compressive stresses in the rocks according to the current doctrines on the subject, but rather to tensile or expansive stresses arising from the relief of load as affected by erosion. The stresses in mountain masses due to simple gravity, as discriminated from tangential compression, which is of course itself a phase of gravitation, are very great and become complexly distributed as the region undergoes dissection. The balance of stress is destroyed in proportion as the surface is uneven and asymetric, and an elastic tension is developed near the surface, which is relieved from time to time by the rifting of joint fissures. This hypothesis, explanatory of jointage of granites in the High Sierra, may not be of universal application;* but it seems worthy of consideration as an alternative to the at present more favorably received hypothesis, which explains jointage as a result of tangential compression, entirely independent of, and antecedent to, erosion.

This hypothesis of jointage as entertained by the writer modifies the views, which might otherwise be entertained, as to the rôle which this structure has played in the general morphogeny of the Upper Kern Basin. If the jointage were strictly an antecedent structure, simply revealed by erosion, then we should expect it to exercise an important influence upon the *direction* of the maximum erosion lines; and this may be true of the vertical jointage. But if the jointage be a function of erosion to any extent, then the control exercised by jointage upon the course of erosion is correspondingly diminished. Nevertheless, since jointage is developed in the rock mass in advance of the surface due to erosion at any given time, it greatly facilitates erosion, whether the latter be effected by atmospheric, stream, or glacial agencies. The relation of the relief to the jointage of the region would require a careful, detailed survey, and no more positive statement can at present be made concerning it.

Faults and Fissures.—No notable faults have been detected in the Upper Kern Basin, but in view of the homogeniety of the rocks this is not surprising, and they may easily exist. Faults are usually made apparent by the discordance of the rocks on either side of the plane or zone of dislocation; but in the case of massive granites such discordance is not in evidence and they escape detection. The character of the eastern rim of the basin is, it is scarcely necessary to say, due to the great fault which limits the Sierra Nevada on the east. The east front of the range is a fault scarp which has been modified by degradation, and in its upper part been accentuated in sheerness by cirque erosion. As will appear in the part of the paper dealing

* Mr. G. K. Gilbert kindly reviewed the MS. of this paper and has communicated to the writer his opinion that only the curved jointage parallel to the surface may be hypothetically explained in the way here suggested. It must be confessed that the statements which are made of the horizontal, oblique and curved jointage cannot be urged with the same force with reference to the vertical jointage, particularly in the sheeted granite. The writer, therefore, does not here attempt to apply the hypothesis to the vertical joints, although he believes that they also are due to expansive stresses and not to compression as ordinarily held.

with Kern Cañon, there is strong inferential evidence that the cañon follows the line of a rift fissure, and in connection with this fissure there has been a certain amount of minor faulting.

THE GENERAL RELIEF AND DRAINAGE.

In attempting to form just conceptions of the relief of the Upper Kern Basin the best, and probably the only satisfactory, method to be followed is to look down upon it from some of the high peaks which command it. The only alternative capable of yielding similar results would be to study the region from the basket of a balloon: but that has its drawbacks. Moved by this doctrine, several of the more commanding points situated either on the rim of the basin, or within it, were occupied and very comprehensive views obtained. The best of these for the study of the relief are afforded by the summits of Mt. Whitney on the eastern rim, Sawtooth on the western, and Mt. Guyot in the more central portion of the basin. Perhaps the finest view of all, judging from its situation, would be that from Kaweah Peak; but this was not occupied. A very impressive view of Kern Cañon is obtained from the summit of Tower Rock, which rises sheer from the river 2150 feet just opposite the mouth of Coyote creek; and from the volcanic cones of Toowa Valley the character of surface of the unglaciated region of the southern Sierra Nevada may be studied to great advantage. The observations made from such points of view, supplemented by others upon the character and form of the surface made at closer quarters, have led to certain definite impressions as to the configuration of the Upper Kern Basin and of its geomorphic evolution which it is the purpose of the present paper to set forth and discuss.

The Upper Kern down to the point where it is joined by the Little Kern drains a hydrographic basin of about 400 square miles. This area when delimited upon a map* is seen to be oval or leaf-shaped, the north and south diameter being 35 miles and the greatest east and west diameter 16 miles (Plate 31). The drainage scheme is like the veination of a leaf, the trunk stream of the Kern flowing due south with a remarkably straight course as a midrib through the center of the area. On either side tributary

* LeConte's blue print "Map of a portion of the Sierra Nevada Mountains, No. 3, Kings-Kern Sheet," is the best map of the region.

streams flow into the Kern at short but irregular intervals. The more important of these on the east side are, in order from north to south, Tyndall Creek, East Fork of Kern River, Whitney Creek, Rock Creek and Volcano Creek, and on the west side in the same order Kern-Kaweah River, Big Arroyo, Rattlesnake, and Coyote Creeks.

The area thus drained is a pronounced basin in the morphological as well as in the hydrographic sense. The rim of the basin is for the most part a chain of lofty peaks and mountain crests. On the west this chain extends from Table Mountain (13,625 feet) on the north, with a trend concave to the basin, to a point near Trout Meadows and is known as the Great Western Divide. It sheds the waters westward to the upper reaches of the Little Kern River, the East and Middle Forks of the Kaweah and the Roaring River branch of the King's, and eastward to the Upper Kern. On the east the chain forms part of the main divide of the Sierra Nevada, the summit crest of the range, and separates the waters of the Upper Kern from those of the Great Basin. This divide extends from Junction Peak (13,916 feet) to Cirque Peak (12,941 feet) as a wonderfully bold mountain crest and includes Mt. Tyndall (14,101 feet), Mt. Whitney (14,522 feet), and Sheep Mountain (14,059 feet). The conjunction of these two great divides on the north, spanning the gap between Table Mountain and Junction Peak, encloses the Upper Kern Basin in that direction, and separates its waters from those of Bubb's Creek, a tributary of the King's. South of Cirque Peak the watershed between the Upper Kern Basin and the South Fork of the Kern is a comparatively low divide, which leaves the summit crest about two miles southeast of Cirque Peak and thence converges upon the Kern River near its junction with the Little Kern, following part of the way the somewhat subdued Toowa Range. This divide is depressed to the drainage line at its intersection by Toowa Valley, in which lies Volcano Creek flowing westward, and South Fork flowing southeastward. This is the lowest point in the rim of the Upper Kern Basin, excepting the main drainage outlet, and a remarkable depression to the north of Trout Meadows to be described later, and has an altitude of about 8600 feet.


LEGEND
High Mountain Zone
High Valley Zone
Glacier Tracks
Volcanoes and Basalt
GREAT BASIN
Mt. Bradley
Mt. Brewer
Junction Peak
Mt. Williamson
Table Mt.
Milestone Mt.
Milestone Creek
Tyndall Creek
East Fork
Tharp Pk.
Kern-Kaweah River
Mt. Whitney
Lone Pine Peak
Whitney Creek
Kaweah River
Lion Rock
Middle Fork of Kaweah River
Summit Upland
Mt. LeConte
Sheep Mt.
Red Spur
Kaweah Peak
Big Arroyo
Mt. Guyot
Guyot Creek
Rock Creek
PLATEAU
Siberian Outpost
Cirque Peak
Cliff Creek
Timber Gap
CHAGOOPA
KERN CANON
Sub-summit Plateau
East Fork of Kaweah River
Mineral King
Sawtooth
Mt. Vandever
Rattlesnake Creek
Laurel Creek
Farewell Gap
Shotgun Creek
Coyote Pass
Volcano Creek
TOOWA VALLEY
South Fork
Coyote Creek
Kern Dome
Tower Rock
Toowa Range
Upper Kern Lake
Lower Kern Lake
Rock Slide
LITTLE KERN PLATEAU
Little Kern River
Trout Meadows Defile
DIAGRAM OF THE UPPER KERN BASIN AND ADJACENT MOUNTAINS
Showing the relation of the High Valleys to the High Mountain Zone and to the Sierran Cañons; also the Limits of Glaciation of the Southern End of the Sierra Nevada.
SCALE 1/375,000
MILES
Based on a Blue Print Map by J. N. LeConte
118°40'
118°30'
118°20'
118°10'
36°40'
36°30'
36°20'
36°10'

At the base of the steep slopes of the high mountains, which thus encircle the Upper Kern Basin from the southern end of the Great Western Divide to Cirque Peak, there spreads out in the central part of the basin a broad valley land of very subdued relief. This valley land is known as the Chagoopa Plateau. From the mountains on either side of the basin it slopes gently with a remarkably uniform surface toward the Kern. Its upper limit at the base of the high mountain peaks and crests is about 10,500 feet, while its lowest part at the brink of the Kern Cañon is from 8,400 feet in the southern part to about 9,000 feet in the northern part, above sea level. Through the central part of this high valley runs the profound cañon of the Upper Kern, a meridional trough sunk in the valley floor to a maximum depth of about 2,500 feet and bordered by almost vertical walls for a large part of its course. The streams which drain the high mountains on either side flow through similarly deep, steep-walled trenches as they cross the Chagoopa Plateau on their way to the Kern, but in no case have they cut as deeply as the master stream.

It thus appears that within the Kern Basin there are three hypsometric zones, distinguished by such marked differences in the character of their relief as to constitute three distinct geomorphic zones. These may be called for convenience, (1) *The High Mountain Zone;* (2) *The High Valley Zone;* and (3) *The Cañon Zone.*

THE HIGH MOUNTAIN ZONE.

The Summit Upland.—This zone has been characterized in the sketch of the rim of the basin as consisting essentially of high peaks and crests. This, however, does not sufficiently describe the geomorphic character of these mountains, and some of their more striking features must be noted particularly. Several of the culminating portions of the summit divide are either flat topped, or have slopes which are so gently inclined as to be in sharp contrast to the more precipitous slopes which abound in the region. The best illustrations of such flat, or gently sloping, summits is that afforded by the summit range from Sheep Mountain to Cirque Peak. The summit of Mt. Whitney itself is nearly flat for perhaps half a mile square, with a very gentle slope to the west. This flat slope is surrounded on nearly all sides by precipices which are, for the most part, the walls of glacial cirques. Sheep Mountain (Plate 32 A), five miles south of Mt. Whitney, shows the same kind of a flat topped summit; but this merges by a simple curve into a westerly slope which is very smooth and even as viewed from a distance, but is much steeper than the summit of Mt. Whitney. Similar characters obtain along the summit divide as far as Cirque Peak, and portions of the flatter summits even slope easterly, at a slight angle, to the brink of the precipices on that side. The same surface is well displayed in a view from Mt. Guyot toward Mt. Whitney (see Plate 33 A). In general, however, the westerly slope of this portion of the summit range in smoothly flowing, sometimes undulating, curves from the flatter summits is its most characteristic feature. This smooth surface, where not interrupted by glacial cirques, descends to an altitude of about 11,500 feet, where it meets a splendidly defined plateau to be described shortly. It has thus a hypsometric range of about 3,000 feet. In this range the flatter portions of the slope are not confined to the highest summits. About half-way between the upper and lower limits there is a flat and quite broad terrace* which is best exemplified in the summit tract between Sheep Mountain and Cirque Peak. (Plate 32 A). Remnants of such a surface as that here described are observable in various parts of the region. It is evidently a significant feature of the geomorphy of the Upper Kern Basin. For convenience of reference it is here named the *Summit Upland*, from the fact that its character is well typified in the summit of the Sierra Nevada from Mt. Whitney to Cirque Peak, and that in this part of the region more people will probably make its acquaintance than elsewhere.

The Sub-summit Plateau.—To the west of Cirque Peak the summit upland descends by insensible gradations to a well defined plateau which is best preserved in the country to the west and southwest of the Siberian Outpost. This plateau may be conveniently designated the *Sub-summit Plateau.* It is best

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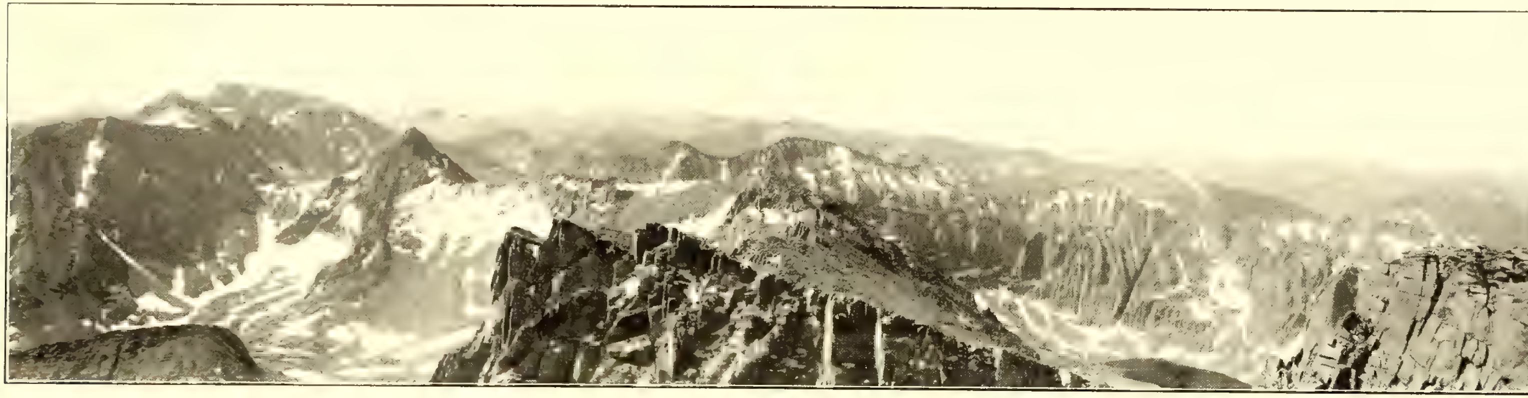
*This term is used as one descriptive of the geomorphic form without implication as to the origin of such form.



A

View south and southwest from summit of Mt. Whitney. Showing remnants of the Summit Upland between Sheep Mt. and Cirque Peak. The destruction of this ancient upland by the development of glacial cirques is well shown.

B

View looking southeast and south from Mt. Guyot. Showing the Sub-summit Plateau on the right and the Rock Creek extension of the Chagoopa plateau on the left dissected by the U-shaped cañon of Rock Creek. Hanging glacial valley above lateral moraine on right side. The slopes of the Summit Upland on the extreme left.

seen from the top of Mt. Guyot looking south and southeast. (Plate 32 B). A more distant view of it is obtained from the summit of Mt. Whitney looking southwest. (Plate 33 A). From both view points it is seen to be a remarkably even and level surface partially dissected by glacial erosion. On its western border, immediately south of Guyot, a sharp but not high ridge rises above its general level, and similar higher ground bounds it on the southwest, so that it presents the appearance of an old, broad, level-bottomed valley lying between this ridge on the west and southwest and the slopes of the Summit Upland on the east. This Sub-summit Plateau extends south as far as Toowa Valley, but in this direction it is much dissected by widely flaring, V-shaped cañons of stream erosion. Glimpses of its flat top are obtained from the summit of the volcanic cone which sits on the divide between Volcano Creek and the South Fork of the Kern. Within these general limits the area of Sub-summit Plateau including its dissection is about 50 square miles. Its general altitude is about 11,500 feet.

Other Plateau Remnants.—No other remnants of plateau surfaces which could be definitely correlated with this Sub-summit Plateau were observed within the basin of the Upper Kern. But on the Great Western Divide and in the region to the west of the Upper Kern Basin, there are remnants of flat topped summits some of which are the undoubted correlatives of the Summit Upland, while others might with equal reason be correlated with the Sub-summit Plateau. The best instance of the Summit Upland on the west side of the basin is that afforded by Table Mountain (13,625 feet). This is clearly the remnant of a plateau which has been, and is being, reduced in area by the encroachment upon it of the steep cliffs which encircle the mountain. Other high peaks to the south of Table Mountain show similar but less pronounced flat tops. These resemble the summit of Mt. Whitney in character, except that the summit of Table Mountain is even more level. Their high altitude seems a fair warrant for regarding them as correlatives of the Summit Upland.

Beyond the limits of the Upper Kern Basin the most notable flat topped summit is a high plateau which lies to the west of Farewell Gap and Mt. Vandever, between the East Fork of the

Kaweah at Mineral King and the head waters of Horse Creek. A fine view of this plateau is obtained from Sawtooth. (Plate 45 A.) Its altitude as found upon the Kaweah sheet of the U. S. Geological Survey is about 11,200 feet. Its northern front is deeply indented by a fine series of glacial cirques; and the topographic map clearly indicates that cirques exist also on the south side. The summit surface is flatly undulating, and although upon the topographic map it appears merely as a high ridge, yet it has the expanse characteristic of the residuum of a plateau. The narrowness of the plateau is clearly due to the reduction of its area by the process of cirque encroachment from either side. This plateau may possibly be an outlying remnant of the Summit Upland, but owing to its lower altitude and to the fact that it abuts upon the steep, upper slope of Mt. Vandever, it seems better to suggest its correlation with the Sub-summit Plateau, with which, in these respects and in its general aspects, it is in better agreement.

It may be well to remember here that, in recognizing and naming these two upland surfaces, we are not dealing with the hypsometric congruence of mountain crests such as is too often relied upon for the identification of dissected peneplains. In the latter case the peneplains are hypothetical. They may in some cases possibly have never existed. But there can be no possible question as to the actual existence of both the Summit Upland and the Sub-summit Plateau. They are observable features of the geomorphy of the region. Hypotheses, of course, come into play the moment we begin to correlate isolated remains of old surfaces, but these, however frail, do not weaken the fact of the existence of these features or their importance in the historical geology of the region.

Sculpture of the High Mountain Zone.—The rugged mountains which girdle the Upper Kern Basin or rise within its area, and which have been placed in a geomorphic zone by themselves, the High Mountain Zone, owe their character to the sculpture of both upland and plateau. They are the remnants of a dissection of a lofty landmass which was, at one time in its history, limited upward by a surface in two general levels, that of the Summit Upland and that of the Sub-summit Plateau. Where sharp

A

A remnant of the Summit Upland. Looking towards Mt. Whitney from Mt. Guyot. U-shaped glacial trough of Guyot Creek on the right. Jointed granite in foreground. Photo. by J. N. LeConte.

B

Transitional slopes between Chagoopa Plateau and the south side of the Kaweah Ridge. Photo. by J. N. LeConte.

peaks and crests prevail these features are due to the intersection of opposing cañon and cirque slopes below the level of this general surface, or to the intersection of such slopes with the steeper slopes of the Summit Upland. Inasmuch, however, as the upper limit of the second geomorphic, or High Valley, zone, the rear of the Chagoopa Plateau, approaches the level of the Sub-summit Plateau, by far the greater proportion of the High Mountain Zone is the result of the sculpture of the mass whose surface was the Summit Upland.

Much of the precipitous ruggedness of the High Mountain Zone in the northern three quarters of the basin is due, as will appear more fully in the sequel, to the aggregation of glacial cirques, which have eaten into the heart of the upland or plateau, as the case may be. The intersection of opposing cirque walls has in many cases reduced the summits to knife-edge crests or lines of sharp pinnacles, which are often much below the level of the original surface. From this point of view the region of the dissected remnants of the upland and plateau might with advantage be designated the zone of cirques. A fuller account of this glacial sculpture is given in another part of this paper. Whether we regard it as representing an ancient upland surface, now left to us in mere remnants, or as a region of remarkable sculpture, the Summit Upland with the subordinate Sub-summit Plateau is a well defined geomorphic zone, which stands out in bold and impressive contrast to the slopes below it.

In the southern quarter of the basin, south of a line connecting the southern limit of the High Sierra, on the summit crest, with the corresponding termination of the Great Western Divide, evidence of the former occupancy of the region by glaciers is lacking. The general altitude is lower, and only in limited areas rises to the level of the Sub-summit Plateau. The Summit Upland portion of the high mountain zone is scarcely if at all represented. The fierce assemblage of high, rugged, mountain peaks and crests here gives way to the more familiar features of an upland subdued by atmospheric and stream erosion. Between the altitudes of 8,500 and 11,000 feet the drainage flows in wide, open, V-shaped troughs of quite moderate grade separated by ridges the crests of which slope toward the master streams. The stamp of maturity is impressed upon the face of the country, and one is staggered by the contrast which it presents with the wilder features of the mountains to the north. The geomorphy here is clearly paragenetic with that of the High Valley Zone, and will be further discussed in that connection.

Significance of Upland and Plateau.—When we attempt an interpretation of the surface features, which have been designated the Summit Upland and the Sub-summit Plateau, a number of interdependent questions arise for which it is difficult to find satisfactory answers. We must first ask: Has the configuration of the Summit Upland any relation to the original upper surface of the granite? It has already been pointed out that the contact surface of the granite with the roof of sedimentary strata, which once presumably arched over it, would constitute an important structural feature, not without influence upon the course of erosion. If we may judge from the Mineral King belt and from analogy with the northern Sierra Nevada that contact was an undulating and locally an acutely uneven surface. The sedimentary rocks of the Mineral King belt are much more easily eroded than are the granite, and if, instead of being sunk down into the granite, as at Mineral King, they formed a shell or covering, that covering might be stripped off and expose the more resistant granite, the surface of which would then be determined by the configuration of the contact plane between the two classes of rocks. In this way there might be evolved flat, gently inclined, or undulating surfaces, as for example such as we find at the summit of Table Mountain, the summit of Mt. Whitney and Sheep Mountain; and, as a detail of such an undulating surface, we might have pronounced terrace effects, such as characterize the summit region between Sheep Mountain and Cirque Peak. Now, of course, it may be urged that such a surface would still be a surface of erosion. But, while this is at once conceded, the recognition of the possibility of such a structural control as that above indicated introduces an important factor in the interpretation of the historical significance of that surface. It presents, in its upper parts, flat areas, gently inclined, undulating and smoothly rounded slopes, which would usually be interpreted as characterizing senility of geomorphic evolution. Such senility implies an approximation by erosional reduction, to base level. But under the hypothesis of differential degradation, if applied to the Summit Upland, no such approximation to base level is implied, and is unnecessary to produce the effects observed. That differential degradation does actually effect the results here ascribed to it is finely demonstrated on the northern flanks of the Caucasus, on the route from Kislowodsk to Elbrus. Here the stripping of soft Cretaceous clays, down to a thick stratum of hard, Jurassic limestone, gives rise to gently sloping plateaux of great expanse which are high above the streams of the region. Farther down the slope a similar stripping of the soft Tertiary sediments, from a hard stratum of the upper Cretaceous upon which they repose, results in similarly expansive, gently sloping plateaux far above base level. The conditions are uot the same as in the case we are here concerned with, but the principle involved is identical.

In applying this hypothesis of differential degradation to the Summit Upland, then, the favoring considerations are: (1) The adequacy of differential degradation to produce the results observed at altitudes far above base level, provided (*a*) that the structural plane involved was near and but little above the present surface of the upland; (*b*) that the plane was uneven in the same sense that the present surface is; and (*c*) that the rocks above the contact on the roof of the granite were much more easily eroded than the underlying granite. (2) That these three provisions are in general realized.

The alternative hypothesis is that the flat summits are the remnant of a region of senile geomorphy, representing an approximation to base level by processes of erosional reduction, independent of structural control. The character of the surface of the Summit Upland as described, and as shown in the photographic illustrations, seems to the writer to favor the former hypothesis rather than the latter.

A remarkable feature of the upland surfaces is the prevailing absence of water courses or incisions of any kind due to stream cutting. This indicates a peculiar status of the erosional process. The surface is everywhere encumbered by blocks of granite, formed by the intersection of joints and dislodged by the heaving action of frost. This veneer of loose blocks is so thick that the waters from summer rains and from melting snows do not gather in run ways, and so establish lines of stream cutting, but flow in a diffused fashion between and beneath the blocks. Even this diffused flow is quite limited, for there is no notable escape of the water at the lower limits of the upland slopes nor at the brink of the cirques which interrupt these slopes. This would seem to indicate that the water which falls upon these surfaces disappears almost immediately into the intricate and abundant system of jointages which traverse the underlying rocks, and so makes its way to lower levels. The water from the melting snow would, of course, meet with the same fate. It is only when we get to the bottom of the cañons and cirques that the granite is tight enough to hold water upon its surface. It would thus appear that these upland surfaces are as free from the attack of running water as are the dryest deserts. This fact explains the remarkable smoothness of their profiles, assures us of their great longevity when once established, and so enables us to understand their survival of the long and vigorous sculpture of other parts of the basin, which were originally not so high.

Having now tentatively adopted the hypothesis of differential degradation as an explanation of the configuration of the Summit Upland surface, a serious question arises as to where we shall stop in its application. Why may not the Sub-summit Plateau represent also a surface determined by the original configuration of the surface of the granite batholith? There is no denying this possibility; but one gets the impression that it is an old valley floor, and it does not present the inequalities of slope and altitude which characterize the Summit Upland. The remnant of the plateau, which lies to southwest of Mt. Vandever at an altitude of 11,200 feet, and which has been correlated with the Sub-summit Plateau, abuts upon the nearly vertical plane of contact between the Mineral King belt of sedimentaries and the granite. This relationship of the plateau surface to the contact between granite and sedimentaries, proves it to be an erosional feature, evolved independently of that structure, and if the writer's correlation of this plateau remnant with the Sub-summit Plateau of the Upper

Kern Basin is correct, then the application of the hypothesis of differential degradation to that surface is negatived, and we must regard the Sub-summit Plateau as having been evolved as a broad valley bottom nearly at base level.

THE HIGH VALLEY ZONE.

Chagoopa Plateau.—The Chagoopa Plateau is, perhaps, the most remarkable feature of the basin of the Upper Kern. It is the ancient floor of the basin before it was trenched by the cañon of the Kern. That trenching, and all the long history that it involves, has left the ancient valley floor singularly intact. Its ancient characters, when it was still functional as a valley floor, are wonderfully preserved and fresh. It is not merely a geomorphic feature to be detected by the trained eye of the geomorphologist; it is a broad and impressive element in the landscape which causes even the amateur mountaineer to pause and wonder. It is best seen from the top of Mt. Guyot, which commands a fine view of the entire central portion of the basin. Looking to the southwest from this vantage point, it spreads out as a broad plain on the far side of Kern Cañon, extending from the brink of the cañon to the base of the precipitous eastern slope of the high mountains of the Great Western Divide. (See Plate 34 A.) Its abutment upon these mountains is a fairly sharp line; but there are transitional slopes, and the plain extends within the salient spurs of the high range. This edge of the plateau, skirting the base of the high mountains of the Western Divide, converges southward upon Kern Cañon in the vicinity of the mouth of Coyote Creek, and beyond that point the plateau is not traceable except, possibly, in certain doubtful terrace-like shoulders on the western side of Kern Cañon. On the north this portion of the plateau is bounded by the high ridge of the Kaweah Peaks and Red Spur, which extends out into the basin from the Great Western Divide as far as Kern Cañon. Its abutment upon the southern flank of this ridge is by well defined transitional slopes. (Plate 33 B). Along the western brink of Kern Cañon the altitude of the plateau is from 8,500 to 9,000 feet above sea level between Coyote Creek and Red Spur. From this line it rises steadily to the northwest towards the headwaters of the Big Arroyo and reaches in that region an altitude of probably 10,500 feet. The Big Arroyo traverses the central portion of the plateau in a deep narrow cañon, cut below its level.

The surface of the plateau is thinly timbered, but the rocky surface may be seen through the trees. This surface deviates from a plain, if we leave out of consideration the cañons which trench it, only by feeble relief which presents the appearance of a very slight modelling. There is but one exception to this, and even that might fairly come within the statement just made. That is a low, rocky mound or smoothly rounded hillock, which has an estimated altitude of about 200 feet above the general level of the sloping plateau. The fact that this low hill is a most striking feature of the surface of the plateau and is without a fellow, is perhaps the best indication of its extreme evenness.

The area of this portion of the high valley land, or Chagoopa Plateau, as bounded by the mountains of the Great Western Divide, the Kaweah Ridge, and the cañon of the Kern, is about 40 square miles.

To the east of Kern Cañon the Chagoopa Plateau has the same character and the same general altitude along the brink of the cañon as on the west side, but is not so wide. It has more the character of a terrace between the brink of the cañon and the steep slopes which lead up to the level of the Sub-summit Plateau. South of Rock Creek this terrace has a maximum width of about a mile and a half, or at most two miles, while, midway between Rock Creek and Volcano Creek, it appears to be almost, if not quite, eliminated by the close approach of the edge of the Sub-summit Plateau country to the western brink of Kern Cañon. South of this point, however, remnants of it again appear on the north of Volcano Creek.

Within the drainage area of Rock Creek, terrace remnants of the High Valley land extend as a long embayment within the High Mountain Zone as far as the rear of the Siberian Outpost plain. This plain is a remarkable feature of this part of the mountains. A nearly flat expanse, chiefly of rock with a veneer of arkose sand, but partly of alpine meadow sward, chilly, featureless and desolate, it excited more surprise and comment

A

Chagoopa Plateau from Mt. Guyot, looking southwest across the Upper Kern Cañon. The Great Western Divide with a great array of glacial cirques and residual crests in the distance.

B

Chagoopa Plateau from Mt. Guyot, looking north-northwest towards Table Mt. The plateau is dissected by the great U-shaped cañon of the Upper Kern.

among the party of mountaineers, with whom the writer was associated, than any other piece of mountain landscape except the view from the summit of Mt. Whitney. The cause of this astonishment lay undoubtedly in the startling contrast which the plain presents to the steeper slopes both above and below it; for it was reached by an arduous, though short, climb from the headwaters of Volcano Creek. This plain has a length of about three miles and is nearly as wide. Its rear is eight miles from Kern Cañon. Here it has an altitude of about 11,000 feet. From this level there is a continuous slope by way of a dissected, but perfectly distinct, terrace on the north side of the main branch of Rock Creek, and the plateau-like ridge between the North and South Forks of Rock Creek, to the lower edge of the Chagoopa Plateau at the brink of Kern Cañon. (Plate 32 B). The slope is about the same as that on the west of the Kern from the upper part of the Big Arroyo to the western brink of the cañon.

Looking north and northwest from Mt. Guyot a magnificent view is obtained of the northern extension of the Chagoopa Plateau. (Plate 34 B). The steep eastern slopes of Red Spur immediately opposite Mt. Guyot are nearly coincident with the steeper cliffs of Kern Cañon, and the plateau is not represented on that side, at the eastern revetment of the great Kaweah ridge. In consequence of the elimination of the plateau at this point, the southern area, thus far described, is connected with the northern area by a terrace, at the western base of Mt. Guyot, which is not much more than a mile wide. North of Mt. Guyot and the Kaweah ridge, however, this terrace expands into a broad sloping plain quite analogous in extent and in general characters so that traversed by the Big Arroyo. In this northern expansion of the High Valley land, its best development is on the east side of the Kern, where it extends as a broad terrace about three miles wide, for a distance of about ten miles to the steep glaciated southern slopes of the divide at the head of the Upper Kern Basin; it even appears to have once been a continuous slope to the pass at the head of Tyndall Creek, which looks out over the Great Basin. This broad terrace borders the western flank of the high mountains of the summit divide and grades into it by transitional slopes which, however, are thickly veneered with alluvium, in the shape of arkose granite sand, derived from the disintegration of the rocks of the higher ground. The altitude of the rear of the plateau along this extent may be placed at from 10,500 to 11,000 feet. From this level it has a uniform slope to the brink of Kern Cañon. The cañon in its upper stretches is, however, not so deep as to the south of Mt. Guyot, and the break from the plateau slope to the cañon walls not so abrupt. The relief of the plateau here is quite like that to the south of the Kaweah Peaks. If we disregard the streams which trench it on the way to the Kern, the sloping plain is nearly featureless except for a slight modelling of the surface.

On the west side of the Kern to the north of the Kaweah Ridge the plateau extends for three or four miles westerly into the basin of the Kern-Kaweah River with a width of about two miles. In this direction it has again transitional slopes connecting it with the northern flank of the Kaweahs; and at its upper end it appears to be nearly coincident in level with the floors of the glacial cirques, which converge upon it from the high mountains at its rear. To the north and northeast of the high spur, which divides the Kern-Kaweah River from Milestone Creek, the plateau extends to the very head of the Kern and seems to pass into a broadly glaciated shelf on the west side of the river which may, very probably, have been the seat of a piedmont glacier fed by several ice streams descending from the group of high mountains, of which Table Mountain is the most conspicuous. The area of the high valley land thus outlined as lying north of the strait between Mt. Guyot and Red Spur may be placed roughly at about 40 square miles. Adding this to the similar area south of the Kaweahs, and estimating 20 square miles as a liberal allowance for other remnants of the plateau such as that extending up to the Siberian Outpost and the discontinuous strip on the east side of the Kern between Rock Creek and Volcano Creek, we get a total area of the High Valley land as 100 square miles,* or about 25 per cent of the entire area of the Upper Kern Basin as defined earlier in the paper.

* This is exclusive of the area of the plateau replaced by Kern Cañon.

Toowa Valley.—Falling within the hypsometric limits of the High Valley Zone is the valley occupied by Volcano Creek in its western part and, in its eastern extension toward the Summit Divide, by the South Fork of the Kern. It will be referred to as the *Toowa Valley* from the neighboring range of that name, since, being occupied by two distinct streams, it cannot be referred to by the name of either without some confusion. This valley is a scarcely less remarkable feature of the mountains than the Chagoopa plateau. It is a high valley, geomorphicly mature, which extends across the southern Sierra Nevada from the cañon of the Kern to a gap in the crest of the Summit Divide, about six miles west from the south end of Owen's Lake. The relations of Volcano Creek and the South Fork of Kern River to this valley are peculiar and merit a brief mention before entering upon a consideration of its more general features.

Volcano Creek rises on the southern slope of Cirque Peak and flows southerly for about eight miles, as a small brook in a mature valley, with a grade of probably 200 to 250 feet per mile. It then enters Toowa Valley and flows westerly to the Kern. The South Fork of the Kern heads in the Summit Divide about three miles southeast of Cirque Peak and flows southwest for six miles as a similarly small brook, entering Toowa Valley at the same point as the upper stretch of Volcano Creek. But instead of flowing west to the Kern it makes an acute bend and flows southeasterly through the eastern part of the valley. The divide between the two streams, where they thus enter the valley, is a low ridge of alluvium so narrow as to have suggested the attempt, which was successfully made, of connecting the two streams by a tunnel, and so diverting the waters of Volcano Creek into the South Fork. These two brooks were at one time clearly tributaries of one stream, which occupied the Toowa Valley, and the separation of the drainage into two distinct streams, one flowing west and the other east in the same valley, is an interesting problem which has its bearing upon the geomorphy of the region, and will be again referred to in a later part of the paper.

The low alluvial divide between Volcano Creek and the South Fork, at the place where they enter Toowa Valley, is about 8,600 feet above sea level; and the general altitude of the meadows of the valley floor may be placed at over 8,200 feet. The general aspect of the valley is greatly modified in places and rendered extremely interesting, both from a scenic and from a geological point of view, by the presence of several well preserved volcanic cones. Six of these came within the writer's observation, two at close quarters by climbing to their summits and the other four only in somewhat distant views. The two which were climbed lie fairly in Toowa Valley and appear as if sessile upon its floor. One of these is situated about five miles east of the Kern River and has an altitude which is estimated at about 400 feet above the general level of the valley. The crater of this cone is breached on its eastern side, and it has been the source of lava streams which, in part, have been spread out in all directions about the base of the cone, and in part have flowed down Volcano Creek almost to the bottom of Kern Cañon. This lava stream filled a gorge in the lower part of Volcano Creek, which had been cut down nearly to the present Kern level, and, since the gorge was thus filled, the stream has cut a new gorge, which descends by a series of cascades, partly in the lava and partly between the lava and the granite, to the Kern. (Plate 35 B). Above this gorge the drainage of Volcano Creek has been variously obstructed by the lavas, the general result of which has been to crowd the stream to the north and northeast sides of the valley.

The second volcano is situated about two miles and a half east of the last, almost directly opposite the point where the upper stretches of Volcano Creek and the South Fork converge and enter Toowa Valley. It is a cinder cone and has an estimated height of 600 feet above the valley floor, occupying almost the entire width of the valley bottom. Its crater ring has a diameter of probably 1,200 feet, and its slopes are the slope of repose of the loose lapilli and ashes of which it is chiefly composed. Its crater is breached on the north side, but no important lava stream appears to have issued from the breach.

Immediately opposite this volcano on the rocky mountain slope of Toowa Valley, perched on a granite knoll, is another small volcano. It appears to consist chiefly of lava when viewed from a distance, but no important stream has issued from the

A

Toowa Valley looking east from summit of volcano shown in Plate 36A. The broad, ancient valley floor has been dissected and since aggraded to the present meadow level.

B

The mouth of Volcano Creek and the floor of Upper Kern Cañon. The creek had once cut down nearly to the level of the bottom of Kern Cañon and was then filled with lava—the dark rock in the middle of the picture. Since then a narrow precipitous gorge has been cut partly in the lava and partly between it and the granite.

vent. Its crater is irregular and ragged and lacks the symmetry of the cinder cone.

Looking eastward along Toowa Valley from the summit of this same cinder cone, one sees at a distance of about six miles two other conical or dome-like hills of dark rock, which are in marked contrast to the white weathering granites of the region. These hills, although not visited, are in all probability volcanic cones. The smaller one lies in the axis of the valley and the larger one lies to the south of it. Both appear as if they were sessile upon the valley floor. The slopes of the two cones are confluent at a level not much below the summit of the smaller cone.

The sixth volcano is situated in the valley which is tributary to Volcano Creek from the north at Groundhog Meadow, about four miles up stream from Kern Cañon.

From what has been said of these volcanoes it is evident that the period of their eruption and the upbuilding of their cones is later than that of the formation of the valley, and that they are features imposed upon, and independent of, the erosional geomorphy of the valley. The valley had attained its present character, as far as erosion is concerned, before the volcanic eruption began, and has been but little modified since eruptive activity ceased, except by aggradation.

Disregarding, then, these volcanic cones as foreign to the discussion of the essential character and geomorphic evolution of the valley in which they occur, we may proceed to describe the general features of the valley as seen from the summits of the two more commanding cones. The floor of the valley is in two stages. The lower of these may be characterized as a broad, flat-bottomed succession of meadows and alluvial plains. This flatness and breadth of the bottom lands is evidently due to a process of aggradation; and this is doubtless, in some considerable measure, a consequence of the interference of the normal drainage by the volcanic accumulations which have grown up upon the floor of the valley, although other causes may have also, perhaps, been concerned in the process. But the breadth of the valley is not measured by its bottom lands. The meadows do not fully occupy the floor, but are simply the lower part of a very wide valley. Looking toward the summit crest from the top of the cinder cone on the divide between Volcano Creek and the South Fork, Toowa Valley is for the most part a rocky platform of subdued, rolling relief, which forms a distinct terrace above the meadows which wind through it. This is the second stage of the valley floor. It is the breadth of this feature which gives the valley its expansive character. The flat bottom lands are a subordinate feature. This upper stage of the valley floor is more or less dissected, but in its general aspect it is a rocky surface of very gentle rise to the sides of the valley, where it merges by transitional slopes into the upland from which the valley has been carved. The altitude of the terrace ranges from about 200 feet to perhaps 600 feet above the bottom lands of the valley, but lower spurs run out from it into the meadows. Views of the valley are given in Plates 35 A and 36 A, B and C.

Toowa Valley, as represented by the upper stage of its floor, is evidently a very mature erosional feature. The character of the surrounding mountains is in harmony with this conclusion. While the country might still be described as rugged, it lacks the fierceness of the glaciated mountains to the north. The ridge profiles are characterized by a flowing rotundity; there is an entire absence of deep shear-wall cañons and of sharply serrate crests and pinnacles; the flaring V-shaped side valleys widen noticeably as they approach the master valley, and the crest lines of the divides between these side valleys have a marked slope. (See Plates 35A and 36 A, B and C). The maturity of this broad transmontaine valley is analogous in degree to that of the Chagoopa Plateau, it lies in the same hypsometric zone, and is separated from it by no barrier and by no break except the cañon of the Kern. We may, therefore, with great confidence and with little chance of error, correlate the two features as slightly different phases of the High Valley system of this portion of the Sierra Nevada. The aggraded bottom lands of Toowa Valley represent a dissection of this high valley, and if this aggraded product were removed we should doubtless find beneath it a fairly incisive cañon due to a relative lowering of the base level, and this depression of the base level may reasonably be referred, as will appear a little later, to down cutting of the cañon of the Kern, the master stream of the region.

A

Toowa Valley. Looking east from summit of a volcano two and a half miles west of the one shown in the picture; illustrating the aggraded valley bottom and the mature character of the surrounding mountains.

B

North side of Toowa Valley from same point of view as in A. Showing the unglaciated mature topography of the upland of the southern High Sierra.

C

South side of Toowa Valley from same point of view as A and B. Showing the unglaciated mature topography of the upland of the southern High Sierra.

Having pointed out the analogies between Toowa Valley and Chagoopa Plateau and correlated them on that basis, it remains to indicate some interesting differences. These lie chiefly in the character of the slopes which border and confine these high valleys. In the case of the Chagoopa Plateau, as we rise from the back of the valley into the High Mountain Zone we enter at once, in almost all directions, into a zone of intensely glaciated country; while, from points which afford the most commanding views of Toowa Valley and the higher country drained by it, no trace of glaciation can be detected, but only those forms of relief which are clearly and unquestionably referable to atmospheric and stream erosion. But since Toowa Valley is hypsometrically and geomorphicly, and, therefore, also chronologically, the equivalent of Chagoopa Plateau, it is evident that the slopes which encircled Chagoopa Plateau, in time anterior to the glaciation of the region, must have reached the same general stage of geomorphic development as had the slopes which confine Toowa Valley. In the mature geomorphy of the High Mountain Zone bordering Toowa Valley with its rounded forms, its flaring valleys, its sloping divides and its low grades, we have presented to us, therefore, in but slightly modified form, the geomorphic character of the High Mountain Zone about Chagoopa Valley at the time of the inauguration of the Sierran glaciation. The fierce and precipitous forms of the relief of the High Mountain Zone in the northern three-fourths of the upper Kern Basin have, for the most part, been evolved from a geomorphy almost as mature as that we see in the country tributary to Toowa Valley.

The modifications referred to above which necessitate the introduction of the word "almost" in the last sentence are due to three causes. (1) The hypsometric range of the High Mountain Zone about Chagoopa Plateau is greater than that above Toowa Valley. This implies, of course, that more erosional work would have to be done in that part of the basin in order to arrive at maturity than in the somewhat lower country to the south. Still, the time necessary for the reduction of the country about Toowa Valley to maturity could not fail of the same general result in the country encircling Chagoopa Plateau. The geomorphy would at least have approximated to maturity, though the latter might not have been so pronounced as in the region where less work had to be done. (2) The second modifying consideration is that, during the Sierran glacial period, the Toowa Valley country continued under the dominion of atmospheric and steam erosion, and so advanced in its geomorphic evolution on the old lines, while glacial forces were at work immediately to the north. This advance is of course proportionate to the length of time represented by the glacial occupation of the High Mountain Zone in the northern part of the basin. This period is believed by the writer to have been brief as compared with the whole time concerned in the evolution of Toowa Valley. The volcanoes and lava flows which encumber and obstruct Toowa Valley are probably preglacial in age, and the extent to which they have been modified by atmospheric and stream agencies is comparatively slight. (3) The third consideration is that in Sierran post-glacial time the geomorphic evolution of the Toowa Valley borders may have advanced again on the old lines, whereas, since the evacuation of the northern part of the region by the glaciers, atmospheric and stream agencies have had to adjust themselves to entirely new conditions. The modification due to this cause is, however, practically negligible, since in the glaciated portion of the region, the glaciated surfaces are still to a large extent intact in the condition in which the ice left them.

The general result is that the mature geomorphy of the country around Toowa Valley was in its essential features attained in time anterior to the Sierran glacial period, and represents very fairly the general character of the upper slopes of the entire Upper Kern Basin up to the advent of glacial conditions; and that we thus have, in a comparison of the glaciated and unglaciated portions of the High Mountain Zone, an approximate measure of the geomorphic revolution which has been effected in the former by ice action.

Another point of difference between Toowa Valley and Chagoopa Plateau is that the latter is dissected by the great cañon of the Kern to a depth of about 2,500 feet; and the tributary streams of the Kern which traverse the plateau have trenched it incisively, though not as deeply as the master stream. Toowa Valley might be expected to be similarly trenched in the effort of the streams which drain it to reach the lower base level established by the master stream. The absence of such an incisive trench traversing the floor of Toowa Valley constitutes an apparent difference between it and Chagoopa Plateau. This difference has been partially explained in the preceding discussion of the geomorphic features of the valley. The succession of meadows and alluvial flats, which constitute the bottom lands of the valley, are there recognized as the result of aggradation, due in large measure to the obstruction of the drainage by volcanic accumulations. These volcanic materials are themselves found to have filled up a gorge which, in the lower stretch of Volcano Creek, had been cut down nearly to the present level of the Kern River in pre-volcanic time. It is not supposed that this gorge had been cut very far back into Toowa Valley; but the facts are sufficient to indicate that Volcano Creek had cut as deeply below the ancient floor of Toowa Valley as other more northerly tributaries of the Kern, Rock Creek, and the East Fork of the Kern, for example, had cut below the floor of the corresponding Chagoopa Plateau.

The Little Kern Plateau.—We have still another plateau which appears to fall into the High Valley system of the southern Sierra Nevada. This is partly within the basin of the upper Kern as defined in the earlier part of the paper and partly extends beyond it. It was first met with in the southern end of the basin, south of Trout Meadows, in the triangular piece of country between the Kern and the Little Kern, beyond the end of the Great Western Divide, and was followed up the west side of the little Kern for some ten or fifteen miles as a broad, dissected terrace. Its general altitude is estimated to be about 7,000 feet. Travelling south from Trout Meadows one crosses an almost perfectly level floor, relieved only by low swales, to the brink of the deep cañon of the Kern near where it is joined by the Little Kern. This level platform is veneered in places by the remnants of a thin sheet of basaltic lava, which tends to accentuate its flatness. The underlying granite appears frequently, however, from beneath the lava and between the remnants of the sheet, but it rises but very slightly, or not at all, above the general level established by the lava surface. The width of the plateau is here about three miles. It terminates abruptly at the brink of a cañon 2,000 feet, or more, deep. Standing on this brink one may look across the cañon and see remnants of the plateau on the far side and of the volcanic rocks which rest upon it, these being in sharp contrast with the prevailing granite of the country. Restoring the portion removed by the cutting of the cañon, the entire width of the plateau is probably not less than five miles. In its relation to the cañon the plateau is a terrace, representing clearly an ancient valley floor evolved at a time when the base level of the region was relatively much higher than it is now; or, as it might be better stated, when the surface of the plateau was coincident with the base level. The Hockett trail from Trout Meadows to Farewell Gap follows this terrace on the west side of the Little Kern nearly to Shot Gun Creek, where it is eventually lost in the narrower cañon of the head waters of the river. This terrace is well defined and affords an easy and comparatively level trail, save where it is dissected by the transverse streams tributary to the Little Kern, which come down from the western slopes of the Great Western Divide. The width of the more level part of the terrace is about a mile to a mile and a half. At its rear it passes by transitional slopes into the rather steep mountain side of the Great Western Divide. Its most level part is that to the east of Burnt Coral Meadow, where it is veneered with a thin sheet of basaltic lava, which covers an area possibly half a mile square. It has here the same perfectly level character as that which prevails to the south of Trout Meadows. The exigencies of mountain travel and the prevalence of timber prevented a more comprehensive view of this terrace. Enough has been observed, however, to make it clear that we have here to deal with the remnant of a high valley entirely analogous in its general features to the Chagoopa Plateau and dissected in the same way. The fact that it lies at a lower level may be explained partly on the supposition that it is farther down stream in the ancient drainage system, but chiefly on the supposition that, toward the head of the Kern, the mountains have been lifted higher than farther south, involving an upward tilting to the north of this high system of ancient valleys. Such a tilting seems to be indicated in the general falling away in the height of the mountains southward of the latitude of Toowa Valley. The writer at least has no serious hesitation in correlating the Little Kern Plateau with the Chagoopa Plateau and Toowa Valley as representing the same stage of the geomorphic evolution of the southern Sierra Nevada.

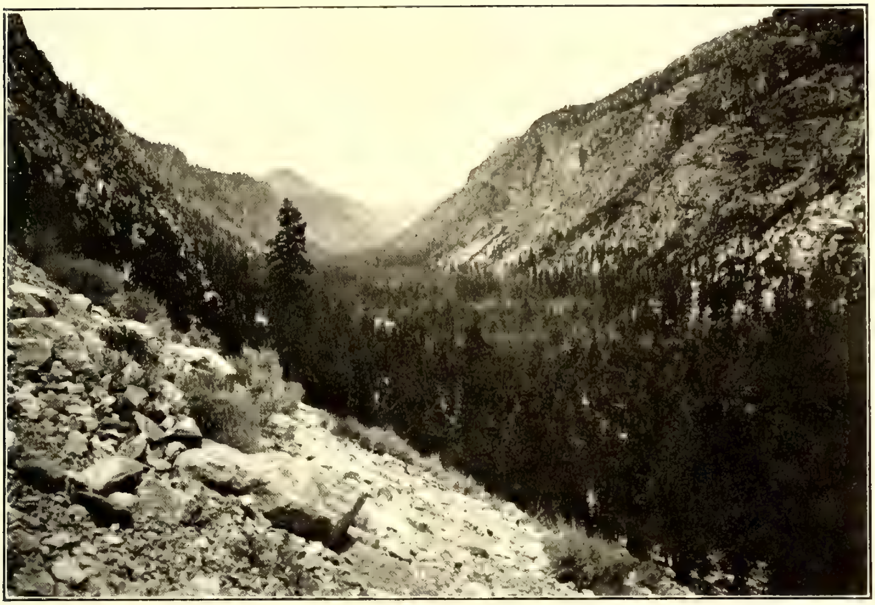
Former Connection of the High Valleys.—Recognizing the synchronous evolution of Chagoopa Plateau, Toowa Valley, and Little Kern Plateau, and the community of their relation to base level, it is probable that, before they were lifted so high above base level, they represented an interconnected system of drainage. What that connection was cannot here be positively asserted; but certain suggestions are permissible in the way of indicating possibilities. There are three possible outlets for the ancient drainage of Chagoopa Plateau: (1) Northeastward, by way of a pass at the head of Tyndall Creek, to the east of Junction Peak, and thence either into the region of the present Great Basin, or between Junction Peak and Mt. Keith into the region of the present headwaters of the King's; (2) eastward from its southern end by way of Toowa Valley or (3) southward along the line of Kern Cañon. The last of these seems to be the least probable, since there is no definite remnant of a High Valley terrace along the cañon of the Kern below Volcano Creek. The possibility of the Trout Meadows defile having been an outlet is discussed later and rejected as improbable because there is no evidence of its having been a stream trench, and because it is lower than Little Kern Plateau and has, therefore, been formed later than it. If the outlet had been originally to the northeast by way of the pass at the head of Tyndall Creek, then the uplift, which initiated the downcutting of Kern Cañon, must have deformed the region to the extent of reversing the general slope of the country. As there is no independent warrant for this supposition, and as the transitional slopes at the rear of Chagoopa Plateau indicate a general southerly slope of the country at the time of its formation, this hypothesis cannot be favorably entertained. The remaining possibility, an outlet by way of Toowa Valley from the southern end of the plateau, has no inherent objection, and by elimination of the other two possibilities seems the most probable hypothesis. In this event the drainage either followed Toowa Valley eastward to a gap in the summit crest, shown in Plate 35 A, and thence out into the region of the Great Basin at the south end of Owens Lake, or it turned, following the course of the South Fork, and joined with the high valley represented by Little Kern Plateau, lower down on the Kern. Unfortunately for the decision of this alternative, the writer has no knowledge of the country traversed by the South Fork after it leaves Toowa Valley; but the extensive Monache Meadows indicate that the South Fork traverses a valley which has characters similar to those of Toowa Valley, and, if this be true, then the ancient drainage probably followed that line.

With the rapid downcutting of Kern Cañon, under the above hypothesis the upper part of Toowa Valley was beheaded and the drainage of its upper part reversed. This reversed drainage may have extended at one time farther up Toowa Valley than at present. Whether this be so or not, the segregation of the drainage into two streams, Volcano Creek and South Fork, is, so far, at least, as the determination of the place of segregation is concerned, an accident due to aggradation caused by volcanic damming of the valley.

The fact that the Kern abandoned the Toowa Valley route after the uplift may be explained on the supposition that the old route, under the new conditions of erosion, was too roundabout to compete with the shorter course, and that a cut-off was effected by a short tributary of a lower part of the Kern capturing the main drainage.

THE CAÑON ZONE.

The cañon of the Upper Kern is one of the great cañons of the Sierra Nevada; and in some respects it is the most remarkable of them all. It represents the most recent dissection of the high mountain mass in consequence of an uplift which raised the floor of the High Valley system far above the base level of erosion, and so caused the streams to sink deep trenches in that floor. But while it is a feature essentially due to stream erosion, its characters as such have been modified by its having been



A

View of Upper Kern Cañon looking north from talus slope on west side above Coyote Creek. The cañon has been occupied by a trunk glacier and shows a fine U-shaped profile. The timbered meadows are due to post-glacial aggradation.

B

View of Upper Kern Cañon looking south from point on the east wall above Volcano Creek. Tower Rock is seen on the left, main terminal moraine in the middle ground, kernbuts lower down.

occupied, for a time, by a long trunk glacier, which extended down the cañon as far as the mouth of Coyote Creek, and which was fed by several tributary glaciers, heading in the cirques of the High Mountain Zone, and flowing to it in the trenches, which had previously been cut across the Chagoopa Plateau by the tributary streams in their effort to keep pace with the sinking of the Kern. In consequence of this episode in its history the cañon above Coyote Creek has the typical U-shape in cross profile so characteristic of glaciated mountain valleys. (See Plates 34 B and 37 A). The bottom of this U-shaped portion of the cañon varies from less than half a mile to nearly a mile in width and averages perhaps half a mile.* The distance between the walls of the cañon at its brink averages probably about a mile, with but little variation from the average. In several places along its length the walls are yet in the same condition as when the ice vacated the cañon, descending sheer to the floor, smooth and fluted by glacial abrasion, and having little or no talus at the foot. In other portions of the cañon, and this is the prevailing condition, the base of the cliffs is buried in talus, part of which has evidently accumulated slowly by the gradual shedding of fragments from the upper face, and part of which has come down suddenly by the detachment of large masses from above in the shape of rock-slides. Some of the blocks that have thus fallen from the high part of the cañon walls are finely scored with glacial grooves. Besides these talus slopes there is, at the mouth of every tributary cañon, a deep alluvial cone furrowed radially by stream channels, one or more of which are functional, the others having been abandoned by the well known shifting of the stream upon its cone. These cones are for the most part composed of coarse boulders, only rudely rounded, and even on the outer flanks of the cone the material is gravelly. The boulders are frequently a yard or more in diameter, and over many acres would average over a foot. The apex of these cones is generally several hundred feet above the cañon floor. These cones are the product of streams which enter the cañon far above its bottom and which, in many cases, flow in glaciated trenches. These trenches are fine examples of hanging valleys. As regards

* Including the talus at the bottom of the cliffs.

its grade, the Upper Kern is not uniform. From its head down to the vicinity of Rock Creek it is a series of cascades and rapids, a torrential stream which has cut a notable trench in the glaciated floor of the cañon. Below Rock Creek and thence to the vicinity of Volcano Creek, where it cuts through a terminal moraine, while still a swift stream, it flows through a timbered meadow, with a more or less sinuous course, in a gravelly bed. This portion of the cañon has been aggraded, and the process of aggradation is probably even now incomplete. The depth of the aggradational accumulation is unknown. Below the nose of the moraine, at the mouth of Volcano Creek, the stream is again a series of rapids except for the interruption of two small lakes to be noted particularly later. It has this character as far as in the confluence of the Little Kern, and for a portion of this stretch it was estimated with the aid of an aneroid to have a fall of about 200 feet in a mile. As in the portion of the cañon above the meadows, it is actively lowering its trench. In general, the grade of the floor of the cañon is notably greater than the northward slope of Chagoopa Plateau, so that near the head of the cañon it approaches much more nearly the level of the plateau than in the middle portion of the basin; and in this upper shallower portion of the cañon the walls are not so precipitous. It here presents the profile of a widely flaring, U-shaped trough (see Plate 34 B), whereas, in the middle portion of its course, the profile is that of a steep or nearly vertically sided U.

The cañon of the Upper Kern having been occupied for 24 miles of its course by a trunk glacier, it becomes a question of interest to inquire to what extent it has been enlarged by glacial erosion. This question, however, involves immediately a comparison of the glaciated portion of the cañon with the unglaciated, below the limit reached by the ice stream; and since this comparison is complicated by certain unique and remarkable features in that portion of the cañon which is below the limit of glaciation, it will be necessary to defer this inquiry till these features have been described. In the portion of the paper dealing more particularly with the glaciation of the region the question here raised will receive attention.

KERN CAÑON AND CRUSTAL RIFTING.

Kernbuts and Kerncols.—A remarkable feature of the Upper Kern, below Volcano Creek, is the departure of the stream from the west wall of the cañon and its crowding upon the east wall. This displacement of the stream is due to obstructions in the shape of a series of rocky buttresses, which adhere to the foot of the west wall, and, projecting out beyond the middle line of the cañon, locally constrict it, causing the stream to occupy narrow gorges between these buttresses and the east wall. In the interval between these buttresses the bottom of the cañon has its normal width of about half a mile from wall to wall. There are several of these buttresses in the vicinity of the Kern Lakes, and the two lakes lie in two of the intervals. In cross profile these buttresses have the character of rather sharp-crested ridges which run parallel to the general trend of Kern Cañon; and a buttress may be a single ridge or a series of two or three ridges, in which case the latter are successively lower toward the east. The buttresses may, therefore, be distinguished as single or multiple according as they present one or more of these ridges in cross profile. The single buttress is exemplified in the one which lies at the south end of Lower Lake and is shown in Plate 38A. It is a simple ridge of rock, over half a mile in length, and having an altitude of about 350 feet above the level of the lake. Its eastern face is steep and is encumbered in its lower part with huge spauls of rock, more or less detached from the face of the cliff, and by aggregations of blocks which have fallen as small rock slides. To the west of the ridge, and intervening between it and the main wall of the cañon, is a depression parallel to the ridge which is followed by the Kern River trail. In crossing this pass the trail climbs probably 250 feet above Lower Lake. The photograph (Plate 38A) of this feature speaks so well for itself that the description needs but little amplification. It may be said, however, that the ridge is a solid mass of rock of the same granitic character as prevails in this part of the cañon; and that on the trail over the pass, at its south end, there is a small stream depositing travertine, which doubtless issues as a spring at the foot of the high cañon wall to the west of the pass. There is no evidence of the pass ever having been a stream course. Its profile is that of an open swale, the floor of which is mantled with the wash from the slopes on either side.

Such a buttress, situated in the bottom of a profound cañon and separated from the wall to which it adhered by a parallel pass or col, is a type of geomorphic form which appears as yet to have failed of recognition. It is proposed here to give it the recognition which it seems to merit, and the best way of doing this, perhaps, is to give it a name. It is desired that this name shall be without implication as to the genesis of the form, at least till our notions of that genesis shall have passed the merely hypothetical stage. From the fact of their being buttresses of a peculiar type recognized for the first time in Kern Cañon the feature is called a ***kernbut***. The correlative pass, or col, which intervenes between the kernbut and the main cañon wall, or between the parallel ridges of a multiple kernbut, is equally in need of a name and is here designated a ***kerncol***.

The buttress which obstructs the cañon between the mouth of Coyote Creek and Upper Kern Lake is a good example of a multiple kernbut. See Plate 38B. Extending south from the mouth of Coyote Creek is a sharp ridge about three-quarters of a mile in length, and having an altitude of about 400 feet above the river. The kerncol which separates this from the west wall of the cañon is a defile, which rises gradually to the south to an altitude of about 250 feet above the river near to the south end of the ridge, whence it drops again more rapidly to the bottom of the cañon on the west side of Upper Lake. A view looking down this kerncol is shown in Plate 39A with the ridge on the right. Overlapping this ridge *en echelon*, to the east of its southern end, is another similar ridge having an altitude of about 150 feet above the river, and a length of nearly half a mile. The kerncol between these two ridges is a long, narrow flat-bottomed defile but little above the level of the river, and was once temporarily occupied as a channel of the river. The stream has, however, since that occupation cut a gorge obliquely across the northern lower end of this ridge, and the stream passing through the rocky gorge, which has a depth of about 50 feet, now flows entirely to the east of the ridge, between it and the east wall of the cañon, and then immediately expands into

A

View looking down Kern Cañon from kernbut between Upper and Lower Lakes. Shows Lower Lake in foreground, great rock slide on left, a typical kernbut on the right with steep wall behind it and the profile of the Trout Meadows defile in the distance.

B

Looking down Kern Cañon from point on west side just above Coyote Creek. Shows series of kernbuts.

Upper Lake. The crest of a low, rocky island appearing above the delta of the lake appears to be an extension of the same ridge, the direction of elongation of the two being in line. To the southeast of the south end of the first, or 400-foot ridge, and so situated between it and the second or 150-foot ridge, is a third ridge, having the same characters as the two described but much smaller in size. A typical kerncol separates it on the west from the southern end of the main ridge, while on the east it slopes down to the kerncol situated between the two larger ridges.

Still another kind of multiple kernbut is one in which the constituent ridges are arranged not *en echelon*, or overlapping, but in succession, one in front of another. This is exemplified by the kernbut which separates Upper and Lower Lakes. When this buttress is viewed from the north end of Upper Lake its profile is distinctly serrate, there being not less than three, and possibly four, ridges with corresponding kerncols. The altitude of these decreases regularly to the east. The lowest ridge of the series has an altitude of about 300 feet above the Kern, and on the stream side presents a precipitous cliff, with many slightly dislodged spauls of rock of large size. There is no talus at the foot of the cliff, and it is so steep that one can pass on foot, between its base and the river, only by risky and difficult climbing. To the west of this ridge the lowest kerncol is a defile having an altitude of perhaps 200 feet above the river and is followed by the river trail.

About two miles below Lower Lake is still another multiple kernbut with two ridges and two kerncols. It is like the others described above and is on the same side of the cañon, but, being on a smaller scale, it is a much less prominent feature in the landscape. Another obscure feature of this kind occurs at the foot of the west wall, about a mile north of Coyote Creek, near the north end of the western limb of the terminal moraine which there spans the floor of the cañon.

Possible Explanations.—These kernbuts can apparently only be explained on the hypothesis that they are vast spauls of the west wall that have been detached from it in some way by a process of rifting. Other hypotheses may be temporarily entertained with respect to their origin, but they have only to be clearly formulated to bring about their speedy rejection. It might be supposed, for instance, that they represent residuals of erosion in the down cutting of the cañon, but this is negatived by the fact that, in the intervals between the kernbuts, the cañon floor has its normal width, and by the fact that there is no evidence of the kerncols having ever been stream channels except in one case, where the kerncol is a little above the present level of the river. It fails, however, to explain the prevailing landslide profile which these kernbuts habitually affect. But even when we accept, as our working hypothesis, the statement that the kernbuts are masses which have been detached from the west wall of the cañon, much remains to be explained concerning them. They may, for example, be interpreted either as of the nature of landslides, or as the butt end of wedges, which have dropped into a rift or chasm opened in the earth's crust along the line of the cañon. The former hypothesis is the less violent of the two, and may be examined first.

Landslide Hypothesis.—In such an examination one turns naturally to a method of comparison with features due to landslide action. Now it must be confessed, to start with, that the geomorphic configuration of these kernbuts is somewhat analogous to that produced by landsliding. In ordinary landslides large or small, the mass which slips is usually of a more or less plastic material, and suffers a partial rotation on an axis parallel to the slip surface. It suffers both plastic deformation and dislocation, and, when it comes to rest, it presents a profile which is characterized by a series of steps. The tread of these steps is in all cases a slope of less inclination than that of the original hill or mountain side in consequence of the rotation above referred to. In many cases this rotation has been so great that the tread slopes down towards the hill-side, giving rise perhaps to a basin. The rise in the step is in all cases a dislocation plane in the slipped mass, and usually hades outward or away from the hill side. In these cases, where the rotation is extreme, the profile of the slipped mass is analogous of that presented by the kernbuts. On the basis of analogy with ordinary landslides in plastic material the kernbuts might be supposed to have a similar origin.

A

View looking north along kerncol followed by the high trail from Coyote Creek to Upper Lake.

B

Upper Kern Lake looking north from south end. Tower Rock on the right. The lake was formed in 1867-68 and the dead timber standing in the lake was drowned at that time.

But the material of which the kernbut is composed is not plastic, and has suffered no observable plastic deformation, and a fairer comparison would be with known rock-slides. Fortunately for such a comparison we have, in this case, not far to seek. On the east side of Kern Cañon, immediately below Lower Lake, there is a colossal rock-slide nearly a mile in length and about 2,000 feet high. This rock-slide differs from ordinary landslides in this important respect, that the slipped mass, being of rigid materials incapable of plastic deformation under the stresses induced by gravity, broke to pieces as it slid, and is now a chaotic aggregation of huge spauls of rock. The same general profile has, however, resulted from the smashing up of the mass and the readjustment of the fragments as is attained by rotation and plastic deformation in more yielding materials; and there is a distinct, though rude, landslide terrace at the top of the fallen mass.

We have here, therefore, an excellent basis of comparison of the kernbuts with an unequivocal rock slide in the cañon of the Kern itself, in the same kind of rock and under the same general conditions that may be supposed to have affected the cañon walls at the time when the kernbuts were formed. The comparison, it is scarcely necessary to point out, is adverse to the hypothesis that the kernbuts are of the nature of landslides. This adversity, however, does not disprove the hypothesis. It may be urged, with good reason, that the rock-slide, which has just been cited, may be only one phase of the results which arise from this process. It is possible that the rock-slide on the east side of the Kern Cañon below Lower Lake has been a sudden slip, a catastrophic event, and that the smashing up of the mass is due to the rapidity of the movement. If such a slide were a slow process, the slipped block might in time descend to the bottom of the cañon without the shattering of the mass. But landslides and rock-slides are in general habitually sudden in their movements;* and the assumption that the kernbuts are the result of slowly moving slides of the landslide type would reverse their habit in

* There are, however, certain exceptions to this general rule, and under special conditions a land-slide may move comparatively slowly. An instance of this kind is described by Gilbert in the Bull. Philos. Soc. of Wash., Vol. XII, p. 244.

the proportion of about ten to one for the Kern Cañon. The cañon of the Kern was traversed after the writer had become familiar with the kernbuts, and the walls were examined to discover what portions of them seemed likely to be affected by slipping in future. A number of such places were fixed upon, as, for instance, Tower Rock immediately opposite Coyote Creek. But in none of these cases did it seem possible that a slip could take place without sudden movement and catastrophic results. In general, then, the kernbuts differ from land- and rock-slides in not having been subjected to internal deformation or intense shattering. They have been detached under other conditions than those which attend such movements.

Rift Hypothesis.—The alternative hypothesis, that the kernbuts represent portions of wedges that have slipped down into an opening rift along the line of the cañon may next be examined. This possibility may at first blush appear an extreme one to entertain as an hypothesis explanatory of these remarkable features. The theory of *graben* or dropt crustal blocks is, however, so well established in geology that we have abundant analogy for the suggestion and are, therefore, warranted in giving it serious consideration. But the moment we attempt to apply this hypothesis, we are confronted with the difficulty that we cannot confine its application to these local features of the cañon. The hypothesis that the kernbuts are in any way due to the process which gives rise to a *graben* involves the larger hypothesis that the cañon of the Upper Kern is itself in some sense a rift valley.

Harmony of Kern Cañon with Rift Hypothesis.—Now, certain remarkable features of the cañon lend themselves to this view. These are: (1) The course of the cañon is different from all the other cañons of the Sierra Nevada that are comparable with it in size and character. These are, almost without exception, trenches of streams which are consequent upon the general tilting of the Sierra Nevada crust block, and flow westerly from the crest of the range to the Great Valley of California. The Upper Kern has on the contrary a meridional trend, parallel to the axis of tilting, and lies but a few miles west of the great fault zone along which the dislocation involved in the tilting occurred. (2) The cañon of the Upper Kern differs from all the other cañons of the

Sierra Nevada, not only in the direction of its trend, but also in the remarkable and unbroken straightness of its trend. This rectilinear character of the cañon persists for about 28 miles and is undoubtedly determined by a structural control of the erosion. In view of what has been said of the homogeniety of the rocks of the Upper Kern Basin, it is difficult to imagine the nature of this structural control if it be not due to a straight rift. (3) On the west side of the cañon about a mile and a half north of the mouth of Coyote Creek there is, above the brink of the cañon, an uneven terrace backed by a cliff which has all the characters of a fault scarp, as yet but little degraded and having a height of about 150 or 200 feet. The line of the apparent fault is parallel to the west wall of the cañon and traverses, for an observed distance of about a mile, an uneven, or rolling, rocky slope, which corresponds to the transitional slopes at the rear of Chagoopa Plateau. The terrace in front of the scarp has the same uneven and rolling character as the surface above it, and is clearly discriminated from a stream terrace by this fact, and by the fact that the back of the terrace is not horizontal, but is solely determined by the intersection of this uneven surface with the plane of the scarp. A critical inspection of this scarp and terrace from the opposite side of the cañon, on the upper part of the trail to Volcano Creek, failed to suggest any other possibility than that we have here an actual fault, whereby a great slab of the west wall has dropped through a distance measured by the height of the scarp.

(4) There are certain short rectangular jogs or reëntrants in the course of the cañon walls which are difficult to explain as products of erosion, but which are in cosonance with the hypoththesis of rifting with sinking of slabs of the cañon walls.

(5) The rocks traversed by the cañon are prevailingly gray granite, but along the west wall of the cañon below the Kern-Kaweah river there is a red streak running through the prevailing gray. This red streak was followed for some miles and was found to be distributed in a plane parallel to the wall and cropping out in its upper part. At one of the jogs above referred to, below Red Spur, this red streak crosses from the west wall to the east wall, and there has a similar distribution nearly as far as the upper Funston Camp. The character of this red streak could

only be determined by the examination of rock fragments in the talus of the cliffs. It appeared to be the ordinary granite of the cañon walls with a stain of ferric iron oxide, derived doubtless from the oxidation of the ferrous iron in the ferro-magnesian constituents of the rock. This staining implies the freer access of oxidizing agents, that is, of meteoric waters to the portions of the rocks so affected. The portion of the granite thus affected has been so weakened that it is much more susceptible to disintegration than the ordinary gray granite; and this zone of easy disintegration exercises a marked control on the sculpture of the cañon wall. This, again, is in harmony with the general hypothesis of rifting or the opening of fissures in the granite parallel to the course of the cañon.

The Trout Meadows Defile.—About three miles south of Lower Lake the cañon in which the Kern flows departs from its rectilinear, meridional course and bears off to the southeast, making a detour or semicircular bend from its normal course, but the straight trend of the cañon is continued in a long, narrow defile through the mountains as far as Trout Meadows, a distance of about four miles. This defile is nearly level throughout its length and has an altitude of about 6800 feet, or about 700 feet above the Kern at the point where it bears away from its meridional trend. The floor of the defile rises, however, with an extremely gentle grade to a point about half way to Trout Meadows and thence descends equally gently toward the south. The west wall of this defile is the unbroken continuation of the west wall of the Kern Cañon. It rises very steeply to altitudes of 2500 feet or more above the level of the defile, in the crest of the southern end of the Great Western Divide. Along portions of this wall was observed the same red stained granite as that constituting the red streak referred to above as occurring in the more northern part of Kern Cañon. The east side of the defile, for the first mile from the north end, is the steep western slope of a narrow rock ridge which on the east drops precipitously to the Kern. The crest of this ridge is about 300 feet above the floor of the defile. A mile from its north end this ridge has been notched, down to the level of the defile, by the headwater erosion of a small tributary of the Kern. South of this notch the east

A

Looking south along the Trout Meadows defile from its northern end. The ridge on the left is 300 feet higher than the floor of the defile.

B

Looking north along the Trout Meadows defile, near its middle portion, showing the level character of the floor of the defile.

wall of the defile rises rapidly again in height, and is in places 1000 feet or more above the floor of the defile. This wall is in places precipitous and cliff-like. It is the western edge of the semicircular area of mountainous country which is circumscribed by the bend of the Kern above referred to. There are no streams entering the defile from either side, and the only water found in it is seepage from underground waters, and this only at one or two places. This seepage flows southerly and accumulates at Trout Meadows, and is the cause of the formation of the meadows. The defile shows no evidence of ever having been occupied by a stream flowing through it. Its floor is mantled with the waste of the granite from the slopes on either side and is chiefly a coarse arkose sand. The width of the defile is least at its northern end, where, at the bottom, it is not much more than 200 feet. This portion of the defile is shown in Plate 40A. Toward the south it gradually widens to about 1000 feet near Trout Meadows. The floor and sides of the defile are generally timbered, but in this timber there are occasional open glades, one of which is shown in Plate 40 B.

This remarkable defile in the mountains can scarcely be explained in any other way than as having been determined by a rift line along the west wall of Kern Cañon. It is structurally the extension of Kern Cañon, though it is not now, and may never have been, functional as a stream course.

This rift hypothesis which thus seems to be forced upon us embraces two possibilities: either, that the defile is a simple *graben*, or, that it is an erosional feature controlled or originated by a rift line. The absence of stream features and of stream gravels in the defile and the fact, not before stated, that at its southern end it is lower than the Little Kern Plateau, which is clearly a stream-cut terrace, militate against the erosional phase of the hypothesis and impel us to accept the *graben* phase as the most probable explanation of this most interesting geomorphic feature. But if we accept this view for the defile it establishes the hypothesis of rifting as a factor in the morphogeny of the whole of the cañon of the Upper Kern; for the west wall of the defile is identical with the west wall of the cañon above the bend.

Thus the difficulty which presented itself on attempting to apply the hypothesis of rifting to explain the kernbuts, viz: that it could not be confined to these, but involved the greater part of the cañon of the Upper Kern, seems not insuperable. A consideration of various features of the Upper Kern Cañon indicates that the process of crustal rifting played a part in the genesis of the cañon, or, at least, that there are many features of the cañon that are in harmony with that notion.

Application of Rift Hypothesis to Kernbuts.—This conclusion not only clears the way for the application of the hypothesis of rifting to the kernbuts but strongly supports the suggestion. If now the kernbuts are due in any way to the slipping of massive wedges into an opening chasm along a rift line, they are either local slips, or they are remnants of much longer slips which locally have not sunk as far as the main mass. Both of these possibilities demand consideration. If they are local slips, then we are confronted with the embarrassing question as to what happened in the intervals between them? These intervals should have the normal cross profile of a V-shaped erosion cañon, plus any aggradation effects due to damming. In that portion of the cañon above the limit of glaciation we may provisionally regard the breadth of the cañon, at its bottom, and the verticality of its walls, as due to the modification of a V-shaped cañon by ice action. But the cañon below the main terminal moraine is just as wide at the bottom, and has just as vertical walls at several places, as it has above the moraine. The width of the cañon for a mile above Coyote Creek for example, cannot be referred to glacial modification. The streamward face of Tower Rock is 2150 feet as sheer above the stream as any part of the glaciated portion of the cañon. Immediately below the kernbut to the south of Lower Lake the cañon widens out and has a very high and very sheer west wall (see Plate 38 A), although the opposite side has the normal slope of a V-shaped cañon. The intervals between the kernbuts occupied by the lakes are also too wide for the normal profile of a V-shaped cañon. This abnormal width and sheerness of the walls is all the more striking when we compare this portion of the cañon with that in the bend of the river outside of the line of suspected rifting. Here the cañon presents the typical V-shaped profile.

These facts, then, are adverse to the supposition that the kernbuts are local slipped blocks. We have, moreover, a difficulty in picturing to our minds the dropping of such blocks into a rift without some similar process taking place on either side of them.

If, on the other hand, we regard them as portions of a long slip, which locally have been retarded in the downward movement, then the anomalies of the cañon profile in the intervals between them would be explained. This supposition is supported farther by the fact that the profile of the cañon drawn through the kernbuts is, in spite of the anomalous character of these features, much more nearly the profile of the typical V-shaped cañon than is the profile for the intervals between them. The wide portions of the cañon below the limit of glaciation are, on this supposition, interpreted as portions of the slope of a V-shaped cañon which have slipped out of sight.

The multiple character of several of the kernbuts indicates that several slip planes were developed in the settling mass. The notched or serrate profile of these further indicates that the down throw on these slip planes was to the west and the slips therefore probably hade toward the west wall of the cañon. For if they haded to the east, and the downthrow was in that direction, we should have quite a different profile due to a series of fault steps, each tread of which should slope toward the east.

Final Statement of Hypothesis.—It thus appears probable that the kernbuts are remnants of the west slope of a V-shaped cañon of stream erosion, which have been isolated by the intervening portions dropping out of sight, between a main rift on the west side of the cañon and an auxiliary slip more centrally situated. The kernbuts have themselves been affected by the same slipping process but to a less degree, and, in those cases where they are multiple, there have been several auxiliary slip planes converging upon the main rift, towards which successive wedges slipped in the course of the adjustment of the mass. The west slope of the kerncols is thus the modified original slope of the cañon prior to the disturbance, while the east slope is a fault scarp; and the floor of the kerncol is the more or less aggraded notch or trough formed by the intersection of these two surfaces.

Application to Kern Cañon.—The fact that the kernbuts may be thus consistently explained on the hypothesis of rifting and the connected settlement of *graben*, adds an important link to the chain of evidence connecting the origin of Kern Cañon with the process of crustal rifting. That such a connection is very probable has been already shown on independent grounds; and it has also been recognized that the adoption of the rift hypothesis to explain the kernbuts necessarily involved the cañon as a whole in the same hypothesis. It remains to be pointed out in what sense the Kern Cañon is to be regarded as a feature due to rifting. As a preliminary to this a distinction must be drawn between rifting and faulting. We have no evidence that the Upper Kern follows the trace of a fault plane. There is no geomorphic or geological evidence of any differential displacement of the country on either side of Kern Cañon. A fault may possibly exist there, but if it does it must have been formed anterior to the evolution of the High Valleys of the region, since there is no perceptible discrepancy in level between the two portions of the Chagoopa Plateau separated by the cañon. But whether it exist or not is immaterial to the thesis that the Upper Kern follows a line of rifting.

At the time when the Chagoopa Plateau was at base level the drainage of the Upper Kern Basin probably had little reference to the present line of the Kern. The drainage probably, as already shown, passed out through Toowa Valley. It seems probable then, that there was no structural control of the drainage at that particular stage of the geomorphic evolution of the region. This view is supported by the fact already mentioned, that the defile to the north of Trout Meadows, which is regarded as a *graben*, is lower than the level of Little Kern Plateau, which is correlated with Chagoopa Plateau and Toowa Valley. Now the down cutting of the Upper Kern, below the level of the High Valleys, was undoubtedly due to an uplift of the region, with renewed dislocation along the great fault which bounds the Sierra Nevada on the east. And, since the Kern seems to have followed its present course since the initiation of the down cutting, the structure which controlled that course must have been inaugurated at the time of the uplift. The structure thus established was not, as has just been shown, a fault dislocating the Chagoopa Plateau, but it might well have been a rift fissure. Such a structure once established would continue to control the future process of erosion so long as the stream bed was above the base level, and it has not yet reached base level. Along such a rift there might be a recurrence of the tendency to open, which tendency would undoubtedly result in the engulfment of wedges formed by the intersection of auxiliary slip planes with the main rift. In this sense the cañon of the Kern is both a rift valley and an erosional trough. Probably only a minor proportion of the cross-section of the cañon is to be accounted for by the process of engulfment of *graben* wedges or slabs, and the most of it has been removed by the ordinary processes of stream erosion.

THE KERN LAKES.

In the foregoing description of the features of Kern Cañon frequent reference has been made to Upper and Lower Kern Lakes. These have been referred to, moreover, as occupying intervals between kernbuts, and the reader may possibly have gained the impression that these lakes are due to damming by the formation of the kernbuts. This is not the case. The lakes are quite recent features of the cañon, and owe their origin to special causes, some account of which may now be given. Lower Lake is the older of the two. It is about half a mile in diameter and is separated from Kern River by a levée of sand and silt on its east side, the stream following a straight course at the base of the east wall of the cañon. The outlet of the lake is by a small rivulet which traverses this levée at its southern end. Prior to the completion of the levée, the lake had been partially silted up by sediment from the river, and since it has been shut off from the river, the silting process has been continued by the minor drainage from the west side of the cañon, and by lake vegitation; so that a considerable fraction of its area is swamp. The dam which holds up the lake is the debris of the large rock-slide, already referred to, which fell from the east wall of the cañon immediately opposite a kernbut about three miles below the mouth of Coyote Creek. This dam is a chaotic aggregation of huge blocks of granite through which the stream makes its way for nearly a mile. Since the fall of this rock-slide a scattering growth of pines has appeared upon the rocks, and the largest of these is over 100 feet high. We have in this fact some check upon the recency of the slide. The largest tree may be 75 years old. The slide probably occurred, therefore, less than a century ago. The rock-slide is shown in Plate 38 A.

Upper Lake (Plate 39B) drains to Lower Lake through a narrow, rocky gorge, about half a mile long, between the second multiple kernbut south of Coyote Creek and the east wall of the cañon. Above this gorge the lake is about a mile long in the direction of the stream and a little less than half a mile wide. The recency of the formation of this lake is attested by the fact that there are numerous stumps of trees standing in the lake. Most of these have been broken off at the water level, but several still project many feet above the surface of the lake. From the upper end of the lake a sand delta extends in a series of fingers, with intervening channels, half way down its length, and the basin may be said to be about half silted up. Upon the surface of this delta at its upper end is a thick growth of young cottonwoods. Regarding the date of the formation of this lake we have fortunately an historical record. Mr. W. T. Grant, who was in the cañon last summer, informed Mr. Gilbert and the writer that he had been in the cañon in 1867, and that in the summer of that year the lake was not in existence; but that on revisiting the cañon again in 1868 he had found the lake where it now is. Mr. Grant ascribed the lake to an earthquake which occurred early in the spring of 1868, and which caused rock-slides to fall from various parts of the cañon walls.

On examining the outlet of the lake, to discover if possible the nature of the dam which sustained the lake, it was found that, at the upper end of the gorge above referred to, two small streams enter the Kern by a series of cascades from the mountain slopes on the east side. One of these streams is immediately at the outlet, and the other is about 200 yards below it. Both of these have debris cones at the foot of the cascades, and both cones cause rapids in the stream flowing through the gorge. They appear to be the only obstructions in the gorge, and are, without question, the cause of the ponding of the waters of the lake. A sudden large addition to these debris cones, in the spring of 1868, seems to have caused the damming which brought the lake into existence. Whether such an excessive dejection of debris in this year is to be ascribed to disturbances caused by the earthquake, which shook the southern Sierra in that year, or whether it was due to an exceptionally heavy winter, remains an unsettled question.*

The extent to which Upper Lake has been silted up by delta extension affords us a check upon the age of Lower Lake. As has been stated, this delta has extended down the lake about half a mile and is, therefore, comparable in extent with the levée which shuts off Lower Lake from the Kern. Probably but little addition has been made to the levée since the formation of Upper Lake, for the sediment has for the most part been trapped by the latter. The levée may, therefore, be assumed to have been completed at the time that Upper Lake was formed, that is, 36 years ago; and if it took as long for the formation of the levée as for the delta accumulation on Upper Lake, the Lower Lake is at least 72 years old; which agrees with the former estimate based on the age of the trees growing upon the rock-slide which dammed Lower Lake.

GLACIATION.

Frequent references have been made in the earlier parts of this paper to the glaciation of the Upper Kern Basin. It is now proposed to devote a more extended, but still summary, note to this part of the subject, as an important factor in the morphogeny of the region. We may conveniently begin at the lower limit of glaciation in the cañon of the Kern.

Terminal Moraines of the Trunk Glacier.—The lowest point reached by the great trunk glacier, which once flowed down Kern Cañon, is just south of the mouth of Coyote Creek. Here the snout of the glacier crowded in toward the west wall of the cañon and pushed up into the north end of a kerncol, for a few hundred

* Professor A. G. McAdie, of the U.S. Weather Bureau, has, since the above was written, informed the writer that the winter of 1867–68 was decidedly one of heavy precipitation. He says: "At Sacramento, the rainfall was nearly 13 inches in December '67, and January, February and March '68 all had good rainfalls. In all likelihood the snowfall was exceptionally heavy in the mountains."

feet, and deposited a terminal moraine, which is the most southerly trace of glaciation in the bottom of the cañon. Its altitude is about 6600 feet above sea level. The moraine is small but distinct, and within it are two other smaller morainic ridges. The terminal moraine is V-shaped in ground plan, with a sharp point extending up the kerncol and a slight concavity on the outer side, particularly on the east limb of the V, due to the attempt of the ice to adjust itself to the configuration of the slopes of the kerncol. The length of the moraine, along both limbs of the V, is less than a quarter of a mile, and its height, on an average, may be placed at 25 feet. The area of its cross section is about 120 square yards. Taking 400 yards as a liberal estimate of its length, the total volume of the moraine is in round numbers 50,000 cubic yards. This is a small dump for so large a glacier as that occupying Kern Cañon for 24 miles of its length, and seems to indicate that the ice front maintained itself at this point for but a short period of time. The eastern limb of the moraine mantles the northern end of the kernbut, which ends to the north at the mouth of Coyote Creek, and abundant morainic material is found on the west of the ridge and on both of its slopes, to an altitude of nearly 100 feet above the moraine within the kerncol. The upstream extension of the west limb of the moraine has been partly washed away by Coyote Creek and partly buried in its debris cone.

The situation of the moraine is rather remarkable. It is distinctly on one side of the valley and is situated for the most part at an altitude of about 150 feet above the Kern River. One might naturally suppose that such a terminal moraine would span the cañon and be more or less symmetrically disposed with reference to its median line. It seems clear, however, that the snout of the glacier, at the time of the most southerly extension of the latter, was not more than half as wide as the cañon, and that the ice stream hugged the west wall. This may be explained either by a deflection of the ice stream or by an excessive ablation of its eastern side. There are no features in the valley which seem competent to have deflected the glacier, and there are two conditions which would have contributed to a relatively excessive ablation of its eastern side. The first of these is the sheer surface of bare rock which is presented by the east wall of the cañon below Volcano Creek. This wall has an altitude to the summit of Tower Rock of about 2150 feet. In the afternoon sun the reverberation from such a surface would contribute in no small measure to the melting of the ice. The second condition is, that the western side of the glacier, in the time of its greatest extension, passed over the place now occupied by the expansive cone of Coyote Creek. Coyote Creek was, with little doubt, caused to cross the glacier, and in doing so, it, with equally little doubt, covered its west side with a veneer of alluvial detritus from the cañon above, which protected the ice and restrained its melting. These two conditions together may have conspired to confine the ice stream to the west side of the cañon and so steer it into the mouth of the kerncol just below Coyote Creek.

Just east of the north end of the kernbut, where it was mantled by the ice, is a series of stream terraces extending up to perhaps 100 feet above the Kern. The slope of these terraces pitches rapidly down stream. Their local character indicates a genetic relationship with the glacier. They are evidently due to the reduction by stages of a locally acute aggradation embankment or alluvial cone. Under the conditions above indicated, whereby Coyote Creek was forced to flow over the surface of the glacier, a large amount of its alluvial deposition would be transferred to the edge of the ice and a cone would be built up. Owing to the migration of the stream riding upon the moving ice and the recurrent adjustment to correct for this migration such a cone would have no well defined apex but would be broad and vague. On the waning of the glacier the stream would be lowered and would cut down the cones in a series of terraces. Such an embankment would tend to crowd the Kern River to the east side of the cañon as it emerged from below the ice somewhat higher up; and this appears to have been the case, for it is evident that the comparatively broad terrace at the base of Tower Rock was once the stream bed of the Kern.

The hypothesis above outlined is, however, not the only one that may be offered in explanation of these terraces. Another which has recently been suggested to the writer by Mr. Gilbert, is that embankment and terraces are due to the Kern River itself as it emerged from beneath the ice, the embankment representing an overwash at the snout of the glacier. This involves the lifting of the stream bed at the snout of the glacier to the summit of the embankment. The writer, not having both hypotheses in mind while in the field, could not now decide as to which is the more probable without a reëxamination of the field evidence.

A mile above Coyote Creek a much larger moraine spans the bottom of the Kern Cañon from wall to wall. This moraine is also rather acutely V-shaped in ground plan, and at the apex of the V the Kern River bisects it. The crest of this moraine along both limbs of the V is about half a mile in length, and its average height is about 100 feet. The cross section of the moraine has an area of about 2000 square yards and its total value is, therefore, about 2,000,000 cubic yards. If now, we regard the volumes of the terminal moraines as proportional to the time necessary for their accumulation, it appears that the front of the glacier maintained itself at the second moraine about 40 times longer than at the first moraine, the limit of its southern extension. If, on the other hand, we estimate the time as proportional to the areas of the cross sections of the moraines, then the ice front maintained itself at the second moraine about 16 times as long as at the first moraine.

If the retreat of the ice front, from the first moraine to the second, had been fitful and slow, we should expect to find evidence of that fact in a series of minor moraines of retreat. No such intervening moraines appear to exist, and it is probable, therefore, that the retreat of the ice front from the first position to the second was a steady and rather rapid movement. The profile of the second moraine is severely simple, and there is no evidence of wavering or fluctuation of the position of the ice front during the accumulation of the moraine.

Above this second moraine there are no other terminal moraines in the cañon, nor moraines of any other kind for about 16 or 17 miles, when we come to a fine series of lateral moraines above the mouth of East Fork. There is no evidence of retreat by stages, and the inference seems clear that when the ice front vacated the position outlined by the second moraine it retreated up the cañon steadily and probably fairly rapidly.

Glacial Modification of Kern Cañon.—The question as to the extent to which the trunk glacier of the Kern modified the cañon in which it flowed may now be briefly considered. As has been already pointed out, the path of the glacier in the cañon falls into two parts, an upper part, in which the Kern has been engaged in vertical corrasion since the retreat of the ice, and a lower part in which it has been engaged in aggradation. Part of this aggradation, may, however, have been accomplished while the ice was still in the upper part of the cañon in the late stages of its retreat. But as the meadows of the cañon floor show no evidence of dissection and are still subject to flooding by the stream which winds through them, it may safely be inferred that the aggradation is still in progress. This portion of the stream then is below grade for the load that it carries, and as the main terminal moraine is well dissected, the latter cannot be regarded as a cause of the retardation of the stream, especially as it flows on bedrock a short distance below the moraine. Now the stream below the limit of glaciation is far above grade, and it seems, therefore, probable that the entire course of the stream in preglacial time was above grade. If this be the case, then it is evident that the portion of the cañon now aggraded represents an over-deepening of the cañon floor by glacial scour, a process which has been exemplified in many glacial troughs, such as in some of the lochs of Scotland and fjords of Norway. The depth of this aggradation is not known, but it may well have been sufficient to have left a lake for a time after the retreat of the ice. Both the degraded and aggraded portions of the glaciated cañon are U-shaped in profile, but the most perfect U-shaped profile is in the former, and is true of the rocky floor and sides of the cañon. The U-shaped effect of the aggraded portion is largely due to the talus slopes at the base of the cañon walls. If the rocky bottom of the cañon beneath the meadow floor be also U-shaped, as is very probable, then the depth of the aggradation accumulation may be not more than a hundred feet.

The width of Kern Cañon, below the Kern-Kaweah River, does not appear to have been appreciably increased by the occupation of the ice. This is practically proven by the following consideration. The depth of the ice in the cañon averaged probably not more than 1200 feet. The walls of the cañon are about twice this height, and the lateral recession of this upper portion of the walls, in consequence of the glacial sapping or scour at their base, could only have been by a process of shedding rock fragments upon the *surface* of the glacier. These fragments would accumulate at the terminal moraine. But the volume of the two terminal moraines together does not exceed 2,100,000 cubic yards. If we distribute this over the upper 1200 feet of both walls of the cañon, for the distance of 14 miles from the Kern-Kaweah River to the main terminal moraine, it would make a layer four inches thick. If we consider that probably half of the moraine came from sources outside of the cañon, the layer would be reduced to two inches. This estimate may be modified and corrected in a variety of ways, but it leaves a quantity for the glacial widening of the cañon which is negligible. The cañon then, had practically the same width before its occupancy by ice that it has to-day.

Tributary Glaciers.—The trunk glacier of the Kern was fed by numerous tributary ice streams, each having several branches, all heading in more or less pronounced cirques, the most of which are situated at the crest of the mountains which rim the basin. Besides these tributary glaciers there were many others which were too short to reach the Kern. The former existence of these glaciers is established beyond question by the usual evidence of the occupation of a region by Alpine glaciers. Vast cirques with stepped floors, each step with its rock-rimmed tarn and its *roche moutonnée* sculpture; bare rock surfaces polished, grooved and striated, and strewn with erratics; lower down, the splendidly defined U-shaped profiles of the cañons, with their occasional meadows; and lastly, the immense lateral moraines which flank the lower and more open parts of the cañons,—all these features are in every case present to attest the course of these tributary glaciers and the work that they did.

The most southerly tributary glacier on the east side of the Kern is that of Rock Creek to the south of Mt. Guyot. This glacier had two main branches, one coming down Guyot Creek in the U-shaped trough shown in Plate 33A, and the other down the north fork of Rock Creek, the path of which is shown in

View of the head of Kern Cañon and Tyndall Creek showing the results of glacial sculpture in the High Mountain Zone, and the beheading of the drainage by the encroachment of glacial cirques from the east side of the summit divide. The table land in the middle of the picture is probably a remnant of the Chagoopa Plateau. Photo. by J. N. LeConte.

Plate 32 B. The former of these had its source in the region between Mt. LeConte and Mt. Whitney; the latter headed at the western base of Mt. LeConte, but may also, perhaps, have been fed in part by a névé lying upon the Siberian Outpost. Where these two glaciers become confluent in the broader cañon of Rock Creek, south and southwest of Guyot, there are extensive lateral moraines, the crests of which are from 500 to 700 feet above the floor of the cañon. These afford an excellent idea of the thickness of the glacier. The lateral moraines on the south side of the glacier are crossed by the trail in descending from the Siberian Outpost to Rock Creek, and are well seen from the summit of Mt. Guyot. Those on the north side are crossed in the climb from Rock Creek to Guyot Pass. Where the summit of these lateral moraines spreads out the surface is marked by numerous ridges, indicating minor fluctuations of the edge of the ice, but where the moraines flank the steeper sides of the cañon two distinct crests are seen, perhaps 100 feet apart vertically. The highest indicates the maximum thickness of the ice and the lower a well defined stage in its shrinkage. The fact that, below the second moraine, there are no other morainal crests indicates that the shrinkage of the ice from that point was at a steady or uniform rate. The behavior of the tributary glaciers, after they had attained their maximum, thus appears to have been similar to that of the trunk glacier in Kern Cañon as inferred from its terminal moraines.

Above these lateral moraines on the south side of Rock Creek is a hanging valley which is evidently the path of a local glacier. The valley is a broad, glaciated trough, cut down into the northwestern margin of the Sub-summit Plateau. It is shown in Plate 32 B. A similar but less extensive hanging valley lies about a mile to the east of it.

The next tributary glacier to the north of Rock Creek, on the same side of the Kern, was that which flowed down Whitney Creek. This stream, above Crabtree Meadows, has also two branches, and from each there came a glacier, the two becoming confluent and forming a common stream from Crabtree Meadows to the Kern. The larger of these two branches of the Whitney Creek glacier was the more northerly. This had its source in two magnificent cirques which lie at the base of the cliffs encircling Mt. Whitney, the one to the south and southwest and the other to the northwest. The southerly cirque is shown in Plates 32 A and 42. This is a fine example of the way in which these glaciers of the Sierra Nevada have eaten into the heart of the mountains. The companion cirque on the northwest of the mountain is similar in character, and the two glaciers were confluent immediately on emerging from the cirques. Below the point where the two glaciers became confluent there is a low, well glaciated median ridge, which is probably nearly coincident with the line of confluence of the two ice streams. This rocky ridge extends for about a mile and rises from 50 to 100 feet above the glaciated sloping floor which it traverses. The crest line of the ridge pitches with the general slope and has a descent of over 600 feet. Besides its *roche moutonnée* character of surface, the ridge presents another feature of interest. The granite of which it is composed is traversed by three systems of joints, one roughly horizontal and two vertical, of which one is parallel to the axis of the ridge and the other at right angles to it, or nearly so. These joints thus divide the granite into parallelopipeds, some of which are elongated in the direction of the ridge, while others are elongated transverse to it. In several places an aggregation of these parallelopiped blocks of granite have been removed from their places and carried away by the ice stream. The result is that there is a series of vertically walled troughs from 10 to 40 feet deep abruptly interrupting the smooth *roche moutonnée* surface of the ridge. At the upper end and middle parts of the ridge these box-shaped troughs are transverse to the ridge; while at the lower end of the ridge the troughs are longitudinal. These troughs have evidently been formed by the removal of blocks of granite after the main sculpture of the ridge had been completed since the vertical walls of the troughs rise to its surface abruptly; yet, while this is true, the ice has glaciated the walls of the troughs to some extent, glacial polish and striation being perfectly distinct upon some of the even, vertical sides of the troughs which were closely observed.

About a mile below the cirque shown in Plate 42 the walls of the cañon on Whitney Creek on the south side are polished

Glacial cirque to southwest of Whitney, the source of Whitney Creek. Tarns at several levels. Precipitous walls fluted in their upper part. Foreground glaciated. Talus a measure of post-glacial degradation.

and heavily scored by the ice for several hundred feet above the floor of the trough; but the surface so glaciated is very uneven in detail, which unevenness is clearly due to the removal of joint blocks by the glacier. The ice immediately flowed into the reëntrants formed by these removals, and glaciated the surface, but failed to smooth out the unevenness.

There are immense lateral moraines on both sides of Whitney Creek. That on the north has a length of about five miles, and its crest is probably a thousand feet above the floor of the glacial trough. Its upper end begins at a point but little below the mouth of the cirque to the northwest of Mt. Whitney. The lateral moraine on the south side of Whitney Creek extends up the south fork of the creek and has an observed length of about three miles. It is crossed by the trail from Guyot to Crabtree Meadows. The volume of these great lateral moraines is comparable to that of the cirques, and they doubtless represent the bulk of the material removed from the cirques in the process of their development by glacial erosion. This fact serves to explain the small size of the terminal moraines of the trunk glacier in Kern Cañon. It also illustrates the short distance of glacier flow necessary for the englacial drift of the cirques to work out to the surface and edges of the glacier.

The next tributary glacier north of Whitney Creek was that which came down the cañon of the East Fork. This stream also had two main branches, the more northerly being again the more important, the ice stream taking its rise in the cirques at the base of Mt. Tyndall and Mt. Barnard. The glacier from the south branch of East Fork headed in a large cirque situated less than a mile to the northwest of Mt. Whitney. The lateral moraines of the East Fork are similar in character and extent to those of Whitney Creek, and on both sides of the cañon were crossed by the trail from Crabtree Meadows to the northern part of the Kern Cañon.

Still farther north, at the head of the Upper Kern Basin, there was a convergence of numerous ice streams toward the main Kern Cañon at the point where it is joined by Tyndall Creek. These glaciers all headed in cirques which cluster about the base of the high peaks stretching from Mt. Tyndall to Table

Mountain. Those which were tributary to the Tyndall Creek trough followed that pathway to the Kern Cañon; but the country to the west of that, which slopes down from Table Mountain and Milestone Mountain, has been so broadly glaciated that there is a strong suggestion of the slope having been occupied by a piedmont glacier due to the coalescence of numerous streams of ice from the cirques above. All this ice became confluent in Kern Cañon at points north of Milestone Creek. This confluence is marked on both sides of the cañon, but particularly on the east side by the development of lateral moraines several miles in extent and rising to an altitude of probably 1500 feet above the bottom of Kern Cañon. These moraines on the east side extend up Tyndall Creek and down the main cañon nearly as far as the mouth of the East Fork. They afford a practicable descent from Chagoopa Plateau into the cañon, the walls of which are elsewhere unscalable. The basin of the Kern-Kaweah River is another expansive glacial track, and was occupied by the convergence of ice streams from many high cirques extending from Milestone Bowl to the north side of Kaweah Peak. The outlet of this ice to the Kern was through a deep U-shaped hanging valley several hundred feet above the floor of Kern Cañon. On the north side of this trough, but quite within it, is a bold dome of granite, the sculpture of which indicates clearly that it lay in the path of the ice, and that the ice passed over it and on both sides of it.

The only remaining glacial tributary of the trunk glacier of the Kern is that which came down the Big Arroyo. This ice stream started in the reëntrant between the Kaweah Ridge and the Great Western Divide, and, flowing down the Big Arroyo, was augmented by numerous other glaciers emerging from the great array of cirques which look down upon Chagoopa Plateau from the west. Glaciers also descended Rattlesnake and Laurel Creeks, but they probably did not reach the Kern. A glacier also extended down Coyote Creek from the west, but it reached only a couple of miles from the divide and formed a heavy moraine behind which there is now an expanse of meadow land with a brook meandering through it.

Glaciation of Outer Border of Basin.—Both to the west and to the east of the Upper Kern Basin the glaciation of the High

Mountain Zone was quite as vigorous as within the basin itself, but there resulted from these high glaciers no such confluent trunk glacier as that which occupied Kern Cañon. To the north-east, however, the convergence of various glaciers gave rise to a notable trunk glacier in the cañon of Roaring River; and to the north in the basin of Bubb's Creek the glaciation was apparently even more intense than in the Upper Kern, and doubtless gave rise to a large trunk glacier in King's River Cañon by the confluence of the ice streams from Bubb's Creek with those of the South Fork of King's River.*

Of this glaciation of the outer border of the Upper Kern Basin the writer's opportunities limited him to glimpses from the summit of Mt. Whitney of the great cirques which indent the eastern scarp of the Sierra, from Mt. Williamson to Cirque Peak, and to a more or less cursory acquaintance with the cirques, glaciated cañons and moraines of the western slope of the Great Western Divide from Little Kern River to Tharp's Peak.

Along this latter belt of country the most southerly glacier tracks observed are three shallow cirques on the eastern side of the divide between the Little Kern and the South Fork of the Kaweah. These appear to have sent ice streams down the slope for not more than a mile or so. At the head of the Little Kern a glacier came down from a series of cirques which indent the southern edge of the high plateau remnant to the west of Mt. Vandever. This descended by a series of steps, each marked by a glacial tarn, to the cañon of the Little Kern. Here it was joined by a short glacier from the flanks of Mt. Florence, and thence flowed for about four miles down the Little Kern. No important terminal moraine appears to have been formed at the snout of this glacier, but huge lateral moraines were deposited notably on the east side of the cañon above the mouth of Shot Gun Creek. This moraine has a height of perhaps 500 feet above the Little Kern, and spilled over the crest of the spur which separates Shot Gun Creek from the Little Kern into the basin of the former.

North of Farewell Gap, in descending the East Fork of the Kaweah River toward Mineral King, there is no evidence of gla-

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* The statements in this paragraph are, in part, based on information given to the writer by Prof. J. N. LeConte.

ciation for about a mile down stream. From that point down, however, the main cañon is glaciated, the ice having come in from a side cañon on the east which heads in a large cirque to the northeast of Mt. Florence. A mile farther down another glacier joined this from the southwest, heading in a cirque in the northern face of the plateau remnant west of Mt. Vandever. A mile farther down stream another tributary glacier came in from the east, which headed partly in the cirque to the south of Sawtooth, in which Silver Lake is situated, and partly in another cirque still farther south. The confluent glacier was 800 feet thick just above Mineral King, as is well shown by the large and well defined lateral moraine which flanks the west wall of the cañon, to that height, down to the point where the cañon turns abruptly to the west just at Mineral King. The crest of this moraine is very sharply marked against the unglaciated upper slopes of the cañon, and it slopes down toward the north, or in the direction of the flow of the ice. Just below Mineral King, where the cañon bends westward, the glacier was joined by another tributary which descended, by a series of steps with glacial tarns, from a great cirque with rather steep floor situated at the base of Sawtooth. This cirque is shown in Plate 43 A. Below Mineral King the glacier arising from the confluence of these various tributary ice streams is not known to have flowed farther westward than about two miles. Beyond that distance below Mineral King no evidences of glaciation were observed. Only traces of a terminal moraine could be detected. This may be due to the haste of observation, but in general the Alpine glaciers of these mountains seem to have developed but feeble terminal moraines, while their lateral moraines are often on a vast scale.

Along the western side of the crest of the Great Western Divide there is a great array of shallow trough-like cirques which followed paths now drained by the head waters of the Middle Fork of the Kaweah. Several of these, the most southerly heading near Sawtooth, originated ice streams which coalesced in a large glacier flowing down the deep cañon of Cliff Creek. Great morainal embankments flank the sides of this cañon, where it is crossed by the trail from Mineral King to the Gian

Forest by way of Timber Gap. The crest of these lateral moraines is at least 500 feet above the bottom of the cañon, and it is probable that the glacier reached the cañon of the Middle Fork of the Kaweah, although there is no evidence of glaciation in the latter below the mouth of Buck's Cañon.

Another large glacier descended the main Middle Fork and left similar, but even higher, lateral moraines, flanking the cañon sides above the confluence of Cliff Creek. This glacier had its main supply of ice in the cirque below Lion Rock at the extreme head of the Middle Fork, but was probably joined by some, if not all, of the glaciers which occupied the great troughs between Lion Rock and Cliff Creek. Three of these troughs are shown in Plate 45 B. There is a large but shallow cirque at the head of Buck's Cañon at the crest of the divide between the Middle and Marble Forks of the Kaweah. The ice stream which flowed from this cirque deposited abundant morainic material not far below the cirque but did not apparently reach more than half way to the Middle Fork. Other smaller cirques occur about this crest in the vicinity of Tharp's Peak, and an extensive one, of a flat and shallow character, lies to the north of the divide, and is drained by a branch of the Marble Fork.

This brief sketch of the extent and general character of the glaciation of the region has perhaps its chief merit in the fact that it places on record the southward limit of the glaciation of the High Sierra, and indicates clearly that it was entirely of an Alpine type. The western limit is also indicated pretty definitely for those portions of the mountains south of Lat. 36° 40′, and may be stated to be Long. 118° 40′ west. The eastern limit is estimated to be within three or four miles of the scarp line of the Sierra crest for the same latitude. The lower hypsometric limit is in the cañon of the Kern at an altitude of 6450 feet above sea level. The distribution of the glaciers is shown in Plate 31.

Cirques.—One of the interesting features of the glaciation of the high mountains which encircle the basin of the Upper Kern is the support which it affords to the doctrine of the glacial destruction of mountain crests as formulated by W. D. Johnson,*

*Science, New Series, Vol. IX, pp. 112–113. The first formulation of this doctrine by Mr. Johnson was in the form of an address to the Geological Section of the Science Association of the University of California, at Berkeley, Sept. 27, 1892.

and as recently discussed by Matthes* in his account of the Glacial Sulpture of the Bighorn Mountains. This discussion of glacial sculpture in the high mountains has been concerned chiefly with the *modus operandi* of the glaciers in effecting the recession of cirque cliffs. That question is not yet completely settled, and its status can be improved by more extended observations, and particularly by comparison of the petrographic and structural control of this erosional process. Cirques appear to be best known in granitic mountains, and it has been suggested that the homogeniety of these rocks favors their development. The peculiar jointage which usually characterizes these granitic rocks seems to the writer not to have been sufficiently emphasized as an important condition favoring cirque erosion; and he is persuaded from his observations on the rim of the Upper Kern Basin that this is one of the chief factors in the problem. As has been shown in another part of this paper, the intensity of the jointage in these high granitic mountains appears to be in part a function of unequal relief of load by degradation. The jointage, as developed by relief of elastic stress, is always in advance of the actual erosional surface, but is in part related to that surface as regards orientation. The jointage is much more abundantly developed in the higher levels of the mountain masses than in the lower.

Since the cirques and cañons of the region have been vacated by the ice there has been a measurable recession of their walls, chiefly by the shedding of blocks bounded by joint planes. The evidence of this consists in the talus at the base of the walls. If an agency were present competent to remove this talus as it fell, and so prevent its accumulation, the recession would be practically as rapid at the base of the cliffs as in their upper part, above the talus slope; and we would have just such a recession of cliffs as has given us these remarkable theatre-like indentations in the mountain slopes. Now the blocks which make up these talus accumulations have been dislodged by the freezing of water in the joint cracks. This process was undoubtedly an active one in the depths of the *bergschrund*, probably many times more active than under present condition, and seems to the writer to be an adequate explanation of a very large part, at least, of the method

*U.S.G.S. 21st Ann. Rpt. 1899–1900, Pt. II, p. 167 et seq.

A

Glacial cirque to the southwest of Sawtooth on the Great Western Divide. The steps and tarns of the cirque are very characteristic. The middle sky line shows arêtes due to encroachment of other cirques from the opposite side of the range.

B

Looking south down the crest of the Great Western Divide from the summit of Sawtooth. Illustrating the glacial reduction of mountain crests by opposing cirques. The cirque in the lower right hand corner of the picture is the one shown in A.

whereby the material from the face of the cliffs was fed to the ice and so removed. In the absence of such jointage the tendency of the glacier to sap the cliffs would fail of realization, and merely shallow troughs would be evolved instead of cirques. If this view be correct it would discredit the hypothesis of glacial sapping as an explanation of such massive and little jointed granite walls as those of El Capitan in Yosemite. The writer recognizes fully the glaciation of Yosemite Valley and the glacial sculpture of its upper part, but the main walls of the valley appear to have an origin independent of and antecedent to its occupancy by ice.

A more important phase of the cirque question, however, as it appears to the writer, and one which is fully appreciated by Johnson, but which has not received the recognition which it merits, as an important morphogenic process, is the efficacy of cirque erosion to reduce mountain summits. Where cirques abound they usually occur on both sides of a mountain crest and have encroached upon the latter from opposite directions. The walls of opposing cirques eventually intersect, and the reduction of the mountain crest, which is thus inaugurated, proceeds rapidly till it may be lowered a thousand feet or more. The writer cannot do better than quote Johnson's graphic picture of the process. He says:*

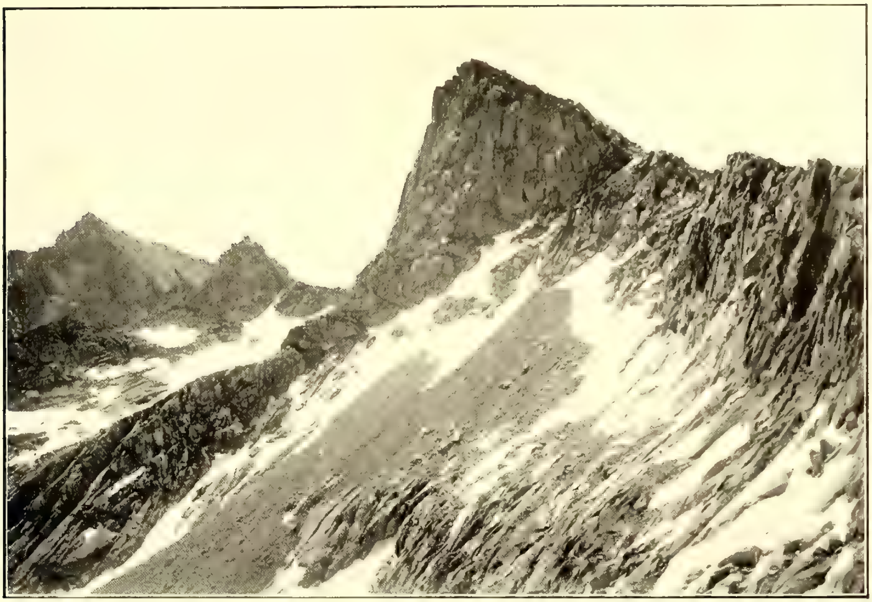
"By recession of the amphitheatre head—and the glacier makes the amphitheatre rather than merely occupies it—the amphitheatral wall is carried backward, and divides are cut through. A summit region, upon either slope of which glacial streams are extended, will be trenched by streams heading thus in opposition. A first effect of the meeting of an opposing pair will be the arête, or thin comb, the most evanescent of mountain forms, the final effect will be the col, a low, level pass between the walls. The ultimate result of continued glaciation must be truncation of the crest region, close to the lower level of the glacial generation."

The principles here laid down are splendidly exemplified in the summit region of the Sierra Nevada as seen from the top of Mt. Whitney and in the approaches to it. The sea of sharp crests seen looking south and southwest from this point, (Plate 32 A), are

*Loc. Cit. p. 113.

all formed by the intersection of cirque slopes at points far below the pre-glacial surface of the Summit Upland, as represented by the remnants at the summit of Mt. Whitney and Sheep Mountain. The general reduction of the altitude of the divide five miles in length, between Whitney and Sheep Mountain, by this process, has been certainly not less than 1000 feet for a belt three or four miles wide; and this refers simply to the altitude of the crests and not to the average reduction of the surface, which would be much greater. In this reduction of the divide the latter has clearly migrated westward, or away from the steeper side of the mountains, for a distance of from half a mile to a mile. From Sheep Mountain to Cirque Peak, the reduction and migration of the divide have been effected by cirque aggression from the east side only, the western side of this part of the range being unglaciated for the most part. Looking north from Mt. Whitney, the same reduction and migration of the summit divide is apparent to an even greater degree. The recession of the eastern scarp of the Sierra Nevada by the sapping of glacial cirques has left Mt. Williamson an isolated stack, in the same sense that stacks are left upon a wave-cut terrace by the recession of the sea-cliff. The summit of this mountain is now a mile out from the crest line at Mt. Tyndall, and half a mile out from the general line of the summit divide. It has been severed from the main mass of the mountains by cirque encroachment from the north. Lone Pine Peak, which stands as an isolated mass over two miles from the eastern scarp of the summit range, appears to be an even more striking illustration of the recession of that scarp.

In viewing from Mt. Whitney the revolution in the geomorphy of the High Mountain Zone which has been wrought by ice sculpture, and particularly by the gnawing of the cirques into the heart of the mass, one cannot but reflect that, had glacial conditions continued for twice as long as they actually did, or at most three times as long, the entire summit tract would have been obliterated, in the sense of being truncated to the level of the cirque floors. It is interesting to reflect further that this process of truncation, as it approaches completion, would not only remove the mountain tops, but thereby, also, do away with glaciation. Glaciation in the high mountains, in so far as it



A

Sawtooth. Showing the wall of a cirque in its relation to the jointage of the granite.

B

Looking northwest from Mt. Whitney, showing in the middle ground a large cirque with tarn. The reduction of mountain crests by the intersection of cirque walls is here well exemplified. The rock in the foreground is the wall of an adjacent cirque not shown.

depends upon altitude, is, therefore, a process which automatically terminates.

The glacial reduction of mountain crests is equally well exemplified on the summit of the Great Western Divide. Plate 43 A shows a large cirque to the southwest of Sawtooth. The The cirque floor descends by a series of hollow steps, each of which holds a tarn. The configuration of the cirque appears to be determined in a large measure by the orientation of the jointage. On the west side of the cirque is a belt of metamorphic sedimentary rocks. Beyond the cirque may be seen the knife edge divide which separates it from opposing cirques. In Plate 43 B we have a view looking south along the crest of the Great Western Divide from the summit of Sawtooth. In the foreground are three cirques, that in the lower right-hand corner being the same as that shown in Plate 43 A. The view is typical for the divides between opposing cirques in this region, and clearly illustrates the fact that such divides are due to the intersection of cirque slopes, and so proves the reduction of the main divide by this process. The divide shown in the foreground of this picture has been reduced not less than 1000 feet. In Plate 44 A a glimpse is given of the upper wall of still another cirque to the east of Sawtooth with the peak of Sawtooth (12,345 feet) in the middle ground. The photograph is chiefly useful as an illustration of the jointage of the granite and its relation to the cirque wall.

Not only are the mountain crests reduced by this opposition of cirques, but plateaux are wholly or in part obliterated by the same process. In Plate 45 A is given a view of the plateau remnant which lies to the west of Mt. Vandever, and at an altitude of 11,200 feet. On the northern front of this plateau, as is shown well in the photograph, there are no less than six shallow cirques or glacial troughs, the rear walls of which have encroached extensively upon the plateau and partly destroyed it. The general horizontality of the sapping process in all six lines of attack is a striking feature of the situation. Other glacial cirque-like troughs scar the southern front of the escarpment in a similar way; and the plateau itself is now but a narrow remnant. It is easy to see that, if the process had been carried a little farther, it would have been entirely obliterated, and nothing left to suggest even the fact of its former existence. That the process has proceeded thus far for most of the Great Western Divide there can be but little doubt. It appears to the writer that we have an illustration of it in the portion of the divide shown in Plate 45 B. Here the divide is broad and massive, but is traversed by a series of shallow glacial troughs running transverse to its trend and separated by acutely serrate, narrow ridges. The shallowness of these troughs is relative only. They are in reality as deep as the cirques of the region usually are, but their great length and breadth give them a shallow aspect. It is very probable here that the intersection of the opposing slopes of the transverse troughs has obliterated a plateau similar in character to that west of Mt. Vandever.

HISTORICAL ARGUMENT AND RESUMÉ.

The granites of the region are intrusive in rocks which, as the fossils collected by Becker indicate, are of Triassic age. They may, therefore, with little hesitation be regarded as having originated at the time of the intrusion of the granites of the more northern portion of the range, and these are of post-Jurassic age. The granite of the Sierra Nevada thus appears to be a vast batholith coextensive with the range. Remnants of the roof of this batholith are abundant in the northern Sierra Nevada, but occur only as mere fragments in the southern part of the range. The Mineral King belt of sedimentaries is one of these fragments. One of the most important facts which the relation of these rocks to the granite reveals is that, whatever may have been the basement upon which they were deposited, there is now no trace of that basement remaining. It has either been resorbed by the granite or has sunk into it. The Mineral King belt, as a whole, is sunk at least a mile in the granite, with approximately vertical, sometimes overhanging, contacts on either side.

The mountain range, established at the time of this granitic invasion at the close of the Jurassic, has persisted as a barrier between the marine basins on the west and the land area of the present Great Basin ever since. By the close of the Tertiary it

A

Plateau west of Mt. Vandever, nearly obliterated by cirque sapping.

B

Glacial troughs and cirques on the summit of the Great Western Divide at the head of the Middle Fork of the Kaweah. Showing the reduction of mountain by intersection of cirque walls.

C

Looking over region of glacial cirques from summit of peak on the east of Farewell Gap. Kaweah Peaks in the distance.

had been, as is now generally recognized, reduced to a region of very moderate relief, and on its western flanks was in the condition of a peneplain. The more eastern portion was, however, still a distinct, though low, mountainous country draining across the peneplain to the sea, and was higher to the south than to the north. This being the case we cannot refer the flat tops of the Summit Upland, such as are exemplified in the summits of Mt. Whitney, Table Mountain, Sheep Mountain and Cirque Peak, to the residuals of a peneplain. If these flat tops of the summit region be remnants of a peneplain, then they must in in later Tertiary time have stood at base level. And if this were so it is difficult to see how they should have escaped submergence in the Miocene sea which overflowed the western flanks of the range and left there a thick deposit of sediments. Again, the gradual mergence of these flat tops into the western slope of the summit region by smoothly flowing curves militates against the notion that such summits were ever at base level. For if such a base leveled plain were elevated it would be sharply dissected, and we should have some trace left of the contrast between the original surface of the peneplain and the more abrupt slopes due to dissection. The smoothly flowing curves by which the flat summits descend to lower levels may indicate advanced maturity of geomorphic evolution, but they lend no support to the view that such summits were ever in the perfectly senile condition implied in a reference of them to residuals of a peneplain.

This hypothesis being rejected, it is sought to explain the flat tops as due to differential degradation under the control of structure, the particular structure involved being the contact plane between the granite and its roof of less resistant rocks. Such a structural feature certainly existed over the region, and must have influenced the course of erosion in no small degree. The only question is whether the contact of the granite and its roof was sufficiently near the present surface to have given character to that surface. Analogy of northern California and the fact that portions of the roof of the granite still remain, even in the region under consideration, indicate that the contact was not far above the present surface of the mountain summits, and may have been coincident with them. The hypothesis of differential degradation is, therefore, adopted as the most satisfactory one that can be suggested to account for these high tables. Under this hypothesis the Summit Upland represents a quasi mature geomorphy, the result of the reduction of a high mountain range down to, and in places considerably below, the upper surface of its core of granite. The present summits of Mt. Whitney and Sheep Mountain were never less than 3000 feet above base level.

While the Summit Upland stood thus, in late Tertiary time, a broad valley was evolved at the western base of that part of it which forms the eastern rim of the Upper Kern Basin. This takes now the form of a broad plateau at an altitude of about 11,500 feet above sea level. It appears to represent the base level for the late stages of the cycle in which the maturity of the Summit Upland was evolved. On morphological grounds it is segregated from the Summit Upland as the Sub-summit Plateau, but chronologically it is, in part, the correlative of the upland. It must, therefore, be regarded, also, as the correlative of the late Tertiary peneplain of the western flanks of the Sierra Nevada. A remnant of a plateau at 11,200 feet, to the west of Mt. Vandever is correlated with the Sub-summit Plateau. The Summit Upland and the Sub-summit Plateau thus appear to antedate the uplift and faulting which dislocated the Sierra Nevada range from the Great Basin. That uplift was not, however, a single event. There were at least two distinct and important movements widely separated in time.

The first movement lifted this portion of the Sierra Nevada about 2,500 feet, the difference in altitude between the Sub-summit Plateau and the High Valley lands. This was undoubtedly the movement which inaugurated the westward tilting of the peneplain of the western flanks of the range. It was also, undoubtedly, but a part of the very much wider disturbance of the Cordilleran region which inaugurated the Quaternary. By this movement a wedge of the earth's crust 2,500 feet thick at its butt, in the region of the Upper Kern, and tapering to nothing toward the present Great Valley of California, which had hitherto been below base level, was lifted into the zone of erosion; and the Summit Upland, sessile upon the butt of the wedge, was lifted into a zone of more vigorous erosion.

Prior to this uplift, however, volcanic vents opened in some of the high valleys and veneered their floors with sheets of basalt. The best example of this, and, indeed, the only example, although others will doubtless be found, is the lava which lies upon the surface of the Little Kern Plateau and which has been subjected to the same dissection as the plateau itself. Into this uplifted mass the streams of the region sank their trenches and, on reaching a grade adjusted to their load, began to meander and widen these trenches into valleys. In this way, with the coöperation of atmospheric erosion, the present High Valleys of the region, Chagoopa Plateau, Toowa Valley, and the Little Kern Plateau were evolved. The time necessary for the evolution of these High Valleys occupied the greater part of the Quaternary. Not only were the High Valleys evolved as broad, flat, or very gently sloping, plains in the midst of the mountains, but the mountains themselves surrounding these valleys were reduced to mature slopes. The second and greater uplift then occurred. This initiated the down cutting of the present cañon system of the Sierra Nevada, of which Kern Cañon is one of the finest examples. But Kern Cañon is evidently controlled by some structural feature, which was probably established at the time of this second uplift. This structure appears not to have been of the nature of a fault of sufficient throw to appreciably dislocate the High Valley floors. It is, therefore, suggested that it was of the nature of a rift fissure. This hypothesis, on critical examination, is found to be in harmony with many features of the cañon, particularly with the evidence of inslipping of slabs and wedges of the cañon walls after the cañon had attained approximately its present form. This inslipping is probably due to a renewal of the opening of the original rift fissure in later time. The inslipping has had the effect of materially widening the cañon; but certain portions of the inslipped masses have failed to slip as far as others, and they now constitute the peculiar buttresses of the cañon walls, particularly the west wall, which appear to be a new type of geomorphic form signalized by their designation as *kernbuts*, the troughs which separate these buttresses from the cañon walls, and the ridges of the multiple kernbuts from one another, being called *kerncols*.

With the initiation of the down cutting of the Kern, below the floor of the High Valley, Toowa Valley was beheaded. This resulted from the capture of the drainage of Chagoopa Plateau by a stream heading up the rift line from the point where the present Kern bends to the east below Lower Lake.

After the cañon of the Kern had been cut very nearly to its present depth certain volcanic vents opened on the floor of Toowa Valley and in the trench which had dissected it. These built up cones, which are still perfectly intact, and caused lava streams to flow down Volcano Creek nearly to the level of the Kern, filling up the trench which had been cut in the floor of Toowa Valley by that stream. Since then the lower end of this lava coulée has been cut away by the Kern and Volcano Creek has cut back an incisive gorge in the lava for a couple of miles.

Very late in Quaternary time the region was subjected to Alpine glaciation. At its maximum a trunk glacier reached down Kern Cañon as far as Coyote Creek, 24 miles from the head of the cañon. The stay of the ice front at this point was brief. It receded a mile up the cañon and remained stationary for a very much longer time; and then vacated the cañon at a uniform rate of retreat. The sculpture of the high mountains by the ice streams which fed this trunk glacier has completely transformed the aspect of maturity which the mountains possessed in pre-glacial time, and which is still splendidly displayed by the unglaciated southern portion of the region about Toowa Valley; which maturity, of course, had been preserved from the time of the High Valley cycle of degradation.

The complete evacuation of the region by the ice is a very recent event, and glaciers still linger in the cirques of the summit divide but a short distance north of the head of the Kern.*

The post-glacial degradation of the region has been very slight. Atmospheric erosion is almost negligible and is measured only in terms of small talus accumulations at the base of some of

*This interesting fact has been communicated to the writer by Mr. J. N. LeConte as the result of his observations in this part of the Sierra Nevada last summer.

the cirque cliffs, while in other cirques little or no talus exists. The bevelled edges of the upper part of the cirque walls are in several cases curiously fluted. This fluting is well seen in Plate 42. It appears to represent a post-glacial process of degradation due to small snow-slides following the same paths year after year. This process of erosion may in many cases be correlated with the talus accumulations at the base of the cliffs. There has been no appreciable rock disintegration of the glaciated surfaces. Even where the floors and walls of the cirques and cañons have been exposed continuously to the weather, with no other protection than the snows of winter, the glacial polish, striation and fluting are perfectly preserved. They appear to have resisted the weather many times more effectively than equally unprotected surfaces in the region of the great lakes, and their exposure to the weather is, therefore, inferred to have been many times less prolonged. The stream erosion is best exemplified in the trench, perhaps on an average 20 feet deep, which has been cut in the glaciated floor of the upper part of Kern Cañon, but probably the greater part of this was cut while the ice still occupied the cirques in the rim of the basin.

The writer has ventured to make a guess at the time ratios of the divisions of the Quaternary which are indicated in the various stages of the geomorphogeny of the Upper Kern Basin. It appears probable that it required eight times as long a period for the evolution of the High Valleys as for the down cutting of Kern Cañon. The cutting of Kern Cañon probably required six times as long a period as was necessary for the glacial sculpture of the High Mountain Zone. And the glacial sculpture fifty times as long as the period that has elapsed since the disappearance of the glaciers. If, therefore, we take post-glacial time as 1, the ratios would be as follows:

I	Evolution of High Valleys	2400
II	Period of cañon cutting	300
III	Glacial period	50
IV	Since disappearance of the glaciers	1

The figures have not much value, the data for a proper estimate of these ratios being entirely inadequate. But they at least bring the relation of the period of glaciation to the entire period of Quaternary time into relief. They bring into equally marked relief the fact that, on the basis of the physical evolution of the region, Quaternary time is divisible into two parts, the earlier of which is many times longer than the later, the demarkation point between the two being the initiation of the second uplift. If we correlate the earlier subdivision with Hershey's Santa Claran epoch,* as the writer is disposed to do, then the estimates of the writer as to the time ratios of the two main divisions of the Quaternary are confirmatory of those made by Hershey.

In view of the exceedingly slight post-glacial erosion in the cirques and of the fact that glaciers still linger in the high mountains to the north of the Upper Kern Basin, it appears to the writer that 1,000 years is a reasonable guess at the length of time which has elapsed since the disappearance of the ice from the basin. With this for our unit, the entire duration of Quaternary time would, on the ratios given above, amount to 2,751,000 years.

* Bull. Dept. Geol. Univ. Cal., Vol. III, No. 1.

University of California,
December, 1903.

APPENDIX.

PETROGRAPHIC NOTES ON SOME ROCKS FROM THE UPPER KERN BASIN.

No systematic attempt was made by the writer to collect materials for a petrographic study of the rocks of the Upper Kern Basin, but where opportunity offered occasional hand specimens were taken as representative of the more important rock masses. The examination of these specimens has been kindly undertaken by Mr. A. Knopf, a student in the department of geology in the University of California; and the results of that examination are herewith appended as a contribution to the geology of the region which could not be conveniently incorporated in the general discussion. The specimens comprise fragments of different facies of the granitic rocks, the inclusions contained in these rocks, and the lamprophyric dykes which cut them, all taken from Kern Cañon in the vicinity of the main camp at the mouth of Coyote Creek. Besides these there are a few specimens of the Quaternary lavas from the Little Kern Plateau and from Volcano Creek.

The Common Facies of the Granite in Kern Cañon.—This rock is a coarse grained, light colored granite, showing numerous large phenocrysts of orthoclase. This structure is best seen in the hand specimen. In thin section it is not so apparent, the rock resolving into a hypidiomorphic granular assemblage of orthoclase, quartz and biotite, with accessory magnetite.

The orthoclase is the dominant feldspar occurring both in Carlsbad twins and large allotriomorphic patches. A lesser amount of finely striated plagioclase also occurs. This is an oligoclase corresponding to an extinction angle of 6°. The feldspar comprises 75% of the entire rock. Quartz occurs in great abundance. The rock is very poor in ferro-magnesian constituents, the latter being represented sparingly by biotite.

A Rather Basic Facies of the Prevailing Granite of Kern Cañon.—A medium-grained rock of uniform texture, possessing the normal granitoid habit. Under the microscope it is seen to be composed of plagioclase, orthoclase, quartz, biotite and hornblende, with accessory magnetite and apatite. The plagioclase occurs in broad plates consisting of closely crowded albite lamellae. Pericline twinning is developed to but slight extent. Incipient kaolinization has rendered the feldspar dull and turbid. The maximum extinction angle measured against symmetric lamellæ was 30°, fixing this feldspar as an acid labradorite. It forms the most prominent constituent, comprising nearly half the bulk of the rock. Hornblende and biotite occur as inclusions. The orthoclase is developed both in Carlsbad twins and as polysomatic aggregates. Feldspars showing albite twinning have been enclosed by the orthoclase. Zonary banding is rarely exhibited. The quartz is present in allotriomorphic patches and in very subsidiary proportions. Apatite needles occur sparingly among the inclusions. The biotite constitutes the most abundant ferro-magnesian mineral present. It shows the characteristic frayed edges and some bending of the plates. The amount of brown-green hornblende is relatively small, but exhibits the strongest approximation to an idiomorphic development.

The composition of the rock accordingly leads it to be classified as a hornblende-biotite grano-diorite. Some evidences of a cataclastic structure can be adduced from the curvilinear deformation of the albite lamellæ with a tendency to rupture in the more acute flexures.

Uralitic Gabbro.—This is a coarse grained rock consisting, so far as can be determined in hand specimens, of feldspar and a dark green, ferro-magnesian mineral. In thin section it appears as an allotriomorphic granular aggregate of plagioclase and hornblende, with large amounts of accessory magnetite. The feldspar occurs in broad plates and patches; the twinning lamellae are broad and yield 36° as the maximum symmetrical extinction angle. This would determine the feldspar as labradorite. The hornblende and plagioclase are present in nearly equal proportions. The hornblende is light green and has the characteristics of a uralitic derivation. The prismatic cleavage is strongly developed; the pleochroism is in tones of green; the central areas are usually light colored, suggestive of its derivation from pyroxene, but no remnants of the original pyroxene can be discovered. The hornblende is often finely fibrous and gives but small extinction angles. It is in places replaced by chlorite.

Inclusions in Granitic Rocks.—Of the inclusions contained in the granitic rocks which are referred to in the general description of the rocks of the Upper Kern Basin (p. 295) three were studied in this section. The first of these to be noted is contained in a grano-diorite similar to that last described. It has an angular outline with a rather sharp but irregular boundary against the containing rock. It is much darker and much finer grained than the grano-diorite. A shear zone running through the grano-diorite forms one boundary of the inclusion. The longest diameter of the inclusion is about four inches.

Microscopically it is a hypidiomorphic aggregate of hornblende, biotite, feldspar and accessory apatite and magnetite. The rock is not very fresh and the feldspars are usually turbid. The plagioclase occurs in shapeless patches and in broad plates showing closely crowded albite lamellæ. The extinction angle of 14° indicates that they are oligoclase-andesine. Numerous large Carlsbad twins occur. The feldspars are often bent and even faulted, the fault zones being filled with a mosaic of feldspar grains. This internal deformation is doubtless connected with a small shear zone which appears in the hand specimen and is common to both inclusion and the containing grano-diorite.

The ferro-magnesian minerals form nearly one-third of the bulk of the rock; biotite predominates, with hornblende in subordinate amount. The biotite does not occur in well developed plates, but in small irregularly oriented laths which are often aggregated in nests.

The second inclusion to be noted is contained in a coarse biotite-granite in which orthoclase crystals, ranging up to half an inch in diameter, are abundant in rude porphyritic development. The inclusion is of the nature of a stout lens with maximum diameter of about four inches, having no pronounced angularity of outline. The contact with the enclosing rock is irregular and interlocking in detail. The inclusion is much finer grained and much darker than the enclosing rock, being of a dark pepper-and-salt gray aspect.

The structure, as seen under the microscope, is that of a hypidiomorphic granular aggregate of feldspar, biotite, hornblende, and quartz, with accessory magnetite and apatite. The dominant constituent is orthoclase and a small amount of associated plagioclase. It is remarkable for the large number of inclusions contained in it, either arranged centrally or zonally, a sharply defined zone of inclusions being succeeded by a margin of feldspar showing poor, irregular crystallographic boundaries. The inclusions consist of biotite and magnetite and indeterminate dark, earthy material. The quartz occurs in very sparing proportions, and cannot be ranked higher than an accessory. Biotite is the most abundant ferro-magnesian mineral; hornblende is present in subordinate amount. Apatite is notably abundant in small prisms.

The third specimen is a fragment of a large inclusion over a foot in diameter, contained in a medium coarse biotite granite.

Macroscopically, it is a fine grained gray rock containing numerous hornblende needles. Microscopically, it consists of a hypidiomorphic aggregate of green hornblende, biotite, feldspar, with accessory apatite and magnetite. Orthoclase is the most abundant constituent, forming nearly 75 per cent of the total content. The greater part occurs in allotriomorphic patches, often showing strain shadows. A small amount of acid plagioclase is also present. Green hornblende is the dominant ferro-magnesian mineral, and is noteworthy on account of its strong tendency to develop idiomorphic forms. Biotite occurs in lesser amount in laths and flakes, and as inclusions in the hornblende.

Lamprophyric Dykes.—Of the numerous small dykes which cut the granite of Kern Cañon between the mouth of Coyote Creek and Lower Lake, four have been microscopically examined. Two of these from the multiple dyke a little above the mouth of Coyote Creek prove to be vogesite, while the others from two dykes near Upper Kern Lake are camptonites.

One specimen of vogesite is a dense greenish gray rock showing abundant porphyritic prisms of hornblende.

The microscope shows phenocrysts of hornblende and feldspar in a panidiomorphic ground. This structure is caused by the recurrence of the hornblende and feldspar in two generations. Accessory magnetite and apatite are present. The hornblende is brown; that of the first period is developed in broad prisms, the transverse partings of which often contain biotite. That of the second has crystallized in slender needles, often showing a fluidal arrangement around the feldspar phenocrysts. The feldspar of the first generation occurs as large Carlsbad twins, turbid and heavily sprinkled with grains of opaque material. The idiomorphic development of the feldspar of the second generation equals that of the hornblende of the same period. Orthoclase is the dominant feldspar, plagioclase occurring in subordinate amount. The hornblende comprises about 40 per cent. of the bulk of the rock.

The other specimen of vogesite differs in only minor respects from the last. The phenocrysts of green hornblende and feldspar are contained in a ground consisting of laths of hornblende and biotite, and shapeless patches of hornblende and feldspar. In parallel light the feldspar appears to be homogeneous, but between crossed nicols resolves into a mosaic of small grains showing an undulous extinction. The hornblende of the first generation occurs occasionally in large prisms intergrown with some biotite. Nearly 40 per cent. of the rock is hornblende. The feldspar of the phenocrysts exhibits marked zonary banding; trains of inclusions parallel to the two cleavages give it a dusty appearance. Remains of other large crystals are indicated by the aggregation of decomposition products. Albite lamellation is very rare, othoclase being the dominant feldspar.

One of the camptonite dykes from the west side of Upper Kern Lake is a fine grained, gray rock, showing prisms of hornblende and occasional feldspars. Structurally the rock is a panidiomorphic aggregate of green hornblende and feldspar, with accessory apatite and magnetite. The idiomorphism of the hornblende is poor, the crystal edges being ragged and irregular. Twinning is common. Some tendency toward a fluidal arrangement is indicated both by the development of long, slender prisms and the parallelism of their major axes. The hornblende constitutes nearly one half of the mineral constituents. A few large phenocrysts of feldspar occur, portions of the interior of which exhibit micrographic intergrowth. The feldspar of the second generation occurs in rather poor laths and shapeless patches which usually show an undulous extinction. Inclusions of hornblende occur.

The dominant feldspar is a plagioclase whose exact character remains indeterminate. The other specimen of camptonite from one of two small dykes at the north end of Upper Kern Lake is a compact, fine grained, dark rock containing numerous phenocrysts of hornblende. The structure is holocrystalline with a strong porphyritic development of green hornblende. Apatite needles are abundant. The hornblende makes up nearly 75 per cent. of the rock. It occurs in two generations; those of the first producing large basal and prismatic sections; those of the second crystallizing in slender prismatic forms. A strong tendency to separate out iron oxides exists. The feldspar is small in amount and occurs as sporadic laths showing albite twinning, and as patches, often polysomatic.

Lava of the Little Kern Plateau.—Two specimens of this lava were examined. One is a fine grained lava of gray color containing an occasional small vesicle. Under the lens the structure is seen to be the typical "intersertal" of Rosenbusch. The dominant constituent is plagioclase developed in sharp idiomorphic laths of almost microlitic dimensions. This abundance of feldspar controls the structure, and forces the augite and magnetite granules to occupy the triangular spaces between the laths. The plagioclase microlites show strong albite lamellation, and yield extinction angles of 30°. This determines them as acid labradorite. Augite is present in large amount in the form of granules only, never exhibiting crystal boundaries. The augite is often red from iron oxide stains. The rock may be classed as a non-oliventic basalt.

The other specimen of lava from the Little Kern Plateau is an exceedingly fine grained, gray lava showing occasional minute vesicles. Microscopically the rock resolves into a pilotaxitic ground composed of augite microlites and granules, plagioclase microlites, and grains of magnetite. Occasional patches of feldspar showing undulous extinction occur. A few small laths of plagioclase have formed, giving extinction angles of 30° and corresponding to acid labradorite.

Augite has crystallized out in two generations, the first, however, occurring sporadically as inconspicuous phenocrysts which have often been stained red from oxides of iron.

The Lavas of Volcano Creek.—These lavas differ from the older lavas of the Little Kern Plateau in containing abundant olivine. Three specimens were examined microscopically, all being olivine basalts. The first of these is characterized as follows:

Macroscopically it is somewhat vesicular and of blue gray color. It possesses a conspicuous porphyritic structure, containing numerous plagioclase laths and olivine phenocrysts embedded in a fine grained matrix. Under the microscope the phenocrysts are seen to consist of plagioclase, olivine and augite. The groundmass is a dense aggregate of plagioclase microlites and small allotriomorphic patches of feldspar, containing abundant granules of augite and magnetite. The plagioclase microlites give an extinction angle of 31°, indicating them to be labradorite. The plagioclase of the first generation occurs in long laths showing albite lamellation. A few are untwinned and these commonly exhibit a marked zonary banding. They often grade in the direction of elongation into the feldspar of the ground mass. Olivine is a very abundant constituent, but has suffered marked chemical corrosion. The augite of the phenocrysts occurs in smaller amount than the olivine, and is developed in short stout prisms, usually surrounded by heavy borders of iron oxides.

The second rock from Volcano Creek in the hand specimen is an exceedingly compact, fine grained dark rock. Only an occasional small phenocryst of plagioclase is visible. The microscope shows a pilotaxitic structure with a marked fluidal arrangement of the microlites. The phenocrysts are neither large nor numerous, and consist of plagioclase, olivine and augite. Augite and magnetite granules are abundant. The microlites yield an extinction angle of 32°, thus fixing them as labradorite. The plagioclase phenocrysts exhibit marked chemical corrosion, in some cases being reduced to ovoid patches showing zonary banding. A few small well shaped laths occur, but yield no proper sections upon which extinction angles could be measured. Olivine is not a prominent constituent. It occurs chiefly as crystal fragments, often containing embayments filled with microlites. Augite occurs in even smaller amount than the olivine, differing, however, from the olivine, in that it shows sharp idiomorphic boundaries.

The third specimen from Volcano Creek is a rather light gray lava of somewhat vesicular habit. Occasional crystals of plagioclase and olivine are visible to the unaided eye. The microscope reveals a holocrystalline structure with a porphyritic development of plagioclase, augite, and olivine. The phenocrysts are contained in a pilotaxitic groundmass consisting of feldspar microlites, numerous granules of augite and patches of twinned plagioclase. Small stringers of magnetite are quite numerous. The structure tends to grade into the intersertal. The plagioclase exists in three generations. That of the first crystallized in exceedingly large phenocrysts. They are not numerous, and have undergone severe corrosion and embayment. Those of the second period occur in well developed laths. The maximum extinction angle is 40°, indicating a labradorite of medium basicity. Augite is present in large amount in sharply idiomorphic forms. The pyroxene is dark brown and often shows a surrounding rim of lighter colored matrix. A subordinate amount of pale green olivine also occurs, but is poorly developed.

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A NOTE ON THE
FAUNA OF THE LOWER MIOCENE IN CALIFORNIA

BY

JOHN C. MERRIAM

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A NOTE ON THE

FAUNA OF THE LOWER MIOCENE IN CALIFORNIA

BY

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In nearly all typical sections of the Californian Miocene it is possible to distinguish at least two divisions of the system based on the geological range of faunas. At least three faunal zones can be recognized in Contra Costa County, if we include the variation in fauna due to change in the character of the sea bottom during the deposition of the Monterey shale. This does not mean that there are only two divisions possible, or that the two mentioned are the same two in different sections, but rather that we are certainly dealing with more than one distinct zone.

One of the most characteristic phases of the Miocene in California is the Monterey shale. The fauna of this formation, as we know it, is limited to foraminifera, radiolaria, fish, cetaceans, a crustacean and a few mollusca. Among the last, *Pecten peckhami*, the indefinite *Tellina congesta* and a *Leda* are the most common forms. The fauna belongs to a deep water facies and must not be confused with the faunas of sandy, shallow water deposits. At many places where sandstone is interstratified with the shales a very sudden change of the fauna is noticed, nearly all of the typical shale species dropping out but reappearing in shaly layers above.

In addition to the shale fauna, there are in Contra Costa County two faunal zones in the Miocene, one above and one below the shale. The upper division has its nearest affinities with the San Pablo, from which it can be distinguished by the presence of *Clypeaster (?) brewerianus*, *Trochita costellata*, several new species of *Modiola*, and other forms.

The fauna of the lower division is much more characteristic than the upper: that is to say, it differs more decidedly from that of the beds immediately above and below it. This fauna includes the following forms:

Agasoma gravida Gabb.
Chrysodomus n. sp.
Ficula n. sp.
Olivella pedroana Conrad.
Neverita near *callosa* Gabb.
Turritella indet.
Crepidula indet.
Dosinia mathewsoni Gabb.
Chione mathewsoni Gabb.
Mytilus mathewsoni Gabb.
Venus n. sp.
Glycimeris near *generosa* Gould.
Leda taphria Dall.
Nucula divaricata Hinds.
Arca n. sp.

The most characteristic species are *Agasoma gravida*, *Dosinia mathewsoni*, *Chione mathewsoni*, and *Mytilus mathewsoni*. These beds rest upon the Tejon, which is very fossiliferous only a few yards below the contact. A large percentage of the species in this horizon do not appear in the upper Miocene and as yet not a single species has been found to extend down into the Tejon. In Contra Costa County the fauna of this zone is more distinctive as that of the Monterey shale, considering even that the latter represents a deep water facies.

The lower fauna is recognized at many places in Contra Costa County, and always next the base of the series. This faunal division might appropriately be called the zone of *Agasoma gravida*. Forms like *A. gravida* have a wide geographic range on this Coast and are apparently characteristic of the base of the Miocene.

South of Contra Costa County the deposits in the middle Tertiary appear to take on quite a different character. Instead of a thin bed of sandstone below the Monterey shale, very considerable thicknesses of heavy sandstone and clay may form the basal beds. These may swell out to make a much more important stratigraphic unit than the basal sandstone of the Contra Costa region. In the Pacific Railroad survey reports, heavy fossiliferous sandstones are mentioned by Antisell* as occurring at the base of the Miocene. Later, Whitney† presented sections of several regions where extensive Miocene sandstones lie below the shale. In the palaeontology of Whitney's report, Gabb‡ refers to the shale as the upper member of the Miocene, evidently having in mind the sandstones below it. In several of these references *Turritella ocoyana* is mentioned as a common form in these beds.

In 1895, Ashley§ described a thick series of sediments which he supposed to rest conformably below the Monterey. He listed several species from it, of which the most important and characteristic is *Turritella hoffmani.* Ashley was uncertain about the age of these beds, thinking they might be partly Eocene.

In 1896, Fairbanks,|| in his discussion of the geology of Point Sal, described extensive Miocene beds of clay and sandstone below the shale. Still more recently in his work on the San Luis Obispo Quadrangle he has carefully worked out the relation of this horizon to the shale and made extensive collections in it. These collections were turned over to the University of California. They were worked over by Mr. F. C. Calkins, who has found in them a very interesting fauna. *Turritella hoffmani* is perhaps the most characteristic species. Along with it are a great many forms not known in the later beds. Other collections made more recently by Dr. Ralph Arnold in the *T. hoffmani* beds described by Ashley show the same fauna as that collected by Fairbanks almost species for species.

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*T. Antisell. Pacific R. R. Rep. Vol. 7, p. 197.

†J. D. Whitney. Geol. Surv. Calif. Vol. I, p. 128, fig. 10, and p. 135, fig. 17.

‡W. M. Gabb. Geol. Surv. Calif., Palaeontology. Vol. II, p. 59.

§G. H. Ashley. Leland Stanford Junior Publications. Geol. and Palaeont. No. 1, p. 291.

|| H. W. Fairbanks. Bull. Dept. Geol. Univ. Calif. Vol. II, No. 1, p. 5.

Search has been made in this fauna for species like those of the lowest Miocene of Contra Costa County. So far there have been found an *Agasoma* very much like *gravida*, a *Dosinia* of the type of *mathewsoni* and a *Chione* of the type of *mathewsoni*. The *Dosinia* and *Chione* are not identical in form with the types but come near them. This fauna probably belongs to the *Agasoma* zone of the lower Miocene, and were it not for certain complications that arise it might be designated as such. For the present it may be called the zone of *Turritella hoffmani*.

The complications just mentioned are due to the fact that in many of the regions in the southern part of the state, where the sandstone phase of the Miocene is developed extensively below the shale, the fauna containing *T. hoffmani* is not discovered, but in its place there is found an abundance of *Turritella ocoyana* along with *T. variata*. In most of the localities only a few species have been found with those two forms, but enough has been seen to make it appear that this is not exactly the same zone as that of *T. hoffmani*. On the other hand, there is evidence enough to show that the two horizons are not far removed from each other. Near Bakersfield, in the beds from which the type of *T. ocoyana* was obtained, an extensive fauna has been discovered. Most prominent among the species are three forms of *Agasoma*, the most common of which is near *gravida*. In some respects it is intermediate between *A. gravida* of the lower Miocene and *A. sinuata* of the upper Miocene.

Both the zone of *T. hoffmani* and that of *T. ocoyana* appear to belong close to the *Agasoma* zone of Contra Costa County. It is also probable that the *T. hoffmani* zone is the older of the two, as its fauna is made up very largely of extinct forms. That of the *T. ocoyana* beds at Kern river contains a much larger number of recent species, it is generally more modern in its appearance, and it also shows the *Agasoma* group much more highly developed and much more common than in the *T. hoffmani* beds.

In the southern part of the state we probably have two fairly distinct zones of the lower Miocene. The question naturally arises; are we to consider the beds in Contra Costa County as the equivalent of one or both of these divisions? This much may be said, viz.: The fauna of the *Agasoma* beds of Contra Costa

County seems to contain a somewhat larger number of recent species than the *T. hoffmani* division and also lacks some of the extinct species which belong to it. That this is probably not simply a geographic variation in the fauna is shown by the proximity of the *T. hoffmani* beds of Ashley to the *Agasoma* beds of Contra Costa County.

When we come to study the subdivisions of the lower Miocene both palaeontologically and stratigraphically some interesting things relating to the movement of the Miocene shore lines are suggested. The *T. hoffmani* zone is found principally in the western or coast region. The *T. ocoyana* zone occurs in the western region and also to the east of the great valley, where the *T. hoffmani* is not yet known. It would therefore appear that the sea had not reached as far east in the earliest Miocene as it did later, and that the thick shale beds over the lower sands of the western region were formed while sandy *T. ocoyana* beds were being deposited to the east.

University of California,
March, 1904.

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THE ORBICULAR GABBRO AT DEHESA

SAN DIEGO CO., CALIFORNIA

BY

ANDREW C. LAWSON

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THE ORBICULAR GABBRO AT DEHESA, SAN DIEGO CO., CALIFORNIA

BY

ANDREW C. LAWSON

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The Discovery.—A few years ago a piece of rock was sent to the University of California by Mr. H. P. Wood, Secretary of the Chamber of Commerce of San Diego. The rock was of peculiar appearance, and it was thought it might prove of exceptional scientific interest. The sample forwarded was found near Dehesa in the valley of the Sweetwater River by Mr. Marion Powers, by whom it was supposed to be a mass of fossil coral. By correspondence with Mr. Wood the writer secured a larger fragment of the rock, a photograph of which is shown in Plate 46A. The photograph shows that the supposition of its being a mass of fossil coral was a natural and excusable one to make, but to the petrographer it appears at once to be an igneous rock characterized by that peculiar and interesting structure commonly called orbicular. The writer made a preliminary petrographic examination of the material and reported the results of his examination in a brief note to the Cordilleran Section of the Geological Society of America at its third annual meeting in December, 1901, and the specimens of the rock were then exhibited and were commented upon by the Fellows of the Society. The writer deferred publishing an account of the rock till he should have an opportunity of seeing its occurrence in the field. Various circumstances, however, prevented his visiting the locality until last summer, when, being in San Diego, he made a trip to Dehesa, looked over the ground, and found the orbicular rock in place.

Geology of the Region.—Dehesa is a store and Post-office situated a few miles east of El Cajon Valley on the Sweetwater. In reaching it from San Diego one passes over the broad mesa lands which border the ocean front of San Diego County, and at El Cajon Valley encounters the underlying surface of granitic rocks upon which the stratified sediments of the mesa repose. These granitic rocks are of quite varied character and have as yet not been subjected to much geological investigation. We have, however, the reconnaissance work of Fairbanks* from which it appears that the region where these granitic rocks abound is an extensive complex of igneous intrusives and crystalline metamorphics, the former greatly preponderating. The igneous rocks comprise, according to Fairbanks, granite, gneiss, syenite, diorite, gabbro and diabase. Near Dehesa there appears in the midst of the granite a large mass of coarse textured basic igneous rock concerning which Fairbanks says: "At Dehesa the granite is replaced by norite which forms a high mountain on the north side of the river and extends southeasterly three or four miles forming two high peaks."† It is on the slopes of this mountain on the north side of the Sweetwater that the orbicular rock occurs which forms the subject of this paper.

Occurrence of the Gabbro.—The area occupied by this basic rock to the northeast of Dehesa has an extent from east to west

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* Geology of San Diego County; also of portions of Orange and San Bernardino Counties. Calif. State Mining Bureau, 11th Rept. State Mineralogist, 1893, p. 76.

† Op. Cit. p. 85.

of about a mile and a quarter and from north to south of about three-quarters of a mile. The summit of the hill is about 1800 feet above sea level or 1200 feet above the bottom lands at Dehesa. The area is bounded on the north and west by granite, and on the east and south by the alluvium of the valley. As is indicated by Fairbanks' statement, there are probably other areas of this rock to the southeast of Dehesa which may be portions of the same geological mass separated from it superficially by stream erosion. These other areas were, however, not visited by the writer.

Petrographic Features of the Normal Facies.—In general the main mass of the basic rock presents the characters of a coarse gabbro, consisting, so far as can be determined by an inspection of hand specimens, of a granular aggregate of light gray, striated feldspar, a dark ferro-magnesian mineral and some black iron ore. The feldspar in most specimens preponderates but in some it is equaled in quantity by the dark constituents. The cleavage faces of the feldspar are occasionally an inch in extent and are very commonly half an inch, although the bulk of the mineral is of smaller dimensions. The cleavage faces of the ferro-magnesian constituent are also occasionally as much as an inch in length, but are prevailingly smaller than those of the feldspar. The rock weathers to a tawny yellow color which gives the hill a reddish appearance at a distance. The rock is, however, not deeply decomposed and fresh specimens may be taken anywhere at the surface. Several thin sections of each of the common varieties of the rock were studied. The variations of the main mass of the rock are of a minor character, and it may be characterized in general as a hornblende-gabbro with notable proportions of olivine and hypersthene. The structure is on the whole allotriomorphic granular except for the tendency to idiomorphism on the part of the olivine.

The plagioclase is perfectly fresh in thin section and nearly all of it shows twinning on the albite law, while occasionally the pericline twinning is also observable. The maximum extinction angles in thin sections normal to the brachy-pinacoid are about 45°, thus indicating that it is a basic labradorite or possibly a bytownite. In some of the sections this basic labradorite exhibits a tendency to idiomorphism but for the most part its outlines are allotriomorphic. There may be occasionally observed a few irregular cracks traversing the feldspar and these are filled with a secondary colorless mineral having a very strong double refraction, probably a carbonate.

The hornblende is of a prevailing olive-green color in transmitted light, and its pleochorism in tints of olive-green, and yellowish green, while distinct is not so intensely marked as is commonly the case in green hornblendes Its maximum observed extinction angle is about 16°. This hornblende has all the characteristics of an original pyrogenous constituent of the rock, there being no indication of its secondary derivation from pyroxene.

Black, opaque iron ore occurs in sparing amounts in all the slides and occasionally it shows the cleavages characteristic of ilmenite. It is often enclosed in the hornblende. Olivine is not found in all of the specimens studied, but in those sections where it occurs it is perfectly fresh, though traversed by characteristic cracks. It generally has more or less rounded or elliptical outlines and is usually surrounded by an envelope of secondary green hornblende which is interpreted as a *reaction rim.*

Hypersthene, like the olivine, is variable and is usually found in those sections containing olivine. It occurs partly intergrown and interlocked with the original hornblende and partly in allotriomorphic grains in the midst of the feldspar. It is perfectly fresh and presents the characteristic optical characters of the mineral.

Titanite in sparing amount is found in a few of the slides. Neither augite nor apatite were detected in any of the slides.

Various Local Facies.—This coarse grained hornblende-gabbro passes locally into a much finer textured and darker variety in which hornblende and feldspar are about equally represented and in which black iron ore is more abundant in small granules evenly distributed through the thin section. Neither olivine nor hypersthene could be detected in this variety. The normal facies of the rock also passes locally to a somewhat finer grained rock which would be more properly designated an olivine-norite. This facies consists chiefly of basic plagioclase, olivine and hypersthene, the latter two minerals being quite abundant and nearly equal in amount. The olivine is usually encased in an irregular envelope of secondary, fibrous, green hornblende, separating it from the feldspar. All the minerals are fresh. Original green hornblende occurs in quite sparing amounts, playing here the rôle of an accessory together with a little opaque iron ore. Locally the normal rock of the mountain passes into distinctly laminated facies. A sample of this facies taken for study proves to be a troctolite. It is finer grained than the normal facies and presents, even in the hand specimen, an even lamination, breaking under the hammer into slabs. This lamination is due to an alternation of layers poor in ferro-magnesian constituents and chiefly feldspathic with thiner layers in which the dark constituents abound. This alternation is best seen on weathered surfaces. The feldspathic layers are from one quarter to one eighth of an inch thick.

In thin section the rock appears as an allotriomorphic granular aggregate of basic plagioclase, entirely fresh, enclosing numerous crystals of fresh olivine, more or less blurred in outline and having in every case a reaction rim of secondary green hornblende encasing it and separating it from the feldspar. These reaction rims are sometimes of even width but are for the most part very jagged, penetrating both the feldspar and the olivine and evidently formed at the expense of both minerals. There are besides some granules of opaque, black iron ore, usually associated with the olivine, and original green hornblende occurs very sparingly in small allotriomorphic grains. The laminated structure is not apparent in the thin sections.

A quite different facies of the rock is one which occurs to some extent as small, vaguely defined areas in the midst of the normal gabbro but which is for the most part found in the form of narrow veins or dykes, corresponding in character to the so-called segregation veins of various plutonic rocks. In these veins the rock consists almost entirely of large well formed crystals of black hornblende, disposed roughly normal to the walls of the vein with a little interstitial feldspar; and in the narrower veins, up to about four inches in width, the crystals may span the space from wall to wall. In other cases, particularly where the vein like disposition of this facies is not apparent there may be a larger proportion of feldspar and the structure may have none of the parallelism shown in the veins. A specimen of such a rock was taken for study. Macroscopically it is a coarse aggregate of black hornblende crystals and gray feldspar. The hornblende greatly predominates and the crystals of that mineral are often an inch in length.

In thin section the hornblende is the same as that found in the normal variety of the gabbro. Associated with it is an occasional allotriomorphic grain of hypersthene. The basic plagioclase is quite fresh. There are enclosed in the latter mineral slender rods of olivine with transverse cracks quite similar to those found in the orbicular structures to be described below. Ilmenite with occasional cleavages and narrow borders of titanite is rather abundant. There is some epidote associated with the hornblende.

A more careful examination of the mountain would doubtless reveal other variant facies of the normal rock. The writer's attention at the time of his visit was, however, directed more particularly to a search for the orbicular facies of the rock, and little opportunity was afforded for detailed study of the mass.

Aplitic Dykes.—Near the summit of the mountain the normal hornblende gabbro is cut by a number of small dykes, striking in different directions. These dykes are very light colored and so present a striking contrast to the gabbro. They appear in the field to be of the nature of fine grained granites or aplites which grade on the one hand into facies so siliceous as to be practically quartz veins, and on the other hand into veins of feldspar. In hand specimens one may recognize that the rock is made up chiefly of quartz and feldspar with a sparing amount of biotite in thin scales more or less decomposed. In thin section, allotriomorphic quartz is the preponderating constituent. The feldspar is for the most part untwinned and is presumably orthoclase, but there are a few grains of an acid plagioclase. The feldspar shows in many cases a well defined idiomorphism and is in nearly all cases murky with kaolinization products. The biotite is decomposed and stained. The only other mineral is epidote in very small amounts.

The Orbicular Facies.—The orbicular facies of the gabbro was found by the writer on the south side of the mountain near the western boundary of the gabbro mass. The orbicular structure appears prominently upon the weathered surface of the gabbro, but the portion of the mass which is affected by this orbicular structure has no sharp boundary against the normal facies of the rock. It rather grades into it insensibly by an increase in the intervals between the orbules and by a feebler development of the latter till eventually they become in the weathered surface indistinguishable from the rest of the rock. Where the orbicular structure is well developed it is apparent on the weathered surface of the rock by reason of the differential weathering of the light and dark constituents as well as by their difference of color. The feldspar has been etched more deeply than the ferro-magnesian constituents, and the latter, therefore, stand out in relief. The sections of the orbules afforded by rock surfaces are in nearly all cases approximately circular, thus indicating the absence of any marked deviation from the spherical form. The limits of the orbules against the rest of the rock are usually sharp, and within these limits there are two pronounced structures which give the orbules their character. One of these is a concentric disposition of the light and dark constituents, and the second is the radial disposition of the dark constituents. The first of these is the more striking and on the rock surfaces gives rise to concentric circular zones of alternating light and dark material, the latter being in relief. A very common arrangement is one in which the circular sections of the orbules present a light colored central area, having a diameter of about one-third the full diameter of the orbule, and composed evidently chiefly of feldspar. Encircling this is a broad zone of dark material in relief, evidently some ferro-magnesian mineral for the most part, although with an admixture of feldspar. Outside of this is a narrow zone almost entirely feldspathic and encasing this is a zone, usually very narrow and sharp, composed of the dark constituent; or there may be two of these very narrow sharp dark zones with an intervening light zone also very narrow. The outermost shell of the orbule appears generally to be represented by this narrow zone of dark mineral. This description would apply to what might be termed a local habit of the orbules. In other cases the concentric structure is more manifold, the outer zone is prevailingly feldspathic and the radial structure of the dark constituent is very pronounced.

The finest specimen of this orbicular facies of the gabbro in the possession of the writer is that sent him by Mr. H. P. Wood of San Diego. Its exact location is not known, as it was evidently a loose block taken from the slopes of the mountain and weathered on all sides. This is made up of spheroids of about six centimeters in diameter having a pronounced concentric and radial structure. A photograph of this mass is shown in Plate 46A. The spheroids are rather closely crowded together and tend to fit together so that the spherical form is deformed by a flattening at the points of abutment. Between the spheroids the matrix is a medium coarse, granular, gabbro-like aggregate of feldspar and a dark mineral. Occasionally, however, this interorbicular matrix takes on the character of a granular aggregate of feldspar in which the dark mineral is disposed in all azimuths in the form of slender, often branching, rods. The structure of the matrix in both conditions is shown in Plate 46B, which is a photograph of a large thin section of one of the spheroids and the adjoining matrix.

Microscopic Characters.—A microscopic study of the rock in thin sections brings out a number of facts which are not very apparent on weathered or polished surfaces. At the center of each spheroid there is characteristically a core consisting of an allotriomorphic granular aggregate of basic plagioclase, probably anorthite, and olivine with a subordinate amount of hypersthene. This core has a diameter of from 12 to 25 mm. Commonly, though perhaps not always, feldspar predominates at the center of this core, and occasionally a single individual of feldspar may be as much as 10 mm. across. This feldspathic portion grades out toward the periphery of the core into an aggregate in which the olivine is not less abundant than the feldspar, and in this portion of the core there is often a more or less distinct radial disposition of the olivine, but not nearly so well marked as in the outer shells.

Encasing this core is a succession of shells which in thin section appear to be much more sharply marked off from one another than would be suspected from a macroscopic inspection. This distinctness of the shells is due to the fact that they are in reality an alternation of thick shells composed of feldspar and olivine in radial disposition and very thin shells composed wholly, or almost wholly, of feldspar. The feldspar in all cases appears to be bytownite or anorthite as determined by the usual optical method. These thin shells of feldspar may be regarded as representing interruptions in the growth of the olivine. The occurrence of the latter mineral is one of the most peculiar features of the orbules. It occurs in slender rods of varying thickness disposed radially. In the thick shells these olivine rods traverse the entire width of the shell as seen in section and stop abruptly upon the thinner shells composed wholly, or almost wholly, of feldspar. Where these thin shells or feldspathic partings between the thicker shells are well defined, an occasional rod of olivine may cross them, but this scarcely detracts from the sharpness of the shell limits. In cases where the thin shell is only feebly developed, the olivine rods cross it rather commonly, but they then often show an abrupt diminution of their thickness where they cross the shell, and the trace of the shell is still well marked in thin section and contributes much to the concentric appearance. There is no even line of any kind between the feldspar of the thick shells and that of the thinner shells or partings. The crystallization of the feldspar appears to have been a continuous process throughout the growth of the spheroids; and the concentric structure is due chiefly to the distribution of the olivine rods, and particularly to the interruption of the growth of the olivine rods at sharply defined spherical surfaces. The relative abundance of the olivine in the different shells also, of course, contributes to the accentuation of the concentric structure. Thus in the outer shells the olivine is, in several cases observed, more abundant than in those nearer the center of the orbules.

If the disposition of the olivine is the chief factor in the concentric structure, the same statement is even more true with reference to the radial structure. The feldspar has no special radial disposition beyond that which is imposed upon it by the olivine. The orientation of the feldspar crystals is entirely irregular, and although between the olivine rods, as seen in thin section, the areas occupied by the feldspar may appear also radial, this is due to the fact that the olivine controls the structure. It is not radially disposed, in the sense that the olivine is, with a definite orientation for each crystal.

In the crystallization of the orbules, then, it is the disposition, regular orientation, and intermittent growth of the olivine to which they owe their peculiar structure.

There are some minor mineralogical variations which may be briefly mentioned. Hypersthene has been mentioned as a subordinate constituent. This mineral is, however, chiefly found toward the central parts of the orbules, becoming scarcer toward the periphery, and is of rare occurrence in the interorbicular matrix. In the orbules magnetite is very sparingly represented by occasional small grains, while in the interorbicular matrix of granular structure it is quite abundant. It is, however, not abundant in that phase of the interorbicular structure in which the olivine is disposed in diversely oriented rods. In such portions of the matrix the crystallization of the olivine has been the same as in the orbules, but has not been controlled by the same orienting force.

The Olivine.—The olivine which constitutes the rods of the orbules required some considerable study to place its determination beyond question. It is in nearly all the slides quite fresh and nearly colorless. The rods are traversed by strongly pronounced cracks, which fall into three categories. The first of these comprises those cracks which are perpendicular to the rods or nearly so, the second those which are approximately parallel to the direction of elongation of the rods, and the third those which are strongly oblique to the direction of elongation but at variable angles. Most of the rods have only the transverse and oblique cracks. The longitudinal cracks are usually found only in those cases where the rods broaden out locally and have the character, in section, of elongated plates. They are usually crossed by transverse cracks. These occurrences are rather exceptional, and the fact that the rods are not sections of plates in general was proved by cutting sections parallel to a radius of an orbule but at right angles to each other and finding the same rodlike character in both sections.

The refractive power of the mineral is very high as shown by its strong relief and the large amount of total reflection of light on the cracks. The thickness of the slides could be fairly closely estimated from the polarization tints of the feldspar, and this being known the polarization tints of the mineral were found to be much higher than those of pyroxene for the same thickness, and to agree closely with those of olivine. Several sections were obtained showing the emergence of bisectrices, and both positive and negative reactions were obtained, but in those cases where the bisectrix appeared to be the acute bisectrix the reaction was optically positive. The optic axial plane is parallel to the direction of elongation. The dispersion is $\rho < v$. The extinction is in nearly all cases parallel to the direction of elongation of the rods and this direction coincides with the axis of maximum elasticity, $\mathfrak{a}$ and therefore, with the crystallographic axis *b*. In sections showing longitudinal cleavage cracks the extinction is at variable angles but quite often parallel, the latter case indicating sections approximately parallel to one of the pinacoids. All of these characters agree with those of olivine. It does not, however, appear to be affected by digestion with hydrochloric or sulphuric acids, a test which is sometimes given for olivine.

The Plagioclase.—The plagioclase of the orbules appears to be more basic than in the normal facies of the gabbro. Optical tests show that it lies at the basic end of the plagioclase series but its exact determination required other methods. Its specific gravity as determined on isolated grains with a westphal balance in the Thoulet solution is 2.724, and in powder the bulk of the feldspar sinks very slowly in a solution having a specific gravity of 2.748 with considerable amounts remaining in suspension for over an hour and none floating. This test shows that the feldspar is not less basic than bytownite. This determination was confirmed by a chemical analysis of the feldspar by Mr. W. T. Schaller, a student in the Department of Mineralogy. The material analyzed by him was a powder repeatedly purified by separation by means of the Thoulet solution. The analysis was made in duplicate and both results are given:

	I	II	Average
SiO_2	44.44	44.33	44.39
Al_2O_3		36.55	36.55
CaO	18.57	18.76	18.67
Na_2O	.83		.83
MgO	none		
FeO	trace		
			100.44

This analysis shows that the feldspar has a composition corresponding to $Ab_1An_{12.7}$ and it must therefore be classed as anorthite.

Chemical Composition of the Orbules.—An analysis of a portion of an orbule representing its mean composition from center to periphery was kindly made for the writer by Mr. James W. Howson of San Francisco. His results in duplicate are as follows:

	I	II	Average
SiO_2	40.50	39.76	40.08
Al_2O_3	23.01	22.71	22.86
FeO	11.96	11.96	11.96
MgO	12.24	12.56	12.40
CaO	11.44	11.39	11.41
Na_2O	1.19	1.33	1.26
K_2O	.40	.37	.38
	100.74	100.08	100.35

The results of this analysis show a larger proportion of soda in the rock as a whole than is contained in the feldspar alone according to Mr. Schaller's analysis, and it seems probable, therefore, that the alkalies may be somewhat too high. The analysis is, however, sufficiently near correct to give a good idea of the general composition of the orbules and the approximate relative proportions of olivine and feldspar. This ratio of olivine to feldspar is estimated to be about 8 : 11, reckoning the hypersthene as an accessory with the olivine; and this estimate involves the assumption that there is a slight excess of alkalies and alumina in the analysis.

It thus appears from the foregoing description that while the main mass of the rock is a hornblende gabbro with accessory olivine and hypersthene, the orbicular facies is mineralogically a troctolite.

Origin of the Orbicular Structure.—The foregoing part of this paper is purely descriptive, and if it were to end here it is hoped that the account given might prove a slight contribution to our knowledge of this interesting class of rocks. But the writer cannot close the paper without at least indicating that in the orbicular facies of this gabbro we have an interesting and important petrogenic problem. That problem can probably only be solved by approaching it from the point of view of physical chemistry. In the crystallization to which the orbules owe their peculiar structure, in the spacing of the orbules, and in their relation to the normal facies of the gabbro, we have various facts the adequate discussion of which would seem to fall clearly within the domain of the physical chemist. Yet it is difficult for the physical chemist with his limited mineralogical and petrographical experience to appreciate these facts, so that the petrographer is constrained, rather than leave the problem wholly unattacked, to offer some feeble suggestions.

We have in the orbicular gabbro magma differentiation presented in a two-fold aspect. The normal facies of the mountain mass is a hornblende gabbro with some olivine and hypersthene. The orbicular facies is a troctolite. Besides this primary differentiation we have within the orbicular rock a secondary magmatic differentiation. The ferro-magnesian unisilicate olivine is, in part, distinctly segregated from the aluminous lime polysilicate, anorthite, the latter mineral crystallizing practically alone at the core of many of the orbules and in some of the concentric shells. The structure of the orbules as revealed by microscopic study shows, moreover, that the magmatic differentiation has been rhythmically recurrent

If now we regard the magma as an intersolution of these two silicates it would seem possible to reduce one aspect of the problem at least to the terms of the "phase rule" of Willard Gibbs. In such an intersolution the component which is in excess would, with falling temperature, reach the saturation point first, and, by crystallization, tend to maintain an equilibrium between the interdissolved silicates which is definite for each particular temperature of the cooling liquid mass. As the temperature falls, however, a stage would be reached—the cryohydrate or eutectic point—where both silicates would crystallize together without further diminution of temperature. If, while this simultaneous crystallization were in progress, the temperature were slightly raised from any cause, the process would be interrupted and the crystallization of the one which was in excess for the new temperature would be resumed, till with falling temperature the cryohydrate point were again reached. Under such an assumed fluctuation of temperature near the cryohydrate point for these two silicates, we would have, in the experimental teaching of modern physical chemistry, a consistant explanation of the rhythmical alternation of the crystallization of feldspar alone and feldspar + olivine.

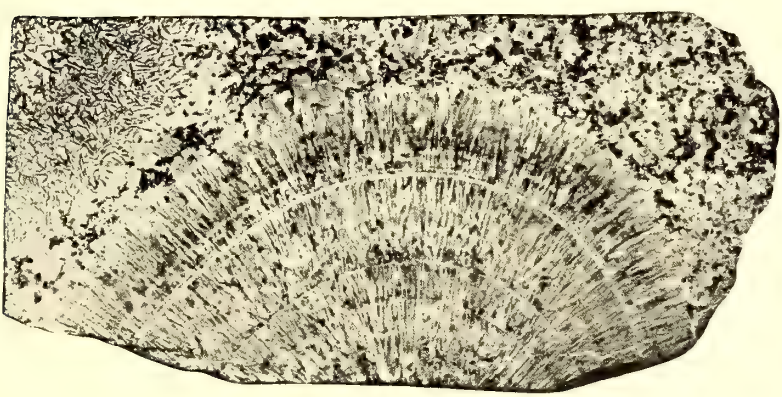
But while this suggestion may explain the rhythm of crystallization or magma differentiation, it by no means explains the specific manifestation of rhythm which is exemplified in the structure of the orbules. Under the assumed conditions of varying temperature in a nearly still magma, the same rhythm might well have found expression in a porphyritic structure or in a laminated structure, or in the form of "basic secretions" or in other ways. We have, therefore, no very clear suggestion from the attempt to apply the phase rule as to the spherically concentric and radial disposition of the products of crystallization, whether at the cryohydrate point or above it.

The general very fairly uniform size of the orbules and the approximately uniform spacing of their centers in those phases of the rocks which are made up chiefly of orbules are, however, significant. This dimensional factor in the problem seems to indicate the spacial limits of osmotic currents within the time necessary for crystallization. If the distance between centers of the orbules be determined by the rather short distances through which osmotic diffusion operates in limited time, may not the radial structure itself be referred to the radial movement of the diffusion currents? If we make this assumption, then the only question that remains to be answered is why, under the control of these radial currents, the olivine alone assumed the attenuated or rod-like form; and the answer to this question probably lies in the habit of growth in olivine, dependent primarily upon its molecular structure, but accentuated by favoring osmotic currents.

University of California,
March, 1904.

A

Weathered surface of orbicular facies of the gabbro showing feldspathic core encased in concentric shells. The thick shells abound in olivine radially disposed and stand out in relief. The deformation of the orbules is well shown to affect the entire series of shells indicating growth in the present relative position. Size ½ nat.



B

Thin section of an orbule showing concentric and radial structure and two facies of the interorbicular matrix. Size nat. x 2⅓.

UNIVERSITY OF CALIFORNIA PUBLICATIONS

Bulletin of the Department of Geology

Vol. 3, No. 18, pp. 397-402, Pl. 47. ANDREW C. LAWSON, Editor

A NEW CESTRACIONT SPINE FROM THE LOWER TRIASSIC OF IDAHO

BY

HERBERT M. EVANS

BERKELEY

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THE BULLETIN OF THE DEPARTMENT OF GEOLOGY OF THE UNIVERSITY OF CALIFORNIA is issued at irregular intervals in the form of separate papers or memoirs, each embodying the results of research by some competent investigator in geological science. It is designed to have these made up into volumes of from 400 to 500 pages. The price per volume is placed at $3.50, including postage. The papers composing the volumes will be sent to subscribers in separate covers as soon as issued. The separate numbers may be purchased at the following prices from the University Librarian, J. C. Rowell, to whom remittances should be addressed:—

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A NEW CESTRACIONT SPINE FROM THE LOWER TRIASSIC OF IDAHO

BY

HERBERT M. EVANS.

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OCCURRENCE AND STATE OF PRESERVATION.

The fossil fish spine described in the following paper was obtained on a palaeontological expedition to southern Idaho, during the summer of 1903, for the purpose of examining the lower Triassic exposures at Aspen Ridge and Paris Canyon. The spine was discovered at the latter locality by Professor John C. Merriam, to whom the author is indebted for advice in the study of the specimen. It was found in an exposure of the lower Triassic in Paris Canyon and about one mile west of the town of Paris.

The associated invertebrate fauna was examined by Professor James Perrin Smith of Leland Stanford Jr. University, who was a member of the party. Professor Smith has made a special investigation of both the Aspen Ridge and the Paris beds, and the geologic position of the Paris horizon is best given in the following note which he has kindly furnished:

"The beds in Paris Canyon are lower Triassic but below the typical Meekoceras beds of the Aspen range. They contain species of the genera *Meekoceras*, *Prionolobus*, *Ophiceras*, *Pseu-*

dosageceras, and *Celtites*. The *Pseudosageceras* seems to be the only species common to these beds and those of the Aspen ridge."

On splitting the slab containing the specimen, the spine broke from the surrounding matrix leaving on the rock, the thin surface layer of the spine, together with the ganoine-coated tubercles which ornamented it. Consequently the ornamentation of the spine by tubercles was not at first evident. As tubercles were supposed to exist, the surface was carefully etched with hydrochloric acid and thus the whole pattern was brought out clearly. Numerous individual tubercles were then extracted and examined under the microscope.

The figure of the spine (Pl. 47, Fig. 1) was based on a study of the complete tubercular pattern which was exhibited after the etching had exposed all of the tubercles present. The arrangement and ornamentation of the tubercles are given exactly as they occur on the specimen.

Three transverse fractures of the spine permitted a study of the cross sections and furnished evidence of the character and extent of the medullary cavity (Pl. 47, Figs. 1*a*, 1*b*, 1*c*). The exact character of the deep posterior furrow at the base was brought out clearly by careful removal of the limestone matrix which filled it. (Fig. 1*d*).

DESCRIPTION.

Cosmacanthus elegans n. sp.

PLATE 47.

Type specimen No. M9087 University of California, Palaeontological Museum.

Spine of medium size, 163 mm. long by 23 mm. greatest width, bilaterally symmetrical, tapering, slightly arched, curving backward, cross-section triangular with a sub-acute anterior angle; anterior edge covered above the base by a rounded enamel ridge. The oblique dorsal line separates a smooth base from the ornamented exserted portion and indicates a posterior inclination of about 45°. The lateral faces are slightly rounded. The posterior face is truncated and hollowed below by a deep furrow which is an extension of the medullary cavity. Upper portion of posterior face longitudinally elevated in a low, rounded, median ridge, or keel, between which and the edges of the face are shallow longitudinal furrows. The lateral and posterior faces are covered with small, closely set, and distinctly sculptured tubercles. The sculpturing of the tubercles is in the form of minute oblique lateral ridges which are generally longer on one side of the tubercle, thus making the pattern somewhat asymmetric; the obliquity of the ridges often approximates a spiral type. The sides of the tubercles curve sharply into a truncated top. On the upper third of the spine, the tubercles are disposed in longitudinal rows parallel with the anterior edge. They increase in number below and dispose themselves in perceptably oblique rows, tending to radiate from the central portion of the posterior edge. The medullary cavity extends for about .85 of the length of the spine and opens in a wide and deep furrow on the lower end of the posterior face. The edges of the lower end of the furrow are sharp and slightly incurved, becoming rounded as they approach each other above to meet near the upper end of the inserted portion.

AFFINITIES.

Isolated dermal spines closely resembling the above in many particulars occur at numerous horizons, being most common on this continent in the Devonian, Sub-Carboniferous, and the Coal Measures. They have been usually grouped under the general term "Ichthyodorulites" and are most frequently referred to the Cestraciontidae.

Among the Ichthyodorulites, a great diversity of form and ornamentation exists, but many spines can be found having some characters in common with the Paris specimen. The smooth base, ornamented faces, and the internal cavity with a low posterior opening, are characters possessed by many genera.

Of the European genera, *Asteracanthus* Agassiz is near this spine in general form and ornamentation, but the similarity breaks down on examination of the individual tubercles and of the posterior surface. One of the conspicuous differences is seen in the entire absence of enlarged tubercles, denticles or teeth on this spine, whereas it possesses a sharply defined enamel keel, which is not present in *Asteracanthus*.

The tendency to arrangement of the tubercles in transverse rows is a character perhaps most marked in *Oracanthus* Agassiz. This genus, however, never shows truncation of the posterior border and the tubercles are also distinctly different from those of the Paris spine.

The general shape of the Paris specimen and its cross-sections, present a strong similarity to the figures of *Nemacanthus monilifer* Agassiz* from the Triassic of England, but the presence of a well marked postero-lateral row of denticles as also the character of the lateral tuberculation in *Nemacanthus* preclude its reference to that genus.

---

*Agassiz L. Recherches sur les Poissons Fossiles. III Atlas 1843. Tab. 7, Figs. 11, 13, 14, 15.

Some similarity also exists between this spine and the fragment from the Sub-Carboniferous which St. John and Worthen* have described as *Glymmatacanthus*, but with such evidence as is at hand one would not be justified in establishing any certain affinities between the two. We know nothing of the character of the posterior face of *Glymmatacanthus*, which, moreover, shows no close agreement in the sculpturing or arrangement of its tubercles and possesses no anterior keel.

The Paris spine can be included in the genus *Cosmacanthus* Agassiz as defined by Woodward.† Its general form, the presence of tuberculation on the lateral faces, and the truncation of the posterior face with low longitudinal keel, are characters which show its relationship to that genus. Of the species which have been included in *Cosmacanthus*, the Paris specimen shows closest affinity with two which St. John and Worthen have described from the Sub-Carboniferous of Illinois and Missouri, and of these, especially with *Cosmacanthus (Geisacanthus) stellatus*. This spine shows clearly the prominent anterior enamel keel, a character which was apparently absent in the type species, *C. malcolmsoni* Agassiz from the old Red Sandstone, as well as in *C. marginalis* Davis and *C. carbonarius* McCoy, from the Irish Carboniferous. It may well be questioned whether this character is not of generic rank and if so the name *Geisacanthus* must be retained for the keeled forms.

The Paris spine is easily separated from the Illinois species by its much greater size, more numerous tubercles and different tubercular pattern, as well as by the difference in the form and sculpturing of the tubercles. For the present we retain it as an Ichthyodorulite, until further information such as its association with teeth, scales, etc. will permit us to identify it with some other form or certainly fix its generic relationship.

At the present time, this is, so far as the author is aware, the only Ichthyodorulite recorded from the American Triassic.

---

*St. John O. and Worthen A. H. Descriptions of Fossil Fishes, Palaeontology of Illinois. Geol. Surv. of Ill. (A. H. Worthen, Director) 1875. Vol. VI, Part II, pp. 446–447; also pp. 440–442.

†Woodward, A. S. Catalogue of the Fossil Fishes in the British Museum. Part II, 1891, p. 111.

It is interesting to note that occurring in the lower Triassic, its affinities are so close with some of the Carboniferous species.

Probably a better knowledge of the ichthyic fauna of our early Triassic will attend a further study of the Idaho beds.

University of California,
May, 1904.

EXPLANATION OF PLATE 47.

Cosmacanthus elegans n. sp.

Fig. 1.—Lateral view of spine. (Natural size).

Figs. 1*a*, 1*b*, 1*c*.—Cross sections of spine taken at *a*, *b*, *c*, on figure 1, showing form and extent of the medullary cavity. (Natural size).

Fig. 1*d*.—Posterior view of base of spine showing character of deep medullary furrow. (Natural size).

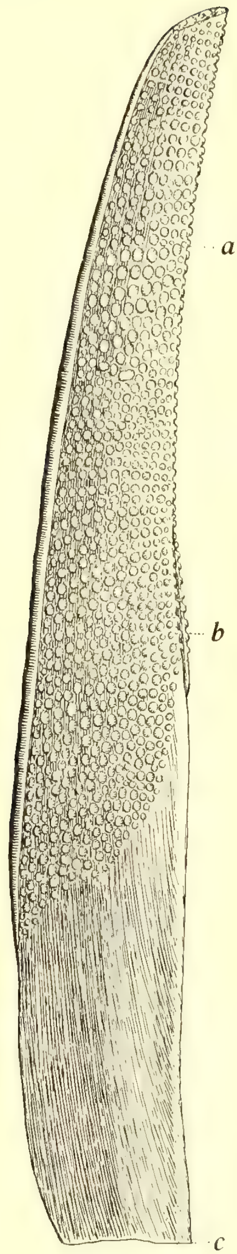
Fig. 2.—Top view of a tubercle showing typical form and sculpturing ($\times$ 12.5).

Fig. 2*a*.—Lateral view of the tubercle shown in figure 2. ($\times$ 12.5).

2

2 a

1d



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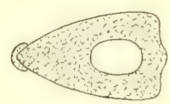
1a



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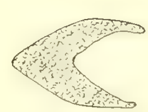

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UNIVERSITY OF CALIFORNIA PUBLICATIONS

Bulletin of the Department of Geology

Vol. 3, No. 19, pp. 403-410, Pls. 48-49. ANDREW C. LAWSON, Editor

A FOSSIL EGG

FROM

ARIZONA

BY

WM. CONGER MORGAN

AND

MARION CLOVER TALLMON

BERKELEY

THE UNIVERSITY PRESS

JUNE, 1904

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BY

WM. CONGER MORGAN

AND

MARION CLOVER TALLMON.

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INTRODUCTION.

Very few instances of the occurrence of eggs in the fossil state have been recorded. The fossil eggs of New Zealand birds are shells which have been preserved by reason of their thickness and strength. The Chelonian eggs of Tertiary age from Auvergne, France, are simply shells filled with hardened mud. An interesting fossil egg from the American Miocene has been described by Oliver C. Farrington* and has been considered the egg of a duck.

The specimen described in this paper was brought to the attention of Professor John C. Merriam some months ago by Mr. G. A. Helmore of San Francisco. It had been in Mr. Helmore's possession for some years and was obtained by him from a prospector who had found it in a large pebble embedded in placer

* Field Columbian Museum, Pub. 35. Vol. I, No. 5, Geol. Series. A Fossil Egg from South Dakota.

gravels on the Gila River in Arizona. Mr. Helmore being unwilling to part with the specimen has kindly loaned it to the University for study and description.

When found, the egg formed the center of a rounded mass of hard calcareous rock which may be called the capsule. The surrounding matrix had been partly removed and the egg broken open before it came into our possession. As it was necessary to obtain a fresh unrubbed surface of the shell for study, the enclosing rock was removed in the laboratory.

Since this seems to be a unique specimen it has been thought advisable to put the principal facts concerning its preservation on record. The authors are indebted to Professor Merriam for many suggestions during the course of this study.

OCCURRENCE.

Unfortunately, the information which we have concerning the occurrence of this specimen does not give us very definite evidence concerning its age. The encapsuled egg is said to have been a pebble in gravels some distance above the present level of the river. If, as has been supposed, the gravels are bench deposits, the egg is at least as old as the Quaternary. If they are of Recent origin we can still hardly suppose it younger than Quaternary, as it is only under the most extraordinary circumstance that deposits of Recent origin can occur as hard pebbles in Recent conglomerates.

THE ENCLOSING CAPSULE.

The nature of the capsule when the specimen was first examined is shown in Plate 48, figures 2 and 4. Some of the matrix had been removed at that time. The enclosing rock forms a flattened ellipsoid measuring about $3\frac{1}{2} \times 4 \times 5$ inches. The surface was sharply ridged, due apparently to differential weathering of the thin layers of matrix. The greater part of the matrix is highly calcareous and might be designated as limestone. The outer layer is of finely laminated clay.

When the capsule was removed its inner surface was seen to be marked with peculiar pits (Pl. 48, figs. 3 and 4), and to be covered with a very thin film of a tarry material, which usually fills the pits completely. The number of pits in any piece of the matrix corresponds in general with the number of visible pores in that part of the shell from which it was removed. (Pl. 48, fig. 1.) These pores in the shell are also filled with tar, and the relative distribution of pits and pores over corresponding surfaces of matrix and shell is the same. Opposite a fine crack in the shell the quantity of tarry material is considerably increased. Chemical examination failed to show the presence of any tar in the matrix except this small quantity on or near the surface in contact with the shell.

THE EGG SHELL.

The egg shell has retained its original composition and microscopic structure. A chemical analysis shows that it does not differ from the shell of a wild goose egg. A thin section (Pl. 49, fig. 2*a*) shows the same structure as that exhibited by a similar section from a hen's egg.

The form of the egg has been perfectly preserved, and from comparison with existing eggs we conclude that this specimen belonged to an aquatic bird. The egg corresponds fairly well to the type of egg laid by the cormorant. Objection might be made that the cormorant's egg is covered with a chalky layer, but when this layer is removed a pitted surface much like that of this specimen is exposed. The minutest markings of the shell are preserved in the matrix, and in this there is no evidence of any scratches such as usually occur in the chalky layer of the cormorant's egg. It seems improbable that the chalky layer would have been washed off without injury being done to the egg, neither is it probable that it was firmly united with the matrix and pulled away in separating the egg shell from the rock.

While the specimen much resembles the type egg of the cormorant, it is also very much like the egg of the larger grebes or herons, the American bittern and the limkin. Again, while the ratio of the short to the long axis is somewhat less than that of the typical egg of a duck, it corresponds almost exactly with measured eggs of many of the larger species of this family. It is probable that when this egg was deposited the region was not near to the sea. Under geographic conditions similar to those now obtaining ducks would be much more numerous than any of the other possible forms, and the probabilities, therefore, favor its anatine origin. Considering that great individual variation often occurs in a single set of eggs, it is evident that specific conclusions as to the parentage of any specimen can hardly be drawn from form alone.

THE CONTENTS.

With the exception of a small space near the periphery, the interior of the egg is filled solidly with a beautifully crystalline mass of the mineral colemanite (Pl. 49, fig. 1). In several places next the shell there is present a dark brown semi-fluid tarry material (Pl. 49, fig. 1, *t*) resembling asphalt in appearance and physical properties. When cold it is brittle, showing a conchoidal fracture with brilliant surfaces, the edges of the fracture becoming rounded on standing. As the temperature rises it grows softer, until at 100° C it becomes a fluid with considerable viscosity. Its specific gravity is a trifle less than that of boiling water. It is readily and completely soluble in petroleum ether, carbon disulphide and chloroform. Hence it resembles very closely that fraction of natural asphalts which has been known as "petrolene."

Between 150° and 250° C a far-reaching decomposition takes place, resulting in the liberation of relatively large volumes of an inflammable gas. Of the residuum in the ignition tube after such treatment, about fifty per cent only is soluble in petroleum ether. The greater part of the remainder dissolves in carbon disulphide, but an appreciable residue is soluble only in chloroform. It is thus evident that the substance obtained after heating cannot be differentiated from a natural asphalt, since it may be separated into the so-called "asphaltene," as well as the "petrolene" fraction, by the ordinary methods.

Submitted to ultimate analysis the same similarity is apparent. Qualitatively examined the tar shows the presence of carbon, hydrogen and sulphur, but not of nitrogen, and although, as it occurs in the egg, the tar contains apparently a smaller percentage of carbon than is found in asphalts generally, the heated material contains the normal constituents in the normal proportions.

These facts tell us something of the history of the fossil during the period in which it lay buried, and also show the relation of the tar it contains to other bituminous matter. Since the tar is completely soluble in petroleum ether without residue of any kind, while the heated product is largely insoluble in the same menstruum, it is evident that the fossil has never been subjected to a temperature as high as 150° C. The tar as it exists in the egg requires simply this slight elevation of temperature to make it indistinguishable from a natural asphalt.

While the colemanite is often in direct contact with the shell, the bituminous material is always so. A large portion of the tar content is collected in one body on what is assumed to be the lower side of the egg (Pl. 49, fig. 1, *t′*). Other deposits lie close to the shell or protrude further into the colemanite, and look like apophyses projecting or depending from the roof of the cavity (Pl. 49, fig. 1, *t′*). At one point a smooth round mass of the bituminous matter is almost surrounded by colemanite.

The relation of the bituminous matter to the colemanite shows conclusively that the tar was present in the shell before the mineral accumulated. When the colemanite entered, a pool of tar lay on the floor of the cavity and smaller quantities were attached to the sides and roof. As the colemanite filled the shell, a pressure, due, possibly, to crystallization, was developed and forced some of the tar out through pores in the shell. A local oxidation or decomposition of the tar may have occurred, producing carbon dioxide, which dissolved the limestone about the ends of the pores and made the cavities or pits of the matrix which were filled with the expressed tar as rapidly as they formed.

While it is easily shown that the tar preceded the colemanite, we naturally inquire concerning the original source of the tar. The explanation which first suggests itself is that it may be a part of the original contents of the egg. It is also possible that the tar may have come in from outside after the egg was inclosed in the rock. In its present condition, however, it is too viscous to make the possibility of its passage through the compact limestone matrix conceivable. It could hardly have passed through the capsule dissolved in some light solvent and have been distributed inside the shell in the various positions in which it is at present found. The possibility of its having entered in a gaseous state is prohibited by its ready decomposition when heated. Furthermore, had it come in from outside there should be traces of it in the surrounding capsule. Analysis of the matrix has shown no tar or other carbonaceous material likely to produce it removed any distance from the egg. That present outside the shell can be accounted for most easily by the assumption that it has been forced out from the interior.

The great improbability that the tar is of external origin is thus clearly indicated. On the other hand the probability that it has been derived from the material originally present in the egg is suggested indirectly by the quantity of bituminous matter estimated to be present in this fossil. Its carbon content is such that it might readily have been derived from the organic matter present in an egg of this size after due allowance has been made for the production and subsequent disappearance of the necessary amounts of ammonia, water, and carbon dioxide. A considerable quantity of methane might have been lost as well. The absence of nitrogen does not argue against this origin, but rather strengthens such a hypothesis, since from his attempts at artificial synthesis Engler was led to the conclusion that the bituminizing process has to do not so much with protein as with fat. From the amount of fat present in a duck's egg of the size of this specimen, all the tar might have been derived even if the proteid matter had entirely disappeared in the form of the ordinary products of decomposition. The chemical character of the original egg content could not have differed materially from that of eggs of existing birds, and in the necessary decomposition and concentration all existing eggs would give a product of practically the same composition.

While absolute proof cannot be given, the evidence amounts almost to a demonstration that the bituminous substance now present in the egg represents a part of its original organic contents. In the absence of any evidence to the contrary we may accept that origin toward which all the evidence points. This specimen presents, then, one of the very few instances, possibly the only one, in which conclusive evidence is at hand to connect bituminous matter with the original material from which it has been derived by a natural process without abnormal conditions.

MEASUREMENTS.

Length of egg	62 mm.
Width " "	40
Circumference (longitudinally)	169
" (transversely)	124
Long diameter of enclosing capsule	120
Average thickness of enclosing capsule	12
Thickness of egg shell	.33

EXPLANATION OF PLATE 48.

A Fossil Egg from Arizona.

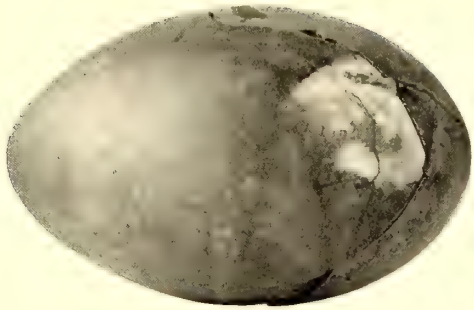
All figures natural size.

Fig. 1.—Side view.

Fig. 2.—Egg in the original matrix.

Fig. 3.—Matrix from inner side, showing pits.

Fig. 4.—In the matrix, end view.



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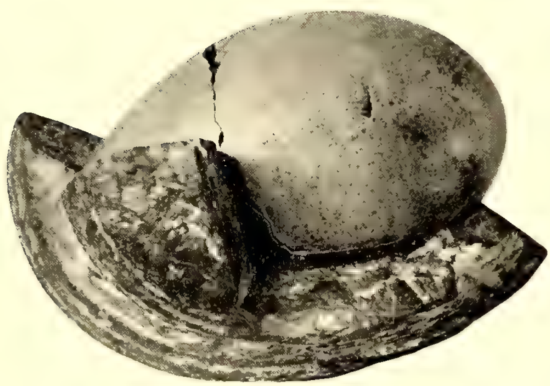

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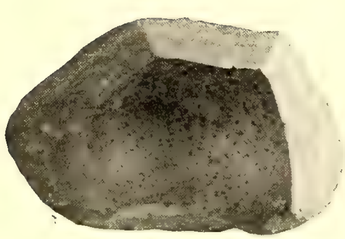

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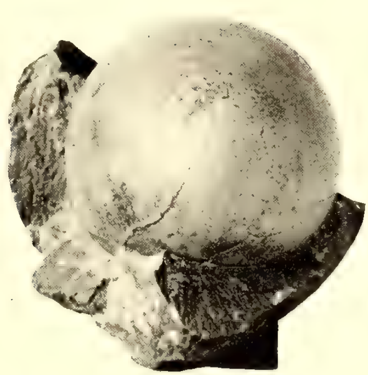

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EXPLANATION OF PLATE 49.

A Fossil Egg from Arizona.

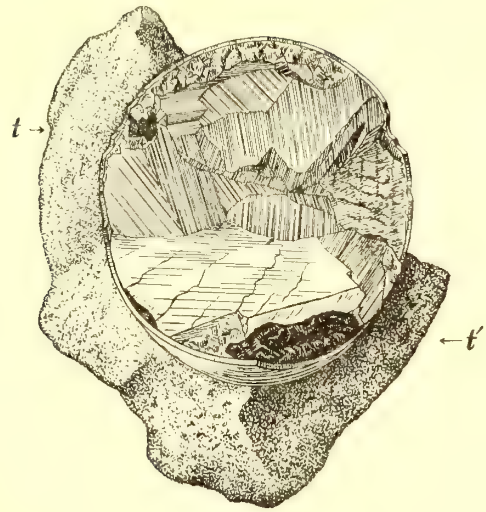
Fig. 1.—Fractured surface of the broken egg, showing the contents; t, t′ and other darkened areas represent the bituminous material; the remainder of the cavity is filled with colemanite. (Natural size.)

Fig. 2*a*.—A portion of the egg shell ground down on one side. *s*, corrugated outer surface; *c*, cellular lower layer. (× 275)

Fig. 2*b*.—Cross-section of the shell fragment shown in figure 2*a*. *s*, corrugated outer surface; *c*, cellular lower layer. (× 275)

Fig. 3.—Outer surface of the shell, showing corrugations of the surface and a large pit filled with bituminous material. (× 275)

Fig. 4.—Cross-section of the pit shown in figure 3. (× 275)



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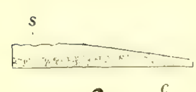
2a



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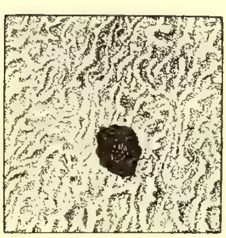

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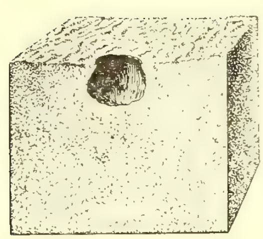

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UNIVERSITY OF CALIFORNIA PUBLICATIONS
Bulletin of the Department of Geology
Vol. 3, No. 20, pp. 411-418, Pls. 50-51. ANDREW C. LAWSON, Editor

EUCERATHERIUM,

A NEW UNGULATE

FROM THE

QUATERNARY CAVES OF CALIFORNIA

BY

WILLIAM J. SINCLAIR

AND

E. L. FURLONG

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EUCERATHERIUM, A NEW UNGULATE

FROM THE

QUATERNARY CAVES OF CALIFORNIA.

BY

WILLIAM J. SINCLAIR AND E. L. FURLONG.

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INTRODUCTION.

While conducting explorations in the Quaternary caves of Shasta County for the Department of Anthropology of the University of California, the writers have frequently found portions of the skeleton of a large ungulate differing in many respects from any existing form. The discovery by Mr. Furlong, during the past summer, of the exceptionally complete specimen described in the present paper, made possible the reference of this more or less scattered material to a new and peculiar genus, for which the name *Euceratherium*[1] has been proposed.[2]

[1] Εὐκέραος, beautiful-horned; θηρίον, wild beast.

[2] Pub. Univ. of Cal. Am. Arch. and Eth. Vol. 2, p. 18.

EUCERATHERIUM COLLINUM Furlong & Sinclair.

PLS. 50 AND 51; TEXT FIG. 1.

Pub. Univ. of Cal. Am. Arch. and Eth. Vol. 2, p. 18.

Generic characters.—Horn-cores solid, situated close together on the posterior extremity of the frontals and far behind the orbits. Frontals reaching to occiput, with strongly developed pneumatic cavities extending into the bases of the horn-cores. Parietal confined to occiput, forming no part of the cranial roof. Lachrymal pit broad and shallow. Dental formula $\frac{0}{}$, $\frac{0}{}$, $\frac{3}{}$, $\frac{3}{}$. Teeth hypsodont, large, without cement or accessory cuspules.

Specific characters.—Horn-cores laterally compressed and curved, elliptical in cross-section at the base, circular in cross-section at the tip. Proximal half of horn-core directed upward and backward, distal half outward and forward. Frontals broadly convex above orbits, slightly inflated toward bases of horn-cores. Occiput with sharp median keel above foramen magnum.

Occurrence.—The type specimen (No. M8751, Univ. of Cal. Palaeont. Mus.) was discovered by Mr. Furlong in the Samwel Cave, situated on the east side of the McCloud River, about thirteen miles north of Baird, Shasta County, and 355 feet above the river. It consists of a cranium without mandible, from which a part of the right horn-core, the jugal process of the right squamosal, and the extremities of the premaxillae and nasals have been broken. The nasals and a part of the premaxillae have been restored in plaster. The superior dentition lacks only the first premolar on the left side. The cranium lay on the surface of a deposit of ossiferous clay flooring a deep vault in the cave, and was almost completely covered by a coating of crystalline stalagmite. The difficulty of preparing the specimen for exhibition was increased by the chalky character and extreme thinness of the bones of the skull, especially in the frontal region where the pneumatic cavities are roofed over by mere shells of bone.

In the Potter Creek Cave, *Euceratherium* is represented by abundant remains which have been found in all the bone-yielding strata. This material comprises broken horn-cores, teeth and podial elements. The horn-cores and teeth agree closely with those of the type specimen.

The age of the deposit in the Samwel and Potter Creek Caves is later Quaternary, but the Potter Creek Cave is probably the older.

Cranium.—The cranium is that of a fully matured individual In size it approximates the skull of a small cow, and resembles *Bos* in the elongated facial region and the restriction of the parietal to the occiput. In the front view (Pl. 51), the facial region appears broad, in striking contrast with the narrowing of the forehead posteriorly. The interorbital area is broadly convex, becoming slightly inflated toward the bases of the horn-cores, as seen in the lateral view (Pl. 50), where the pneumatic cavities approach the surface, reducing the thickness of the frontals to a mere shell. The prominent orbits are well in advance of the horn-cores. Opposite the posterior rim of each orbit there is a small supraorbital foramen. The frontals reach the occiput, excluding the parietal from the cranial roof, and confining that element to the back of the skull.

The horn-cores are supported by the frontals at the posterior extremity of the skull. Although situated close together, their bases do not coalesce. Internally, the cores are filled with cancellous bone tissue and are not penetrated beyond their bases by the pneumatic cavities of the forehead. Proximally, the horn-cores are elliptical in cross section but become circular toward the tips. The proximal portions of the cores are directed backward and upward. Distally, they curve outward and forward with a slight upward turn toward the tip. They are pierced by many nutrient foramina and are deeply marked on the outer side by vascular channels. The anterior margin of the left horn-core bears two low prominences situated about half way up the shaft. These were not observed on any of the horn-cores from the Potter Creek Cave.

On the back of the skull the parietal and occipital elements are fused into a vertical plate, which meets the frontal plane at an acute angle. Superiorly the occiput is narrow corresponding with the great narrowness of the forehead. It widens toward the middle, supporting a median tubercle for muscular attachment. The tubercle unites inferiorly with a sharp median keel which becomes less prominent toward the superior border of the foramen magnum. Lateral ridges extend from the median tubercle outward and downward over the mastoid as in the sheep.

The base of the skull resembles that of *Haplocerus*, and the foramina for the exit of the cranial nerves are the same in character and position as in that genus. The bullae are imperfectly preserved in the type, but in another specimen (No. M8464) from the Potter Creek Cave they are seen to be quite different from the corresponding parts in existing North American cavicorns. Instead of being high and narrow as in the cattle and sheep, they are flattened, presenting inferiorly a slightly concave surface with diamond-shaped outline. Anteriorly and externally, the boundaries of this surface are sharply defined; posteriorly and internally they are less clear. The bullae are low, extending but a short distance (6 mm.) below the level of the post-glenoid process. In *Ovibos*, the rugged bullae present a mammilated crest inferiorly, quite different from the flattened surface in *Euceratherium*.

The free borders of the palatines at the anterior margin of the posterior nares are pinched in a short distance below the narial border, producing on either side a shallow fossa which is not found in any of the North American cavicorns with which this genus has been compared.

The contour of the dental series is the same as in *Ovis* and *Haplocerus*, and as in these forms the posterior palatine foramina open on the maxillo-palatine suture.

In the lateral aspect of the cranium (Pl. 50) the superior border of the temporal fossa is seen to be sharply limited by a ridge which extends from the upper margin of the postorbital bar beneath the base of the horn-core to the lateral border of the occiput which bounds the fossa posteriorly.

The malar arch is robust. That portion of it which is included between the inferior orbital rim and the ridge which extends backward as the lower border of the jugal process is broader than in the domestic cattle.

The lachrymal pit is a broad shallow concavity, limited above by a low ridge along the line of the fronto-lachrymal suture. Anteriorly and inferiorly the boundaries of the fossa are indefinite.

The maxillary is considerably inflated some distance above the alveolar border, giving to the face a swollen appearance.

The anterior opening of the infraorbital canal on the left side is double and is situated above the anterior margin of the fourth premolar, the smaller foramen opening above the larger one. On the right side, the opening of the canal is single.

Dentition.—The dentition resembles closely that of *Ovibos*, but the length of the superior series is somewhat shorter than in that genus. The teeth are hypsodont, without trace of cement or accessory cuspules. The second premolar on the left side is wanting, and the third is abnormally inserted with its outer wall in contact with the anterior margin of the fourth. In the occlusal view (Fig. 1) the premolars of the opposite side have been drawn.

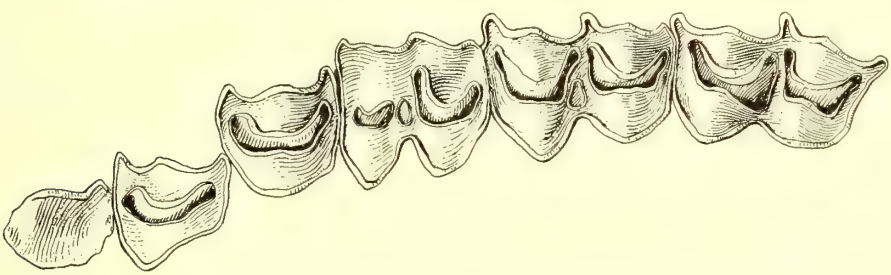

Fig. 1. *Euceratherium collinum.* Left superior dental series, $\times \frac{1}{1}$.

The pattern of $P^{\underline{2}}$ has been obscured by wear. The wall of the inner crescent of $P^{\underline{3}}$ is interrupted by a sharp angulation, while that of the fourth presents the usual lunate outline. The teeth possess the typical selenodont structure characterizing the Ovinae. The external styles are prominently developed, bounding depressed areas with broadly convex median ribs. The lakes are narrow, and owing to the absence of cement remain open even in well worn teeth. The molars display the deep pit produced by the confluence of the walls of the inner crescents which is characteristic of *Haplocerus* and the sheep. Superior incisors and canines were undoubtedly absent.

As the teeth wear, those of the superior series increase in transverse diameter and decrease anteroposteriorly. This is due to the great obliquity of the inner crescents which slope from the triturating surface toward the palate, and to the anterposterior constriction of the long tooth crowns as the roots are approached. In the last superior molar, the anterposterior diameter remains more constant than in the other teeth, due to the posterior prolongation of the metastyle which tends to increase in width toward the alveolar margin.

Affinities.—The closer affinities of *Euceratherium* are not clear. It may be placed in the sub-family Ovinae but can not be regarded as intimately related to any existing North American member of that group. The cranium is larger than in the bighorn sheep while the horn-cores are smaller, are situated much farther behind the orbits, and differ greatly in form and curvature. Although there is a resemblance to *Ovibos* in dental structure, the horn-cores are of entirely different type. A relationship with the cattle is excluded by fundamental differences in dental structure. *Euceratherium* is separated from the goats by the presence of a lachrymal pit. This character serves to distinguish it from *Haplocerus*, from which it differs also in greater size, in the shape and position of the horn-cores and in the exclusion of the parietal from the cranial roof.

As *Euceratherium* belongs to a comparatively late subdivision of the Quaternary, it is probable that the genus will be found to be represented elsewhere on the coast in some of the ossiferous alluvial deposits unless it was restricted to mountainous regions where its remains would stand little chance of being well preserved unless they were entombed in caves. It is not probable that an animal of such size and weight was confined to the higher summits like the sheep and goats, but rather, as the specific name suggests, frequented the lower hills. Its absence from the typical Quaternary plains faunas of California and Oregon may be interpreted in favor of the latter view.

MEASUREMENTS.

Basilar length of cranium from the anterior border of the alveolus of P^2 to condyle, inclusive	285 mm.
Greatest length of frontal from fronto-nasal suture to occiput	168
Width between superior orbital rims	160
Width across bases of horn-cores	112
Width of palate at M^3	73
" " " " P^1	62
Greatest extent of malar arches measured between inferior rims	170
Depth of malar arch below orbit	37
Anteroposterior diameter of horn-core at base	76
Transverse " " " " "	43
Length of superior dental series on alveolar borders	120
P^2 Greatest anteroposterior diameter on triturating surface	14
Greatest transverse diameter on triturating surface (approx.)	12.5
Length of crown internally below alveolar border	12
P^3 Greatest anteroposterior diameter on triturating surface	16
Transverse diameter across middle of triturating surface	16
Length of crown internally below alveolar border	10.5
P^4 Greatest anteroposterior diameter on triturating surface	17
Transverse diameter across middle of triturating surface	15
Length of crown internally below alveolar border	15
M^1 Greatest anteroposterior diameter on triturating face	20
Transverse diameter through middle of anterior crescents	20.5
Length of crown internally below alveolar border	11.5
M^2 Greatest anteroposterior diameter on triturating face	25
Tranverse diameter through middle of anterior crescents	19
Length of crown internally below alveolar border	13
M^3 Greatest anteroposterior diameter on triturating face	29
Transverse diameter through middle of anterior crescents	17
Length of crown internally below alveolar border	12

University of California,
June, 1904.

EXPLANATION OF PLATE 50.

Euceratherium collinum Furlong and Sinclair.

Figure reproduced about one-third natural size (i.e. .36)

The cranium from the left side. The nasal region is restored from other specimens. The extent of the restoration is indicated by a dark line.

EXPLANATION OF PLATE 51.

Euceratherium collinum Furlong and Sinclair.

Figure reproduced about one-third natural size.

The cranium from above. Limits of restoration in the nasal region indicated by a dark line.

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A NEW MARINE REPTILE
FROM THE
TRIASSIC OF CALIFORNIA

BY

JOHN C. MERRIAM

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UNIVERSITY OF CALIFORNIA PUBLICATIONS

Bulletin of the Department of Geology

Vol. 3, No. 21, pp. 419-421. ANDREW C. LAWSON, Editor

A NEW MARINE REPTILE

FROM THE

TRIASSIC OF CALIFORNIA

BY

John C. Merriam.

In the collections of marine Triassic reptiles at the University of California there are a number of specimens representing a heretofore unknown form of swimming reptile. In advance of a more complete discussion of the structure and affinities of this group, the following description of the type specimen is presented.

Thalattosaurus alexandrae, new gen. & sp.

Figure 1.

Cranium elongated, with slender snout. External nares separated and not far in front of the orbits. Dentigerous portion of the premaxillaries elongated but shorter than the maxillaries. Premaxillaries and maxillaries sculptured on the external surface.

Vomers with two rows of flat, button-like teeth. Pterygoids with four or more rows of curved, conical teeth. Palatines not known to be dentigerous. Teeth of the premaxillaries and of the anterior end of dentary slender conical. Posterior part of dentary and probably of maxillaries with button-like, flat or only slightly tuberculate teeth.

Vertebrae amphicoelous, neural spines slender. Dorsal ribs single-headed. Coracoid reniform, elongated antero-posteriorly. Scapula narrow. Humerus short, much expanded distally. Radius and ulna about half the length of the humerus; radius with median constriction. Pelvic arch robust, inferior elements not plate-like.

The type specimen (No. $\frac{1013}{9085}$ Pal. Mus. Univ. Cal.) was found in the Trachyceras beds of the Hosselkus limestone in the Upper Triassic of Shasta County. It includes the anterior two-thirds of the skull and a portion of the temporal region; also parts of over thirty vertebrae, numerous fragmentary ribs, the principal elements of the pectoral and pelvic arches and a considerable portion of an anterior limb.

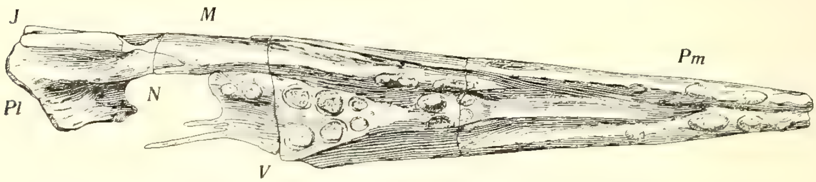

Fig. 1. *Thalattosaurus alexandrae.* Inferior side of the anterior portion of the cranium. *M*, maxillary; *Pm*, premaxillary; *V*, vomer; *Pl*, palatine; *J*, jugal; *N*, narial opening. $\times \frac{1}{2}$.

This species is named in honor of Miss A. M. Alexander, who has not only contributed generously to the financial support of the work on the vertebrates of the marine Triassic but was herself the discoverer of the type specimen furnishing the largest part of our information concerning the group.

In its fundamental outlines, the skeletal structure in *Thalattosaurus* is strongly suggestive of the Rhynchocephalia, but like many of the so-called rhynchocephalian groups it differs so far from the typical forms represented by *Sphenodon*, *Homaeosaurus*, etc., that it can not be included in the same ordinal division. It is likewise so different from all of the other described reptilian families and orders that it must be given an independent position. The family name *Thalattosauridae* and the ordinal name *Thalattosauria* are therefore used to express its position in the scheme of classification.

Recently a number of groups possessing rhynchocephalian characters have been tentatively brought together as orders in a superorder, Diaptosauria, by Osborn.* Although diaptosaurian in one sense simply spells *primitive*, this classification serves to emphasize the distinct kinship certainly shown by many of these

*H. F. Osborn. The Reptilian Subclasses Diapsida and Synapsida and the Early History of the Diaptosauria. Mem. Am. Mus. Nat. Hist., Vol. 1, Part 8, 1903.

forms. For the present the Thalattosauria may be placed in the superorder Diaptosauria, though it is doubtful whether it will be retained in that division or even whether the Diaptosauria can hold together when the various forms included in it become better known. With increased knowledge of the Triassic reptiles, it will naturally become increasingly difficult to determine whether or not some of the orders classed with the Diaptosauria are more deserving of a position in that group than, for example, the rhynchocephaloid Parasuchia having an independent position.

Inside the Diaptosauria the closest affinities of the Thalattosauria are with the Proganosauria and Choristodera. From both groups they differ more widely than these two differ from each other. In many respects, particularly in limb structure, the Thalattosauria represent more highly specialized aquatic forms than the other two orders.

Outside of the Diaptosauria there are noticable resemblances to the Parasuchia and to the Lacertilians. The common characters are, however, almost without exception, primitive or rhynchocephalian characters which we find persisting in the Parasuchia and Squamata.

Some of the most interesting points of resemblance to known forms shown by *Thalattosaurus* are found in its similarity in parts of the skull to *Proterosuchus* Broom, from the Karoo Beds. This form is referred to by Broom as " . . . a primitive Rhynchocephalian which shows a considerable degree of specialization along the line which gave rise to the early Crocodiles and Dinosaurs." Here as in other groups compared, the skull structure shows important differences. Judging from these differences and from the occurrence of *Proterosuchus*, we may expect that the limbs in that form will prove to have a structure very different from that in *Thalattosaurus*, and will tend rather toward the crocodilian type. While showing noteworthy affinities, it would be impossible to bring *Proterosuchus* and *Thalattosaurus* nearer to each other than related orders of the Diaptosauria could come.

UNIVERSITY OF CALIFORNIA PUBLICATIONS
Bulletin of the Department of Geology
Vol. 3, No. 22, pp. 423-475. ANDREW C. LAWSON, Editor

THE RIVER TERRACES
OF THE
ORLEANS BASIN, CALIFORNIA

BY

OSCAR H. HERSHEY

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THE RIVER TERRACES OF THE ORLEANS BASIN, CALIFORNIA

BY

OSCAR H. HERSHEY.

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INTRODUCTION.

The village of Orleans is situated on the north bank of the Klamath River, in the northeastern part of Humboldt County, California. Its vicinity is characterized by the finest display of river terraces that I have ever seen. A somewhat desultory study of them has yielded evidences of changes of grade and of climate that are worthy of record. I will first briefly outline the bed-rock geology and the geomorphogeny of the region, after which I will give a detailed description of the various terrace remnants, followed by a summary of their characteristic features and differences, then discuss the problems presented by them and finally correlate them with the Quaternary terrace system as developed in other portions of the State.

THE ROCKS OF THE REGION.

Structurally, the region about Orleans is characterized by two eastwardly tilted fault blocks. They are separated by one of the great thrust faults of the Klamath Mountains. It occurs less than two miles east of Orleans and has a course from north to south. The throw is at least one mile and probably two, and the hade seems to be toward the east at a rather high angle. The formations on opposite sides of this fault are totally different. On the east there are mainly Paleozoic cherts and slates intruded by vast quantities of igneous rock. There seem also to be a few limited areas of more ancient schists, and a few limestone lentils have been noted. The igneous rocks play a more important rôle than do the stratified rocks, especially along the Klamath River. They occur chiefly in immense irregular masses rising vertically or nearly vertically through the Paleozoic strata. They occupy much larger areas than the latter.

On the west of the fault there is a long north-south belt of Bragdon slates and crushed sandstones. It is from three to five miles in width and is not interrupted by igneous rocks with the exception of a few serpentine and granite areas. It is underlaid by igneous rocks which have been sheared and altered to sericitic and other schists. They rise along the west border in a narrow north-south belt and are bordered on the west by another fault, beyond which occurs another Bragdon area.

All the rocks of the region are resistant to erosion, but the Bragdon slates, by reason of their sheared condition, are much less resistant than are the Paleozoic strata and igneous rocks. This is an important factor in the control of the topography. The mountain summits of the Bragdon belt are lower than those on either hand, and the valleys are broader, especially than those excavated in the igneous rocks.

BRIEF OUTLINE OF GEOMORPHOGENY.

The higher summits of the northeastern portion of Humboldt County represent the Klamath peneplain.* The finest remnant is the flat-topped "Trinity Summit," 13 miles south of Orleans.

*Topographic Development of the Klamath Mountains. *U. S. Geol. Sur., Bull.* No. 196, pp. 15-18.

It has an altitude of nearly or quite 7,000 feet. A long, even-crested ridge from 8 to 12 miles northwest of Orleans is another undoubted remnant of the same peneplain. It constitutes the divide between the Smith River drainage basin and that of the Klamath, and extends far to the north on the line between Del Norte and Siskiyou Counties. It seems to have a general altitude of about 6,000 feet.

The summit of Orleans Mountain, four miles east-southeast from Orleans, although it is not flat, is approximately another remnant of the Klamath peneplain. It has an altitude of about 6,500 feet. Orleans Mountain rises abruptly on the southeastern border of the Orleans Basin, so that we have here a range in altitude of about 6,000 feet in less than three miles. East of the Klamath River and north of the Salmon River abundant remnants of the peneplain have altitudes no less than 7,000 feet. It is thus evident that the Klamath peneplain in the Orleans region is due at 6,000 to 7,000 feet above sea level, and its level at Orleans may be given at 6,500 feet.

The Sherwood Valley of the Klamath River is not well defined in this region, but there are sufficient evidences to approximately fix the level at which its floor is due at Orleans. Apparent remnants of this floor occur northeast of the basin, near the mouth of Salmon River, at altitudes of 4,000 to 4,200 feet, and southwest from the basin at similar altitudes. The Sherwood valleys of the Klamath region appear to have been characterized by long, gentle, curved slopes leading from the neighboring mountains to the flat central portion. The valley over the Orleans Basin appears to have had a width of ten or twelve miles, although the flat portion was perhaps only a third as much. The depth in the center was 2,500 feet.

The Sierran cañon of the Klamath River is a profound trench, comparable in width and depth with the great Sierra Nevada cañons. Between the mouth of the Salmon River and the mouth of the Trinity River, a distance of twenty miles, it is 3,500 feet deep. It does not have the true cañon form, as the walls are not straight and precipitous, so that it is hardly proper to write of its "brink." The rocks of the region have been extensively cracked to great depth, and consequently will not stand in mural precipices. This robs the "Klamath Cañon" of the grand scenery to which its depth entitles it. To one standing in the valley its walls have the appearance of two high, steep, uneven-crested mountain ranges, whose bases nearly adjoin. At the level of the floor of the Sherwood Valley, altitude 4,000 feet, the width of the cañon is from five to eight miles where trenched into the Bragdon slates, and from three to five miles where cut in igneous rocks. The width of the bottom of the cañon is from 100 to 300 feet in the igneous areas, and from 500 feet to one mile in the Bragdon areas. Although high precipices do not occur, slopes exceeding 45° are not uncommon. At Shelton Butte, opposite the mouth of Bluff Creek, the cañon wall rises very steeply from the river's edge to near the summit of one of the most prominent peaks of that region.

The Orleans Basin is simply an abnormally wide portion of the Klamath Cañon. It is due to the comparative softness of the Bragdon slates, the main belt of which the river crosses obliquely for seven miles. Above and below the basin the river flows in exceedingly narrow, rocky gorges, but within the basin there is a valley floor from two to fifteen times as wide as the river, and the slopes above this floor are beautifully terraced to a height of 850 feet above the stream. Long, narrow slate ridges extend far out into the basin and naturally separate it into three divisions, which it will be convenient to refer to as the Upper, Middle, and Lower basins.

The Upper Basin, lying above the Redneck Rock, is about three miles long and one-half to three-fourths of a mile wide, although above the 850-foot terrace level, it is fully a mile and a half wide. The river enters it at the northeastern end from an exceedingly narrow gorge (which it has been following for several miles) and passes through it in a serpentine course, leaving extensive terrace remnants on the inner sides of the curves. The south side of the basin, between the Reece ranch and Pearch Creek, has immense landslides, composed largely of serpentine debris. This strip of territory is exceedingly irregular in topography, but back of it there is apparently a remnant of the highest terrace. The 675-foot terrace is well represented north of the southwestern portion of this basin, but otherwise the terrace remnants represent mainly the lower members of the series, particularly the 120-foot terrace.

The Middle Basin, extending from Redneck Rock to the Wilder Ferry, is about two and one-half miles from north to south and one and one-half miles from east to west. The three highest terraces are well represented along the northern border of the basin, where it is entered by the small Sims Creek and the large Camp Creek. The river in early times displayed a strong tendency to undermine the northern wall of the basin, and thus excavated the valley in that direction to an abnormal distance from the main line of the river. There is a central basin one and one-half miles from north to south and one-half mile in average width, floored by broad expanses of the two lowest terraces. It is largely cultivated in farms owned by the Orleans Bar Gold Mining Company. The village of Orleans is situated near its eastern border. In early times the river seems to have endeavored to cross this basin on as long a course as possible, but now it runs straight across it in a southwesterly direction until it impinges on a slate ridge, where it is sharply deflected toward the northwest. The basin also contains very important remnants of the 120-foot terrace. The slate mountains bordering the basin rise from 2,000 to 3,000 feet above it, probably none of them quite reaching the Sherwood level.

The Lower Basin is two and one-half miles in length and one-fifth to one-third of a mile in width at the level of the "forty-five foot terrace." Most of this width is ocupied by the river and extensive gravel bars, but long, narrow strips of the lower terrace remain on the southern side of the river. They are in large part cleared and cultivated, as the Wilder farm, comprising thirty-five acres. Higher terraces are sparingly represented, although there is an important remnant of the highest, and also one of the "120-foot terrace." The slate hills bordering the basin have slopes of 20° to 45° and rise 1,000 to 2,000 feet above it, with much higher mountains at a short distance farther back. The basin is terminated at the lower end by the river passing into an exceedingly narrow, crooked rock gorge.

DETAILED DESCRIPTION OF TERRACE REMNANTS.

The figures of the heights of terraces given in the succeeding pages were derived largely by a very rough method of leveling, but are sufficiently accurate for the purpose of this paper. Through the courtesy of the superintendent of the hydraulic mine of the Orleans Bar Gold Mining Company, Mr. Fred Hale, I have been able to avail myself of information contained in a blueprint topographic map of the company's property, comprising all of the Middle Basin north of the river. This map bears evidence of being based on careful leveling, and by means of it I am able to accurately determine the altitude and height above the river of the different terraces in the Middle Basin.

The following table will introduce the reader to the terrace system:

TERRACES OF THE ORLEANS BASIN.

Height Above River.	Depth to Bed-Rock, Average.	Height of Bed-Rock.
850 feet.	125 feet.	725 feet.
675 feet.	70 feet.	605 feet.
475 feet.	70 feet.	405 feet.
120 feet.	30 feet.*	90 feet.
70 feet.	25 feet.	45 feet.
45 feet.	35 feet.	10 feet.

The 850-Foot Terrace.—West of Sims Gulch (on the northern border of the Middle Basin) and north of the ditch of the Orleans Bar Gold Mining Company, is Donahue Upper Flat, about 125 feet above the ditch level, and clearly the highest river terrace in the basin. It has an area of eleven and one-half acres. The altitude of the central portion is 1,326 feet. The surface slopes very gently toward the southwest, but is quite regular. A small creek has cut a ditch into it near the western end, and this ditch, just above the company's ditch, shows ten feet of coarse river gravel, containing thickly packed cobbles and boulders up to a foot in diameter. The rock species are mostly greenstone phases from up the river, but also a considerable percentage of granite and dioritic rocks. The bottom of this gravel bed must be at about the ditch level. The gravel is gray in color, but the

*This figure of thirty feet thickness of alluvium applies only to the outer border of the terrace; the thickness of the alluvium farther back is much greater. In this respect this terrace differs decidedly from the others.

slopes above are covered by a deep red soil in which pebbles occur to the level of the flat. Indeed, the red soil of the flat contains small gravel mixed with local debris.

For some distance along the mining ditch the bed-rock surface varies from four feet above the waterlevel to several feet below it, thus exposing the basal portion of the gravel. Except for one or two small channels, like that described from the creek ditch, the gravel is not thick or coarse. The bank has a deep-red color to the very base of the gravel, 125 feet below the flat, but this may be due largely to oxidation, since the lower layers were exposed by erosion. Much of the waterworn fine gravel scattered plentifully in the red soil to the top of the bank has had a local origin. Back of the flat a long, gentle, curved slope leads up to a small, rounded slate mountain whose altitude is 2,008 feet.

The same gravel deposit is exposed along the flume on the east side of Sims Gulch. Sims Creek has cut beneath the surface of this deposit a V-shaped cañon 150 to 300 feet deep. The soft slate under the gravel was easy to erode.

On the east side of Sims Gulch there is a rather narrow ridge leading up from Tennessee Flat. Its summit is gently rounded or slightly truncated. At first it shows slate debris and rock in place, and higher it shows the old channel gravels. The cobbles and small boulders lying about on the surface have a rotten and very ancient appearance. Higher yet the ridge shows only local debris.

The Donahue channel may be traced off to the eastward for a long distance. Back of the Tennessee and Bacon Flats there is a narrow belt of country having a general slope toward the southwest, but it has been cut by a number of little creeks into an undulating tract. The banks of these little creeks show waterworn river gravel embedded in red sandy clay, and the same cobbles and pebbles are scattered about on the soil along the belt.

Along the mining ditch at the point where, going upstream, it passes into the deep valley of Camp Creek, there is rather fine waterworn gravel (no boulders) in the bank just above the ditch.

On the south of the river and north of Pearch Creek, there is a flat of even surface but a gentle slope toward the river. Its outer edge is probably 1,000 feet above the stream, and hence it cannot be referred to as a portion of the 850-foot terrace, but it appears to be a remnant of the gentle slope which bordered the alluvial plain of the 850-foot terrace period. The gentle slope on the north of the river which rises back of Donahue Upper Flat has an elevation and altitude very similar to this flat. The latter has a length of several hundred yards transverse to the slope, and extends back over 100 yards.

The Owl mine, situated high in the hills on the north of the river, opposite the Wilder Ferry, has been worked to the extent of about a third of an acre, exposing waterworn bed-rock of black slate, overlain by a comparatively fine gravel bed, very few boulders exceeding a diameter of one foot. The local slate formation is largely represented, but boulders from above the slate belt occur in sufficient abundance to prove that at this point at least it is an ordinary river deposit. The colors near the base are light brown, yellow and gray, but higher deep red prevails. The fine, soft material above has slidden into the mine and obscured the section. This fine material contains a great quantity of waterworn and subangular slate debris.

At 165 feet above the exposed bed-rock the flat surface of the terrace occurs. The extent of this flat was not measured, but was estimated at twelve or fifteen acres. It is bordered on the west by a shallow ravine, and beyond this there is a narrow slate ridge rising about 150 feet higher than the terrace. On the east there is an undulating tract rising somewhat higher than the flat, and apparently composed of slate. The surface of the flat is even, although it rises quite perceptibly toward the north, but is cut off in that direction by the deep gulch of Salstrom Creek. The terrace remnant appears to be the flat floor of a valley about 1,000 feet wide and trending north-south. In the same direction, beyond Salstrom Creek, a depression of the proper size and shape to be another remnant of the bed-rock floor of this valley, leads into the valley of Camp Creek, near the point where Donahue Upper Flat approaches Camp Creek Valley. Therefore, the Owl Flat may represent a stage of the main river or of Camp Creek. The latter seems the more probable from the slope of the surface, and the great predominance of slate pebbles and boulders. (Camp Creek drains a slate country). No means were at hand for accurately determining the altitude of Owl Flat, but from various points of view it seems to be slightly higher than the Donahue Upper Flat, although the bed-rock floor of the two channel remnants is probably of similar altitude. By considering it a deposit largely of Camp Creek, it may be referred to the same stage as the 850-foot terrace without any difficulty being raised by the great thickness of the deposit and its superior height. Small patches of gravel are known to exist at about the level of the Owl mine, along the north side of the Lower Basin, for a mile and a half downstream.*

The 675-Foot Terrace.—This is represented by a single remnant, but it is so extensive as to be the finest development of the upper terraces. It lies north of Orleans and has an east-west course. The surface is cut into two flats by a deep ravine. The most easterly, Bacon Flat, has an extent of twenty-seven and one-half acres. Its average altitude is 1,150 feet. For such an old terrace, the surface is remarkably even. A ditch on the river side displays the following section in descending order:

BACON FLAT SECTION.

	Thickness.
1. Deep red, horizontally but indistinctly stratified clay, containing small, angular fragments of Bragdon slate and quartz..................	17 feet.
2. Light brown clay, containing much fine river gravel	3 feet.
3. Light reddish brown stiff, sandy clay, containing a few small river pebbles..................	5 feet.
4. Light reddish brown argillaceous sand, containing some small river pebbles...............	5 feet.
5. Light brown rather fine river gravel, no cobble exceeding six inches in diameter, most under four inches and many only one inch in diameter	40 feet.
Total	70 feet.

Base of gravel not seen.

*The Owl Mine building is situated on a small flat eighty-five feet above bed-rock in the mine, and forming the floor of a small amphitheater. Two-thirds of the distance to the top of the steep slope forming the wall of the amphitheatre there is a fresh perpendicular scarp (due to sliding of the gravel toward the mine) five to ten feet high. At the time of my visit, March 18, 1904, the length of this scarp had been increased several inches all along the wall since the last rain, on the morning of the preceding day.

Comparatively coarse river gravel is exposed on the point southwest of Bacon's field, including a boulder eighteen inches long, but finer gravel appears again in a deep ravine northwest of the field. The surface of the terrace is nowhere gravelly but consists of red soil containing small fragments of slate debris.

Tennessee Flat, near Sims Gulch, has an extent of twenty-seven and one-half acres, and an average altitude of 1,160 feet. It has not yet been mined, but externally it presents the same characteristics as Bacon Flat. On its inner border there is a distinct rise to the 850-foot terrace behind it, and on its outer border a rapid descent of 200 feet to the next lower terrace.

This terrace is such a sharp-cut and extensive bench that it readily attracts the attention of one looking down on the basin, and also is a prominent feature of the scenery to one coming up the river. Back of Sandy Bar, one mile above Orleans, there is an exceedingly steep slope of slate which has an even crest 600 feet above the bar, yet this crest is only the edge of Bacon Flat.

The 475-Foot Terrace.—The Orleans Bar Gold Mining Company is at present working off Brown Flat, about three-fourths of a mile northwest of Orleans and immediately south of Sims Gulch. The original extent of the flat was probably thirty-five acres, of which about one-half is worked off. It is bordered on the northeast by the slope leading up to Tennessee Flat, and on the southwest by a gravel capped residual of the next higher terrace. Between these bordering slopes it had a width of about 1,500 feet. The river, in forming the channels under it, must have left the main valley and passed behind the residual just mentioned, into what is now the valley of Camp Creek. The surface of the flat is remarkably even, but slightly sloped toward the south. It has a general altitude of 950 feet, or 475 feet above the river at Orleans, but it is somewhat higher along the north border.

The bed-rock in the mine has a general altitude in the lower channel of 880 feet, but slightly higher channels are being exposed toward the north. They are all comparatively shallow, and apparently about as wide as the present river. The bank exposed in mining is about seventy feet in average height. It exposes three principal types of deposits, but the thickness of each varies greatly from section to section. At the base there is moderately fine river gravel from five to thirty-four feet thick, but mostly ten or fifteen feet thick. Until recently a boulder requiring blasting was rarely encountered, but now the operations are uncovering a bed of large, waterworn granite boulders, apparently of a local origin. Over the gravel there is usually light reddish brown and gray non-pebbly sandy silt, one to twenty feet in thickness. The remainder of the bank displays an irregularly stratified but perfectly waterworn mixture of fine gravel, sand and clay, in which local slate debris, probably from Sims Gulch, plays an important part. Near the surface this deposit is largely replaced by nearly non-pebbly clay. The color is a bright brick red, varying to reddish brown. The deep red stain extends down fifty feet or more; in fact, to the gravel bed and deep into the latter where there is sufficient iron oxide. Blue gravel is not found except in one shallow bed near bed-rock. In other words, the deposit is thoroughly oxidized nearly to the base, even at the center of the original flat.

Directly opposite Sims Gulch there is another remnant of this same terrace, apparently as extensive as the original Brown Flat. Sims Creek has cut a sharp cañon several hundred feet across this terrace.

The residual above mentioned is a narrow, uneven-crested ridge, about half a mile long, and reaching a maximum altitude of 1,113 feet, or 638 feet above the river at Orleans. No traces of the Brown Flat deposits are found in the deep, narrow Camp Creek Valley on the west side of the residual, but Kentucky Flat, at the extreme southern end and just above the old Graham Flat mine, is evidently another remnant of the same terrace. It has an average altitude of 943 feet and an extent of probably five acres.

The 120-Foot Terrace.—The Rocky Point Mine is situated on a point on the south side of the river, near the upper end of the Upper Basin. It has a waterworn but irregular rock bench of black slate at a level approximately eighty feet above the river. This is covered by five to fifteen feet of very coarse river gravel, in which occurs a coarse, somewhat rough variety of placer gold, quite unlike that usual to these deposits, and which has evidently had a local source. Overlying this there is a bed fifteen to twenty feet thick, consisting of very large, angular rock masses, surrounded by a finely stratified brown fine gravel and sand. Above this there is about thirty feet of debris, consisting of a compact clay containing great quantities of rounded and semi-rounded fragments largely of serpentine, and also many large, angular rock masses. The color is greenish near the base, but decidedly red near the top. There is no stratification. From its general appearance I would at one time have pronounced it a glacial deposit, but now I recognize it clearly as the basal portion of an immense landslide. For a long distance back of the mine the country has the peculiar landslide topography. Where this landslide rests on the river deposit there is a comparatively straight and sharp line. The formation of the channel deposit immediately preceded the landslide. In fact, the middle formation shows the desperate effort the river made to dispose of the earlier landslide material.

The Markusen Mine, situated on the north of the river, about two miles above Orleans, has been operated mainly on one of the finest remnants of the 120-foot terrace, of which about fourteen acres have been mined off, leaving an expanse of boulder-strewn bed-rock about 1,500 feet long and 300 to 500 feet wide. This consists of an irregular platform 90 to 100 feet above the river, back of which there is a channel (the width of which is not yet known) twenty to thirty feet deeper. Over the bed-rock there was fifteen to twenty feet of moderately coarse river gravel. Scattered about on the bed-rock there were a few large boulders which remain intact and are the most remarkable feature of this deposit. The bed-rock is black slate, but these boulders are composed of a light yellowish or gray fine grained material, apparently largely igneous, but containing abundant inclusions of a hard laminated cherty rock, so that the term breccia is properly applied to the boulders. I do not know where this rock occurs in place, but I expect to find it up a neighboring gulch along the line of the great thrust fault, as somewhat similar breccia occurs along the fault toward the south.

Seven of these boulders were roughly measured and found to have dimensions about as follows:

1. 15 x 12 x 10 feet.	5. 18 x 10 x 18 feet.
2. 15 x 10 x 10 feet.	6. 12 x 10 x 12 feet.
3. 20 x 15 x 12 feet.	7. 20 x 12 x 18 feet.
4. 30 x 12 x 12 feet.	

There are somewhat smaller boulders of the same material, but there is not a gradation from the largest to the smallest, so that these boulders bear a relation to the ordinary gravel similar to that between large glacial erratics and the finer rock fragments of an ordinary till. They are perfectly waterworn on all visible sides. At first I was appalled by the problem which they seemed to raise, but now I consider them the residua of a landslide.

The present bank of the mine has a height varying between sixty and ninety feet. Above the ordinary river deposit it contains mostly local debris, which is distinctly stratified. Near the upper end of the mine there is much angular debris of serpentine and other local rocks from a neighboring gulch. The upper twenty feet is a reddish brown clay, containing rock fragments. This red clay stratum gradually thins downstream, and only a few feet in thickness is left at the top of the bank near the lower end of the mine.

The following section in descending order was made nearly midway of the bank, and is fairly typical of the deposit:

SECTION IN MARKUSEN MINE.

1. Reddish brown sandy clay, with angular rock debris	15 feet.
2. Gray, finely stratified layers, mostly made up of angular and subangular slate debris...	40 feet.
3. Reddish brown sandy silt, containing few rock fragments	10 feet.
4. Ordinary river gravel	20 feet.
Total	85 feet.

No. 2 is a torrent fan of slate debris formed at the mouths of several small ravines in the face of the steep slope back of the mine. Its surface constitutes the present terrace remnant about 100 yards wide which rises at a considerable angle from the edge of the bank to the foot of the steep mountain slope. During the winter there are small creeks in the ravines, and they cross the terrace in sharp cañons cut partly through the torrent fan, but in one case not to its bottom. It is probable that much of the slate debris was swept down from the slope without issuing from these ravines.

A single small remnant of the original surface occurs near the outer edge of the bed-rock platform. The bank displays twenty feet of gravel, overlain by ten feet of reddish brown sandy clay with small slate fragments. The surface is at least 120 feet above the river, but the terrace may have declined another ten feet to the outer edge.

Opposite the lower end of the Markusen Mine there was an extensive remnant of the same terrace which has been mined off to the extent of at least ten acres. The mine occupies a point which projects beyond the center of the basin. It is bordered on the riverward side by a precipitous black slate bluff about ninety feet high. Portions of the rock platform, in the form of shallow channels, may be only eighty feet above the river. The high bank left at the inner edge shows at the base about twelve feet of ordinary river gravel, overlain by a horizontally stratified, reddish brown deposit, consisting of alternate layers of sand and similar sand layers containing many small well rounded slate pebbles. The thickness is about thirty feet. Over it are fifty to seventy-five feet of non-stratified green and red serpentine landslide debris, being the outer edge of the great landslide belt mentioned in the paragraph describing the Upper Basin.

Farther out on the point the gravel was heavier, and twenty feet or more deep, while the fine, gravelly material over it was reduced to five feet. I cannot be certain that any portion of the original surface is left here, but I am of the impression that it formed a terrace about 110 feet above the river, going back with a distinct slope until the presence of overlying landslide material gave it an undulating surface. On the bed-rock floor there are some large, waterworn rock masses not strictly local in origin, as the bed-rock is fissile black slate. Boulders two or three feet in diameter were comparatively rare.

This is undoubtedly a remnant of the same channel as the upper channel of the Markusen Mine, and apparently also the upper channel of the Pearch Mine, to be described next. The important feature of it is the landslide debris resting on the inner border of the alluvium.

The Pearch Mine is situated on the south side of the river, between Pearch and Chinech Creeks, and it has been opened chiefly on a channel which belongs to one of the most extensive remnants of this terrace. The timber has been cleared from the surface, and much of it is comprised in the Pearch farm, about twenty acres in extent. The outer edge of the terrace has been deeply cut by mining, and probably twenty acres of it removed.

On the outer border there is a rolling, waterworn bed-rock platform about 100 yards wide, and whose average height above the river is about ninety feet. It is encumbered with the coarser portions of the gravel, including boulders up to three or four feet in diameter. None of the original gravel is left on this broad rim, but it is safe to say that it was at least twenty feet thick, including the fine layers at the top, so that the surface of the original outer edge of the terrace was probably about 110 feet above the river. Mr. Pearch corroborates this estimate. Back of this ninety-foot platform there is a channel ten to fifteen feet deeper, the width of which is not known, as mining has not yet exposed the back rim. The perpendicular bank fifty to fifty-five feet high is composed almost entirely of moderately coarse river gravel of a rusty color, except in a few places, where, by reason of its remaining in its original unoxidized condition, it has a deep blue color. There are some strata of sand and fine gravel displaying false-bedding. The gravel in places extends practically to the top of the bank, but its surface is irregular and the depressions are filled by a dark red clay nearly free from rock fragments.

The portion of the terrace remnant remaining is about fifty acres in extent. It is distinctly undulating and rises toward the base of the hills at a rate along one line of fifteen inches in twelve feet. This topography is due to a series of torrent fans (consisting largely of slate debris) which have been built up over the river gravel at the mouths of several ravines back of the terrace. Hence, the inner edge of the terrace is an undulating line from 50 to 125 feet higher than the present outer edge. Back of the terrace the slate hills rise as abruptly as a river bluff. One of the most significant of the alluvial fans occurs in front of a comparatively small ravine which does not contain a creek today and has not in recent times yielded sufficient water to cut a channel across the terrace.

Redneck Rock, probably 150 feet long, 100 feet wide and 100 feet high, is the largest of a series of huge erratics extending southeasterly from near the river to the valley of Chinech Creek. They are composed of hornblende schist identical in character with the Salmon hornblende schist formation. They rest on a slope having the irregular topography of a landslide deposit, and associated with them are many angular and subangular fragments of the other rock species occurring in the valley of Chinech Creek. This landslide came a distance of several miles, and appears to have run out on to the 120-foot terrace at the time it was the valley floor. By subsequent erosion many of the huge rock masses have been let down to the river's edge. Redneck Rock is very prominent because of its steep face toward the river and its overlooking the central basin like a giant sentinel. It rises to probably 300 feet above the stream level.

Opposite Orleans, and just southwest of Redneck Rock, there is a very prominent terrace remnant which has been extensively mined by Mr. Ferris. In the old mine facing Orleans the bedrock of black slate is 135 to 150 feet above the river, and the outer edge of the terrace is about 200 feet above the stream. The gravel is fifteen to twenty feet thick and covered by a stratified sandy silt and gravelly layers of a reddish brown color. The present mine shows flat rock platforms at 150 feet above the river with numerous depressions fifteen feet lower. Over these there are from ten to twelve feet of moderately fine river gravel, whose upper limit is a rather sharp and straight line. It is overlaid by about ten feet in thickness of a finely stratified dark blue silt and muck, containing vegetable debris, including pieces of wood. Much of this wood has been lignitized, and Mr. Ferris says that when he finds a piece of sufficient size he burns it in his forge for sharpening tools. Some fragments that were not converted to lignite were secured and forwarded to

Mr. J. S. Diller for examination by Professor F. H. Knowlton, who submitted them to Professor D. P. Penhallow. I have not found any large pieces in the condition of lignite, but small fragments have an unmistakable coaly character. This is the only late Quaternary lignite I have ever seen.

The mucky layer contains very little gravel, but is inclined to stand in a steep bank. It wears into dark brown rounded cobbles, which (as well as wood fragments) are abundant in the tailings. Over the muck there is from fifty to sixty feet of finely and nearly horizontally stratified fine gravel and dirt of a dull, reddish brown color. This material is local in origin, being composed chiefly of slate debris from the neighboring mountain. Many of the slate fragments have been rounded by water action, and the undulating surface of the terrace shows that the material is in the form of local alluvial fans.

This Ferris Channel, from its superior height above the river, is evidently not the same as that of the Pearch Mine, less than one mile farther upstream; but my reason for including it in the 120-foot group will come out later in the discussion. In fact, this group has given me considerable trouble in correlating in the Middle and Lower basins, as it is very complex.

Graham Flat was situated on a point which projects far out into the valley from the north, at about three-quarters of a mile west of Orleans. It was about 800 x 1200 feet in extent, or about twenty-two acres, of which about twenty acres have been mined off. The bed-rock occurs in the form of several distinct channel levels. The higher has a height of about 150 feet above the river, and displays a broad rock platform, behind which there is a shallow channel about 150 feet in average width. This upper bed-rock level corresponds to the bed-rock level of the Ferris Mine, as may be clearly seen by looking across to the latter. The steep bank left at the close of mining operations on the inner side of the mine has a height varying from 90 to 150 feet. In some sections it displays largely slate capped by deep red residuary clay, but in others fragments of the terrace deposits remain. One section presents six feet of brown sand at the base, followed by fifteen feet of ordinary river gravel, thirty feet of horizontally and heavily bedded reddish brown sandy silt, and finally twenty feet of red clay and slate debris, some of the latter occurring in large masses. In fact, nearly all the slate seen is probably of the nature of a landslide deposit which came down over the river deposits. Above the bank there is a steep slope leading up to Kentucky Flat.

The second channel of the Graham Flat Mine has an average height above the river of 120 feet, or thirty feet lower than the high rock platform. It is characterized by small basins, from ten to thirty feet deep, which give it an irregularity not usual to the old channel floors of this region. About two acres of the outer portion of Graham Flat remain, and the very even surface has a height of 145 feet above the river. (This level corresponds to the 110-foot level of the Upper Basin.) The inner bank contains moderately coarse river gravel until within a few feet of the surface, where it is replaced by a reddish brown sandy clay, except that toward Camp Creek similar reddish silt layers occur lower.

Opposite Camp Creek from Graham Flat there is another extensive remnant of the same terrace, opened as the Salstrom Mine. About six acres have been removed and about the same amount is left. The surface of the flat appears to have a height similar to the upper levels of Graham Flat, but the bed-rock floor seems to correspond to the lower channel under Graham Flat. The surface has a marked slope and rises in a distinct alluvial cone, whose apex is at the mouth of the valley of the comparatively small Salstrom Creek, while there is no corresponding cone apexing on the line of the large Camp Creek. Over the regular river gravel the mine bank shows much reddish brown sandy silt nearly free from pebbles, and near the top of the bank there is a heavy bed of slate gravel. A new cut just opened near Salstrom Creek shows that near the apex of the cone the red silt is replaced by coarse slate gravel.

Camp Creek has cut a cañon 500 feet wide and 150 feet deep between Graham and Salstrom flats, and this is partly floored by long, narrow strips of lower terraces.

The Rough and Ready Mine, owned by A. B. Wilder, is situated on the south of the river above Boise Creek. About one and one-half acres have been mined, exposing the rock floor of the channel at a height of at least 260 feet above the river. There is from five to fifteen feet of moderately fine river gravel, overlaid by twenty feet of finely stratified, non-pebbly sandy silt bed contained driftwood, flattened by pressure. Some of this was secured and forwarded to Mr. Diller, and ultimately reached Professor Penhallow. Mr. Wilder states that he found many fine impressions of leaves on the thin layers of silt, particularly in a light colored stratum. He identified the leaves of alder and a tree locally known as pepperwood. Mining has destroyed this fossiliferous bed, and no specimens of the leaf impressions could be secured. Over the silt there is at least 150 feet of light gray stratified slate debris, a remnant of an alluvial cone formed at the mouth of a neighboring gulch. The strata as well as the surface slope distinctly toward the river. The nearly flat surface has an extent of four or five acres, but the channel remnant is known to be much larger.

The characteristics of this Wilder Mine are almost identical with those of the Ferris Mine, and I would not hesitate to class them as remnants of the same channel and its deposits if it were not for the superior height of the former. I will later develop the probability of a differential uplift of the region, but the difference of level between the two mines is so great that I am constrained to consider the Wilder channel as a slightly earlier member of the same group as the Ferris channel.

Opposite the Wilder Mine a long narrow strip has been mined off as the Yellow Jacket Mine. The bed-rock floor seems to be of sufficient height above the river to indicate the lower of the two main channels buried under the "120-foot terrace."

The 70-Foot Terrace.—Outside of the 120-foot terrace of the Markusen Mine there may have been a lower terrace which has been practically mined off and the original surface nowhere remains. The rim of the channel has a level of seventy-five feet above the river and the channel behind may be fifteen feet deeper. It is possible that this belonged to the 120-foot terrace. Outside of the rim there is a narrow strip of gravel resting on bed-rock at forty to forty-five feet above the river, and this probably represents the seventy-foot terrace. In proceeding downstream it becomes a distinct channel remnant several acres in extent, but the original surface seems nowhere preserved.

The outer and lower channel of the Pearch Mine has been pretty thoroughly cleaned out, and displays a trough 200 to 300 feet wide, which is separated from the river by a distinct rim or rock ridge about twenty feet high. The floor of the channel is at present about thirty-five feet above the river and the crest of the rim about fifty-five feet. The gravel in the channel appears to have been moderately coarse, but boulders over two feet in diameter are rare. Over the outer rim there are a few remnants of the terrace deposit. At the base there is a thin layer of gravel, over this a ten foot stratum of brown sand and above this a five foot stratum of brown sandy clay abounding in small, waterworn slate fragments. There are a few small remnants of the original surface at a level sixty-five or seventy feet above the river. There can be little question that this is a remnant of the seventy-foot terrace.

There is a fragment left of the original surface over the inner rim, but it is fifteen or twenty feet higher than the terrace level on the outer rim. Over the bed-rock there is thin gravel, then brown sand, followed by a fine pebbly layer as in the outer edge of the deposit. It appears that the terrace had a distinct slope toward the river. But a remnant of the 120-foot terrace so abruptly overlooks these lower terrace remnants as to make it evident that one did not merge into the other, but they preserved their individuality here as elsewhere.

Immediately above Orleans, on a long point that projects out into the valley, there is an old mine, commonly known as the "Wilder Diggings." It exposes two channels which have courses nearly at right angles to the present river. The higher has been worked off to the extent of about 700 x 400 feet. There is a broad, comparatively even rock platform at sixty-five feet above the river, and back of this there are traces of a slightly lower channel surface. The original deposit is exposed around two-thirds of the circumference of the mine, and presents some significant features. Over the bed-rock there is a moderately coarse gravel bed with lenses of false-bedded sand and fine gravel, these lenses usually having a decided dip. The thickness of the gravel is from ten to twenty feet. It is overlaid on all sides of the mine by three to eight feet of reddish brown sandy silt, which in places is nearly free from rock fragments and in other sections has small angular and rounded fragments. It is a marked horizon throughout the mine. Along the outer edge it is thickest and constitutes the surface formation. It appears to have formed a comparatively even terrace at about eighty-five feet above the river. Along the inner side of the mine it is overlaid by slate debris of gray color. This has slidden from the steep slope back of the mine and is disposed in the form of two rather sharp fans, in the axis of each of which the material reaches a thickness of thirty feet. But these are landslides and not torrent fans. In one the material is thoroughly broken up, but in the other large masses of the slate remain practically unbroken, from which the exposure resembles a bed-rock bluff. Curiously, the gravel and red silt pass under this mass of rock, at first sight startling the observer. Near the border of the deposit contorted slate in a bed only six feet thick overlies the red silt with a nearly even line of contact.

The lower channel on this point has an average width of only 150 feet, and its floor has a height above the river of forty feet. The debris piles left on the floor include a number of rather large boulders. The bank at the head of the excavation consists of about twenty-five feet of moderately coarse gravel overlaid by a few feet of brown dirt, the surface of which is that of the terrace. Near the river there are no remnants of the surface of the terrace, but it was probably sixty-five or seventy feet above the stream.

Back of the village of Orleans this terrace spreads out into a broad plain possibly seventy-five acres in extent. The outer border is comparatively even (except for shallow ravines) at a level which at the cemetery is nearly seventy-five feet above the river. The surface rises toward the hills in a series of gentle undulations.

Between the Salstrom Mine and the Salstrom Ranch Flat there are about eight acres of the "seventy-foot terrace," which however, is here probably nearer 100 feet than seventy feet above the river.

The 45-Foot Terrace.—Directly opposite the Markusan buildings there is a narrow channel remnant, possibly several hundred yards long. The bed-rock floor is eighteen feet above an ordinary stage of the river. It is overlaid by fifteen feet of ordinary river gravel of a brown color, containing waterworn boulders several feet in diameter. Over this is about twelve feet of a mixture of angular debris and sandy clay of a brown color, very slightly inclined to red. This is not a landslide deposit, as its surface is even and forms a distinct terrace at forty-five feet above the river. Back of it is the immense landslide already mentioned, but this terrace is newer.

Farther downstream the same channel has been extensively mined, showing a rock bluff twelve feet high along the river, a broad rock platform depressed behind the rim rock, then a bank in which ordinary river gravel twenty feet thick occupies the lower portion, and above this there is six to eight feet of finely stratified fine gravel, largely of local slate debris, and evidently the alluvial fan of a tributary stream. This passes upward into five or six feet of sandy clay containing many angular rock fragments of cobble size. The colors of the bank are dark brownish gray and light brown, and there is no decided reddish tint even in the top layer. The surface constitutes an even terrace about forty-five feet above the river.

Sandy Bar, a cultivated strip of land opposite the Pearch Mine, is about 2,000 feet long and 300 to 500 feet wide. Near the upper end, where the terrace form is best preserved, the height of the outer edge of the bank is forty-five feet above the river. For a long distance there intervenes between the river and the Sandy Bar Flat a sort of lower terrace, which, however, seems to be due to the erosion of the upper formation. Along the bank bed-rock rises to ten feet above the stream, and over it there is from eight to twelve feet of an exceedingly coarse gravel bed in which waterworn boulders from two to five feet in diameter are very numerous. This deposit seems to pass under Sandy Bar, and to be overlaid by twenty feet of finer dark brown gravel, whose surface constitutes the dark brown sandy soil of the flat. It is replaced farther downstream by a thick bed of dark brown sand. In places the bar rises at a considerable angle toward the inner edge because of slate debris having been worked down on to it from the high bluff back of it. From mining done at low water, and from a shaft sunk several years ago, it appears that back of the rim whose surface is ten feet above the river, there is a channel nearly or quite as deep as the present river level. In the highest floods the river reaches within fifteen feet of the top of the bar. However, this bar is distinctly older and higher than any modern deposit of the river.

Between the Pearch Mine and Redneck's house there is a flat several acres in extent whose surface is about forty-five feet above the river at its ordinary stage. No bed-rock is exposed along the bank, but it may occur to twelve or fifteen feet above the river, as a modern gravel bar 300 feet wide and ten feet high intervenes between the bank and the stream. Redneck is mining along the bank, the bottom of his excavation being about fifteen feet above the river. It shows a moderately coarse river gravel of brown color in the lower twenty feet, and a finer gravel in the upper ten feet, with a black soil at the surface. Where the material in the bank is damp it has a dark brown color. The Redneck buildings apparently stand on another small remnant of this terrace.

West of the village of Orleans this terrace spreads out into a broad plain comprising about 200 acres. It has an average altitude of 526 feet, but the surface is slightly undulating. Bed-rock is exposed along the river, rising mostly to ten or twelve feet above low water, although downstream it gets lower. Over it there is a coarse, bouldery gravel bed fifteen to twenty feet thick. This is overlaid by fifteen feet of dark brown sand. It is the erosion of this sand bed which gives the terrace its gently undulating surface. Near the river the sand has been scoured off the gravel in strips several hundred feet wide, producing an apparent lower terrace, as at Sandy Bar. These lower levels are gravelly on top, thus differing from the regular terraces.

The Orleans post-office stands on this terrace, at an altitude of 520 feet. Opposite it the river at low water has an altitude of 475 feet, thus yielding forty-five feet as the height of the terrace.

On the south of the river, west of the Ferris Mine, there is a broad cove extending into the hills, and it is floored chiefly by a broad, low alluvial fan of a tributary stream, the outer edge of which merges into the forty-five-foot terrace. By reason of erosion the bank near the river is of unequal height. Just below the Ferris Mine there is a small flat at about thirty feet above the river, and this is succeeded by a flat rising to about sixty or seventy feet above the river. Its steep outer slope shows horizontally stratified fine gravel of a gray color and a local slate composition. It declines rapidly downstream until it merges into a flat whose height is forty feet above low-water mark. The steep bank facing the river displays brown sand and silt in horizontal layers, with very little gravel. The flat is cultivated as the lower farm of the Orleans Bar Gold Mining Company, and consequently is above high-water mark.

Opposite this farm the river makes a great bend to the south around Graham Bar, about thirty-four and one-third acres in extent, which at high water is an island cut off from the mainland by a channel 300 feet wide and 700 feet long, leading to Camp Creek. The bar has a maximum height of forty-five feet above the river. Bed-rock is exposed near the river on two sides, but does not rise high. The surface of the bar is very bouldery except a patch at the west end, where the soil is a dark brown sand, as at Sandy Bar. This portion of the bar is slightly higher than the bouldery portion, and the latter, it seems evident, has had the sandy layers removed by the river at high water. On the west side of the bar, at the mouth of Camp Creek, there is a narrow strip representing a terrace twelve feet lower than the forty-five-foot terrace, and corresponding to a terrace on the opposite side of Camp Creek, occupied by the Salstrom farm. This lower terrace consists of fine material (mainly sand), and may be considered local to the Camp Creek system, although there are traces of a similar level at many places along the river.

In the Lower Basin, the forty-five foot terrace has been mined from the mouth of Boise Creek to one-fourth of a mile up the river, and probably eight acres removed. The river floods the mine at extreme high water and has buried the bed-rock floor under sand, but there are traces of an outer rim at about ten feet above low-water mark. Over this the bank displays moderately fine river gravel fifteen feet thick, and above this a bed of dark brown, non-pebbly sandy silt twenty-five feet thick. Its surface at fifty feet above the river is the surface of the terrace.

The Modern Cañon.—In the Upper Basin, the Klamath River has an estimated average width at ordinary stages of 300 feet, but the Modern cañon is mostly from 500 to 800 feet wide. The river is building and rebuilding bars on the inner sides of the curves. There is no flood-plain properly so called, except at a very few places where it has recently piled sand and fine gravel over the ordinary coarse gravel bars. At high water the cañon is flooded from wall to wall. At low water the stream winds about in a manner suggesting overloading, but I think this is due largely to the abnormal amount of material thrown into the river during the past half century by the placer miners. In fact, this disturbance of the natural conditions makes it inadvisible to use the Modern river deposits as a basis for comparison.

The present river channel opposite Orleans is probably 400 to 500 feet wide. Below the village the channel widens to from one-fifth to one-third of a mile. At high water this is flooded from side to side, but at low water the river flows through it in a shallow channel from 100 to 150 yards wide, bordered by bare gravel bars which rise to a maximum of ten or twelve feet above the stream. This is one of the few places where the Klamath Valley widens sufficiently to admit of the formation of extensive Modern gravel bars. In the Lower Basin the Modern cañon is comparable with that in the Upper Basin.

CHARACTERISTICS AND DIFFERENCES OF TERRACES.

The three highest terraces, namely, the 850-foot, the 675-foot, and the 475-foot terrace, have almost identical characters, and may be considered together under the designation of the Upper Group. The channel gravels of this group are relatively fine and usually thin. The reddish brown sandy silts over the gravel beds are flood-plain deposits built by the river during periods of high water. They are unusually thick. The main tributary streams build broad, low alluvial fans of fine material on the borders of the river's flood-plain. The characteristics of this group of terraces are the evenness of surface, the fineness of the materials, the uniformly great thickness of the deposits, the absence of landslides, and the deep red color.

The so-called 120-foot terrace buries an upper group of channels having common characters, and even the bed-rock floor of which may be more than 120 feet above the river. The channel gravels are comparatively fine and thin. They are overlaid by the usual flood-plain silts, which in two mines are fossiliferous. These silts are overlaid by remarkable torrent fans, which contrast strongly with the alluvial fans of the Upper Group. The former are small, thick torrent fans built up on the flood-plain at the mouths of small ravines, while the larger creeks, such as Pearch and Camp, did not build any corresponding fans. On the higher terraces similar small ravines did not yield such fans, but the large creeks built fans. It is because of this diference that the 120-foot terrace everywhere is characterized by a markedly undulating surface, quite unlike that of any other terrace. Further, where the torrent fans are absent, landslides commonly rest on the inner border of the flood-plain.

The lower channel under the 120-foot terrace has coarse and thick gravels, and they are not covered by thick flood-plain silts, although red clay generally forms the surface deposit. This is the outer edge of the terrace, and has an average height above the river of 110 feet in the Upper Basin and 145 feet at Graham Flat, but is due at Orleans at 120 feet, hence my derivation of the term "120-foot terrace." The surface sweeps up over the torrent fans in an unbroken slope. But the torrent fans and landslides do not overlie the lower channel, from which I infer that they were forming on the flood-plain while the river occupied the lower channel.

Red is he prevailing color of the flood-plain deposits of this terrace, and even of the torrent fans where there is much clay, but it is not as intense a tint as in the Upper Group, and does not penetrate as deeply into the gravel. Where the torrent fans are thick, gray and light brown are the prevailing colors.

On the whole, the observer is impressed with the fact that this is not nearly as red a terrace as those higher.

The seventy-foot terrace has no marked characteristics. It buries several channels and has a sloping surface. The reddish brown flood-plain deposits are rather thin. There are no prominent torrent fans and few landslides in connection with it. The gravels are moderately coarse. The total thickness of the deposits is less than in the case of any other terrace. The prevailing color is reddish brown, of the same tint as in the 120-foot terrace.

The forty-five-foot terrace is characterized by coarse gravel in heavy beds, a flood-plain deposit more sandy than usual, an even surface with no alluvial fans except at the mouths of several creeks (and they are not prominent), no landslides, and a dark brown color. This terrace may be described as the flat valley floor. The dark brown sandy soil at its surface contrasts strongly with the red clay soil of the other terraces.

The Modern river deposits are similar in coarseness to those of the lower terrace, but the sand beds have a light brown rather than a dark brown color.

RELATION TO NEIGHBORING GLACIAL DEPOSITS.

A the mouth of the North Fork of Pearch Creek, three miles east of Orleans, there is a morainic patch about 100 x 200 feet in area and forty to sixty feet deep. The first flood in the fall of 1903 made a fresh excavation along the base of the perpendicular bank, showing the glacial deposit in a perfectly fresh condition. The lower portion is a dark blue-gray stiff clay, abounding in angular and subangular rock fragments up to three feet in diameter. The dark bluish color is largely due to its clay base, containing much finely ground black slate. The upper portion to a depth of at least ten feet is oxidized to a light brown color. Most of the rock fragments are smoothed on one or more sides, many of them distinctly scratched and some beautifully striated. In fact, for a glacial deposit, scratched stones are more than usually abundant. The fragments represent all the varieties of rocks occurring thence to the head of the valley, including black slate, granite, diabase, diorite, and various greenstone phases. The fresh bank shows fragments of wood at various levels down nearly to the base. The end of one log was worn round by glacial abrasion. I sawed off a twenty-inch and a ten-inch log and forwarded fragments to Professor Knowlton, who has not yet reported on them. There is not a trace of stratification visible in the mass, and this wood occurs without orientation, as do the boulders. The deposit rests on a bed of coarse, angular rocks, which resists removal, and the creek in consequence is here very high grade. It seems to have eroded about as much of the glacial deposit as it has left. The till is partly covered by an extensive landslide from the steep mountain on the south, and has by it been preserved from entire removal.

Although this deposit is as typical of glacial action as any in America, from its low altitude, and the absence from the valley above of common glacial characteristics, I was at first seriously inclined to consider the possibility of its being a landslide. When I first came into this region I discovered that I was not always able to discriminate readily between a landslide and a glacial deposit. Many of the larger landslides have a topography similar to that of the great Kettle Moraine in Wisconsin, even to the presence of small enclosed basins containing lakelets. Curiously, the moraines of these mountains are smoother in outline, and the landslides have nearly a monopoly of the exceedingly undulating topography. Where a landslide is several hundred feet in thickness the lower side of it is commonly lined by a sheet of stony clay, from one to twenty feet thick. This is the result of the great weight and the kneading of the mass where it slides over the solid rock. The softer particles of the rock are crushed into stiff clay, while the harder particles are rounded, smoothed, and in not a few instances distinctly scratched. The process is very similar to that by which a glacier forms its ground moraine, and in consequence the product often bears a strong resemblance to a glacial deposit. In the Pioneer Mine, with which I am connected, we have tunneled through several extensive landslides, and after passing a loose mass of angular fragments we invariably find a sheet of stiff clay containing round rocks. Streaks of clay containing small rounded, pebble-like rock fragments, sometimes only a quarter of an inch thick, have been produced by a dislocation of the bed-rock only amounting to one or two feet. Similar clay seams containing rock fragments mark the veins where the pressure was not too great. In the latter case all the rock was crushed and the clay selvages, or "gouges," of the ordinary mineral veins resulted.

Where a very large landslide moved a long distance down a mountain, over a variety of rock formations, the clay at its base may be very thick, the included smooth rocks may be of considerable variety, and the harder may have scratched the softer. If, then, erosion removes the landslide deposit down to this clay base, there is danger of the latter being discriminated as an old glacial deposit. If I remember rightly, I once examined such *pseudo* moraines (old landslides) in the Black Hills of South Dakota, and subsequently a geologist who was not a glacialist described them as evidences of glaciation.

In the Orleans region I find that the scratches on stones in the landslides are less distinct and much less numerous than in the undoubted glacial deposits, and the composition of the former indicates a more local origin for the material. After examining a great number of landslides, I find that the difficulty of discriminating them is greatly lessened. In the case of the deposit at the mouth of the North Fork of Pearch Creek, the great variety of rocks present, the beautiful and abundant striation, the character of the clay base, and the inclusion of logs point strongly to a glacial origin.

A few hundred feet farther upstream, on the opposite side, there is a terrace-like remnant of the same deposit, rising fifty to sixty feet above the creek, which latter has evidently cut at this point a post-glacial cañon in till, 100 feet wide and fifty to sixty feet deep. The slopes above are extremely rugged and present no evidences of glaciation. Thence to the head of the creek, the stream flows in a narrow rock cañon abounding in falls ten to twenty feet high. If one keeps in this cañon, near the creek, he sees no evidences of glaciation. But, curiously, if he will climb up the slopes at almost any place, at the height of 100 to several hundred feet, he will find a strip of bouldery debris in which scratched stones are quite common. This resembles the eroded ground moraine of the so-called Intermediate glacial deposits near the head of the South Fork of Salmon River.* The cañon subsequently eroded in hard slates and greenstone also points to the ''Intermediate stage'' of glaciation as the age of these deposits.

Immediately northwest of the summit of Orleans Mountain (altitude 6,500 feet) there is a shallow basin about one-half mile long and one-fourth mile wide, whose smooth floor and hummocky sides make it evident that it was once the gathering ground of a glacier. It is drained northward into Butler Creek and it is also evident that the main glacier descended along the Butler Creek Valley. On the northwest this glacial basin is separated from the basin of Pearch Creek by a low, undulating tract (hardly a ridge), whose hummocks are composed of black slate rounded by glacial action into *roches moutonnées* and partly covered by a sheet of glacial debris. The head of Pearch Creek Valley is extremely abrupt, being, in fact, a precipitous wall of nearly bare black slate, several thousand feet high. The glaciated tract just mentioned ends abruptly at the brow of this profound declivity, and beyond doubt glacial material, and even ice itself, plunged down into the valley of Pearch Creek. At one place it appears to me that I can trace down over the slope a strip where the black slate was smoothed by glacial action, and doubtlessly this connects with the narrow strips of glacial material which extend far down Pearch Creek. Curiously, with the exception of the narrow strips of glacial debris which one often encounters upon climbing several hundred feet above the creek, the basin of Pearch Creek is singularly free from the usual evidences of glaciation, there being no flats, no meadows, no lakes, no distinct smoothed rock surfaces (with the exception mentioned above), no lines of perched erratics, and no distinct moraines. All we have to prove glaciation are remnants of as typical a glacial till as any glaciated area affords—a till more than usually abundantly supplied with striated rock fragments.

*''The Relation Between Certain River Terraces and the Glacial Series in Northwestern California.'' *Journal of Geology,* Vol. XI, No. 5, July-August, 1903.

North of Pearch Creek, opposite the fine till exposure at the mouth of the North Fork, there is a small cove between two rock points. At its head glacial debris extends up the bank to a height of at least 100 feet above the creek, where a bank yields striated boulders. Climbing above this, one finds a mass of broken rock and dirt extending up the valley of the North Fork for several hundred feet. It lacks the granite boulders and other characteristic features of the glacial deposit, but is in the form of a narrow ridge, the crest of which occupies the position of the central line of the old valley of the North Fork. It appears that the glacier which came down the main valley built its terminal moraine across the valley, exactly at the mouth of the old North Fork Valley. At about the same time a mass of coarse debris came down the North Fork Valley and disposed iself just above the mouth, and partly resting on the north end of the moraine, in the form of a torrent fan. The North Fork Creek was compelled to flow into the depression on the west side of the central ridge, and in consequence has excavated a cañon from fifty to seventy-five feet deep, the west wall of which shows bed-rock and the east wall local debris. Before the stream reached the main creek it was turned completely out of the old valley across a rock ridge, over which it now cascades very steeply.

The glacial deposit probably owes its preservation so near the bottom of the valley to its having been deeply buried under the torrent fan from the North Fork Valley and the landslides which came down the mountain on the south. At first examination the post-glacial erosion at this locality appears less than farther up the creek, but when the overhanging coarse local debris is taken into account, it is evident that as much erosion since the glacialation is here indicated as by the rock cañon farther upstream.

After repeated visits to this locality and a careful consideration of the possibility of this glacial deposit having slidden from some higher position, I have concluded that it is beyond doubt in its original place, and that it is directly the product of ice action. By rough leveling from a point in the Orleans Basin, whose altitude is given on the topographic map of the Orleans

Bar Gold Mining Company's property, the altitude of this deposit was determined as about 2,100 feet. It is, therefore, the lowest *bona fide* glacial deposit yet reported from the State of California.

For several hundred yards downstream the valley is a narrow gorge, whose steep, rocky walls are nearly bare of soil to a height exceeding 500 feet, and whose rugged face negatives the idea of glaciation. The bottom of the gorge is encumbered with huge boulders, over and between which the stream cascades, descending at a rate probably little less than 1,000 feet per mile.

At about one-fourth of a mile the gorge widens, and the north side shows traces of two terraces, which continue downstream for several hundred yards. The surface of the lower terrace is a flattish strip of boulders thirty to fifty feet wide, declining downstream as rapidly as does the present stream-bed. The heterogenity of the boulders and the presence with them of ordinary creek gravel, make it evident that this is an older stream-bed. It is bordered on the outer side by a precipitous bluff from forty to fifty feet high. Exposures along the bank are poor, but it seems to be composed largely of boulders and gravel, although in places the bed-rock seems to rise one-third or one-half way up the bank.

The higher terrace consists of coarse torrent fans built up at the mouths of two ravines and the outer portions removed by stream erosion in the formation of the lower terrace. The surface of this upper terrace is a moderate slope leading up the ravines, but the outer border is a very steep slope. Drainage being now largely through the coarse-textured material of the terrace, no cañons have been cut into the fans, so that the floors of the mountain ravines end abruptly at the top of a steep bank, constituting a sort of "hanging valleys." The outer edge of the terrace is about 125 feet above the creek.

These torrent fans apear to be of the same system as that at the mouth of the North Fork, which seems to overlie one end of the glacial moraine; at any rate, they are of similar age, as is evidenced by subsequent erosion by the main creek. Further, I suspect they are the product of an abnormal climatic condition which obtained for a short time in this region, for I do not think there is at the present time sufficient water in the ravines to produce them, and it appears that no such fans have been in process of formation at least since the main creek abandoned the lower terrace level.

For the first half mile below the terraces just described the valley is a narrow, rocky gorge, within which there are no distinct traces of terraces. At one place the creek descends over two vertical falls each twenty feet in height. Several hundred feet farther downstream there is a small rock bench twenty to thirty feet above the creek. It may or may not be related to the lower terrace farther upstream. Opposite it there is a great landslide deposit, which must originally have filled the gorge to a depth of 300 or 400 feet, but has been trenched to the bottom, an amount of erosion which seems to connect this landslide, in so far as age is concerned, with the torrent fans farther upstream

At a mile and a quarter from the mouth of the creek the valley widens to several hundred feet, and the floor is occupied by an exceedingly irregular alluvial plain of recent age. It consists largely of piles of boulders, being simply a series of abandoned creek beds similar to the one now occupied by the stream. Small, boulder-strewn flats are developed at various levels between five and fifteen feet above the creek. These Modern deposits have a character which enables one to readily distinguish their correlatives higher in the valley, and there is no cause for confusion of them with the terraces described above. But at several points there occur remnants of a creek terrace at thirty feet above the present stream, and I am inclined to connect them with the lower terrace described from the valley near the North Fork.

In the angle between the South Fork and the main Pearch Creek there is a deposit of loose material which I was at first inclined to consider glacial in origin. It is probably about fifty acres in extent. The surface is rather sharply undulating, and contains a few closed basins like the "kettle holes" of a moraine. At a rather fresh exposure I found rounded cobbles on which were distinct scratches like glacial striae. I supposed this deposit might have been formed by a glacier coming down the

South Fork Valley, but I subsequently determined the fact that the valley above is a remarkable V-shaped gorge, presenting no evidence of glaciation. I am now satisfied that the deposit is a landslide which came down the high mountain on the southeast and obstructed the valleys of the main Pearch Creek and its South Fork. These streams have trenched it to depths between 100 and 150 feet, the main creek with a valley several hundred feet wide. Consequently, it is bounded on the creekward sides by a steep bluff, above which it rises more gently to perhaps 500 feet above the streams. The surface is covered with coarse, angular fragments of rock, with a few scattered waterworn cobbles.

It is important to know the position with reference to Pearch Creek of the bed-rock under this landslide. I could find no rock exposures at the foot of the bank along the South Fork, but the loose material appeared to go to the creek-level. On the Pearch Creek side a later deposit intervenes between the old landslide and the creek. However, it is practically certain that the valley had been cut down to nearly or quite the present stream-level before the landslide occurred. This limits its age to comparatively recent times. Further, the erosion of cañons in it to depths of 100 to 150 feet seems to warrant its reference to the time or about the time of the formation of the torrent fans and landslides farther up Pearch Creek.

It seems that Pearch Creek was subsequently interrupted just above the mouth of the South Fork by a landslide from the north side of the valley. This partly overrode a creek deposit which is now exposed in a perpendicular bank, and partly incorporated the creek gravel into its mass, so that waterworn pebbles, cobbles and boulders occur with the angular rock debris, embedded in a reddish clay. The comparative recency of this landslide is evident from the fact that Pearch Creek passes it in a narrow gorge, instead of having a valley several hundred feet wide, as above and below this point.

Next, the creek passes a narrow belt of resistant Paleozoic chert, where, although the floor of the valley is 100 to 150 feet wide, the walls are steep and rocky and no terraces appear. After this the stream enters on the relatively soft Bragdon slate, and the valley widens to several hundred yards, including the terraces on the slopes. The first terrace on the south side appears to be a landslide deposit. It has an undulating surface several acres in extent at about seventy-five feet above the creek. It stands in front of a small cove in the mountain slope, out of which it has evidently slidden. It is bounded by a steep erosion scarp on the valley side, which shows only angular rock debris. The bed-rock surface on which it lies must be nearly or quite down to the creek-level. From its position and subsequent erosion on it, I place it in the same category as the older landslides upstream.

At the lower end of this landslide there is the upper end of a prominent terrace, whose surface, unlike that of the Modern creek deposits, is even to a width of several hundred feet, but slopes distinctly down the valley. Its height is about forty feet above the creek, or twenty-five to thirty feet above the Modern alluvium. On the mountain side it is bordered by a steep bluff 50 to 100 feet high, and on the creek side by an equally steep bluff, which displays well rounded creek gravel, abounding in large boulders. Fragments of this same terrace occur on the opposite side of the valley, and display some bed-rock in the lower portion of the bank. It is evident that this terrace deposit once floored a flat bottomed valley from 100 to 150 yards in width, but the creek has excavated in it and possibly partly into the bed-rock below it, a steep-walled cañon, 40 feet deep and 50 to 100 feet wide, which is floored by the exceedingly irregular Modern creek deposits. These latter rise mostly five to ten feet above the creek, with a few remnants of a level nearly twenty feet above the stream. It must be remembered that, from the glacial locality far up the creek to the mouth, these Modern deposits have peculiar characters which distinguish them, and there is no reason for confusing them with older deposits. The forty-foot terrace just described bears such a relation to these Modern deposits and to the higher and older landslide terrace as constrains me to place it in the same category as the lower terrace described from several points up the creek, particularly a short distance below the North Fork Creek. It appears that after the glacial, torrent fan and landslide deposits had been deeply trenched by the creek, there was a period when, although the stream was still large enough to move boulders, there was a tendency to a filling of the valley (perhaps connected with the climatic conditions of the last glacial stage), but this was succeeded by the present period of active trenching.

Opposite the upper end of the forty-foot terrace, the north side of the valley contains a gently undulating tract about five acres in extent, lying mostly between 50 and 100 feet above the creek. Ditches show serpentine debris, and it is evidently a landslide from the serpentine hills back of it. It is bordered on the creek side by a steep bank of erosion. A broad, undulating belt of similar landslide material sweeps around into the valley of the Klamath River just back of the forty-foot terrace.

The broad, even-surfaced forty-foot terrace reaches the mouth of Pearch Creek Valley thirty feet below the level of the terrace on which is situated the Pearch ranch, the 120-foot terrace of the Orleans Basin system. They approach each other in such a way as to place this relation beyond doubt. A strip of the Pearch ranch terrace several hundred feet wide approaches close to Pearch Creek Cañon. It is bordered by a distinct slope, which leads down on to the other terrace. A remnant of the latter over an acre in extent occurs in the downstream angle between the creek and the river and is bordered on the river-ward side by a steep bluff sixty-five feet high, of which possibly forty-five feet is bed-rock and the remainder river gravel. This terrace distinctly overlooks Sandy Bar on the opposite side of the river. There are no other remnants of it in the immediate vicinity, but it is evidently represented by the lower terrace of the Pearch Mine.

In approaching the Klamath River, Pearch Creek descends rapidly in a narrow rock cañon, twenty to forty feet deep. The lower strands of the Modern alluvium disappear into this cañon, being scarcely represented in it, but an upper strand becomes a distinct terrace of creek gravel leading back a short distance from the edges of the cañon. Near the river this terrace reaches thirty feet above the creek, and forty-five feet above the river, so that it is very prominent in appearance, but when it is traced up the creek it passes into the cañon eroded below the "forty-foot terrace" level.

It is apparent that the forty-five-foot terrace of the Orleans Basin system, upon being traced up Pearch creek, soon loses its individuality and merges with the Modern alluvium. The seventy-foot terrace has representatives to a distance of over two miles up the creek, and among them is the lower terrace near the North Fork. The 120-foot terrace, with its characteristic torrent fans and landslides, is represented in Pearch Creek Valley by similar phenomena. This torrent-fan and landslide forming period immediately succeeded the maximum extension of the glacier in Pearch Creek Valley. Therefore, the 120-foot terrace may be referred to the time of the "Intermediate Glacial Stage." Because of the great gaps in the terraces along Pearch Creek, this conclusion is not absolute, but later I will adduce other evidences that the 120-foot terrace is of the same age as the so-called Intermediate glacial deposits. It is out of the question that the Klamath River has cut 100 feet into solid rock since any part of the last, or Wisconsin, glacial stage, and hence the glacial deposit in Pearch Creek Valley must be referred to some older period.

GENERAL DISCUSSION.

Changes of Grade.—The present river is abnormally high grade. According to the topographic map already mentioned, it descends from 482 feet (altitude at low water) opposite Sandy Bar to 467 feet just below the Ferris Mine, a distance of about a mile and a half, and it maintains at least the rate of ten feet fall per mile through the basin. It falls 1,300 feet from Happy Camp to Orleans, a distance of sixty miles, or over twenty feet per mile. It is said that it accomplishes 114 feet of this fall in less than two miles, at the Ischapischa and Mackyarum Falls, near the mouth of Salmon River. From Orleans to the mouth a distance of sixty miles, it falls 475 feet, or nearly eight feet per mile; but much of this is accomplished in the first seventeen miles to Weitchpec, in which section it may fall over fifteen feet per mile.

Its natural condition at all stages is that of a swift mountain stream, abounding in rapids. In high floods it rises thirty feet at Orleans, where the channel is wide, and 80 to 100 feet near Weitchpec and Martin's Ferry, where it is in narrow rock cañons; yet it is unable to climb out of its Modern cañon and flood the valley floor. At extreme high water the present river erodes the banks, instead of depositing fine alluvium. If this river had an ordinary grade, similar to eastern rivers, it would be half a mile wide, for it drains an extensive territory and is one of the largest streams of the State. It has a width of 60 to 100 feet in certain gorges, and 300 to 500 feet in the Orleans Basin.

There is historical evidence that the river is at present aggrading its channel. Old settlers say that at Orleans the bed has risen five feet, and some say ten feet, in the last half-century. This is wholly due to the abnormal amount of material thrown into the river by the placer miners. It is beyond question that if left in its natural condition it would be a strongly abrading stream. Under normal conditions, before the river could materially widen its cañon it would have to cut to a much lower grade. I do not believe that the deposits of the forty-five-foot terrace, including a broad, sandy flood-plain, could have been formed while the river had its present high grade. A reasonable increase or decrease of the volume of water would not have materially affected this problem, because the contrast between the broad valley floor and the Modern cañon is too great. Taken in connection with evidence drawn from all parts of the Klamath region, I feel reasonably safe in maintaining that the cutting of the present tiny cañon is the result of a Modern tilting of the Orleans Basin, presumably toward the southwest. The forty-five-foot terrace descends at practically the same rate as the present river, and consequently this particular period of tilting post-dates the deposition of the terrace deposits.

The terraces above the forty-five-foot terrace do not follow the present river grade. At times I have had the impression that the terraces on the south of the river are higher than the corresponding levels on the north of the river, but this is far from conclusive, and will not be discussed. However, it is practically certain that the higher terraces (all above the forty-five-foot terrace) are, 1st, approximately parallel to each other; 2nd, do not materially descend downstream, but, rather, 3d, are slightly tilted upstream. To determine the amount of this tilting would require a more accurate survey. However, a channel level which at the Pearch Mine has an altitude of about 572 feet seems to have a corresponding level at Graham Flat of 583 feet. The distance involved is about a mile and a half, and, making allowance for an original downstream grade, this would indicate an upstream tilting of about ten feet per mile. It is a matter of observation that the interval between the forty-five-foot and seventy-foot terraces rapidly increases downstream. From this I infer that the river abandoned the flood-plain of the seventy-foot terrace because of a tilting of the basin in an upstream direction. Subsequently there was a reverse tilting toward the southwest, but not to as great an amount as the former north-east tilting, so that the upper terraces still retain part of the earlier slant.

The Upper Group of terraces were apparently formed under comparatively low-grade conditions. This is indicated by the fineness of the gravel, great thickness of the flood-plain deposits and great width of the valleys excavated. At the time that the surface of the 850-foot terrace was the valley floor, the flat central portion was probably from a mile to a mile and a half wide, and this was bordered on each side by a gently sloping tract about one-half a mile wide. The gradual rise of the valley floor to the steeper mountain slopes was not due to local alluvial fans, as in the case of the 120-foot terrace, but to a gradual rise of the bed-rock floor. This gave the upper valley a broad U-shape, indicative of considerable age. Subsequently cut portions of the present valley are more distinctly cañon shaped.

The terraces indicate an uplift, or a series of uplifts, of the Orleans Basin. The bed-rock floor of the highest terrace is 1,200 feet above sea-level. If this has not been uplifted since the river abandoned it, the stream, granting it a grade equal to the present, must have extended over seventy-five miles beyond the pesent coast-line. However, the evidence is that during the formation of these terraces the river has been extended. At least the lower of the marine terraces along the coast must be the correlatives of these river terraces, as they all date from the latter portion of the Quaternary Era. With the exception of a slight very recent subsidence, the coast line seems to have been rising intermittently for a considerable period. At any rate, the river has not been materially shortened during the down-cutting from the 850-foot terrace. It is out of the question that the river could have descended 1,200 feet in sixty miles and yet eroded such a broad valley. Taking into consideration the present high grade of the stream and the past lower grade, it is probable that, although the bed-rock floor of the highest terrace is but 725 feet above the river at Orleans, it has been uplifted about 1,000 feet. This elevation has been intermittent and, so far as the Orleans Basin is concerned, not differential in character until after the completion of the deposits of the seventy-foot terrace. One of the principal uplifts is represented by the interval between the 475-foot and the 120-foot terraces, and if it extended over a broad territory it may have been concerned in the formation of the glaciers of the Intermediate stage. The last uplift, to which the Modern cañon is due, was perhaps of equal importance.

Perhaps I should state that I do not expect the same relative importance between the different uplifts to obtain throughout the Klamath region. It is my impression that in general, and especially farther east than Orleans, the last uplift greatly preponderated over the others in amount of elevation. It was of a decidedly differential character, decreasing to almost nothing at the present coast-line.

Changes of Climate.—When I entered upon this study I hoped to gain an intimation of variation in the climate by a comparison of the size of the channels of the different terraces, but I have not been able to get any decisive evidence on this point. The various channels appear to be similar in size to the present. If there is any difference it is that the channels of the Upper Group are smaller than the present channel. The size of the channel is conditioned upon the grade as well as the volume of water; therefore, considering the original low-grade condition of the Upper channels, if they are smaller, or at least no larger than the present channel, they indicate a smaller run-off (less precipitation) than the present.

The second line of evidence which I hoped would yield an intimation of climatic change is the color of the various flood-plain deposits. We have in the basin a sudden change from red to dark brown. I believe that the red indicates a warm but not arid or semi-arid climate. In a paper entitled "Subaerial Decay of Rocks and Origin of the Red Color of Certain Formations,"* I. C. Russell shows that red residuary soils are characteristic of countries having a warm, moist climate, and not an arid climate. The same red soil material deposited in bodies of water in the absence of much organic matter will yield red formations. J. S. Newberry says: †"The fact that it is generally in this condition, and therefore the rock is red, proves that it contained little or no organic matter when deposited, for whenever decaying organic matter is present in any considerable quantity it reduces he peroxide of iron to protoxide, and makes the color, so far as influenced by the salts of iron, gray, green or blue." However, on the Isthmus of Panama, I found a deep red soil prevailing in the dense jungles, even where the underlying rock was black, gray or yellow, while on the grassy plains that are dry half the year, unless the underlying rock was red, the soil was never of that color. Red and other bright hues occur on deserts, but it is not the brick red tint of the moist tropics. The prevailing colors of desert soils are ashen gray and light brown, unless the underlying rocks are red.

It is a question whether the red color of the upper terraces was original or has subsequently been produced by oxidation. One fact leads me to think that the flood-plain silts were deposited red. The color is uniformly reddish brown (except in the few places where it is dark blue because of deoxidation on account of the presence of much drift-wood), and these silts preserve this color where they pass under thick masses of gray slate debris or green serpentine landslides. If originally red, it implies that the river drained a country having a prevailingly red soil. Whether the red color of the silts was original or subsequently produced, it indicates a comparatively warm and not arid climate for the earlier portion of the terrace period. In fact, these red silts occur down to the seventy-foot terrace.

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*Bulletin No. 52, U. S. Geol. Survey.

† Monograph No. 14, U. S. Geol. Survey, pp. 7, 8.

The dark brown color of the flood-plain deposits of the forty-five foot terrace is due to the presence of much carbon. The soil was prevailingly dark brown. It implies a luxuriant vegetation and a cool, moist climate. As I will correlate this lower terrace with some portion of the last great glacial epoch, it will appear that the lowering of the temperature which caused the great extension of the Wisconsin glaciers, changed the soil of Northwestern California from red to brown. Since the glacial period has terminated the soil has gradually become lighter in color, as evidenced by the lighter tint of the Modern silts.

Professor D. P. Penhallow's report to Mr. Knowlton on the fragments of wood from the Ferris and Wilder Mines is as follows. Set No. 1 is from the Wilder Mine, and Set. No. 2 from the Ferris Mine:

"I have completed an examination of your specimens and have to report that they are all Coniferous. They present some interesting features of preservation, which I shall discuss at a later date in another connection. I have numbered the specimens from 1-7.

No. 3, Set No. 1, is Pseudotsuga macrocarpa.

No. 4, Set No. 2, is Juniperus californica.

Nos. 1 and 2 of Set No. 1 represent a species of Juniperus which could not be determined on account of structural alterations, but there is reason to believe it may be J. californica.

No. 5 of Set No. 2 is not determinable, owing to the very high state of alteration, which would not permit of sectioning.

Nos. 6 and 7 of Set No. 2 are either Pseudotsuga, Picea or Larix. It is impossible to decide definitely between them, but the probability seems to lie in favor of the first.

With respect to the relation to existing representatives of the same genera, it is to be noted that Pseudotsuga macrocarpa is still extant in the same region. Juniperus californica appears to have receded somewhat toward the south, as its northern extension is at present confined to the valley of the Sacramento, thence southward along the Coast Range. While these facts are not in any way conclusive, they suggest the possibility that present conditions are slightly more boreal than during the time our trees were living. This would seem to agree with the evidence of fossil representatives of Pseudotsuga and Sequoia from other regions of the West, which shows a definite recession from previously occupied areas.''

The most startling result of this study is the discovery of practically conclusive evidence of a comparatively short period of excessive rain-fall. This was first suggested by the torrent fans on the 120-foot terrace. It must be remembered that these fans occur only at the mouths of such small ravines as did not produce similar fans on any higher or lower terrace. Corresponding fans in the mountain gulches away from the river are so coarse and so peculiarly ridged along the central line leading up the small gulches as to imply rapid formation as the result of cloud-bursts. Now, cloud-bursts are characteristic of arid climates, and for a time it was a question in my mind whether these torrent fans indicate excessively humid conditions or semi-arid conditions. I could not find any satisfactory solution for the problem until it occurred to me that the landslides furnish the key.

It is a remarkable fact, established by abundant observation, that the great majority of the landslides bear an intimate relation to the 120-foot terrace. A few landslides occurred earlier, and some later, even down to the historical period, but the larger landslides, and by far the greater number, occurred during a short period which was identical with the torrent fan period. In this connection there are three hypotheses worthy of consideration:

1. That in cutting from the 475-foot to the 120-foot terrace such high, steep slopes were produced as especially favored landsliding. The objections to this are that many large slides along the serpentine belts moved several miles, and from positions not at all affected by erosion below the 475-foot level, and that these landslides did not occur in considerable numbers until after the upper channels under the 120-foot terrace were completed. They clearly date from a particular portion of the time occupied in forming the 120-foot terrace.

2. Many of the settlers attribute these landslides to earthquakes. The region is one of the most stable on the continent, and, so far as I am aware, no severe earthquakes have been expe-

rienced here within the historical period. There is no collateral evidence of a period of severe earthquakes in the latter portion of the Quaternary Era, and, besides, I doubt the efficiency of a series of earthquakes to produce the phenomena observed.

3. The hypothesis which I accept is that the landslides connected with the 120-foot terrace are due to the same abnormal climatic condition as produced the torrent fans. This condition was one of excessive rainfall. Cloud-bursts with prevailing semi-arid conditions would not soak the earth to a sufficient depth to cause such a general landsliding. It required long, heavy rains. This season has been one of abnormal precipitation. From the 3rd of February to the 29th of March there was almost continuous storm, and about forty inches of rain fell in Orleans. Many of the smaller landslides settled several feet, but no large ones were formed, and no torrent fans similar to those of the 120-foot terrace. The torrent-fan and landslide-forming period must have been one of almost continuous heavy rain for months, with frequent cloud-bursts. It was almost of a cataclysmal nature—a sort of incipient "Deluge." I am a firm believer in the usually mild processes of Nature, but we certainly have evidence here of something abnormal.

During this period of excessive precipitation, the river occupied the lower channel under the 120-foot terrace. The gravels of this channel are markedly coarser and thicker than those of preceding channel. This is due largely to the coarse debris thrown into the channel by the landslides and coarser torrent fans. The river must have been greatly increased in volume, otherwise the sudden influx of this coarse material would have caused its channel to be aggraded much more than it was. Thus the conditions of the channel furnish corroborative evidence of excessive rainfall.

This supposed period of excessive humidity appears to have immediately succeeded the maximum extension of the glaciers of the so-called Intermedite Stage. It is probable that the warm rains caused the glaciers to be rapidly melted away. If I am correct in correlating these "Intermediate" glacial deposits with the Iowan drift of the Eastern States, it will appear that the period of excessive rainfall in the Orleans Basin was identical with the period of deposition of the Iowan loess in the Mississippi Basin. This suggests the idea that the loess may have been due to more abnormal conditions than simply a subsidence of the region.

Relative Age of Different Terraces.—In comparing the cañons excavated between the different terrace levels. I will ignore the alluvial deposits. The time occupied by their removal is a very small fraction of the entire period of cañon cutting, and consequently they introduce a needless complication into what will at best be a very rough computation.

By inquiring among the Indian fishermen and others who are acquainted with the river, I have derived the estimate that the average depth of the bed-rock below present low-water mark is about ten feet, and as the bed-rock floor of the forty-five-foot terrace averages ten feet above the river, twenty feet may be assumed as the average depth of the Modern rock-cañon.

The most delicate part of this discussion is the determination of the probable age of the Modern cañon. We have no natural chronometers, such as are constituted by Niagara and St. Anthony Falls. Extensive inquiry among the old settlers has not yielded very definite results. However, it is certain that the cañon has not been eroded within a period of several hundred years. By reason of the placer miners' tailings, the river has been aggrading its channel for some years, but that does not prevent it from eroding the banks. In 1860, and again in 1890, severe winters caused many landslides along the river, but, considered as a whole, there has been no appreciable widening of the channel in the past fifty years.

Less than one-half mile downstream from the Orleans post-office, and on the same side of the river there is an old Indian village site. The edge of the bank is about twenty-five feet above the river, and a gentle slope leads back from it to a flat plain which is about 250 feet wide and has a height of about thirty-five feet above the river. Back of it, another gentle slope leads up to the flat plain of the forty-five-foot terrace. The lower terrace is composed mainly of a deep bed of dark brown sand. Similar sand beds occur at this level at various places along the river, and they are usually essentially non-pebbly. But at this place the sand contains great quantities of river cobbles, very many of which are broken. They are scattered about on the plain over a space fully 200 yards long by 100 yards wide, and patches of them occur on the higher terrace. Along the bank where the river at flood times is eroding the sand into a perpendicular bank from three to six feet high, it is seen that in places the cobbles only extend to a depth of two feet, but in others are thickly packed to a depth of five feet. By the removal of the sand the cobbles accumulate at the foot of the bank, where they form extensive beds. They attract attention by reason of the comparative uniformity in size (by far the larger number being three or four inches in the longer diameter), and by the large proportion that are broken. Many of them are reddened by fire, and nearly all are supposed to have been used in cooking acorns, by which they became brittle and were easily broken. Along with these cobbles there are many angular fragments of white quartz, and occasionally an obsidian flake, but implements are not common, although I am told that mortars and pestles have been found. The remarkable feature of the deposit is the great quantity of these old cooking stones. It is no exaggeration to assert that hundreds of thousands are now exposed to view at the foot of the steep bank, and many times as many may remain buried in the sand of the terrace. From inquiry among the Indians I learn that each family used from five to ten stones in a set. It is a question of how frequently they were broken and how many families lived in this village, but it is beyond doubt that this site was occupied for many centuries or else the population was very great. Yet this village dated entirely from a time subsequent to the abandonment of the forty-five-foot terrace by the river, and was nearly unoccupied half a century ago.

I am strongly inclined to consider the uplift to which the Modern cañon is due as also the cause of the great extension of the glaciers in the last, or Wisconsin stage, and on this supposition the age of the Modern cañon may be placed at 5,000 years. However, this figure will imply an unreasonably great age for the upper terraces, and, in place of it, I will arbitrarily assume 2,000 years as the age of the Modern cañon. It is not my intention of pretending to approximate closely to the age of the terraces, but simply to fix minima which everyone can accept.

Basing the estimates solely on the depth of the erosion, we will get the following result: The rock cañons have depths respectively of 20, 35, 45, 315, 200 and 120 feet. The corresponding periods of time will be 2,000, 3,500, 4,500, 31,500, 20,000 and 12,000 years, or a total for the terrace-forming period of 73,500 years.

But the above is obviously not a fair estimate, as it fails to take into account the very important factor of different widths of the several cañons. I will allow the Modern cañon an average width of 750 feet, which is a liberal estimate. With higher cañons I will be more strict in my estimates. The upper two may be considered approximately equal in width, because the lower occupied as much new territory as it left in the form of the 675-foot terrace.

The average widths of the cañons are respectively 750, 1,500, 2,000, 3,000, 5,000 and 5,000 feet, and the corresponding cross-sections, 15,000, 52,500, 90,000, 945,000, 1,000,000 and 600,000 square feet. By this method we derive as the length of time occupied in the formation of the cañons, 2,000, 7,000, 12,000, 126,000, 133,000+ and 80,000 years, or a total for the terrace-forming period of 360,000 years. The age of the 120-foot terrace, which I correlate with the Intermediate glacial deposits, will thus be 21,000 years. This agrees fairly well with estimates of the probable age of the Iowan drift of the Mississippi Basin, and constitutes another point in favor of considering the Intermediate drift as pre-Wisconsin in age.

The last estimate of the age of the respective terraces seems large, but is probably fairly conservative. It is based on the supposition that the abnormally rapid rate of erosion of the high-grade Modern cañon obtained throughout the terrace period. However, it is a well-known fact that the rate of erosion greatly decreases as the valley widens and the grade lowers. Taking this into consideration, it is probable that the age of the Modern cañon could be cut to 1,000, or even 500 years, without necessarily reducing the age of the 850-foot terrace below the 360,000 years which I have assigned to it. However, I will arbitrarily reduce the assigned age of the highest terrace to 250,000 years.

The portion of the Sierran Cañon above the 850-foot terrace is more than three times as deep as that below, several times as wide, and has characteristics indicating a much greater age. It is undoubtedly conservative to assign it a period of erosion not more than three times as great as the age of the highest terrace, or 750,000 years. This yields a total age for the Sierran Cañon of 1,000,000 years, and that figure also represents my idea of the probable length of the Quaternary Era.

The Sherwood Valley has the appearance of being at least five times as old as the Sierran Cañon, or 5,000,000 years. The geologists who are working in the Pacific Coast country are inclined to assign much longer periods of duration to the Pliocene and Pleistocene than do those whose field lies in the Eastern States. Recently Dr. A. C. Lawson has given* as a possible duration for Quaternary time, 2,751,000 years. However, he includes in the Quaternary the period of erosion of a series of "High Valleys" of the Upper Kern Basin, which valleys appear to me to be the correlatives of the Sherwood Valleys of the Klamath region. My figure corresponding to his given above is 6,000,000 years.

For several years I have entertained the idea that the Sierran Cañons have been in process of erosion for at least a million years. I have been diligently searching for evidence of rapid erosion, and in general have secured only negative results. I will not deny that in places the streams are actively undermining steep slopes and causing landslides, but the total amount of material thus removed in a century is very small. Along the South Fork of Salmon River there has been little change in the positions of large boulders in half a century. Fir trees 300 years old frequently stand on low Modern flood-plains in the small gulches. On the steep mountain sides, although the surface debris is very loose and apparently in movement down the slopes, there can be little lowering of the surface in a period of 100 years, as may be determined by an observation of the timber. The debris accumulates against the upper sides of

Bull. Dept. Geol., Univ. Calif., Vol. 3, No. 15, p. 368.

large trees and slides away from the lower sides, thus furnishing a means of a fairly good estimate of the rate of movement of the surface debris. Trails which were established fifty years ago, and not repaired since, have a curious and aggravating serpentine course. Where they passed above trees they remain in their original position, but between the trees they have worked down the slopes from several to ten feet. By a careful study of these trails it is learned that there has been a continued movement of the debris down the slope, but it has been very slow. Trails which are not used during the winter months are not severely injured unless locally by landslips. Abandoned trails on steep slopes are not obliterated for scores of years. Large trees occur on narrow mountain summits, and demonstrate that in general these summits are not lowered one foot in a century. If the Klamath Cañon was now being enlarged at a rate sufficient to have produced it in 100,000 years, the timber could not maintain a foot-hold on its slopes and it would be uninhabitable. The Pleistocene erosion throughout the central portion of the Klamath region is equivalent to the removal of a sheet of very resistant rock from 500 to 2,000 feet thick, and all of this material was passed out through the mouth of a single stream that, before the arrival of the placer miners, was "clear as crystal" nearly all the year. One million years is a conservative estimate of the time required.

CORRELATION.

For the purpose of correlation, only three of the terraces are important, namely, the highest, the 120-foot and the lowest. Remnants of this system occur in all the principal valleys of the Klamath region, but reach their finest development on the western slope, near the coast.

The small Modern cañons are characteristic of the country west of a line whose course seems to be a little east of north, and whose position is just west of Scott Valley, nearly midway between Trinity Center and Summerville, and traverses the Trinity River, probably near Junction City. This is the axis of the uplift to which these cañons are due. Now, two large rivers, the Klamath and Trinity, rise east of the axis and cross it. The

Scott River, below Scott Valley, crosses the axis. Lawson has called my attention to the fact that the broad-floored Scott Valley presents strong evidences of being an aggraded valley. It appears that the arching across the lower Scott River has been so pronounced that the stream has been unable to cut a cañon through it down to an average grade, and a filling of Scott Valley has resulted. The Upper Trinity Valley, lying east of the axis, also shows evidence of aggrading, but to a less extent than Scott Valley. For fifteen miles the Upper Trinity River, instead of flowing in a small cañon, has a Modern flood-plain that averages a quarter of a mile wide.

The maximum elevation seems to have been at a point near the head of the South Fork of Salmon River, where the mountains are now highest and the glacial phenomena of the last stage most intense. West of the axis the tilting seems to have been toward the west-southwest. The lower terrace seems to be higher where the streams are flowing in that direction than where they are flowing northwest. This is only a suggestion, as very little accurate information on the subject is available.

Last year I discussed* the terrace system as it is developed near Summerville, in the valley of the South Fork of Salmon River. The highest terrace (that over Channel A) of the Summerville Basin corresponds to the 850-foot terrace of the Orleans Basin. Associated with the former there are apparent very old glacial deposits, representing the first glacial stage. The 120-foot terrace of the Orleans Basin has its counterpart in the terrace over Channel C of the Summerville Basin. The latter has a similar height and the characteristic coarse torrent fans. I traced it into direct connection with deposits of the Intermediate glacial stage. I want to emphasize the fact that in two distinct areas, thirty-five miles apart, I have found glacial deposits closely related to a terrace which has unique characters. Being mutually corroborative, they greatly strengthen the hypotheses of a short period of excessive rainfall immediately following the maximum extension of the glaciers in the Intermediate stage.

The lowest terrace of the Orleans Basin is the correlative

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probably of the terrace over Channel E of the Summerville Basin. I cannot correlate these lower terraces with the glacial series except in a general way. It is my impression that the seventy-foot terrace represents an early sub-stage of the Wisconsin glacial stage, and the forty-five-foot terrace a late sub-stage of the same epoch.

Throughout the Klamath region the highest terrace is characterized by fineness of materials and the red color. It seems to attain to its greatest height along the Klamath River between the mouth and a point above Happy Camp. In the valley of the Trinity River it rarely reaches 300 feet above the stream. In Scott Valley it is very low and indefinite. On Clear Creek and the Sacramento River above Redding it is fairly well represented, but at heights usually less than 200 feet above these streams.

I wish to call particular attention to one fact in connection with this upper terrace, namely, that it marks an important line of division of the Sierran Cañons into a comparatively broad, upper non-terraced portion and a narrow, lower terraced portion. The contrast between the two portions is great enough to point to a change in conditions. The latter portion of the period during which the upper division was being eroded was a time of quiescent conditions. There were no important changes of level or of climate, and the streams had long cut to low grade and greatly widened their valleys. The upper terrace is simply a portion of the valley floor at the close of that quiet period. The remainder of the Quaternary Era has been one of repeated earth movements and changes of climate, and the terrace system is the result.

In much softer formations than those of the Klamath region, the broad upper cañon would be represented by very broad, basin-like valleys, or even, on incoherent late Pliocene strata, by small peneplains. In the softer rocks of the Coast Range province, the Klamath River could probably have excavated a valley 2,000 feet deep and fifteen miles wide in the time which has occupied it in eroding the upper division of the Sierran Cañon. This fact must be taken into account in correlating valleys and terraces throughout the State.

The 850-foot terrace of the Orleans Basin I will correlate with the Red Bluff formation of the Great Valley. This is based on the fact that the highest late Quaternary terrace of the Klamath region may be traced out of the mountains, and it becomes the prominent Red Bluff terrace on the northern border of the Sacramento Valley. The internal structure and the history involved in the Red Bluff formation have not yet been thoroughly elucidated. The Red Bluff proper is comparatively old, as is evidenced by the undulating topography of most of its area. North of the latitude of Sacramento it has the deep red color which is characteristic of the upper Quaternary terraces of the neighboring mountains. So far as I am aware, there are no Quaternary terraces higher than the Red Bluff on the borders of the Great Valley. It marked the end of a long quiet period and the beginning of the disturbed, terrace-forming period. Taking all these facts into consideration, I believe that the correlation of the Red Bluff formation with the Quaternary terrace of the Klamath region is fairly safe.

In 1902 I discussed* a system of river terraces carved on a late Pliocene series in the valley of the Santa Clara River of the South, in Los Angeles County. The highest, estimated at 400 feet above the river, marked the end of a long quiet period (during which the Pliocene Basin was almost reduced to a peneplain), and the begining of a terrace-forming period. On the principle that the Quaternary history of the Klamath region was in a general way duplicated throughout the State, I must correlate this 400-foot terrace of the Santa Clara Valley in Southern California with the 850-foot terrace of the Orleans Basin. Before I had gained the idea that the highest late Quaternary river terraces in all portions of the State should be considered equivalent in age, I had referred the 400-foot terrace mentioned above, and the highest terrace of the Sierran Cañons of the Klamath region to the Red Bluff epoch on the basis of erosion studies.

In short, the upper division of the Sierran Cañon at Orleans must be referred to the Santa Clara epoch of the classification

*"The Quaternary of Southern California." *Bull. Dept. Geol., Univ. Calif.*, Vol. 3, No. 1, pp. 10-11.

proposed in the paper just cited, the Red Bluff horizon occurs at the 850-foot terrace, the space between this terrace and one at least as low as the 120-foot terrace represents the Los Angelan epoch, the San Pedran horizon is due at or near the seventy-foot or 120-foot terraces, and the Glacial epoch is represented probably by the forty-five-foot terrace and the space between it and the seventy-foot terrace, and probably also by the latter.

During the first few years of my residence in California the river terraces did not appear to present any interesting problems, but the deeper I delve into their history, the more fascinating grows the study. They are important because they indicate orogenic disturbances and changes of climate, and because by means of them we will be furnished the best chronometer of glacial events. It is possible that they may yield facts bearing strongly on the cause of the great Quaternary glaciations. They furnish the basis for the classification of Quaternary land faunas. Further, the relics of early man in California may be referred to the different terraces, and thus some idea gained of their relative ages. So far, in the Orleans Basin, I have failed to secure authentic evidence of the presence of man until after the completion of the forty-five-foot terrace. Mr. Pearch reports that he mined out an Indian mortar from a depth of twenty-five feet below the seventy-foot terrace level, but there is no certainty that this mortar did not come from near the top of the bank.

Berkeley, California,
May 25, 1904.

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