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A GEOLOGIC RECONNAISSANCE

OF THE

INYO RANGE AND THE EASTERN SLOPE OF THE SOUTHERN SIERRA NEVADA, CALIFORNIA

BY

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WITH A SECTION ON

THE STRATIGRAPHY OF THE INYO RANGE

BY

EDWIN KIRK

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ILLUSTRATIONS.

PREFACE.

By F. L. Ransome.

In the summer of 1912 Adolph Knopf was instructed by Waldemar Lindgren, then chief geologist and in charge of the section of metalliferous deposits of the United States Geological Survey, to investigate the geology and mineral resources of the Inyo Range, and to give particular attention to the mining districts. As Walcott and others had shown that the range contained a full representation of Paleozoic sedimentary rocks, Edwin Kirk, paleontologist, was assigned to assist Mr. Knopf in the study of the stratigraphy of these beds.

The field work, so far as it related to the mineral deposits, was completed in 1912, and a report[1] on the economic geology of the region examined was published in 1913. The work might have stopped at this point, but in view of the unusual geologic interest of the region, which includes a section of the fault zone which divides the Sierra Nevada from the Great Basin and along which movement has taken place up to very recent time, Mr. Knopf, assisted by F. H. Lahee, was instructed to continue studies in the same region in 1913 and to give special attention to problems connected with the geologic history of the Sierra Nevada and with the structural relation of that range to the lower arid country on the east. The work accordingly was extended across Owens Valley to include part of the steep eastern front and a section of the summit region of the range.

Modern geologic knowledge of the southern Sierra Nevada may be said to begin with the publication of A. C. Lawson's paper on the geomorphogeny of the upper Kern basin.[2] The area studied by Mr. Knopf overlaps in part that studied by Prof. Lawson, whose work is to some extent thus supplemented by that of Mr. Knopf. The more recent study, however, has led to the conclusion that glaciers had a larger share in shaping the canyons than is accorded to them by Prof. Lawson. Mr. Knopf, moreover, differs from his predecessor in assigning the second and major uplift of the Sierra Nevada to early Quaternary rather than to late Quaternary time. Additional light on these questions should be afforded by the results of the detailed work now being done in the Yosemite region by F. E. Matthes and F. C. Calkins. Mr. Knopf differs from Prof. Lawson also in his interpretation of the "Summit Plateau," which Prof. Lawson regarded as a surface approximately coincident with the original top of the Sierra Nevada batholith. The present report offers convincing evidence not only that the batholith is a composite intrusive mass, offering a fine subject for petrologic study, but that the overlying rock cover, as shown by parts of it not yet wholly stripped away, was exceedingly irregular and affords fine examples of long roof pendants. According to Mr. Knopf the peaks that Prof. Lawson supposed to be remnants of the Summit Plateau are merely projections of resistant rock left in relief during the erosion of the Subsummit Plateau and are remnants neither of the top of a batholith nor of an old erosion surface.

The evidence for two epochs of Quaternary glaciation is convincingly set forth, and the careful observations of the results of glacial action recorded will be of great value in further studies of the later geologic history of the Sierra Nevada.

[1] Knopf, Adolph, Mineral resources of the Inyo and White mountains, Cal.: U. S. Geol. Survey Bull. 540, pp. 81–120, 1914.
[2] California Univ. Dept. Geology Bull., vol. 3, pp. 291–376, 1904.

OUTLINE OF REPORT.

GENERAL GEOLOGY.

The region described in this report comprises Owens Valley, in eastern California, and the portions of the Inyo Range and the Sierra Nevada between which it lies. (See Pls. I and II, in pocket.) The Sierra Nevada, bordering the valley on the west, here attains its loftiest height, culminating in Mount Whitney, which rises 14,501 feet above sea level; and here also it attains its greatest relief, rising abruptly 8,000 feet above Owens Valley. The Inyo Range, bordering the valley on the east, averages 10,000 feet in altitude—somewhat less than the Sierra Nevada. It is a typical Great Basin range, which rises above the valley in a steep scarp that is less rugged than that of the Sierra Nevada.

Owens Valley, lying between these two mountain masses like a deep trough, ranges in width from 2 to 8 miles. A few isolated groups of hills project through the alluvial floor of the valley, but they are dwarfed into insignificance by the lofty bordering ranges. The highest of these hills is Crater Mountain, so named from the basaltic cinder cone forming its summit, which stands 2,000 feet above the floor of the valley.

The drainage of the region is derived almost wholly from the Sierra Nevada. The principal stream is Owens River, which empties into Owens Lake, at the south end of the valley.

The sedimentary rocks of the Inyo Mountains are more than 36,000 feet thick and range in age from pre-Cambrian to Triassic. The Silurian is the only Paleozoic system not represented. Although the rocks of the successive systems are as a rule separated by unconformities, the strata, from the base to the top of the stratigraphic column, are without conspicuous angular discordances. However, in post-Triassic time, probably late in the Jurassic period, the beds were faulted and folded and the region was then invaded by great masses of quartz monzonite and allied rocks. During this revolution the Inyo Range acquired the major portion of its complex internal structure, but it acquired its present topographic form by profound faulting that occurred at the end of Tertiary time. During this faulting the range was blocked out diagonally to the structural axes established by the earlier deformation.

Underlying the lowest beds of the Cambrian system and separated from them by a pronounced erosional unconformity is a great thickness of sandstone and dolomite which is regarded as of pre-Cambrian age. These rocks may be subdivided into three lithologic units—a series of sandstones and thin-bedded impure dolomites at the bottom, the Reed dolomite above these, and, locally, the Deep Spring formation at the top. The Reed dolomite is well exposed in the northern part of the Bishop quadrangle, and is best known on Wyman Creek, in whose gorge it is exposed to a thickness of 2,000 feet. The Deep Spring formation consists of 1,600 feet of sandstone and dolomitic limestones. In places it appears to have been completely removed by erosion before the overlying Cambrian strata were deposited.

The Cambrian system has an aggregate thickness of more than 12,000 feet, representing Lower, Middle, and Upper Cambrian time. Lower Cambrian rocks predominate, having a thickness of at least 10,200 feet. They are subdivided into the Campito sandstone, which forms the base of the system, and the overlying Silver Peak group. The Campito sandstone, 3,200 feet thick, consists chiefly of dark fine-grained feldspathic quartzite with many thin argillitic or phyllitic partings. Cross-bedding and ripple-marked surfaces are characteristic of the formation. No fossils have been found in it. Toward the top it grades into the Silver Peak group, and because of this gradation, as well as the occurrence of sandstone at some horizons in it similar to that in the Silver Peak, it has been placed in the Cambrian system. The Silver Peak group, 7,000 feet thick, consists largely of calcareous shales, sandstones, and limestones. Fossils occur in sediments of all three types. The Middle Cambrian, which has not heretofore been recognized in this region, is represented by 900 feet of calcareous sandstone and limestone. Above these are about 1,000 feet of arenaceous limestones and shales of Upper Cambrian age.

Ordovician rocks are widely exposed throughout the Inyo Range. They overlie the Cambrian conformably. The basal series, which consists of heavy-bedded limestones aggregating 3,800 feet in thickness, is correlated with the Pogonip limestone of the Eureka section and is therefore of Lower Ordovician (chiefly Beekmantown) age. Above this lies a series of argillaceous limestones, 500 feet thick, also of Lower Ordovician (Chazy) age; and resting on this is a series of arenaceous shales, 750 feet thick, also of Lower Ordovician (Normanskill) age.

Above the Ordovician rocks are 1,400 feet of impure thin-bedded limestones of Devonian age, which are correlated with the Nevada limestone. They are best exposed in the foothills east of Kearsarge (formerly called Citrus), where they are exposed from the Ordovician to the Mississippian.

The Carboniferous system is represented by Mississippian, Pennsylvanian, and Permian strata, aggregating in thickness at least 8,000 feet. The Mississippian is represented by the White Pine shale, 1,000 feet thick. Its base is marked by a 5-foot bed of conglomerate, indicating an unconformity, but the formation rests in angular accordance on the subjacent Devonian. The Pennsylvanian comprises, in ascending order, 500 to 1,000 feet of limestones, overlain by the Diamond Peak quartzite, 3,500 feet thick, by later Pennsylvanian limestone and shale 3,000 feet thick, and by the Reward conglomerate, 250 feet thick. The Diamond Peak quartzite appears to rest unconformably upon the underlying basal Pennsylvanian limestones. The later Pennsylvanian limestone is well exposed southwest of Cerro Gordo where it consists of an assemblage of beds of limestone generally ranging in thickness from 6 inches to 2 feet. These beds weather in brilliant tints and closely resemble the overlying Triassic rocks from which, however, they are readily distinguished by the presence of *Fusulina*. The Reward conglomerate is a notable member of the Carboniferous. At the type locality it is highly lithified and consists largely of chert pebbles; farther south it contains, at several horizons, well-defined potholes as much as 2½ feet in diameter, whose inner surfaces are polished, indicating that it is of fluvial origin.

The Permian is represented by the Owenyo limestone, which is 125 feet thick and carries abundant marine fossils of *Spiriferina pulchra* fauna. Both the base and the top of the formation are exposed. The top of the limestone is weathered and irregular.

The Triassic rests on the weathered Permian in sharply defined and clearly marked unconformity. Its basal member is a calcareous sandstone, inclosing conglomeratic lenses and capped by mud-cracked limestone and attains a maximum thickness of 12 feet. The typical Triassic commences sharply above the basal bed. It consists of calcareous shales and thin-bedded arenaceous limestone. In the higher part of the section andesitic tuffs and breccias predominate. Because of the complex folding and faulting, the thickness could not well be determined, but it is thought to exceed 6,000 feet.

The Tertiary and Quaternary systems are represented by detached areas of lake beds and by alluvial cones of great height and wide areal extent. The lake beds of the different areas can not well be correlated, as some contain fresh-water gastropods, others fresh-water diatoms, and still others brackish-water or marine (?) ostracodes. The largest area of lake beds occupies the broad depression between the Inyo and Coso mountains; they consist of arkose, shale, calcareous sandstone, and rhyolite breccias and tuffs. They carry minute ostracodes, which, according to Ulrich, indicate brackish-water or even marine conditions, but the probability that they are of marine origin appears to be small. After they were deposited they were partly covered by basalt, and subsequently the Inyo Range was blocked out by step faulting.

The great alluvial cones that flank the mountains between which Owens Valley lies constitute one of the most striking features of the region. Their development differs notably on the two sides of the valley; along the Sierra Nevada they overlap and form a continuous alluvial slope that merges almost imperceptibly into the valley floor, but along the Inyo Range they occur only at the mouths of the canyons and are distinct topographic units which stand out in bold contrast to the level floor of the valley.

The alluvial slope that flanks the Sierra Nevada is 1 to 7 miles wide. The apexes of the cones stand 1,000 to 2,000 feet above the valley, but it by no means follows that any of the alluvial cones are 2,000 feet or more thick. The average inclination of the alluvial slope is between 6° and 7°.

Alluvial cones of two ages occur along both flanks of the Inyo Range, but they are especially prominent along the western. The older cones stand 2,600 feet above the floor of Owens Valley, and, unlike those flanking the Sierra Nevada, extend well back into the canyons from which their material was derived. They differ also from those along the base of the Sierra in that they are deeply dissected and eroded, some of them to a depth of 500 feet. Their partial destruction has yielded the alluvium which makes up the great cones that project so conspicuously into Owens Valley. Their erosion was begun by a renewal of faulting along the base of the Inyo Range and appears to have been accelerated by the advent of the more humid conditions of the first glacial epoch. The later history of the alluvial deposits indicates a succession of climatic conditions similar to those recorded by the glacial deposits on the east slope of the Sierra Nevada.

Igneous rocks are widely distributed in the region. The oldest whose age is definitely known are a series of andesitic lavas and breccias of Middle Triassic age, which are best shown in the Inyo Range, where they are at least 4,500 feet thick. Rocks presumably of the same age make up the Alabama Hills in Owens Valley and form roof pendants in the batholithic masses of the Sierra. In these deposits considerable rhyolite is associated with the andesite.

The extrusion of these rocks was followed by intense folding, after which, probably in late Jurassic or early Cretaceous time, there were great intrusions of granitic rocks. The escarpment of the Sierra is composed dominantly of such rocks, which are exposed on Lone Pine Creek through a vertical range of 8,000 feet, probably unduplicated by faulting. Quartz monzonite is the predominant rock, and is represented by two varieties—a normally granular quartz monzonite and a porphyritic variety containing large crystals of orthoclase. These two varieties grade into each other, but the zone of transition is narrow. In the Mount Whitney region, where the relation between them is best displayed, the normal quartz monzonite lies below the porphyritic variety, which makes up the summit region of the range. The porphyritic quartz monzonite persists with little change of composition or texture over a wide area and forms the largest homogeneous mass of granitic rock in this part of the Sierra. Its smaller specific gravity, coupled with its occurrence in the topmost part of the range, suggests that it is a gravity differentiate, in which the prevalence of phenocrysts of orthoclase is due to the flotation of crystals of orthoclase from the lower parts of the magmatic chamber. Chemical analysis, however, fails to show the enrichment in potash demanded by this explanation, and the petrographic data suggest that the porphyritic development of the orthoclase is more probably due to its more rapid crystallization, starting from a few centers of crystallization. The possibility that gravity has controlled the differentiation of the other constituents is not, however, ruled out.

A younger rock than these quartz monzonites is a coarse light-colored granite, which is practically barren of dark minerals. It is composed of albite, quartz, and orthoclase, in the order named, with about 1 per cent of biotite. This granite forms large areas of homogeneous rock throughout this part of the Sierra.

Diorite and hornblende gabbro occur in minor amounts. A notable feature of the escarpment is the extraordinary development of plutonic complexes consisting of hornblende gabbro, quartz diorite, porphyritic and nonporphyritic quartz monzonite, granite, aplite, and diorite porphyry of lamprophyric affinities. The ramification of the darker rocks by intrusions of light-colored granite and aplite on a grand scale is well displayed on the east flank of Olancha Peak.

All the plutonic rocks except, perhaps, the orthoclase-albite granite are cut by aplite dikes. In places these dikes, which extend from the alluvial slope at the foot of the range to its highest summit, are so abundant and lie so nearly parallel as to give the Sierra escarpment a striped appearance. Aplite also occurs abundantly in larger masses along the crest of the range from Mount Whitney southward to Cirque Peak. Local pegmatite dikes are common but are mainly restricted to roof pendants and the adjacent plutonic rocks.

Remnants of the pregranitic rocks that once formed a roof over the intrusions occur at a number of places in the Sierra, especially in the headwater region of Bishop Creek. These rocks are highly metamorphosed and are cut by numerous dikes. The space relations of these detached fragments of the batholithic roof are excellently revealed in the great canyons and cirques of the upper part of the range, where it can be seen that they project downward deep into the granite masses, affording notable examples of the "roof pendants" of Daly. One on Bishop Creek extends at least 2,500 feet downward into the granite. The essentially undisturbed character of such long, narrow roof pendants indicates that the granite was emplaced without great tectonic disturbance.

The sequence of intrusion for the quartz monzonite and granite was in the order of increasing silicity, but the evidence as to the relation of the more basic rocks to the others is somewhat contradictory.

Volcanic activity was widely prevalent in Tertiary and Quaternary time, rhyolite, latite, and basalt being erupted. Rhyolite was the earliest, and it is perhaps most abundant in the lake beds at Haiwee and north of Owens River, where it consists generally of pumice, although flows of obsidian occur at one place. Latite occurs at Monachee and Templeton mountains, on the summit of the Sierra. Basalt, which is by far the most abundant volcanic rock, was extruded at three separate times at least. In the oldest extrusions the basalts forming the plateaus at the south end of the Inyo Range were erupted. Subsequently, when the range was blocked out, the superposed sheets of basalt were faulted in a succession of steps and now afford valuable data on the orogenic history of the range. After the alluvial cones flanking the Sierra Nevada had attained their present heights, small flows of basalt were emitted. At one locality the basalt of this epoch accomplished the remarkable feat of rendering columnar the granite through which it was erupted. Basalt was again erupted in late Quaternary time, in the interval between the two epochs of glaciation recognized in the region. At this time the striking group of cinder cones that stands on the alluvial slope between Big Pine and Independence was formed. Some of these cones stand upon fault lines marked by fresh alluvial scarps, and one of them has been cut in two by a fault marked by an alluvial scarp 80 feet high.

The east slope of the Sierra Nevada is a great fault escarpment. It attains its greatest and most abrupt relief west of Owens Valley, rising from an altitude of 3,600 feet on Owens Lake to 14,500 feet on Mount Whitney. The long alluvial slope at the base of the range extends up to altitudes of 5,000 to 6,500 feet, however, and the spurs are markedly oversteepened only below the 10,000-foot level. The predominant element of the escarpment is therefore the steep granite wall that rises abruptly from the piedmont alluvial slope and ranges from 4,000 to 5,000 feet in height. This great wall seems to tower almost vertically above Owens Valley, but in reality its inclination nowhere exceeds 28°. Triangular facets of extraordinarily impressive dimensions have been cut by displacement upon the spurs between the deep canyons that indent the eastern slope. In general, the displacement appears to have taken place mainly along a single fault surface, but in places distributive faulting has occurred, producing terrace-like forms. Faulting is still in progress, the last notable dislocation having taken place during the memorable earthquake of 1872. A considerable number of fault scarps of late Quaternary age were discovered and mapped during the present reconnaissance. They occur not only at the edge of the piedmont alluvial slope of the Sierra, as noted by Whitney and

Gilbert, but at intervals on this slope and also on the bedrock slope of the range itself. Some alluvial scarps of late Quaternary age, 80 feet in height, were measured.

Extensive remnants of topographies that antedate existing land forms are preserved west of the crest line of the Sierra Nevada, west and south of Mount Whitney, and east of the crest south of Bishop Creek. They throw light on the orogenic history of the range during the later Cenozoic, showing that the Sierra attained its present altitude, as first pointed out by Lawson, by at least two uplifts, which were separated by a protracted halt. The earlier uplift, amounting to about 2,500 feet, led to the carving of a system of broad valleys in an old surface of erosion that is correlated with the peneplain on which the early Tertiary auriferous gravels accumulated. This uplift was epeirogenic, lifting not only the Sierra Nevada but also at least a portion of the Great Basin east of the Sierra. During the halt between this and the later uplift certain eastward-flowing streams eroded sufficiently far back to capture some of the headwater tributaries of the westerly drainage. The second and major uplift, which probably took place at the beginning of the Quaternary period, raised the range to its present altitude, produced a scarp about 6,000 feet high west of Owens Lake, and gave the streams of the eastern slope great erosive powers, though none of them have yet succeeded in capturing more of the headwater branches of the westward-flowing drainage.

The Inyo Range, bounding Owens Valley on the east, is delimited by faults along both flanks; it is a fault-block range of the "horst" type. The evidence of faulting is both physiographic and stratigraphic, but the stratigraphic is perhaps the more impressive. The south end of the range shows a series of basalt sheets, which rest horizontally on vertical strata of Carboniferous and Triassic age and form the plateau summit of the range. The western flank consists of a series of steps capped with basalt and representing segments faulted from the main basalt-capped mass. The structure is revealed with diagrammatic clearness in the deep gorge extending back into the plateau southeast of Keeler, where it is manifest to the most casual observer.

Owens Valley is a deep trough of tectonic origin. Most of its bedrock is deeply buried under extensive alluvial deposits, but in places, as, for example, west of Lone Pine, the alluvium is merely a veneer over the bedrock granite. The basin in which Owens Lake lies appears to be due to comparatively recent differential displacement along the old fault lines. The notable oversteepening of the basal slopes of the spurs overlooking the lake on the west points strongly to this probability. A number of ancient strand lines encircle the lake, the highest standing somewhat over 200 feet above the present lake level.

The canyons of the east slope of the Sierra were occupied by ice during two widely separated times. The earlier ice streams were at least twice as thick as the later and descended to altitudes as low as 4,500 feet. Those of the last glaciation did extend lower than 6,300 feet. The older moraines are many times larger than the younger. That considerable time elapsed between the two epochs of glaciation is shown by the deep dissection of the older moraines. Gulches several hundred feet deep have been eroded into them and reveal the widespread and thorough disintegration of older glacial deposits. Many boulders, some of them 5 feet in diameter, are so deeply disintegrated that they crumble under slight pressure. The moraines of the younger glaciation, on the other hand, are intact and the granite blocks they contain are brilliantly fresh. During the interval between the two glacial epochs a mass of basalt, accompanied by cinders, was erupted into Sawmill Canyon. The interglacial epoch was probably three to five times as long as the time that has elapsed since the maximum stage of the last ice advance.

The sculpture of the glaciated region points to great ice erosion. The striking contrast between the unglaciated and the glaciated parts of the canyons scoring the Sierra escarpment is one of the more remarkable features of the region. The glaciated canyons have been transformed on an unrivaled scale into what Russell calls cyclopean stairways. The high hanging valleys and the diversion of the drainage of Charlotte Creek by glacial capture also afford clear evidence of the efficiency of ice erosion. The notable control that jointing has exerted on the development of the cirques and the quantitative equivalence of the moraines northwest of Baker Creek with the cirques from which they were derived, suggest that in this part of the Sierra Nevada glacial erosion took place largely by the plucking and removal of joint blocks.

MINERAL RESOURCES.

The principal mineral resources of the region are silver, lead, zinc, tungsten, gold, copper, and marble, which are largely confined to the Inyo Mountains, and sodium carbonate, which is derived from Owens Lake. In the Sierra Nevada the only ore body under development in recent years is that of the Bishop Creek gold mine, on Middle Fork of Bishop Creek, at an altitude of 8,500 feet. The deposit, which consists of a quartzite band carrying auriferous pyrrhotite and arsenopyrite, forms part of a sedimentary roof pendant that projects deep into the granitic masses of the range. Recently large deposits of contact-metamorphic tungsten ore have been found west of Bishop.

The premier producing mine in the Inyo Mountains is now, as it has been in the past, the Cerro Gordo. It has yielded more silver-bearing lead ore than any other mine in California, having produced between 1869 and 1877 base bullion to the value of $7,000,000. In 1911 large bodies of zinc carbonate, long overlooked, were discovered in the old mine and led to its rehabilitation. Further exploration led to the discovery of rich shoots of silver-bearing lead ore, and in consequence the mine has entered upon a new era of prosperity.

The lead ore bodies of Cerro Gordo consist of lenticular masses distributed through a zone 1,500 feet long and several hundred feet wide. The predominant rock of the zone is a white, finely saccharoidal marble, essentially a pure calcite rock, of Carboniferous age. Some interstratified slate and dikes of monzonite porphyry, quartz diorite porphyry, and diabase also occur in the ore-bearing zone, but the ore bodies, with one notable exception, are inclosed in the marble. The primary ore is galena, with which is associated tetrahedrite, zinc blende, and pyrite. The most productive shoot of argentiferous lead ore mined in late years, constituting the notable exception referred to above, occurs in a much-sheared portion of a narrow diabase sill.

The zinc ore, to whose discovery the revival of Cerro Gordo is due, forms irregular masses and pipes in the limestone walls of the old lead stopes, principally in the footwall. Near the old stopes the zinc ore consists largely of limonite mixed with bodies of pure white halloysite, but with increasing distance from the stopes the zinc ore becomes progressively purer—locally, indeed, it is theoretically almost pure. It consists essentially of the carbonate smithsonite, the main impurities being limonite and calcite. It is fine grained and is characteristically banded or laminated in places in a very remarkable convolute fashion. As the smithsonite has resulted from the replacement of a fine-grained structureless marble the lamination is strongly suggestive of rhythmic precipitation. The most notable feature of the ore deposits of Cerro Gordo is probably the localization of the zinc as carbonate in large bodies of high-grade ore in comparison with the small proportion of zinc blende in the primary ore. The zinc carbonate was derived from the blende by a process involving oxidation, solution, migration, and precipitation—a rather complex process that apparently afforded numerous chances for the dispersal of the zinc; but although the proportion of blende in the unoxidized lead ore is extremely small, certainly not exceeding 1 or 2 per cent, the zinc has been concentrated to a remarkable extent.

The primary ores are probably related genetically to the granitic intrusions common in the Inyo Range. This relation, however, is less obvious here than it is in the Darwin district, 25 miles southeast of Cerro Gordo, where the lead ore bodies range from contact-metamorphic deposits, consisting of galena intergrown with andradite garnet, to fissure veins having the normal character of hydrothermal deposits.

The gold deposits of the Inyo Range are mainly small, narrow quartz veins that occur either in the borders of the granite intrusions or in the surrounding country rock at no great distance from the granite. Some of the more notable veins, such as the Reward, differ from the normal California type of gold quartz vein in that the principal sulphide is galena, apparently in response to their occurrence in a metallogenetic province in which lead is the dominant metal.

A GEOLOGIC RECONNAISSANCE OF THE INYO RANGE AND THE EASTERN SLOPE OF THE SOUTHERN SIERRA NEVADA, CALIFORNIA.

By Adolph Knopf.

FIELD WORK AND ACKNOWLEDGMENTS.

The field work on which this report is based covered parts of the seasons of 1912 and 1913. The part of the Inyo Range that lies within the Bishop, Mount Whitney, and Ballarat quadrangles was mapped between July 6 and October 18, 1912, special attention being given to the economic geology. In this work the writer was efficiently assisted by Mr. Edwin Kirk, who studied principally the stratigraphy and paleontology of the range. (See pp. 19–48.) The east flank of the Sierra Nevada was mapped between June 1 and August 14, 1913. In this work Prof. Frederic H. Lahee, of the Massachusetts Institute of Technology, rendered able assistance, and to him must be credited a large share of the results of the reconnaissance of this part of the region. The geologic reconnaissance maps in this report (Pls. I and II, in pocket) show the stratigraphy of the region as thus determined.

It is also a pleasure to acknowledge here the hospitality of Mr. L. D. Gordon and to thank him for his generous aid in facilitating the study of the region around Cerro Gordo, in the Inyo Mountains.

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GEOGRAPHY.

LOCATION AND GENERAL FEATURES OF THE REGION.

The region described in this report is a rectangular area in eastern California whose western boundary coincides in general with the main divide of the Sierra Nevada and whose eastern boundary lies along the eastern base of the Inyo Range—the first range east of the Sierra Nevada. Between these two ranges lies the deep depression known as Owens Valley, at whose south end is the saline sea called Owens Lake. The area extends from the south end of Owens Valley northwestward for 100 miles to the great bend of Owens River. It is wholly in Inyo County, which contains the lowest and highest points in the United States—Death Valley and Mount Whitney.

Two railroads enter Owens Valley, one from the north and the other from the south. The Nevada & California (formerly the Carson & Colorado), a narrow-gage line, now a part of the Southern Pacific system, passes along the east side of Owens River. It connects with the Tonopah branch at Mina, Nev., and its southern terminus is Keeler, on Owens Lake. A broad-gage branch of the Southern Pacific has recently been built northward into the valley from Mohave, primarily to facilitate the construction of the Los Angeles Aqueduct, and connects with the narrow-gage line at Owenyo.

Whitney, writing in 1872, said that Owens Valley was terra incognita; and this characterization has remained essentially true until recent times. Because of its remoteness the valley remained dormant until about 1900, when the establishment of Tonopah and numerous other mining camps in adjacent parts of Nevada created a demand for its products. More vital to its prosperity than this, however, was the construction of the railroad from Mohave, which by making Los Angeles an easily accessible market for its products led to its healthy agricultural growth.

It is highly probable that when its roads and railway facilities are improved Owens Valley will become famed for its magnificent scenic attractions. The Sierra Nevada forms the west wall of the valley, and here the range displays its loftiness more impressively than anywhere else along its whole course; in fact the greatest relief within the United States is that along the eastern flank of the Sierra Nevada, in the region of Mount Whitney. The accessibility of the higher parts of the range by trails that diverge from the small towns in the valley—Lone Pine, Independence, Big Pine, and Bishop—is another attractive feature. From Bishop one may travel by automobile in a few hours to the headwaters of Bishop Creek, whose profoundly glaciated canyons and spacious cirques are among the most impressive in the whole range.

TOPOGRAPHY.

OWENS VALLEY.

Owens Valley is a long, narrow depression lying between the Inyo Range on the east and the Sierra Nevada on the west. Its floor is 2 to 8 miles wide and the distance from crest to crest of the confining mountain chains ranges from 40 miles at the north end to 25 miles at Owens Lake, near the south end, the minimum distance, which is found in the part of the valley between Bishop and Big Pine, being 15 miles. The floor, which is notably even, slopes southward at the rate of 7 feet to the mile—from about 8,000 feet above sea level at the north end to 3,600 feet at Keeler, on Owens Lake, the lowest point in the valley. A broad alluvial divide, whose lowest point is 3,760 feet above sea level, separates the valley from Rose Valley on the south.

A few isolated groups of hills—Poverty, Tungsten, and Alabama Hills—rise above the general level of the valley, but they are dwarfed by the great bordering mountain ranges. A volcanic field lies southwest of Big Pine, and its finely preserved cinder cones and lava flows are notable features of Owens Valley. The highest of the extinct volcanoes is Crater Mountain, which rises 2,000 feet above the valley floor and is composed largely of black basalt flows capped by a cinder cone with a crater in its top.

THE INYO RANGE.

The Inyo and White mountains form the east wall of Owens Valley. Together they make a single continuous chain 110 miles long, the Inyo Mountains forming the southern portion and the White Mountains the northern portion. The line of demarkation has usually been placed along the Saline Valley road, which crosses the range east of Big Pine. The arbitrary character of this division was recognized by J. D. Whitney,[1] and his opinion has been concurred in by all subsequent observers. H. W. Turner has contended that the whole chain should be known by a single name, and fittingly called it the Inyo Range, a native name that has the merit of distinctiveness. J. E. Spurr,[2] however, called it, for convenience, the White Mountain Range, and local usage in recent years has tended to sanction the employment of "White Mountains" as a name for the entire range, although the extreme southern part is still often referred to as the Inyo Mountains. In this report "Inyo Range" is adopted for the whole chain.

The range trends northwestward. On the south it is separated from the Coso Mountains by a broad depression and on the north it terminates in Mount Montgomery, whose white granite scarp is visible for many miles. The average elevation of the range is 10,000 feet. Its western face slopes off abruptly toward Owens Valley, and is but little less precipitous than that of the Sierra Nevada on the opposite

[1] California Geol. Survey, vol. 1, p. 546, 1865.

[2] Spurr, J. E., Descriptive geology of Nevada south of the fortieth parallel and adjacent parts of California: U. S. Geol. Survey Bull. 208, p. 206, 1903.

side of the valley. Its western border is thus determined by the floor of Owens Valley and as a whole is remarkably straight. Its eastern border is not so sharply marked. In its northern part it is marked by Fish Lake Valley, but between this valley and Saline Valley to the south there is an irregular mountainous area that is not clearly separated from the Inyo Range on the west nor from the ranges on the east. Still farther south the deep elliptical depression known as Saline Valley, whose floor is 2,500 feet lower than that of Owens Valley, separates the Inyo Range from the Ubehebe Range on the east. The flank of the Inyo Range is here exceedingly steep and rugged—in fact, it is fully comparable in height and precipitousness with the great escarpment of the Sierra Nevada.

Deep canyons penetrate the western slope of the Inyo Range, and great "washes" or alluvial cones extend from the mouths of the canyons far out into the valley.

THE SIERRA NEVADA.

The Sierra Nevada forms the west wall of Owens Valley. It ranges from 11,000 to 14,501 feet in height, culminating in Mount Whitney, the highest point in the United States outside of Alaska. The main divide directly overlooks the valley. The full relief is attained within a short horizontal distance and is about 8,000 feet in the region of Mount Whitney. The east slope of the Sierra Nevada is therefore extremely abrupt and is tremendously rugged. It is scored by a large number of great canyons, spaced at fairly equal intervals. The dominating peak as seen from Owens Valley is Mount Williamson (14,384 feet); it is, in fact, the second highest peak in the range, and its great height, its sharply serrated form, and its position more than a mile east of the main divide give it commanding eminence. Mount Whitney is at the head of the deep canyon of Lone Pine Creek, and stands relatively far back of the main Sierra Nevada escarpment, and is, in consequence, not visible from Owens Valley, except within a rather small section near Lone Pine.

From points southwest of Lone Pine three "peaks," much alike in general appearance, with massive square-browed summits and broad, gently westward-sloping tops, crown great vertical eastward-facing walls and impress themselves upon the view. They are, named from north to south, Mount Whitney (14,501 feet), Lone Pine Peak (12,951 feet), and Mount Langley (14,042 feet). Of these Lone Pine Peak, which stands more than 2 miles east of the main crest and rises directly to its full height above the piedmont slope, seems to be the highest. Mount Langley also seems, because of its greater nearness, to be higher than Mount Whitney. The supremacy of Mount Whitney is therefore nowhere apparent from Owens Valley. It is this fact that in part, in 1871, led Clarence King, who had discovered and named Mount Whitney in 1864, to make the error of thinking he had accomplished the ascent of Mount Whitney from Owens Valley, when in reality he had ascended the summit now known as Mount Langley. This error was discovered by W. A. Goodyear in 1873, who pointed out that the peak climbed by King was not Mount Whitney but one that had been named Sheep Mountain in 1864. Fortunately, this banal name for one of the most majestic summits in the whole Sierra Nevada has since been changed to Langley, in honor of one of America's most distinguished men of science.

Between the level floor of Owens Valley and the base of the Sierra is a barren boulder-strewn belt of alluvial wash, which is 1 to 7 miles wide and attains a height of 1,000 to 2,500 feet above the valley floor. Unlike the isolated alluvial cones built up at intervals along the front of the Inyo and White mountains on the east side of the valley, it forms a continuous piedmont alluvial slope. It reaches its greatest development in the area between Independence and Owens Lake.

DRAINAGE.

The principal stream of the region is Owens River. It rises in the Sierra Nevada near San Joaquin Pass, and in its upper course it is a turbulent stream, descending the east slope of the range and passing through a long canyon cut 800 feet deep into the volcanic table-land and north of Bishop before it enters Owens Valley proper. Below the great bend of the river it pursues a meandering course southeastward toward Owens Lake. Practically all its tributaries enter from the west, and are fed almost wholly by snows that accumulate just east of the main Sierra divide.

Owens Lake, into which the river empties, lies in an undrained depression at the south end of the valley, and its inflow is probably disposed of wholly by evaporation. Its waters are a strong solution of common salt, sodium carbonate, potassium sulphate, borax, and other salts. The recovery of sodium carbonate is an important chemical industry established near Keeler. The area of the lake in February, 1913, was 97 square miles and its greatest depth 29.6 feet. On account of the shallow shelving shores of the lake on all sides except the west small fluctuations of its water level are accompanied by large changes in its areal extent.

CLIMATE.

Because of the great range in the altitude of the region the climate of different parts of it is very diverse. In general the climate is typical of the southern half of the Great Basin, of which it is a part. In Owens Valley the summer temperature often exceeds 100°, yet, owing to the low humidity, it does not become oppressive; but in the deep depressions that are encircled by high mountains, such as Saline Valley, the temperature is oppressively hot from June to October, without much intermission day or night. The winters are comparatively mild in the valleys.

The average precipitation[1] ranges from 3 inches a year at Owens River to 40 inches on the Sierra Nevada crest. The moisture-laden winds from the Pacific Ocean are largely robbed of their moisture before reaching the Inyo Range. This is notably true in the southern part of the range, which is opposite the highest part of the Sierra Nevada. North of Bishop, however, the Inyo Range averages nearly as high as the Sierra opposite it, and sufficient snow falls to support several small perennial streams.

[1] Lee, C. H., An intensive study of the water resources of a part of Owens Valley, Cal.: U. S. Geol. Survey Water-Supply Paper 294, pp. 15–31, 1912.

GEOLOGY.

STRATIGRAPHY OF THE INYO RANGE.

By Edwin Kirk.[2]

DIFFICULTIES OF THE PROBLEM.

The Inyo Range, in common with many of the Great Basin ranges, offers many obstacles to satisfactory stratigraphic work, and particularly to reconnaissance work like that done for this paper. It is true that exposures are abundant and that few of the sections examined are covered with vegetation or talus, but the range is exceedingly rugged, and in many places it was hard to find good sections in the time available. Information in regard to many areas that are of great interest was obtained only in the course of travel from one camp to another, so that but a brief time could be devoted to detailed work. The necessity of covering a large area in a short time made rapid progress in the work essential, and it was possible to revisit only two or three sections. The strata have been greatly faulted and folded and have been intruded by numerous igneous masses. Fossils are generally rare, and in many places the rocks have been so much metamorphosed as to destroy all organic remains. For these reasons the difficulties of intensive stratigraphic work in this region are unusually great. It is to be hoped that a detailed examination of the sediments of the region may at some time be made. The Carboniferous strata and the part of the stratigraphic column between the top of the Lower Cambrian and the base of the Devonian are particularly worthy of study.

SKETCH OF THE STRUCTURE.

MAJOR FOLDS.

The structure of the Inyo Range is broadly simple, but has been made very complex in detail by faulting, folding, and the intrusion of large igneous masses, which have greatly obscured and in places completely masked the

[2] Mr. Kirk's contribution ends with the description of the Upper Triassic rocks on p. 48.

primary structure. The dips and strikes are extremely variable, so that the great underlying structural features can be determined only by considering the range in the mass.

The sedimentary rocks of the range are involved in a broad, low anticline and a complemental syncline lying west of it. The anticline and syncline pitch steeply to the south. Their axes have a general northwesterly trend, which does not coincide with the course of the range, which trends more nearly northward. In the northern part of the area here described the anticline occupies most of the breadth of the range, but in the southern part it trends diagonally across the range and finally passes out on its east side. Farther south the syncline is the dominant structural feature of the range. The oldest sedimentary rocks are in the northern part of the Bishop quadrangle; and, owing to the southward pitch of the folds, younger and younger sediments succeed one another to the south. In the northern half of the Bishop quadrangle, where the anticlinal structure is best developed, the axis is marked by the resistant and conspicuous Reed dolomite of pre-Cambrian age. This dolomite disappears beneath the Campito sandstone not far north of the Molly Gibson mine. Farther south the anticline is not well shown, owing to extensive faulting and to the fact that the sedimentary masses involved are more or less homogeneous. The eastern limb of the anticline passes out of the range along Deep Spring Valley, and its axis may be considered as disappearing in the general region of Waucoba Mountain. The western limb of the anticline, which, of course, forms the eastern limb of the syncline, continues to the south end of the range.

The syncline is best developed in the part of the range that lies east of Keeler, and from New York Butte south it is the dominant structural feature, though it is greatly faulted and scarcely recognizable as a syncline. The trough of the syncline is filled with nonresistant Triassic sediments, which are flanked on both sides by resistant Carboniferous rocks, a fact that accounts in large measure for the topographic features of this part of the range. In the northern half of the Bishop quadrangle a well-defined syncline, clearly shown in Silver Canyon, lies west of the anticline. The Cambrian beds at the mouth of the canyon are repeated at its upper end, and much crumpled beds of later age lie in the trough. The arrangement thus outlined is largely ideal, for the original structure of the range has been greatly deformed by faulting and igneous intrusion. In the main, however, the relative positions of the stratigraphic units and their distribution in the range are determined by the major features of the structure.

The secondary deformation may be conveniently discussed under two heads—the intrusion of the igneous masses and the faulting and the attendant minor folding. Of the two, the intrusions have caused less displacement of the sediments and are not here described in detail, though a few examples are cited, merely to give a general idea of the structural complexity.

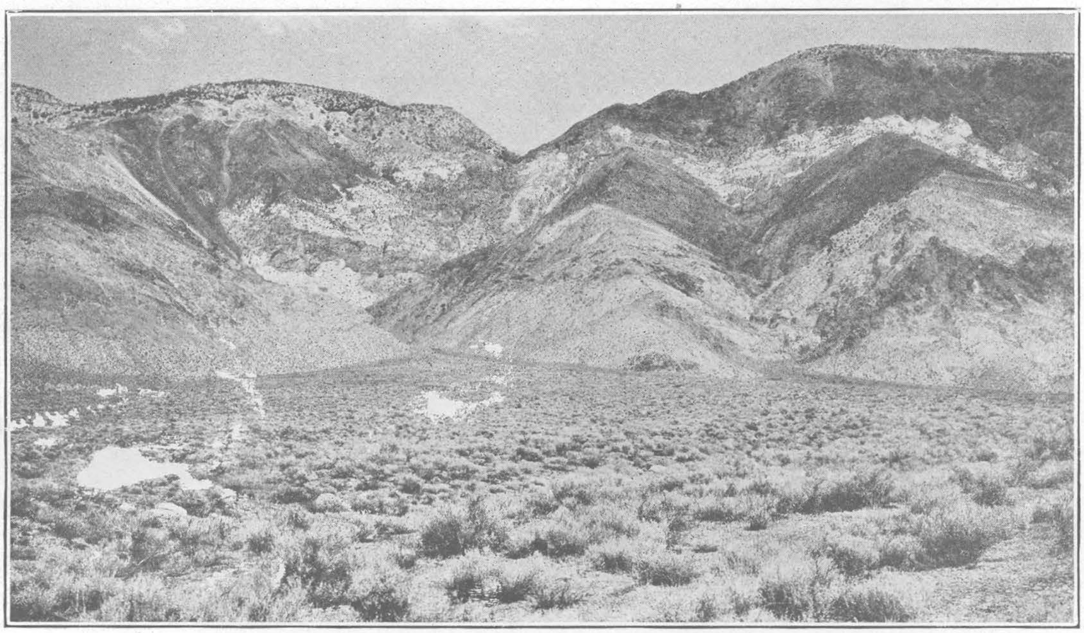
DEFORMATION BY INTRUS

Only the larger masses of igneous rocks could be shown on the map (Pls. I and II, in pocket), but there are many smaller masses and on the southwest side of Saline Valley thin beds of sediments cover great intrusive bodies, which are exposed only in the canyons. The relation of the large igneous masses to the structure of the range is well shown by the great granitic intrusive mass that forms Waucoba Mountain and Squaw Flat. On the east side of Waucoba Mountain the lower part of the Silver Peak group crops out instead of the much higher Cambrian beds, which would normally appear there. A part of the Lower and all the Middle and Upper Cambrian that fronts Squaw Flat on the north should normally front it also on the south, but instead the Ordovician strata alone appear. These changes in the normal sequence and similar changes noted in other areas adjacent to great intrusive masses are apparently due entirely to intrusion. The smaller igneous bodies, however, do not materially displace the sedimentary beds.

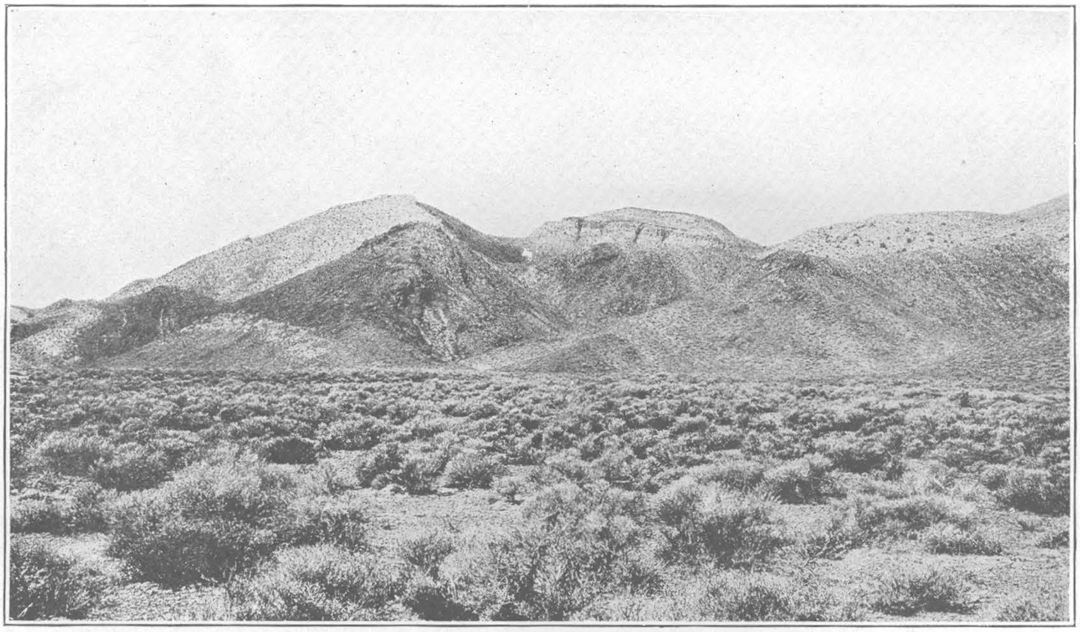
Besides actually displacing the sedimentary beds the igneous masses have extensively metamorphosed them.

FAULTING.

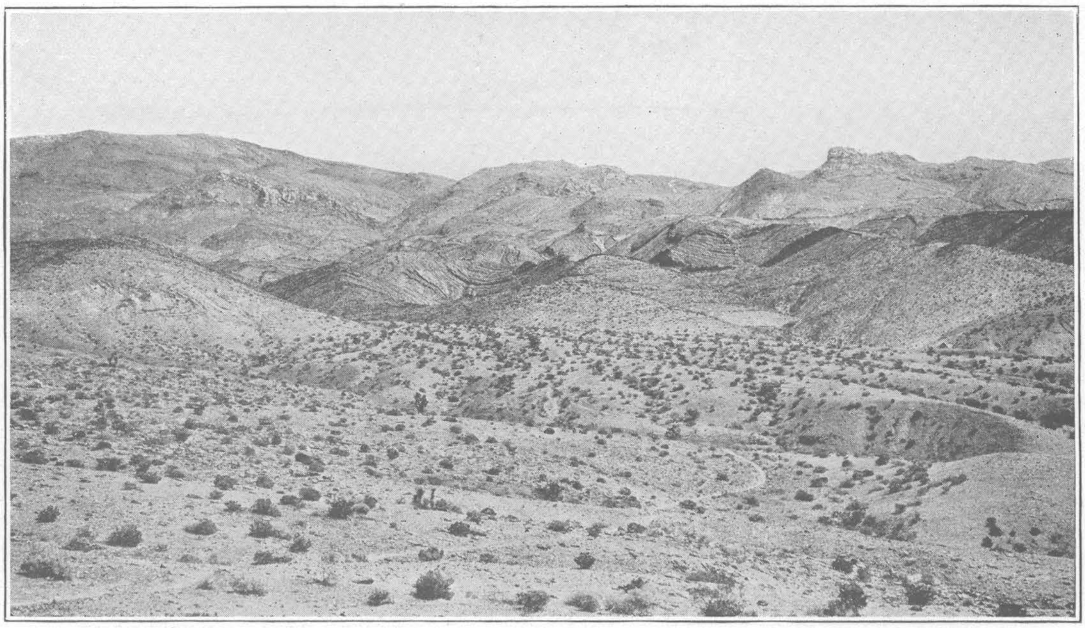
The most notable modifications of the simple folds are due to faulting, which in the Inyo Mountains is exceedingly complex and has determined in large part the major physiographic



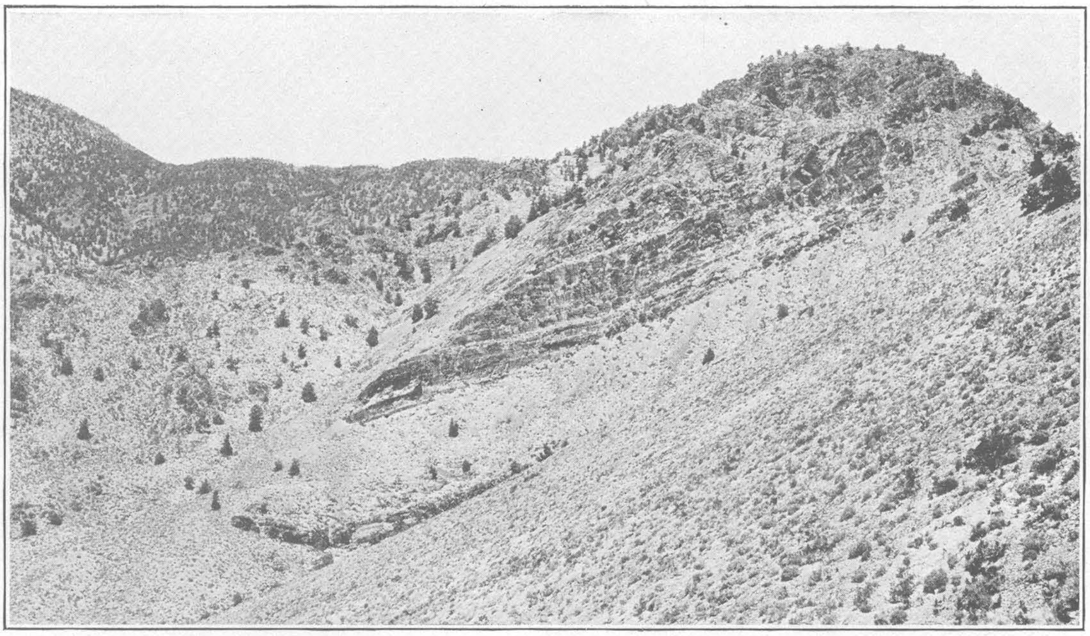
A. FACE OF INYO RANGE 5 MILES SOUTH OF MONTEZUMA MINE, BISHOP QUADRANGLE.



B. FAULTED AND FOLDED CAMBRIAN BEDS ON WEST SIDE OF DEEP SPRING VALLEY, BISHOP QUADRANGLE.



A. FOLDED CARBONIFEROUS AND TRIASSIC SEDIMENTS ALONG UBEHEBE TRAIL, 6 MILES SOUTHEAST OF KEELER.



B. MINOR NORTH-SOUTH FAULT NORTH OF TOLLHOUSE ON DEEP SPRING VALLEY ROAD, BISHOP QUADRANGLE.

features of the range. The faults may be divided into three groups—(1) those that are roughly parallel to the trend of the range, (2) those that are approximately at right angles to the trend of the range, and (3) those that follow intermediate directions. The faults of the three series appear to have no definite relation in age. Apparently the greatest faults run parallel to the range, and the next greatest run diagonally to it. Conspicuous faults that run at right angles to the range are rare. This grouping of the faults is arbitrary; probably certain faults that are assigned to groups 1 and 3 are more closely related as regards origin or dynamics than some faults that fall within group 3 itself. Some of the faults placed in group 3 could as well be referred to group 1 or group 2. At no place was there any indication of thrust faulting. The faults of group 1 determine the outline of the range. The west front of the range, facing Owens Valley, and its east front, along Saline Valley, are determined by fault planes. Deep Spring Valley and Cowhorn Valley are intramontane valleys bounded by fault planes.

The throw of the faults bounding the range must be very great. One of the large faults that take part in the formation of Saline Valley is estimated, from the sediments brought into juxtaposition, to have a throw of not less than 8,000 feet. This fault passes down the Saline Valley road, in the southwestern corner of the Lida quadrangle, and continues southward into the Ballarat quadrangle, where its further course is concealed by basaltic flows and detritus. It may run along the east side of Saline Valley at the foot of the Ubehebe Range or it may pass into the valley proper. In the neighborhood of the Montezuma mine, at the base of the west side of the range, there is a fault with a throw of at least 5,000 feet. This appears to be only one of several step faults that delimit the front of the range. (See Pl. III, *A*.)

Within the mountain mass itself there are numerous faults which run parallel or nearly parallel to the axis of the range. Among these are the faults that bound the Triassic sediments in the synclinal trough east of Keeler. (See Pl. IV, *A*.) The throw of the fault on the east side probably does not exceed 1,500 feet, but that of the one on the west side is greater by perhaps 2,000 feet. Another fault of fair dimensions lies north of Andrews Mountain in the Bishop quadrangle. Nearly on a line with the west side of Deep Spring Valley and perhaps continuous with the fault in that valley there is a fault that extends southward through the Cambrian sediments and that involves the Campito sandstone and Silver Peak group. (See Pl. III, *B*.) This fault must have a throw of several thousand feet. Many similar faults might be mentioned.

Most of the faults of group 2 are indicated by canyons that penetrate the range. The Cambrian sediments that form the walls of Silver Canyon have been greatly folded, and the beds on one side of the canyon have been dropped with relation to those on the other. This fault bifurcates at the head of the canyon. Almost every other canyon in the range will furnish similar evidence of faulting. Deep Spring Valley is terminated at its south end by an abrupt wall, some 2,000 feet high, which is evidently a fault scarp. Many of these eastward-trending faults are considerably older than the latest great displacements along the sides of the range, as is clearly shown along the west side of Saline Valley.

Group 3 is intended primarily to include faults that cut diagonally across belts of sediments bounded by faults parallel to the axis of the range. One such fault is well shown east of Keeler, where the Triassic sediments are bounded on the east and the west by fault planes. About midway between the Saline Valley Salt Co.'s road and the road from Keeler to the Cerro Gordo mine a fault crosses diagonally this belt of Triassic rocks. The Triassic volcanic series is well developed north of the fault but is gradually cut out on the south, being replaced by Lower and Middle Triassic sediments, and ultimately disappears in the neighborhood of the Ubehebe trail. Several such diagonal faults appear on the west side of the range between New York Butte and Cerro Gordo. They, together with the faults that follow the trend of the range, have thrown the strata into great confusion.

In addition to the well-marked diagonal faults, group 3 contains a great number of faults that trend in every conceivable direction, though most of them trend northward. They vary in throw from a few feet to several thousand feet. Many sections show as many as 10 to 15 minor faults in the space of a hundred yards. Among the more notable faults of this group are those lying between the Deep Spring Valley road and Marble Canyon, in the Bishop quadrangle. (See Pl. IV, *B*.) The south face of Black Mountain shows a number of faults, and Black Canyon marks a well-defined fault plane. The road from the Mollie Gibson mine south follows a fault of considerable magnitude. The faults of Cowhorn Valley, noted under group 1, really fall in this class. In the Mount Whitney quadrangle extensive faulting along Mazourka Canyon greatly disturbs the strata. A fault crossing the Union Wash is of importance in that it cuts out the higher Carboniferous beds and the basal Triassic, its throw being more than 4,000 feet.

The beds along the front of the range in the immediate neighborhood of the major fault planes are intensely disturbed. (See Pls. III and IV.) It is generally impossible to gain any conception of the nature and succession of beds along the face of the range, because they have been greatly disturbed, and therefore, in order to determine the stratigraphy, it is necessary either to study the sections in the canyons or to go well back in the range.

Faulting occurred in at least two widely separated geologic periods; the earlier movements accompanied the folding of the rocks in the Jurassic or Cretaceous, and the later accompanied the late Cenozoic elevation of the range. The displacements appear to have been greatest along faults that originated at the time the range was uplifted, and some of these faults, as already noted, probably involve throws of as much as 5,000 feet. The relation between the earlier and later series of faults is most plainly shown at the south end of the range, southeast of Keeler, where a series of horizontal flow of basalt rests upon the eroded edges of folded Carboniferous and Triassic sediments. The basalt is dislocated by a series of step faults, and the underlying sediments are traversed by faults that antedate the basalt flows.

GENERAL STRATIGRAPHIC SECTION.

The sedimentary rocks of the Inyo Range have an aggregate thickness of more than 36,000 feet—about 7 miles—and range in age from pre-Cambrian to Triassic. On eliminating the Triassic and pre-Cambrian, it is found that the Paleozoic rocks have a thickness of 5 miles. This figure becomes even more impressive if it is remembered that the section includes no beds that represent large parts of the Paleozoic. The Middle and Upper Cambrian are not greatly developed; the Ordovician, except for strata of Beekmantown (Lower Ordovician) age, is poorly represented; the Silurian is absent; the Devonian is represented only by Middle Devonian sediments; the Mississippian is probably represented by only its upper portion; and the Permian is thin. The great thickness of the Paleozoic rocks is due to the presence of large quantities of clastic sediments that accumulate rapidly under favorable conditions.

The following tabular section gives the approximate thickness of the stratigraphic units:

Generalized section in the Inyo Range, Cal.

	Feet.
Triassic:	
Upper Triassic (and Jurassic?) shales interbedded with volcanic rocks consisting chiefly of waterlaid tuffs and breccias	5,000
Lower and Middle Triassic calcareous shales and thin-bedded arenaceous limestones, with calcareous sandstone at base	1,500
Permian: Owenyo limestone	125+
Pennsylvanian:	
Reward conglomerate	250
Later Pennsylvanian limestone and shale	3,000±
Diamond Peak quartzite	3,500+
Basal Pennsylvanian limestones	1,000
Mississippian: White Pine shale	1,000
Devonian: Middle Devonian limestone	1,400
Ordovician:	
Arenaceous shale, probably of Normanskill age	750
Limestone containing Chazy fossils	500
Limestone, probably of Beekmantown age	3,500
Sandstone	300
Upper Cambrian: Arenaceous limestone and shale	1,000±
Middle Cambrian: Calcareous sandstone and limestone	900+
Lower Cambrian:	
Silver Peak group	7,000±
Campito sandstone	3,200
Pre-Cambrian:	
Deep Spring formation	1,600
Reed dolomite	2,000
Oldest sandstones and dolomites	(?)

PRE-CAMBRIAN ROCKS.

GENERAL RELATIONS.

Underlying the lowest Cambrian sediments in the Bishop quadrangle is a great thickness of sandstone and dolomite. Spurr[1] notes that in the northeastern part of the Silver Peak quadrangle, Nev., below the lowest fossiliferous Cambrian horizon, there are "several thousand feet of dolomitic limestones and marble, quartzites, and green knotted schists." These he refers to the Cambrian. Turner,[2] referring to these same beds, says that "it is quite possible that they represent the base of the Cambrian" but suggests also that they may be pre-Cambrian in age. The sediments exposed in the northern part of the Bishop quadrangle beneath the Reed dolomite were apparently not seen in the Silver Peak quadrangle.

The basal dolomite of Spurr and Turner is doubtless to be correlated with the Reed dolomite of the present report, but there is some question as to the correlation of the quartzites and schists of the section. In the Bishop quadrangle a series of beds with an observed maximum thickness of 1,600 feet overlies the Reed dolomite in one place and is practically cut out in another place a few miles away. The quartzites and schists of Spurr and Turner may represent either this 1,600-foot series in whole or part, or the overlying Campito sandstone, or both.

The pre-Campito sediments may be subdivided, on lithologic grounds, into three units. The lowest is a series of sandstones and thin-bedded impure dolomites of unknown thickness, which because of its slight areal extent and its unsatisfactory exposures has not been named. Above comes the Reed dolomite, which is locally overlain by the Deep Spring formation. The Campito sandstone on the west side of Deep Spring Valley rests on the Deep Spring formation, and at the head of Wyman Creek on the Reed dolomite, with possibly a remnant of the Deep Spring formation between.

Walcott maintains that all the pre-Cambrian sediments on the continent are nonmarine. The pre-Cambrian sediments in the Inyo Range are certainly shallow-water deposits, as shown by ripple marks, mud cracks, and lithologic features. The same arguments might be adduced for their nonmarine origin as for that of the pre-Cambrian sediments of the northern Rocky Mountain region. But there seems to be no definite evidence one way or the other.

OLDEST SANDSTONES AND DOLOMITES.

The oldest sedimentary rocks exposed in the area are found in the extreme northern part of the Bishop quadrangle. In this area there are large intruded masses of igneous rocks and much of the surface is covered with extruded basalts. In addition the structure of the region is made more complex by numerous faults, some of which are of considerable magnitude. The structural complexity of the region, its inaccessibility, and the short time available made detailed work impossible; but it appears that the rocks under the Reed dolomite are exposed immediately east of the range formed by the Reed dolomite and north of Wyman Creek. It is probable also that a considerable series of these beds forms the western and northern faces of the mountain (elevation 10,121 feet) that stands in the eastern angle between Wyman Creek canyon and the southward-trending canyon which is traversed by the road to Coldwater Spring. The rocks in the low area north of Wyman Creek are greatly disturbed by faulting and folding.

The beds immediately under the Reed dolomite are well shown on the north side of Wyman Creek canyon. The sediments here consist of thin-bedded arenaceous slates which grade downward into more heavily bedded sandstones. As only a few feet of the beds are exposed, it is not possible to determine whether they are the initial deposits of the Reed or the terminal deposits of the underlying series. In general, the series as seen at several points seem to consist of thin beds of arenaceous slate, some beds of impure dolomite, and thin beds of sandstone. Most of the sandstones are dark brownish black with reddish streaks. The impure dolomitic limestones break down into blocks that form white talus slopes somewhat similar to those of the Reed dolomite though different in their smoother contours and smaller blocks, and in the mixture of sandstone with

[1] Spurr, J. E., Ore deposits of the Silver Peak quadrangle, Nev.: U. S. Geol. Survey Prof. Paper 55, p. 18, 1906.

[2] Turner, H. W., Contribution to the geology of the Silver Peak quadrangle, Nev.: Geol. Soc. America Bull., vol. 20, p. 238, 1909.

the dolomite. The rocks are generally considerably metamorphosed and many of them are schistose. The sandstones are at many places cross-bedded. Ripple marks and mud cracks are abundant.

The only fossils seen were problematic structures, 6 to 8 inches in diameter, that are possibly referable to Cryptozoa.

REED DOLOMITE.

The Reed dolomite is one of the most striking features in the northern part of the Bishop quadrangle. It forms the axis of a southward-pitching anticline and disappears beneath the Campito sandstone in the region north of the Mollie Gibson mine. It is also exposed along Marble Canyon, on the west side of the range, from a point below the mouth of Black Canyon to about the point where the 6,200-foot contour crosses the canyon. Along the west side of Deep Spring Valley it is exposed by faulting at the heads of the canyons north of Antelope Spring and on the crest of the range. Farther south it was not definitely recognized, but it may be locally exposed by faulting.

The Reed dolomite forms bold, forest-clad mountains and a long white ridge that stands out sharply from the dark basal sandstones and is clearly visible for miles. Blanco Mountain, which is practically the northern limit of the dolomite, is composed wholly of it. The contrast in topography and appearance of outcrop between the Campito and Reed is strongly marked. (See Pl. V, *A*.) The Reed is well forested, and the Campito is practically treeless.

The name of the dolomite is taken from Reed Flat, along whose eastern side it is prominently exposed for several miles. The best section is in the canyon at the head of Wyman Creek, in sec. 7, T. 6 S., R. 35 E. At the east end of the canyon, through which the road passes, the base shows clearly in the north wall, and at the west end the contact with the overlying sandstones may be seen. The thickness of the dolomite as paced through this canyon is about 2,000 feet, and, as no evidence of repetition by faulting is apparent, this estimate is doubtless reasonably accurate.

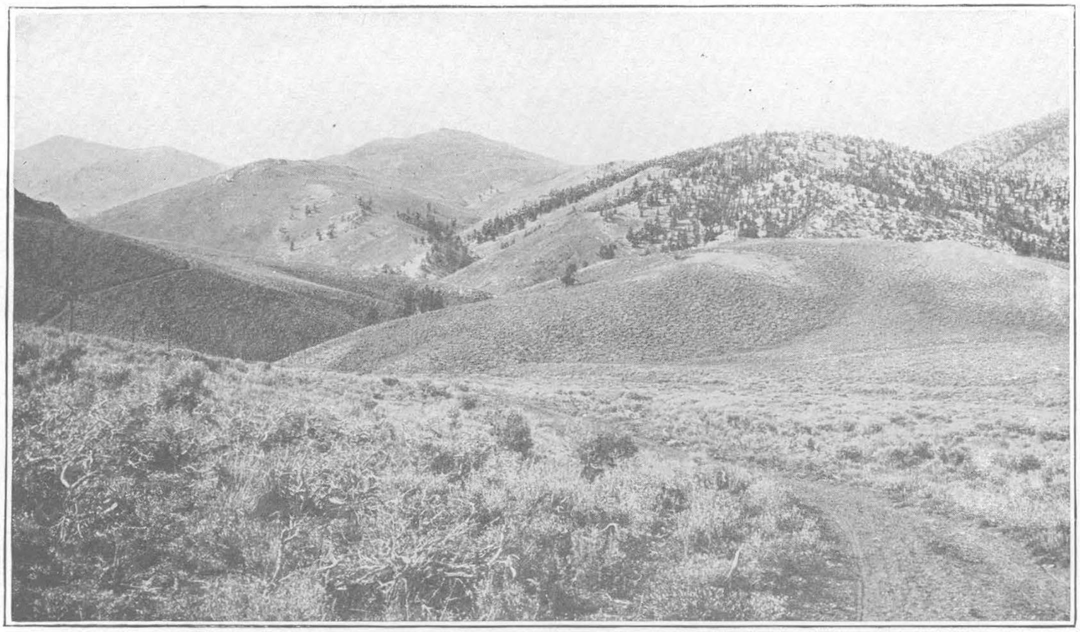
The dolomite is heavy bedded. Indeed, in the Wyman Canyon section it was impossible to recognize bedding planes, and the dip could be measured only at the base and top. The dolomite is much jointed and breaks up into large angular blocks that form rough talus slopes. Lithologically it varies from almost aphanitic to coarsely crystalline. In fresh fracture it is typically white or slightly bluish, but on weathering it becomes slightly creamy to buff. The talus as a whole appears white, but many of the beds are mottled and speckled by stains caused by small particles of iron oxide.

The only fossils found in the Reed dolomite are poorly preserved forms that strongly suggest calcareous algae of the type of *Girvanella*. In certain layers these algae were abundant. None seen was larger than an inch in diameter.

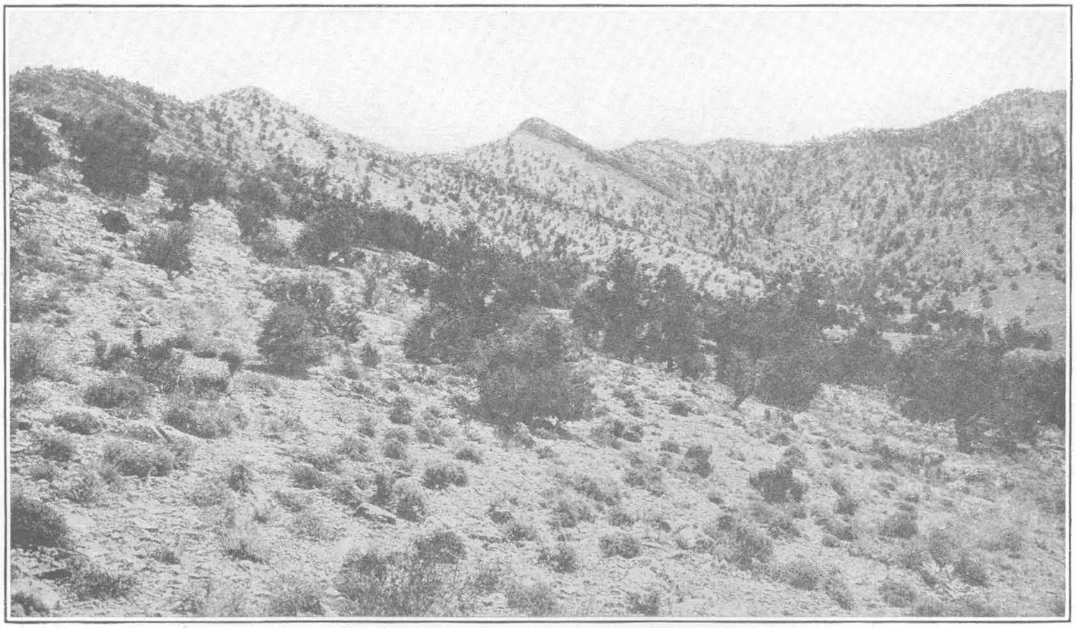
DEEP SPRING FORMATION.

The Deep Spring formation derives its name from Deep Spring Valley, along whose west side, in the canyons north of Antelope Spring, it is splendidly exposed. At the head of the second canyon north of Antelope Spring about 1,600 feet of the sandstones and dolomitic limestones of the formation, dipping 40°, unconformably overlies the Reed dolomite, which forms the main mass of the mountain, and is unconformably overlain by the Campito sandstone. The same series is apparently shown in part on the lower portion of Wyman Creek below the Roberts ranch, but the rocks there are greatly disturbed, and any correlation must of necessity be based on lithologic similarity and be of uncertain value.

Along Reed Flat and at the head of Wyman Creek the Deep Spring formation is absent or is at most represented by a negligible remnant. Near Goat Spring in Reed Flat the rocks immediately above the Reed are poorly exposed for a thickness of approximately 175 feet. The surface material indicates that this interval is represented by reddish-weathering sandstones, which break down into small angular fragments. Above these sandstones come the characteristic dark purplish-red cross-bedded sandstones of the Campito, which break down into large angular blocks. Lithologically these beds do not resemble any in the Deep Spring formation, which, if represented at all on the western side of the range, has a thickness of not more



A. EXPOSURES OF REED DOLOMITE AND CAMPITO SANDSTONE NORTH OF GOAT SPRING, BISHOP QUADRANGLE.



B. EXPOSURE OF SILVER PEAK GROUP, ANDREWS MOUNTAIN, BISHOP QUADRANGLE.

than 200 feet. In Marble Canyon the Campito appears to rest directly on the Reed.

The following section of the Deep Spring formation shows its lithologic character. The formation rests unconformably on the Reed dolomite, and is overlain unconformably by the Campito. No organic remains were found in it.

Section of Deep Spring formation in second canyon north of Antelope Spring on west side of Deep Spring Valley.

	Feet.
Sandstone, massive, irregularly bedded, buff, calcareous	35
Sandstone, heavy, blue to gray, calcareous	170
Sandstones and arenaceous slates, dark brown in fresh fracture, weathering black	150
Sandstone, massive, bluish and gray, calcareous	40
Limestone, buff, with well-marked iron-stained bands	120
Sandstone, massive, blue, quartzitic	10
Sandstone, thin bedded to massive, grayish white, weathering platy; iron stained in bands; near top distinctly banded in bluish gray and white	70
Shales, arenaceous, with interbedded quartzitic sandstone	6
Sandstone, white, quartzitic, thinly bedded at base, more massive above	42
Sandstone, shaly, merging upward into overlying blocky sandstone	9
Sandstone, fairly massive, buff	25
Sandstone, bluish, platy, quartzitic, weathering in blocky angular fragments; banded with browns, reds, and grays	186
Sandstone, massive, fairly soft; grayish toward base, buff above	40
Sandstone, quartzitic; buff toward base, grayish above; marked by a very characteristic, sharp, ribbon-like banding	100
Sandstones, quartzitic to fairly soft, thin to heavy bedded; ranging in color from buff to dark gray	139
Sandstone, white, massive; weathering slightly buff	30
Sandstone, quartzitic; irregular contact at base; basal portion deeply iron stained, dark buff above	45
Limestone, very coarse, crystalline	15
Limestone, heavy bedded, buff and white, saccharoidal, arenaceous; weathering readily	130
Limestone, dirty white	15
Sandstone, massive, coarse grained, banded, weathering buff	25
Sandstone, thin bedded, greenish and buff weathering, quartzitic	60
Limestone, heavy bedded, buff weathering	5
Sandstone, thin bedded, platy, grayish and buff, quartzitic, in one or two fairly thick beds	47
In part concealed. The greater part apparently grayish, crystalline limestone. Some heavy, white quartzite banded with brown	81
Quartzite, thin banded, copper stained (locally), brownish	8
	1,603

UNCONFORMITY AT BASE OF CAMPITO SANDSTONE.

It seems best to draw the base of the Cambrian in this region at the base of the Campito sandstone. The Deep Spring formation and the underlying rocks have little in common lithologically with what is here regarded as Lower Cambrian, and have much in common with pre-Cambrian sediments found elsewhere in the Western States. It is but natural to assume that the first sediments deposited on the floor of the Lower Cambrian sea which invaded this area would have formed a series of sandstones, and this assumption is best met by the Campito. The unconformity at the base of the Campito appears to be the most striking of those noted in this region. It seems certain that within a few miles, 1,500 feet or more of the Deep Spring formation has been eroded away, indicating erosion covering a long period. The absence of any organic remains other than calcareous algae and Cryptozoa (?) in the rocks below the unconformity is negative evidence, to be sure, but is nevertheless important. The Campito likewise (so far as is known) carries no fossils other than annelid trails and trilobite (?) tracks, but its lithologic affinities are all with the overlying fossiliferous beds. The position of this great series of sandstones and dolomites, here classed as pre-Cambrian, beneath the lowest known fossiliferous Lower Cambrian (the oldest Lower Cambrian known in America) is in itself strongly suggestive of its pre-Cambrian age.

CAMBRIAN SYSTEM.

GENERAL CHARACTER.

The first account of the Cambrian sediments in the Inyo Range was that of Gilbert,[1] who crossed the range from Deep Spring Valley to

[1] Gilbert, G. K., Geology of portions of Nevada, Utah, California, and Arizona: U. S. Geog. and Geol. Surveys W. 100th Mer. Rept., vol. 3, pt. 1, p. 169, 1875.

Owens Valley and measured the section given below. He expressed no opinion as to the age of the beds seen and apparently collected no fossils, although the richly coralline beds of this region are well shown along the road on the west side of the range. According to Gilbert's description it seems probable that the beds measured by him are confined to the Silver Peak group.

Rocks exposed on the east face of the Inyo Range at pass between Deep Spring Valley and Owens Valley.

		Feet (estimated).
Quartzite and siliceous schist:		
Schist, greenish, siliceous; blue-gray quartzite at base	500	
Quartzite, calcareous, pale gray	50	
Schist, hard, pale green; bands of quartzite and limestone	200	
		750
Limestone, massive, blue; veined with white calcite		75
Clay shale and calcareous quartzite:		
Quartzite, yellow	20	
Shale	200	
Quartzite, yellow	20	
Quartzite, umber brown	50	
		290
		1,115

Not until the Cambrian sections of the Inyo Range (White Mountains) had been studied by Walcott was there any definite conception of the age or approximate thickness of the Cambrian. The work of Turner and Spurr in the Silver Peak quadrangle, Nev., northeast of the Bishop quadrangle, although it threw some light on the Cambrian of the region, was not sufficiently detailed to afford much definite information.

The Cambrian sediments of the Inyo Range have an aggregate thickness of more than 12,000 feet. Lower, Middle, and Upper Cambrian time are represented, but the Lower Cambrian makes up the bulk of the deposits, having a thickness of not less than 10,200 feet, more than half of which consists of clastic sediments. The Lower Cambrian of this area is not only notable for its great thickness, but it contains the oldest Cambrian deposits known on the continent. The Lower Cambrian is here divided into the Campito sandstone at the base and the Silver Peak group above. The Middle Cambrian, which has not previously been recorded from this area, comprises some 900 feet of strata, most of which are clastic sediments. The Upper Cambrian is represented by 1,000 feet or more of calcareous sandstones, impure limestones, and arenaceous shales, which are doubtless equivalent to most of the Emigrant formation of Turner.

LOWER CAMBRIAN ROCKS.

GENERAL FEATURES.

The Lower Cambrian rocks of the area here considered lie almost entirely within the Bishop quadrangle. That part of the range which lies north of the Saline Valley road contains no other sedimentary rocks. The rocks south of that road, on the west side of the range, are higher Cambrian and Ordovician. East of Waucoba Mountain the Lower Cambrian, which should be considerably beneath the surface, has been exposed by the great upthrust of igneous rock that forms Waucoba Mountain. There is no place in this whole area where an even reasonably complete section is to be had. The Campito sandstone is exposed in all the canyons north of Black Canyon along the west side of the range and in Deep Spring Valley, in the second canyon north of Antelope Spring. Fine sections of different parts of the formation may be seen in Payson Canyon. The Silver Peak group is involved in the folding along the west front of the range from the northern limit of the Bishop quadrangle to Squaw Flat. The best section seen is along Andrews Mountain. The formations here described extend northeastward into the adjacent Silver Peak quadrangle, which is the type area of the Silver Peak group.

The Lower Cambrian section in the Inyo Range is of exceptional interest. It is thicker than any other known Lower Cambrian deposit in America and carries the oldest known Cambrian fauna. Because of these facts Walcott has chosen this area as the type area of the Lower Cambrian in America. The term Georgian applied in former days to the Lower Cambrian series is preoccupied, so in place of this term Walcott has proposed the name Waucoban series. His type section, in which the Silver Peak group alone is represented, lies on the east side of Waucoba Mountain on the northwest side of Saline Valley. The section is incomplete in its upper and lower portions, and the beds are somewhat disturbed, the faulting and folding shown in the rocks here being doubtless due to the proximity of the Waucoba Mountain intrusive mass. A better section is exposed northeast of Waucoba Mountain, along Andrews Mountain. (See Pl. V, *A*.) The section here is complete except for the basal sandstones (Campito) of the Cambrian, which are apparently not shown to advantage south of Deep Spring Valley. Walcott,[1] indeed, notes the presence of a small mass of Lower Cambrian sediments west of Big Pine, in the foothills of the Sierra Nevada, but this probably represents some part of the Silver Peak group.

CAMPITO SANDSTONE.

Distribution.—The Campito sandstone, which, next to the Silver Peak group, is the most widely distributed Cambrian or pre-Cambrian formation, is well exposed in the canyons on the west side of the range in the north half of the Bishop quadrangle. At the head of Coldwater Canyon and on Campito Mountain it is prominently displayed, though perhaps not so well as at some other places which are unnamed and are therefore difficult to cite. A particularly good section is afforded in the canyon opening into Deep Spring Valley about a mile north of Antelope Spring. A photograph of a part of the series in Soldier Canyon is given by Walcott.[2] The base of the Campito may be seen in Black Canyon near its mouth, along the east side of Reed Flat at different points, at the head of Wyman Creek, and in the canyon on the west side of Deep Spring Valley.

Relations.—In Deep Spring Valley, where typical basal Campito rests on the Deep Spring formation, the contact is somewhat obscured but appears to be one of well-defined unconformity. Along the west side of the range the Reed dolomite is overlain by a yellowish-brown cross-bedded sandstone 12 to 15 feet thick, which is in turn overlain by nearly 175 feet of soft reddish-brown sandstones that carry some thin beds of impure limestone. On the east side of the range, on the other hand, at the head of Wyman Creek, dark purplish-red sandstones of the Campito type underlie the limestone lenses. The exposures of this part of the section are not good, for most of them are on slopes which are largely covered with débris, and for this reason it is difficult to say with certainty whether the 200 feet or less of strata overlying the Reed represents the base of the Campito or the base of the Deep Spring formation. The writer is inclined to believe that the Deep Spring formation has been eroded away and that the Campito rests directly on the Reed dolomite.

The upper limit of the Campito is placed at the lowest horizon at which fissile calcareous shales and fairly pure masses of limestone appear. No good exposures of this portion of the section were seen, and it is not known whether or not an unconformity exists between the Campito and the overlying Silver Peak group. The gradual increase in shale upward in the Campito and the presence in the Silver Peak group of sandstones that resemble those of the Campito indicate a close relationship between the two. The marked lithologic difference between the two groups of sediments in the mass, however, and the essential unity of character of each are sufficient justification for giving the sandstone a name. Broadly speaking, the difference between the two is that the Campito represents deposition in shallow water and the Silver Peak group deposition in fairly deep water.

Thickness.—Walcott[3] estimated the thickness of the Campito sandstone at 2,000 feet from the exposures in Silver Canyon; but careful estimates made by the writer at more favorable places along the west side of the range show that it is not less than 3,000 feet. On the west side of Deep Spring Valley, where the Campito is well exposed throughout its mass, a paced measurement gave 3,200 feet. Corrections were made for irregularities in the course of the canyon, and the thickness as computed should be fairly accurate. It is certainly underestimated rather than overestimated.

Character.—What might be called typical Campito sandstone is on fresh fracture a dense,

[1] Walcott, C. D., Lower Cambrian rocks in eastern California: Am. Jour. Sci., 3d ser., vol. 49, p. 141, 1895.

[2] Walcott, C. D., Cambrian geology and paleontology (No. 5); Cambrian sections of the Cordilleran area: Smithsonian Misc. Coll., vol. 53, pl. 18, 1908.

[3] Walcott, C. D., Lower Cambrian rocks in eastern California: Am. Jour. Sci., 3d ser., vol. 49, p. 143, 1895.

fine-grained grayish sandstone with conspicuous fine dark lines that indicate highly complex cross-bedding. Under the microscope it is seen to be composed largely of quartz and plagioclase. The cement has recrystallized chiefly to chlorite and sericite. Magnetite, probably to the extent of 2 or 3 per cent, is present, as are also minor amounts of detrital tourmaline and zircon. On weathering the sandstone becomes a reddish brown to dark purplish red. With sandstone of this type, which constitutes the greater portion of the mass, are associated some bands of very dense lighter-colored quartzitic sandstone, separated by thin layers of siliceous slate. The latter occur as partings between the layers of dense sandstone. The beds in the upper third of the series are somewhat more slaty and include zones that are curiously and, near the top of the series, very notably speckled by ferric oxide. Throughout the series flecks of chlorite are abundant. Well-developed joints traverse the beds and cause the sandstone to break down in angular blocks.

The dark Campito sandstone exhibits remarkable cross-bedding at several horizons, but especially in the lower part of the formation in Reed Flat and in the upper part near the head of Soldier Canyon. The cross-bedding is poorly shown on fresh fracture, but on weathered surfaces it is plainly marked by black lines that contrast sharply with the reddish-brown quartzite. The bedding planes dip at a low angle and are very complex. The cross-bedding is on a small scale and is of a kind that would probably be produced only in shallow water or on tidal flats. A characteristic feature is the truncation of one set of bedding planes by the superjacent series.

No fossils except annelid trails and trilobite (?) tracks have been found in the Campito sandstones.

Correlation.—The Campito formation is probably to be correlated with the Prospect Mountain quartzite of eastern Nevada, which at Prospect Peak, Eureka district, Nev., according to Walcott, consists of about 1,500 feet of gray and brown quartzitic sandstone. Its only fossil remains are annelid trails and trilobite tracks. It probably lies at the base of the lower Cambrian section and extends westward through Nevada, and may well have been laid down contemporaneously with the Campito. The basal quartzitic material, which is of Cambrian age and attains a great thickness at many points in Nevada and Utah, may be well correlated, in part at least, with the Campito. The evidence seems to indicate that the initial Cambrian sea spread widely throughout this general region and everywhere deposited dense quartzitic sandstones.

SILVER PEAK GROUP.

The name Silver Peak was proposed by Turner[1] and used by Walcott[2] for the fossiliferous series of Lower Cambrian sediments in western Nevada and eastern California. Turner's type area is in the Silver Peak quadrangle, northeast of the Bishop quadrangle. The group apparently has the same lithologic and faunal characters in both areas.

Distribution.—The Silver Peak group is the most widely distributed of the Cambrian or pre-Cambrian units in the Inyo Range, having been identified from Coldwater Canyon on the north to Waucoba Mountain on the south. Good sections of parts of the group may be found in any of the canyons on the west side of the range as far south as Waucoba Canyon, but in most of them the strata are greatly faulted and folded. The two most complete sections are that north of Waucoba Springs on the northwest side of Saline Valley, which was measured by Walcott, and that along the northwest face of Andrews Mountain, northwest of Waucoba Mountain. (See Pl. V, *B*.) No opportunity for studying the Waucoba Springs section in detail was offered, but a fair idea of it was gained and parts of it were roughly correlated with the section along Andrews Mountain.

Walcott's section (north of Waucoba Springs) does not show the Campito sandstone, so it is evident that an unknown amount of the basal portion of the Silver Peak is wanting; and comparison of the section with the one along Andrews Mountain northwest of Waucoba Mountain shows that some of the upper beds also are missing. The Andrews Mountain section probably lacks more of the basal

[1] Turner, H. W., A sketch of the historical geology of Esmeralda County, Nev.: Am. Geologist, vol. 29, pp. 264–265, 1902.

[2] Walcott, C. D., Cambrian sections of the Cordilleran area: Smithsonian Misc. Coll., vol. 53, p. 185, 1908.

portion than that at Waucobà Springs, but accurate correlation of the two is difficult. The basal portion of the Andrews Mountain section, however, is probably represented within series 1 of Walcott's section.

Thickness.—More than half the section at Andrews Mountain was carefully measured and the rest estimated from the dip and the width of the outcrop, the total amounting to not less than 6,000 feet. In the portion estimated there was no evidence of repetition by faulting. The series as measured by Walcott at Waucoba Springs has a thickness of 5,670+ feet. Farther north, where the relations of the Campito and Silver Peak are fairly well shown, several hundred feet of shales, sandstones, and limestones (above the Campito) underlie massive limestones like those at the base of the section at Andrews Mountain. The Silver Peak group in this region has therefore a minimum thickness of 6,500 feet and a probable thickness of 7,000 feet or more.

Character.—The Silver Peak group consists in the main of calcareous shales, sandstones, and limestones, all three of which are fossiliferous. The sandstones are generally calcareous and those in the lower half of the group are light in color but weather buff to brown. Those in the upper half on weathering break down into fragments similar to but smaller than those of the Campito, from which they may easily be distinguished when fresh by their distinctly greenish cast. They have the same fine black lining indicative of cross-bedding. Many of the shale layers in the Silver Peak are soft and most of them are distinctly greenish. The limestones are of several types, all of which are massive and marine and carry large numbers of corals at several horizons. Cross-bedded, bluish-gray, oolitic strata are rare, and light-colored limestones weathering buff are abundant. There are also crystalline limestones, which weather gray and contain large numbers of orbicular bodies of clear calcite, as noted by Spurr, Turner, and Walcott. These bodies are evidently products of recrystallization, but it is not known whether the original spherules were of organic origin, for no structure is now visible. The bodies range from one-fourth to three-fourths of an inch in diameter; those measuring half an inch are very abundant. The shales, sandstones, and shaly partings in the limestones are generally highly micaceous. The characteristic difference of the Silver Peak group from the underlying sediments is that it contains calcareous fissile shales and true marine limestones.

The following section of the Silver Peak group as exposed on the northwest side of Saline Valley just north of Waucoba Springs is taken from Walcott.[1] The section as given has been somewhat abridged:

Section of Silver Peak group, Lower Cambrian, east of Waucoba Springs, on the Saline Valley road, Cal.

	Feet.	
Bluish-gray compact limestone with irregular, inosculating threads and stringers of yellowish to buff magnesian limestone. Immense numbers of dark concretions one-fourth to 1 inch in diameter occur in the greater proportion of the layers. The latter vary from 6 inches to 2 feet in thickness. Fauna: Sections of a calcareous brachiopod and a large *Orthotheca*-like shell occur about 50 feet from the base	525	
Light bluish-gray limestone	115	
Massive bedded dark bluish gray limestone	60	
Lead-colored arenaceous limestone with layers of sandstone 1 to 2 inches thick in bands in lower portion, with a band of cross-bedded buff calcareous sandstone about 50 feet from the base. Layers of bluish-gray limestone, banded dark and light gray limestone, and a few layers of brown quartzitic sandstone occur at irregular intervals. Fauna (105 feet from the base): *Salterella*, *Holmia weeksi* n. sp	340	
		1,040
Dark siliceous indurated shales, shaly sandstone, and quartzitic sandstone in alternating layers. Fauna: Annelid trails, *Cruziana*	35	
Buff, drab, and bluish-gray arenaceous limestone, alternating in layers and bands	120	
Gray and dirty-brown sandstones, with bands of light-gray quartzitic sandstones	125	
Gray limestone, becoming arenaceous and passing into gray and dirty brown sandstone. Fauna: Traces of fragments of trilobites on the surface of the sandstone	105	

[1] Walcott, C. D., Cambrian sections of the Cordilleran area: Smithsonian Misc. Coll., vol. 53, pp. 185–188, 1908.

	Feet.	Feet.
Gray and dirty-brown, compact sandstone in layers from 2 inches to 2 or 3 feet in thickness. In the lower portion of the strata are layers of massive-bedded gray quartzitic sandstone. Small concretions 1 to 2 millimeters in diameter are very abundant in many of the upper layers	365	
Hard brown and gray shaly sandstones, with an occasional irregular thin layer of bluish-gray limestone	155	
Bluish-gray arenaceous limestone in thick layers	25	
Greenish-colored arenaceous shale	120	
Alternating bands of arenaceous shale and massive-bedded gray quartzitic sandstones. Fauna (50 feet from the top): *Salterella*, *Olenellus* (fragments); *Scolithus* occurs abundantly in many of the quartzitic sandstones	430	
Gray quartzitic sandstones in layers 8 inches to 3 feet in thickness, passing below 35 feet into buff to yellowish shale with greenish buff bands, with some interbedded gray quartzitic sandstones. Fauna (in quartzitic layers): *Scolithus* like *S. linearis* Haldeman; (in lower portion) *Obolella* sp. undet., *Holmia rowei*, n. sp	485	
Gray and brownish-gray quartzitic sandstones in layers 6 inches to 3 feet in thickness. Fauna: Annelid trails on the surface of the layers	790	
		2, 755
At summit a band of bluish-gray limestone, with sandstones and occasional layers of thin-bedded limestone below. At 290 feet down a band of arenaceous limestone 50 feet thick occurs. Below this, brown sandstone and sandy shales, with interbedded thin layers of limestone in the lower 100 feet. Fauna (430 feet from base): Numerous fragments of *Olenellus*	650	
Argillaceous and sandy shale, with a few thin beds of limestone. Fauna (160 feet from base): *Obolella* sp. undet., *Trematobolus excelsis* Walcott	200	
Alternating arenaceous limestones, shales, and dirty-brown sandstones that break into angular blocks and fragments. Fauna (275 feet from base): *Archaeocyathus* is very abundant	575	
Shaly indurated sandstones, with a few thicker layers of almost quartzitic sandstone. Fauna (on west slope of hill just east of the summit, where the Saline Valley wagon road passes down the slope toward Waucoba Springs): Annelid trails, *Cruziana*, *Trematobolus excelsis* Walcott, *Holmia rowei*, n. sp.; (on the east side of the hill and in lower portion); *Archaeocyathus*, *Ethmophyllum gracile* Meek, *Mickwitzia occidens* Walcott, *Obolella* sp. undet., *Trematobolus excelsis* Walcott, *Hyolithes* sp., *Holmia rowei*, n. sp	450	
		1, 875
		5, 670

In this section the genus *Olenellus* ranges through 4,900 feet of strata, and its lower limit is unknown.

The following section gives the character of the uppermost 557 feet of the Lower Cambrian as exposed on the west end of Andrews Mountain close to the Buckhorn mine. The measurements are approximate but fairly accurate. None of the beds is apparently represented in Walcott's section. Above them is a 50-foot ledge of quartzite that forms the crest of the mountain and is held to be the initial deposit of the Middle Cambrian.

Section of uppermost part of Lower Cambrian on west end of Andrews Mountain, Cal.

	Feet.
Shale, greenish, with some sandstone layers near base; higher up heavy sandstone ledges up to 5 feet in thickness. Shales at base are heavily bedded and arenaceous; above they are fissile and weather down in small thin fragments; fresh shale is olive-green, weathering to reddish brown and to decided red	200
Limestone, impure, brownish buff (prospect hole in this)	10
Sandstone, fairly massive, greenish brown, calcareous, micaceous; annelid trails and *Arthrophycus*-like structures	80
Limestone, blue, with reddish-brown laminations	2½
Limestone, crystalline, weathering buff to reddish brown, spherulitic	15
Shale, greenish, lined with darker green	50
Limestone, grayish blue to nearly white, with calcite veins; oolitic in places; spherulitic in layers	200
Sandstones, weathering brick-red. In fresh fracture decidedly greenish.	

Fossils.—More complete faunal lists than those given in the Waucoba Springs section are to be found in Walcott's monograph on the Cambrian Brachiopoda.[1] Some of these follow:

Locality 7. Shaly beds about 1,000 feet above the quartzitic beds, Silver Canyon, White Mountain Range, Inyo County, Cal.

Kutorgina perugata.
Yorkia wanneri?

Locality 8. Limestone in Tollgate Canyon, about 15 miles east of Big Pine, White Mountain Range, Inyo County, Cal.

Kutorgina sp.
Obolella vermilionensis.
Wimanella inyoensis.

Locality 53. Sandstones in the lower portion of third of the Waucoba Springs section, 1 mile east of Saline Valley road, about 2.5 miles east-northeast of Waucoba Springs, Inyo County, Cal.

Mickwitzia occidens.
Obolella vermilionensis.
Trematobolus excelsis.
Archaeocyathus.
Ethmophyllum gracile.
Hyolithes sp.
Wanneria gracile.

Locality 312. Sandstones of third [at bottom] of the Waucoba Springs section, east of Saline Valley road, east of Waucoba Springs, Inyo County, Cal.

Trematobolus excelsis.
Cruziana.
Holmia rowei.

Locality 176. Shales and interbedded limestones between massive limestone containing *Archaeocyathus*, at the south end of Deep Spring Valley, Inyo County, Cal.

Obolella vermilionensis.
Obolella? sp.
Trematobolus excelsis.
Wanneria gracile.
Olenellus fremonti.

Locality 178a (slightly higher than 176 but same locality).

Trematobolus excelsis.
Billingsella highlandensis?
Wanneria gracile.
Olenellus fremonti.

The coral faunas noted in the several limestones are of considerable interest. In places they are so abundant that they suggest reef structure, occurring in richly coralline limestone masses that appear to be lenticular and to have a restricted areal distribution.

MIDDLE AND UPPER CAMBRIAN ROCKS.

Distribution.—In the Inyo Range the Middle Cambrian is represented by a series of calcareous sandstones and limestones 900 feet or more thick, which are typically exposed on the divide between Squaw and Harkless flats. The basal quartzite of the series forms the crest of the peak just west of the Buckhorn mine on the west end of Andrews Mountain, and the higher beds extend westward along the ridge from this point. The rocks, so far as known, have a very small areal distribution, having been seen only on the ridge indicated and in poor exposures along Harkless Flat.

The section as exposed is given below. The thicknesses are approximate.

Section of Middle Cambrian rocks.

	Feet.
(?) Limestones, granular, fossiliferous	100+
Quartzite, thin bedded, and calcareous sandstones	750
Quartzite, white; in beds from 6 to 8 feet in thickness	50
	900+

The only known exposure of the Upper Cambrian is on the divide between Harkless and Squaw flats, west of the Middle Cambrian section; and it was, unfortunately, impossible to follow it westward to the Ordovician strata. South of Squaw Flat the Upper Cambrian is apparently not exposed. North of Squaw Flat faulting has occurred, but the hasty examination possible disclosed none that would materially affect the relative positions of the beds or notably change their apparent thickness.

The shales of the series form the floor of the western portion of Harkless Flat and outcrop at several places on the divide to the south, but no good exposure of them was seen. Their thickness is estimated at about 1,000 feet.

Age.—The age of the granular limestones overlying the sandstones is doubtful. The only fossils found were identified by Dr. Charles D. Walcott as *Nisusia* sp. (probably new) and *Hyolithes* sp. From this meager evidence he concluded that the beds can not be younger than Middle Cambrian. As a matter of fact, the fossils suggest Lower Cambrian types. It does not seem probable that there is a fault in this part of the section, but only the most hasty examination of the section could be made. There can be no question as to the age of the apparently underlying sandstones, however, for they carry characteristic Middle Cambrian

[1] Walcott, C. D., Cambrian Brachiopoda: U. S. Geol. Survey Mon. 51, pp. 170 et seq., 1912.

trilobites that were identified by Dr. Walcott as *Ogygopsis* sp. near *O. klotzi.*

A few fossils found near the base of the arenaceous limestones of the Upper Cambrian series were determined by Dr. Walcott as *Ptychoparia* sp. and *Obolus* sp., which indicate Upper Cambrian age. The beds seem moderately fossiliferous, and a fair fauna could doubtless be collected from them in a few hours.

Character.—The basal 50 feet of the Middle Cambrian consists of an exceedingly dense, white quartzite in beds 6 to 8 feet thick. So dense is the quartzite that prospectors have taken out claims on it, thinking it a quartz ledge. It caps the peak above the Buckhorn mine and runs northwestward, forming the crest of an eastward-facing escarpment for about 2½ miles.

The overlying sandstones are much less resistant and form a distinct saddle in the ridge. The main mass of these beds consists of thin-bedded calcareous, somewhat micaceous sandstones that weather a dark reddish brown.

The limestones overlying the sandstones are crystalline to oolitic in texture. When fresh they are bluish gray, but on weathering they develop small ocherous bodies that give them a decidedly reddish-brown appearance. On the knob west of Andrews Mountain (marked 9,115 feet on Pl. I) they are well exposed, and it was here that fossils were collected.

Lying above the Middle Cambrian calcareous sandstone and limestone are arenaceous limestones and shales which are correlated with part of the Emigrant formation (Upper Cambrian).

The basal quarter or third of this series of beds consists in the main of thin-bedded arenaceous limestones, which break down in small, irregular, angular fragments. In fresh fracture the beds are as a rule gray, but all of them weather to bright colors, some of them to brick-red and others to buff and brown. Associated with the limestones are greenish shales like those higher in the formation.

The bulk of the series consists of greenish fissile shales which break down into small fragments and on weathering show bright-red and buff coloration. Interbedded with the shales are sandstones and some impure limestones. Lithologically the beds agree very well with Turner's description of the Emigrant formation.

Correlation.—Strata of Middle Cambrian age have not heretofore been recognized in this region. Middle Cambrian fossils were determined by Walcott[1] from a locality near Resting (Freshwater) Springs, on Amargosa River, in the southeastern part of Inyo County. It is possible that the Middle Cambrian is present in the Silver Peak quadrangle, but it was not recognized there by Turner, who may have included it in his Emigrant formation.

In Emigrant Pass, in the northern part of the Silver Peak Range, in the Silver Peak quadrangle, Turner[2] found a series of thin-bedded limestones and reddish slates with some black chert, resting unconformably on the Silver Peak (Lower Cambrian). This series of strata he named Emigrant formation and assigned to the Upper Cambrian. If, as seems probable, Turner included Middle Cambrian beds in his Emigrant formation, they should be excluded and the name Emigrant should, in the writer's opinion, be applied only to the Upper Cambrian strata. Turner reports transitional beds with an admixture of faunas between the Emigrant and overlying Ordovician, but this observation will probably be found to be incorrect.

The exact relations of the Middle Cambrian, Upper Cambrian, and Ordovician sediments in the Inyo Range were not determined.

ORDOVICIAN SYSTEM.

SUBDIVISION.

In the Inyo Range four subdivisions of the Ordovician have been recognized. The lowest is the basal sandstone, 300 feet thick. Overlying this is a great series of limestones, probably of Beekmantown age. Above these limestones is a series of argillaceous limestones which is equivalent to the upper part of the Pogonip limestones of Hague and is of Chazy age. Apparently above these argillaceous limestones there is a series of arenaceous shales which is probably equivalent, at least in part, to the Palmetto formation of Turner.

[1] Walcott, C. D., Cambrian Brachiopoda: U. S. Geol. Survey Mon. 51, p. 185, 1912.

[2] Turner, H. W., A sketch of the historical geology of Esmeralda County, Nev.: Am. Geologist, vol. 29, p. 265, 1902.

It is possible that rocks of Richmond age also occur in the range, constituting a fifth unit. There is evidence of faulting wherever the uppermost portion of the Ordovician and basal Devonian were examined. On the ridge just north of Barrel Spring in Mazourka Canyon a much-faulted section apparently includes a part of the Devonian and some of the higher Ordovician. A small, poorly preserved fauna found in the Ordovician rocks suggests late Ordovician or Richmond—particularly a species of *Plectambonites* whose affinities seem to be closest to Richmond types. The information in regard to this section is, however, too indefinite to justify more than a suggestion that rocks of late Ordovician age may be present.

CORRELATION.

Turner[1] described graptolite-bearing shales in the Silver Peak quadrangle to which he gave the name Palmetto formation. According to his and later determinations, the shales are from two distinct geologic horizons, the Beekmantown and the Normanskill. All the material collected by Turner appears to come from the foothill country, from fault blocks whose relations are uncertain. By far the greater part of the fossils are of Normanskill age, only one collection from a locality southwest of Piper Peak being positively identifiable as of Beekmantown age. The Normanskill graptolites were, without exception, collected several miles farther south and east. It is unfortunate that Turner included the beds containing Beekmantown fossils in his Palmetto formation, as the type locality in the Palmetto Mountains apparently includes only post-Beekmantown beds. Lithologically the two zones differ widely in the Silver Peak quadrangle; and the name Palmetto should, in the writer's opinion, be restricted to the beds of Normanskill age.

In his description of the Emigrant formation (Cambrian), Turner states that apparently there is a transition between this formation and the Palmetto. This would indicate that the shales carrying the Beekmantown graptolite fauna immediately overlie the Upper Cambrian and probably hold the same stratigraphic position as the basal Ordovician sandstone and shaly beds in the Inyo Range. If this is true, the two graptolite zones are widely separated stratigraphically, which is possible, for Turner apparently nowhere found his two zones in the same area and grouped them together simply because they both carried Ordovician graptolites. He apparently did not recognize the beds of Beekmantown age, which, if present in the Silver Peak quadrangle, he may have taken for Cambrian.

In his report on the Eureka district, Nev., Hague[2] gives the following section of the Ordovician as measured by Walcott at White Pine, Nev.:

Section of Ordovician rocks at White Pine, Nev.

	Feet.
Trenton:	
Evenly bedded, pure, bluish limestones	50
Dark, siliceous limestone in massive beds	500
Eureka:	
Light, vitreous quartzite, ferruginous near the base	350
Pogonip:	
Dark-blue and black limestones, with numerous shaly belts, characterized by the fossils of the Upper Pogonip, as seen at Eureka	900
Dark, evenly bedded limestones, with more or less siliceous bands	4,300

Ball[3] recognized the Pogonip limestone with a thickness of 2,000 to 4,000 feet in the Belted, Amargosa, and Panamint ranges, which are not far east of the Inyo Range. He also recognized the Eureka quartzite on stratigraphic grounds. What he calls the Eureka quartzite has a thickness of some 1,200 to 1,500 feet in the Kawich Range, in southwestern Nevada, where, he says, it is "underlain by interbedded quartzites, shales, and limestones, transitional beds from the Pogonip limestone." These "transitional" beds are probably the equivalent of the Palmetto formation of Turner.

DISTRIBUTION.

Ordovician rocks cover a large area in the Inyo Range. The lower series of massive limestones are particularly prominent, forming bold topographic features and apparently making up the entire west front of the range north and west

[1] Turner, H. W., A sketch of the historical geology of Esmeralda County, Nev.: Am. Geologist, vol. 29, p. 265, 1902.

[2] Hague, Arnold, Geology of the Eureka district, Nev.: U. S. Geol. Survey Mon. 20, p. 191, 1892.

[3] Ball, S. H., A geologic reconnaissance in southwestern Nevada and eastern California: U. S. Geol. Survey Bull. 308, p. 28, 1907.

of Squaw Flat. The rocks along the trail from the Montezuma mine to Harkless Flat are greatly disturbed and metamorphosed. (See Pl. III, *A*, p. 20.) Back from the faulted face the limestones form bold light-colored hills. The great mountain mass south of Waucoba Canyon between the Mazourka Canyon and Saline Valley is composed chiefly of these limestones. (See Pl. VI, *A*.) The limestones on the west side of the range are cut out by faulting in the neighborhod of Coyote Spring, but on its east side rocks of the same age appear in the low hills in the northern part of Saline Valley west and north of Rattlesnake Cabin and they constitute the greater part of the sediments north of Willow Spring. The most favorable exposures for study are along Mazourka Canyon and to the north, around Badger Flat, in which the Bluebell mine is situated. Along Mazourka Canyon the rocks dip 45°–65° W. Farther east they flatten out and cover a great area.

Mazourka Canyon
Bluebell mine

The basal Ordovician sandstones were seen only along the southern border of Squaw Flat, where they rest against the intrusive granitic mass. They probably show to better advantage on the divide between Harkless and Squaw flats, a locality that was not visited.

The shales overlying the limestones were seen only at the head of Mazourka Canyon and in Badger Flat.

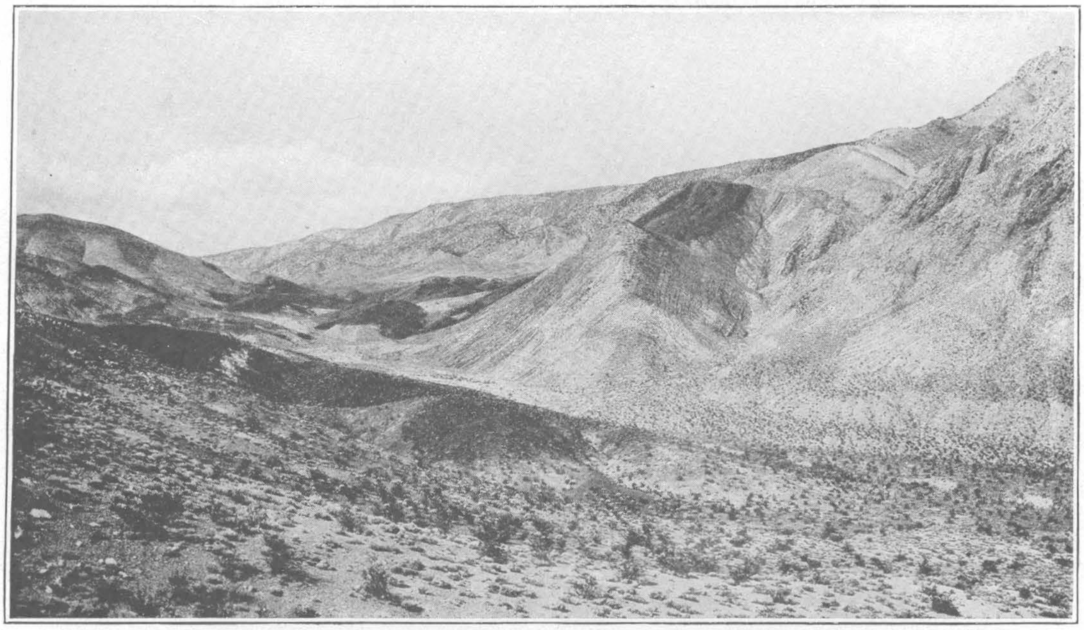
The limestones of the Ordovician fall into two divisions, the thickest of which rests upon the sandstones that immediately overlie the Cambrian. Stratigraphically higher are argillaceous limestones carrying an abundant fauna of Chazy age and having an estimated thickness of not less than 500 feet. They were examined only along the road in Mazourka Canyon about two-thirds of a mile south of the point where the Lead Canyon trail branches off.

The shale series correlated with the Palmetto of Turner overlies the fossiliferous limestone. It was seen only in Badger Flat and near the head of Mazourka Canyon. South of the Lead Canyon trail, however, it has apparently been faulted out, for there the limestone of Chazy age is apparently overlain by a massive, dense quartzite 30 feet thick. The limestones lie on the east of the road and the quartzite on the west. Above the quartzite comes 90 feet of bluish limestone carrying a few crinoid columnals, and upon this rests 35 feet of heavy-bedded limestone carrying a considerable amount of black chert. Higher beds having a thickness of about 30 feet are poorly shown, above which the section is cut off by a fault which brings the black shales of the Carboniferous in contact with the limestones. In Badger Flat the Ordovician shale series is capped by 75 feet of quartzite, overlain by bluish limestone and these by dark limestones carrying black chert, above which the section is terminated by a fault. The succession of beds and their lithologic character in the two localities appear to be identical. In both places the beds overlying the quartzite strongly resemble lithologically the basal beds of the Devonian east of Kearsarge (Citrus). If the quartzite and limestones in Badger Flat and Mazourka Canyon are identical, it is evident that the shale series has been eliminated by faulting in Mazourka Canyon. The structure of the area supports this assumption.

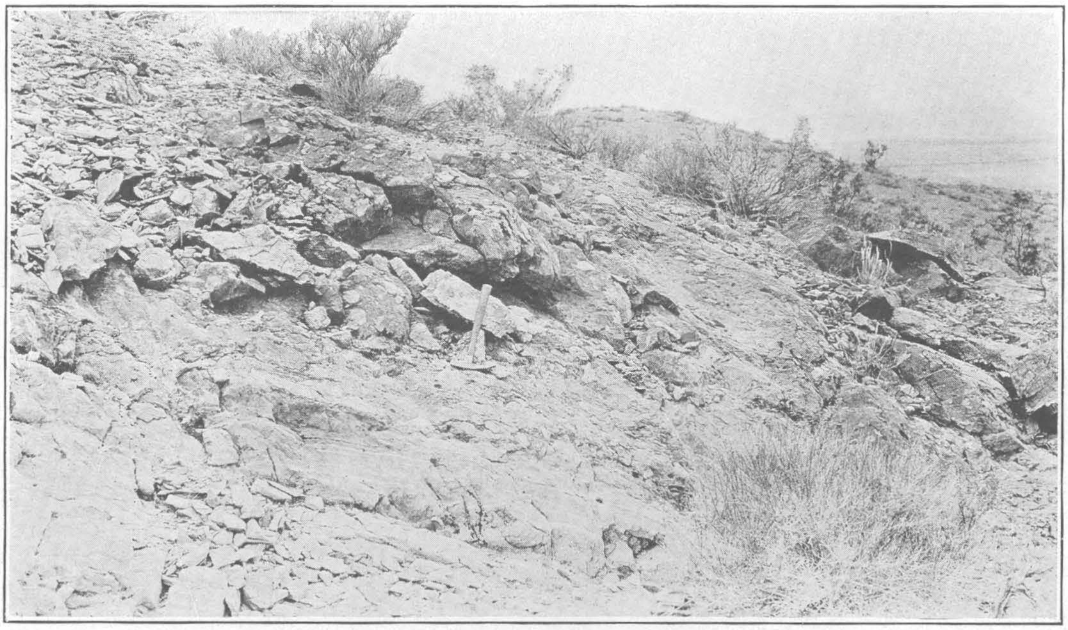
LIMESTONES, PROBABLY OF BEEKMANTOWN AGE.

The term "Pogonip" has been somewhat loosely used in Nevada. In its later usage, however, it has come to be applied to the great masses of limestones of Ordovician age that are extensively developed in the State. The main mass of the Pogonip exposed in the type area is of Beekmantown age, as determined by the faunal content, and to this mass the term Pogonip should, in the writer's opinion, be restricted. The upper part of the Pogonip limestone of Walcott, which has a thickness of 900 feet at White Pine, carries a Chazy fauna. This same series is shown in the Inyo Range. In Nevada the Pogonip beds of Beekmantown age have a thickness ranging from 2,000 to 4,300 feet, according to published descriptions.

In the Inyo Range there are some 3,500 feet of massive limestones of undoubted post-Cambrian and pre-Chazy age. Determinable fossils were not seen in this series, but they could doubtless be found by adequate search. Indistinct light lines, seen only on weathered surfaces, in some of the beds probably represent organic remains and suggest types of gastropods and cephalopods known in rocks of Beekmantown age. Comparison of the stratigraphic position and lithologic character of the series



A. ORDOVICIAN, DEVONIAN, AND MISSISSIPPIAN ROCKS EXPOSED IN MAZOURKA CANYON, MOUNT WHITNEY QUADRANGLE.



B. BASAL CONGLOMERATE OF MISSISSIPPIAN, 3 MILES EAST OF KEARSARGE (CITRUS), MOUNT WHITNEY QUADRANGLE.

with known sections to the east prove beyond reasonable doubt that these strata represent the lower part of the Pogonip limestone of Walcott in the Eureka district and are of Beekmantown age.

No accurate measurement of this lower series of Ordovician limestones was possible in the course of the present work. An estimate based on average dip and width of outcrop gives the series a thickness of 3,000 to 3,500 feet, the latter being probably more nearly correct.

At the base of the limestones, as shown at the granite contact on the south margin of Squaw Flat, lies a series of sandstones, apparently interstratified with shaly layers, of which perhaps 200 to 300 feet is poorly exposed. These basal sandstones, as exposed, are more quartzitic in their basal portion and are softer and more calcareous above. At no place are they massive, their outcrop consisting of relatively thin platy fragments.

The overlying limestones apparently vary in composition from dolomites to relatively pure limestones. The basal portion weathers blue-gray to dull lead-colored. The higher beds are lighter in color in the mass, the hills showing white to buff. No accurate description of the limestone is possible, for it was seen only in part and only from a distance.

Walcott[1] says that the Lower Cambrian occurs at the head of Mazourka Canyon, but the material that was supposedly derived from Mazourka Canyon, on which he based his assertion, is exactly like rock from Deep Spring Valley. A fragment of sandstone in one lot has impressions of *Trematobolus;* and a fragment in the other lot has the original brachiopods which made the impressions. The two pieces of sandstone fit together perfectly.

ARGILLACEOUS LIMESTONES CONTAINING CHAZY FOSSILS.

The only good exposure seen of the argillaceous limestone containing the Chazy fossils is along the road in Mazourka Canyon about half a mile below the Lead Canyon trail, but it doubtless outcrops at many points along the east side of the canyon near the base of the mountain and in the low foothill country west of the mouth of the canyon. This area is much faulted and folded and contains numerous outcrops of intrusive rocks.

The Mazourka Canyon section comprises about 500 feet of limestone, which, in the main, is bluish to almost black and is crystalline, but in places is somewhat argillaceous. Shaly beds also occur. In certain zones the limestones are highly fossiliferous, carrying a rich molluscan fauna.

In the White Pine district the upper part of the Pogonip consists of 900 feet of dark-blue and black limestones with numerous shaly belts. This upper Pogonip is quite different stratigraphically from the main mass of the Pogonip, the great lower series being of Beekmantown and the upper series of Chazy age. The Chazy fauna is identical with that found in the argillaceous limestone of Mazourka Canyon and in the lower part of the Simpson formation of Oklahoma.

The following fauna, collected from the Mazourka Canyon locality, probably represents only a small percentage of the total fauna of the beds. No doubt all the upper Pogonip species listed by Walcott[2] could be obtained from the argillaceous limestone in the Inyo Range. Few specific determinations are possible, as the material is more or less imperfect and many new species are represented.

Diplograptus sp.
Orthis sp.
Triplesia n. sp.
Maclurea n. sp.
Liospira sp.
Hormotoma sp.
Fusispira sp.
Pleurotomaria? ionensis Walcott.
Modiolopsis sp.
Ctenodonta sp.
Endoceras sp.
Leperditia biva White.
Leperditella sp.
Nileus sp.
Amphion? nevadensis Walcott (pygidia identical with those referred to this species by Walcott).

ARENACEOUS SHALES, PROBABLY OF NORMANSKILL AGE.

Turner's Palmetto formation[3] included all the graptolite shales seen by him within the Silver Peak quadrangle. The name should,

[1] Walcott, C. D., Cambrian Brachiopoda: U. S. Geol. Survey Mon. 51, pt. 1, p. 227, 1912.

[2] Walcott, C. D., Paleontology of the Eureka district, Nev.: U. S. Geol. Survey Mon. 8, pp. 270–272, 1884.

[3] Turner, H. W., A sketch of the historical geology of Esmeralda County, Nev.: Am. Geologist, vol. 29, p. 265, 1902.

in the writer's opinion, be restricted to the higher series of shales of Normanskill age.

The Beekmantown graptolite zone may lie above the series of massive limestones of the Inyo Range, but even were the beds of Chazy age absent the two series of strata would be easily separable by their lithologic characters. The Beekmantown graptolite zone, however, was not seen in the Inyo Range, and its exact stratigraphic position is not known.

The shale series at the head of Mazourka Canyon and in Badger Flat is very similar in lithologic character to the Ordovician shale of Normanskill age in the Silver Peak quadrangle and in other portions of Nevada. No graptolites were seen in the shale, which, however, was examined in a most cursory way. The apparent stratigraphic relations of the shale and its lithologic character seem to point to its correlation with the Palmetto formation of Turner. The shale has a minimum estimated thickness of approximately 750 feet. Its exposure as a whole is very poor, as it underlies Badger Flat. Portions are exposed along the road near the head of Mazourka Canyon, but give a poor conception of it as a whole. To the south the shale is apparently cut out by faulting.

The formation is predominantly shaly but contains some bands of sandstone. The shales vary from thin and fissile to fairly heavy and arenaceous. In color the series is prevailingly light, ranging from green through several shades of brown, according to the degree of weathering.

Turner, in his description of the Palmetto formation, notes the presence of dark cherts, with which are interbedded felsitic rocks that, he thinks, represent altered rhyolitic or dacitic tuffs and lavas. This, he claims, is "certain evidence that in Ordovician time there were volcanic eruptions in the region." No rocks of this type were seen in the Ordovician of the Inyo Range, but they might easily have been missed or they may have been cut out by faulting. It is not possible from Turner's brief statement to locate these beds in the section.

From the scant evidence at hand it seems probable that the shale of Badger Flat lies between the limestone containing Chazy fossils and the Devonian and is to be correlated with the Palmetto of Turner.

DEVONIAN SYSTEM.

Hague[1] has described 4,000 to 6,000 feet of Devonian limestones from the Eureka district, Nev., to which the name Nevada limestone has been applied. Lithologically the Nevada in the Eureka district consists of gray to dark crystalline limestone, interspersed with shaly beds and sandstones. In the Inyo Range about 1,500 feet of limestones, shales, and sandstones of Devonian age are present, and unquestionably should be correlated with the Nevada limestone, probably with the lower portion of that formation.

Rocks of Devonian age were recognized along the Inyo Range from the upper portion of Mazourka Canyon to Cerro Gordo, and they probably continue to the southern end of the range, along the Keeler-Darwin road. They may occur along the west front of the range west and south of Harkless Flat, where they have been brought up by faulting, but this seems unlikely. They are also exposed along the Big Pine-Saline Valley road in the southwestern corner of the Lida quadrangle; and they have been faulted up to form the long ridge south of Marble Canyon, the mountain to the west of the road consisting of Lower Cambrian. The only complete section seen is in the foothills about 3 miles east of Kearsarge (Citrus), where the Devonian is exposed from its contact with the Ordovician below to the Mississippian above. Both north and south of this locality it is progressively cut out by faulting. The section follows:

Section of Devonian rocks about 3 miles east of Kearsarge (Citrus), Inyo Range, Cal.

	Feet.
Limestones, thin bedded, platy; with intercalated beds of calcareous shale and some calcareous sandstone. The limestones are as a rule gray to black in color. Some beds are coarsely crystalline and crinoidal. Bands and nodules of black chert are common. Fossils are abundant	1,150
Limestone, massive, bluish, crystalline. Throughout at intervals are irregular seams and lumps of black chert. In the upper portion are some layers of more thinly bedded argillaceous limestones. Fossils are rare	250
Quartzite, heavily bedded, white; somewhat iron stained	30+
	1,430+

[1] Hague, Arnold, Geology of the Eureka district, Nev.: U. S. Geol. Survey Mon. 20, p. 63, 1892.

What is considered the basal bed of the Devonian is a quartzitic sandstone. The overlying limestones may roughly be divided into a lower part, 250 feet thick, of massive limestones that are sparingly fossiliferous and an upper part that is more thinly bedded and somewhat argillaceous. Black cherts are characteristic of the formation, one band in the upper third of the lower part being 3 feet thick. The main mass of the Devonian consists of calcareous sediments that are predominantly thin bedded, intercalated with many thin beds of bluish shale and with some beds of calcareous sandstones. The limestones as a rule are coarsely crystalline and crinoidal. They carry large numbers of corals, which, though reasonably plentiful, are badly weathered as a rule at the outcrop. Well-preserved fresh material is to be had in Mazourka Canyon a short distance north of Barrel Spring. Brachiopods are rare.

Although fossils are abundant little time was available to gather other than weathered specimens, and as a result specific determinations are as a rule doubtful and are for the most part not given.

Stromatopora sp.
Cladopora, 2 species.
Heliolites sp.
Favosites cf. F. hemisphericus.
Favosites sp.
Alveolites sp.
Amplexus sp.
Diplophyllum fasciculum.
Syringopora cf. S. perelegans.
Ptychophyllum infundibulum.
Phillipsastraea sp.
Atrypa reticularis.
Stropheodonta sp.
Othoceras sp.
Dalmanites meeki.
Proetus sp.

These forms are identical with material collected in the Nevada limestone of the Eureka and White Pine districts, and they agree very closely with the Devonian fauna of Arizona, as found at Bisbee and in other areas. On the whole, the affinities of the fauna seem to lie with the Middle rather than with the Lower Devonian. The later Devonian types found by Walcott in Nevada are not represented in this region and it is probable that the section as seen here represents only the lower portion of the Eureka district section.

CARBONIFEROUS SYSTEM.

GENERAL FEATURES.

The Carboniferous rocks of the Inyo Range include Mississippian, Pennsylvanian, and Permian. The most northern exposure of the Carboniferous is along the west front of the range near the Montezuma mine in the southern part of the Bishop quadrangle, where a narrow strip of Carboniferous has been faulted along the base of the mountain, presumably lying against the Ordovician. From nearly 5 miles north of Kearsarge (Citrus) to the south end of the range the Carboniferous is very important, but at no place is a reasonably complete section of it shown. In the great canyons east of New York Butte there appear to be good sections, presumably of the Carboniferous, but these are nearly inaccessible. The Carboniferous is very thick, and it is impossible without very detailed work to piece together the isolated fragments of sections. The most that can be done at present is to discuss the sediments and their supposed relations in such manner as to be of aid to anyone who may wish to work out the section at some time in the future.

The base of the Carboniferous and its contact with the Devonian is exposed east of Kearsarge (see Pl. VI, *B*) and apparently also in the neighborhood of the Cerro Gordo mine. The best exposures of the overlying Mississippian shales and limestones (White Pine shale) for purposes of collecting fossils are along the Cerro Gordo Spring trail north of Cerro Gordo. The shales in Mazourka Canyon and south of it for a few miles are too highly metamorphosed to furnish fossils. The Pennsylvanian limestones overlying the shales are exposed north of Kearsarge, south of Coyote Spring, and at the top of the range from near New York Butte southward. The great chertlike quartzites (Diamond Peak) are most typically displayed in the canyons penetrating the range east of Keeler. The thin-bedded, platy, arenaceous limestones and shales next succeeding are well exposed on the side of the mountain just east of the Estelle Mining Co.'s tunnel, on the road from Keeler to the Cerro Gordo mine. The Permian was seen only between the Reward mine and Union Wash, the first large canyon north of Owenyo.

MISSISSIPPIAN SERIES.

WHITE PINE SHALE.

Hague[1] describes a great series of shales, having a maximum thickness of approximately 2,000 feet, that overlie the Nevada limestone in the Eureka district, Nev. To these shales he gave the name White Pine and referred the formation to the Devonian. Girty,[2] however, correlates it with the Caney shale of Arkansas, which he refers to the Mississippian.

In the Inyo Range a shale occupying the same relative stratigraphic position as the White Pine carries the Caney fauna and without doubt should be correlated with the White Pine shale of eastern Nevada. The evidence indicates, therefore, that Girty's correlation is valid.

As described by Hague, the White Pine shale differs considerably in lithology in different sections. It also differs considerably from place to place in thickness, at White Pine measuring only 600 feet and in the Eureka district reaching 2,000 feet. From some sections it appears to be absent. From the nature of the deposits and the abundance of the plant remains that they contain Hague concludes that the White Pine is a shallow-water deposit. In the Inyo Range the White Pine shale carries some limestones but apparently few of the sandstones noted by Hague in the Eureka district. Certain beds contain an abundant marine fauna.

The White Pine shale is exposed at three places in the Inyo Range. The most northern exposure is along Mazourka Canyon, where it forms the canyon floor for several miles. The beds here lie in the trough of a narrow syncline. Farther south the contact of the White Pine shale and the top of the Devonian limestone may be seen east of Kearsarge, where a considerable thickness of the beds is exposed. Still farther south the shale is gradually cut out by faulting until it disappears near Coyote Spring. In this general region the shale is highly metamorphosed, containing innumerable chiastolite crystals. No recognizable fossils were seen. The third locality, and the only good one for collecting fossils, is north of the Cerro Gordo mine, where the beds are exposed on a dip slope and are little altered.

The base of the Mississippian, which is well exposed east of Kearsarge, consists of a 5-foot conglomeratic bed of grayish limestone, weathering buff, which carries irregular, mostly well rounded, limestone pebbles 5 inches or less in diameter. (See Pl. VI, *B*.) Upon the upper surface of the conglomerate lies an 8 to 10 inch seam of brownish-black, apparently phosphatic material, which is overlain by 12 feet of sooty-black shale weathering gray. Above these comes the subjoined section. The exact sequence at the base is obscured by minor faulting, but the stratum given is probably the lowest bed of the Mississippian and is the one that appears in the bottom of Mazourka Canyon for several miles. Its thickness may be much greater than that given. The higher beds of the section were measured a few hundred yards to the south.

Section of White Pine shale in the Inyo Range east of Kearsarge, Cal.

	Feet.
Quartzite, white, weathering reddish	25
Conglomerate; matrix of highly siliceous limestone	50
Sandstone, impure, quartzitic, weathering in large blocks; carries some intercalated lenticular masses of gray limestone	75
Similar sandstone, weathering reddish brown and breaking down in small, irregular blocks	50
Limestone, massive, gray, crystalline, crinoidal	3
Shale, black, calcareous, with some sandstone	15
Limestone, massive, gray, carrying small crinoid columnals	100
Shale, black, fissile, weathering platy	250
Sandstone, quartzitic, weathering in reddish-brown angular blocks	25
Shale, arenaceous, weathering red and brown	150
Shale, brown, arenaceous, weathering in thin plates 2 to 3 inches thick, filled with chiastolite	300
	1,043

G. H. Girty, of the United States Geological Survey, has examined three fossil collections from the Mississippian, all made north of the Cerro Gordo mine. In the black fissile shale, which is well exposed along the Cerro Gordo Spring trail, about $1\frac{1}{2}$ miles north of the mine, the following forms were found:

Solenomya? sp.
Caneyella wapanuckensis.

[1] Hague, Arnold, Geology of the Eureka district, Nev.: U. S. Geol. Survey Mon. 20, p. 68, 1892.

[2] Girty, G. H., Relations of some Carboniferous faunas: Washington Acad. Sci. Proc., vol. 7, pp. 11–12, 1905.

Caneyella n. sp. aff. C. richardsoni.
Orthoceras, several species.
Gastrioceras aff. G. richardsonianum.
Goniatites sp.
Eumorphoceras bisulcatum?
Plant remains.
Fish remains.

In regard to this fauna Mr. Girty says: "The latter is an interesting and peculiar fauna of the Caney shale of Oklahoma, and the related but less well-known fauna of the White Pine shale of Nevada. These faunas I refer to the upper Mississippian."

From the sandstones that underlie the black shale the following forms were identified by Mr. Girty:

Sponge?
Derbya or Schuchertella.
Chonetes aff. C. illinoisensis.
Productus aff. P. burlingtonensis.
Productus aff. P. pileiformis.
Spiriferina? sp.
Pleurotomaria? sp.

Comparing this fauna with that of the black shale, Mr. Girty states that it "presents a somewhat different facies, which may also be called upper Mississippian. It may, however, be lower Mississippian, but it does not show the familiar facies of the Madison limestone which is common in the lower Mississippian horizon of the West." From the stratigraphic relations of the beds the writer would consider them of very nearly the same age.

At another locality about 2 miles farther north two species of *Zaphrentis* and two of *Productus* were found in the limestones below the black shale. These fossils were determined as Mississippian by Mr. Girty.

PENNSYLVANIAN SERIES.

DISTRIBUTION.

Hague[1] divides the Pennsylvanian rocks of the Eureka district into four formations, as follows:

General section of the Pennsylvanian series in the Eureka district, Nev.

	Feet.
Upper Coal Measure limestone	500
Weber conglomerate	2,000
Lower Coal Measure limestone	3,800
Diamond Peak quartzite	3,000

[1] Hague, Arnold, Geology of the Eureka district, Nev.: U. S. Geol. Survey Mon. 20, p. 84, 1892.

Probably each of these four divisions is present in the Inyo Range. The exact relations of the sections seen can, however, be only approximately determined, and no attempt has been made to describe in detail any of the units except the conglomerate and the overlying limestones, which may or may not be correlative with the Weber conglomerate and Upper Coal Measure limestone of Hague. The Pennsylvanian quartzite in the Inyo Range is considered to be undoubtedly the Diamond Peak quartzite, and it is so called. The conglomerate in the Inyo Range that may be correlative with the Weber conglomerate of Hague is here given the local name Reward conglomerate.

To the overlying limestones of Permian age in the Inyo Range the local name Owenyo limestone is here applied. The basal Pennsylvanian limestones (see below) and the later Pennsylvanian limestone and shale of the Inyo Range, neither of which has been carefully studied, are not given geographic names.

In the Inyo Mountains the Pennsylvanian rocks are exposed only in the Mount Whitney and Ballarat quadrangles. The rocks are much faulted and folded and in many places considerably metamorphosed. On the west side of the range the most northern exposure of consequence is a mass of limestones facing the valley about 3 miles north of Kearsarge. This mass is faulted on both sides and its stratigraphic relations are not clear; it may overlie or underlie the Diamond Peak quartzite. From this point southward the Pennsylvanian appears at irregular intervals to the southern extremity of the range. South of New York Butte the Pennsylvanian rocks form an important part of the range, outcropping on both the east and the west sides. This portion of the range is the west limb of the great syncline, which is flanked on both sides by Carboniferous rocks and is filled with Triassic sediments. The syncline is greatly broken by faults, and a reasonably complete section of the Carboniferous rocks is nowhere exposed. On the east side of the range, in the canyons south of New York Butte, some excellent sections are exposed, but they are difficult of access and can not be closely studied. East of the range proper, Carboniferous sediments appear in the low hills at the south end of Saline Valley and in the Ubehebe Range, bordering Saline Valley on the east.

BASAL PENNSYLVANIAN LIMESTONES.

In the Inyo Range the lowest Pennsylvanian strata seen are limestones which crop out along the crest of the range south of New York Butte, where they are unconformably separated from the overlying Diamond Peak quartzite. Other limestones exposed along the west front of the range 2½ miles north of Kearsarge may have the same stratigraphic position or may possibly overlie the Diamond Peak. Limestones of the same character also appear about three-fourths of a mile south of Coyote Spring. At the head of Union Wash and north of the Cerro Gordo mine Pennsylvanian limestones definitely underlie the quartzite. These are the only localities where the limestones were seen in a fairly undisturbed condition. In the exposures examined the limestone has a thickness of between 500 and 1,000 feet. It consists in the main of very hard, fairly thin, siliceous limestones in which silicified fossils are fairly abundant. *Productus*, *Zaphrentis*, and *Fusulina* were identified. Owing to the hardness of the limestone the beds are very resistant to weathering.

DIAMOND PEAK QUARTZITE.

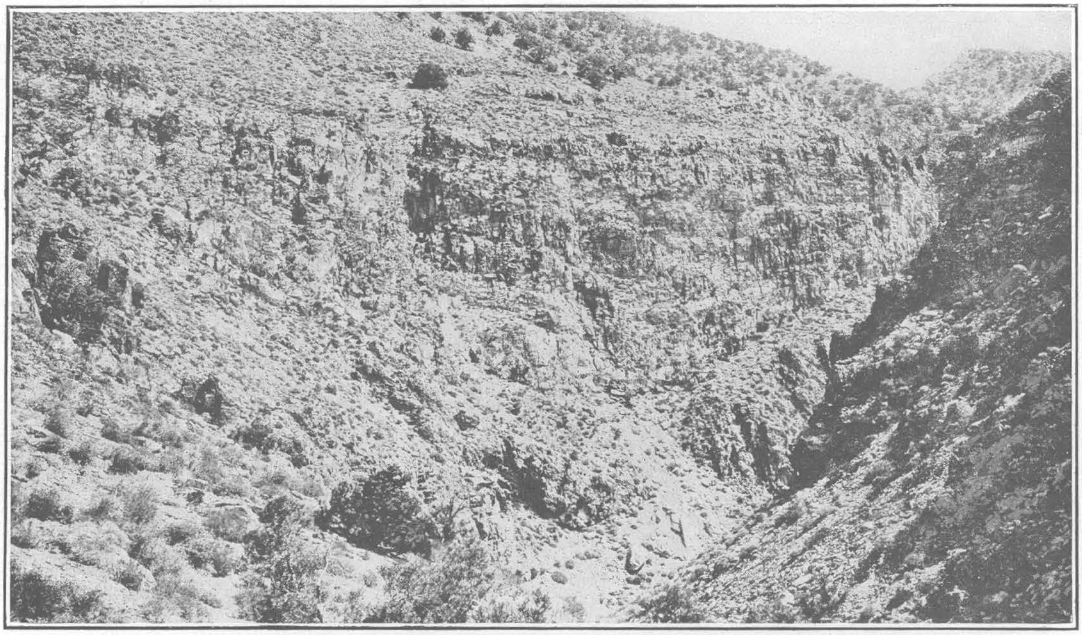
In the Eureka district the Diamond Peak quartzite has an estimated thickness of 3,000 feet and consists in the main of vitreous quartzites (according to Hague). A limestone bed about 500 feet above the base carries a Pennsylvanian fauna. In the quartzite itself no fossils were found. On stratigraphic grounds and lithologic similarity a great mass of quartzites in the Inyo Range has been correlated with the Diamond Peak, and the name used by Hague has been applied to it.

In the Inyo Range this quartzite unconformably overlies the series of basal Pennsylvanian limestone. It is prominently developed on the west side of the range from Coyote Spring south to well below Keeler. On the west side of the Saline Valley it is excellently shown in some of the canyons, as near the head of Hunter Canyon.

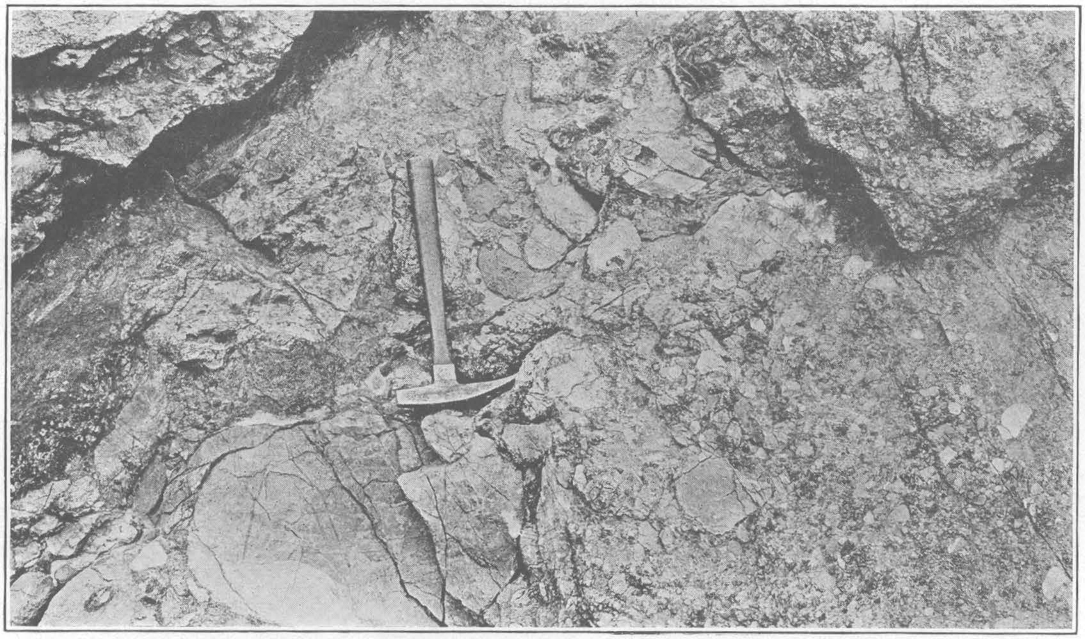
No continuous section through the entire mass of quartzite was seen. Near the head of Union Wash, north of Owenyo, the contact with the underlying limestones is well shown. From here the quartzite extends westward toward the Triassic, but a large part of its upper portion is cut out by faulting. In several canyons east of Keeler the Diamond Peak is well shown (see Pl. VII, *A*), but nowhere apparently is the entire formation present. On the east side of the range a section of what appeared to be nearly the entire mass was seen at a distance, but it was very difficult of access and, even if reached, could not be accurately measured. It is estimated, however, that the quartzite has a minimum thickness of 3,000 feet.

Owing to its resistant character the Diamond Peak quartzite forms fairly bold topographic features. Canyons cut in it are extremely rugged and have precipitous walls.

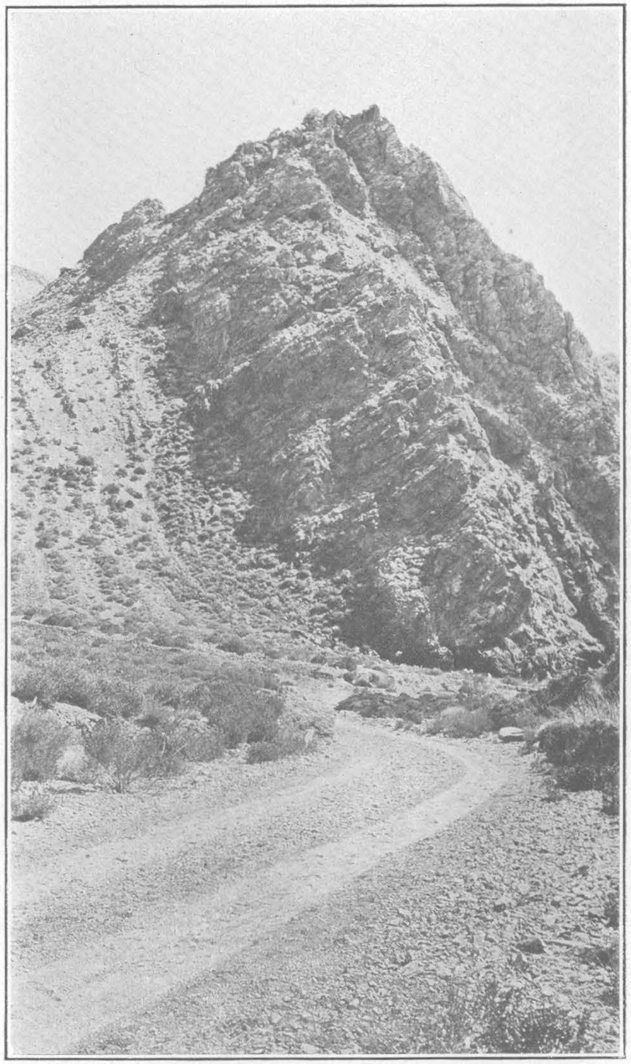
The base of the Diamond Peak quartzite is clearly shown near the head of Union Wash, where the Saline Valley trail leaves the canyon and starts up the side of the mountain. Its contact with the underlying limestone is very irregular and marks an unconformity. The basal beds are somewhat argillaceous and weather an intense red. Near the contact are large amounts of iron pyrites. The formation consists in the main of very dense fine-grained quartzites, which range in color from pearl-gray to black on fresh fracture. As a rule, the rock carries disseminated iron pyrites. In some of the beds spherulitic structures 2 to 3 millimeters in diameter are abundant. On weathering the quartzite breaks down in irregular fragments whose size varies according to the portion of the formation from which they are derived. When broken with a hammer the fine-grained rock fractures like chert. The weathered quartzite varies from gray to brown or deep reddish-brown, its color depending on the amount of iron present and its degree of oxidation. Near the base of the quartzite and at irregular intervals in the mass are layers of black arenaceous shale from a fraction of an inch to several inches in thickness, which weather red. The finest-grained material when examined under a microscope proves to have almost the appearance and character of chert and not to be a quartzite in the strict sense of that word. True quartzites are present, however, and the greater portion of the mass con-



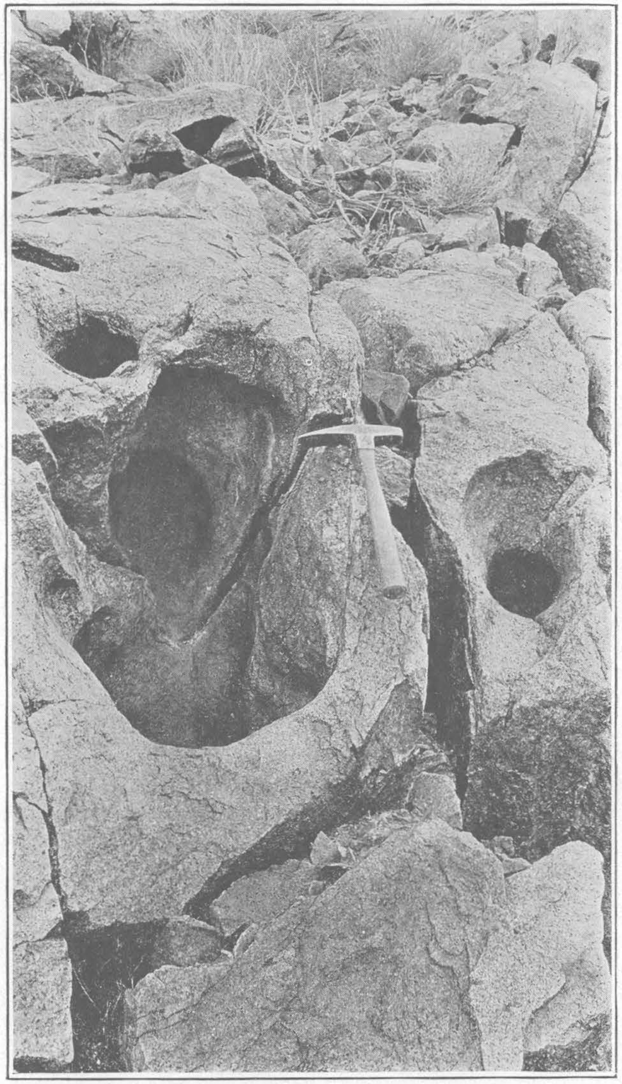
A. CANYON IN DIAMOND PEAK QUARTZITE EAST OF KEELER, BALLARAT QUADRANGLE.



B. DETAIL OF REWARD CONGLOMERATE, SALINE VALLEY SALT CO.'S ROAD, BALLARAT QUADRANGLE.



A. EXPOSURE OF REWARD CONGLOMERATE, SALINE VALLEY SALT CO.'S ROAD, BALLARAT QUADRANGLE.



B. POTHOLES IN REWARD CONGLOMERATE, REWARD MINE, MOUNT WHITNEY QUADRANGLE.

sists of beds intermediate in character between quartzite and the chertlike rocks.

LATER PENNSYLVANIAN LIMESTONE AND SHALE.

Overlying the Diamond Peak quartzite in the Eureka district are some 3,800 feet of limestones, to which Hague applied the name "Lower Coal Measure limestone." Extensive faunal lists are given by Walcott[1] and by Hague.[2] On paleontologic evidence it appears that a portion of these beds represents fresh-water deposits. No detailed study of the correlative limestones in the Inyo Range was possible, and subdividing the series or giving the mass a distinctive name was not warranted.

Along the west side of the Inyo Range this group of sediments may be seen to best advantage from New York Butte to south of the Cerro Gordo road, but the only good exposures are on the eastern side of the anticline. A good section of the upper part of the limestone may be seen immediately east of the Estelle Mining Co.'s plant, where the side of the mountain is almost entirely made up of these beds between the exposures of Diamond Peak quartzite and the Triassic. Large masses of the limestone are shown along both the Saline Valley Salt Co.'s road from Swansea and the road from Keeler to the Cerro Gordo mine. All through this area, however, the beds are greatly faulted. It is probable that a less faulted section may be seen near the crest of the range along the Ubehebe trail, east of Keeler.

These sediments in the Inyo Range consist in greater part of calcareous shales and sandstones and of thin-bedded impure limestones. Either in the basal portion of the series or in the upper part of the Diamond Peak crystalline limestones of normal marine type appear, associated with sandstones and shallow-water deposits. The upper portion of the mass, as shown in and above the Estelle Mining Co.'s tunnel, consists of thin-bedded platy limestones and shales, which are remarkable for the brightness of their coloring on weathering, lavender and magenta being common. Such coloration is characteristic of portions of the Triassic, but this is the only place where it was seen in the Carboniferous. Through these thin-bedded limestones, at irregular intervals, occur beds of conglomerate of small and well-rounded pebbles. Some of the layers are ripple marked. Throughout, the sediments as a rule indicate shallow-water deposits. Their estimated thickness is about 3,000 feet. The Pennsylvanian age of the beds is definitely established by their stratigraphic position and by their contained fossils.

It is possible that this series of calcareous beds contains fresh-water deposits comparable with those described by Hague.[3] Along the Saline Valley Salt Co.'s road from Swansea to the summit, at an elevation of nearly 6,700 feet, are calcareous shales and impure limestones of unusual character. The only fossils seen were great numbers of small gastropods, which suggest fresh-water rather than marine types. Owing to the faulting it is impossible to place the beds definitely, but they probably occur in the lower half of the series. In one place there is evidence of an erosional unconformity of considerable magnitude, the significance of which could not be determined. It lies some distance below the zone of possible fresh-water origin and may mark the base of the calcareous series. The fresh-water deposits of the Eureka district lie near the base of this series.

Fossils are not abundant in these Pennsylvanian limestones and shales except in narrow zones. In the upper thin-bedded portion, as exposed east of the Estelle Mining Co.'s plant, few were seen other than an occasional *Fusulina*. At the crest of the range about 1½ miles north of the Saline Valley Salt Co.'s tram a limestone carrying abundant fossils may lie within the calcareous series or may belong with the Diamond Peak group, whose upper part is believed to carry intercalated layers of limestone. This locality lies in a wedge bounded by fault planes, owing to which the exact relations of the limestone could not be determined. On the whole, the evidence points to the post-Diamond Peak age of the beds.

From this locality the fossils were collected from limestones having an aggregate thickness of about 50 feet. The forms were determined as follows by Mr. Girty:

Fusulina sp.
Lithostrotion? sp. a.

[1] Walcott, C. D., Paleontology of the Eureka district: U. S. Geol. Survey Mon. 8, 1884.

[2] Hague, Arnold, Geology of the Eureka district, Nev.; U. S. Geol. Survey Mon. 20, pp. 89–91, 1892.

[3] Hague, Arnold, op. cit., p. 87.

Lithrostrotion? sp. b.
Polypora sp.
Fistulipora? sp.
Rhipidomelia nevadensis?
Enteletes hemiplicatus?
Meekella striaticostata?
Productus semireticulatus.
Productus aff. P. inflatus.
Productus subhorridus?
Productus aff. P. mexicanus.
Productus cora?
Productus sp.
Pugnax rockymontanus?
Spirifer cameratus?
Pleurotomaria? sp.
Orthoceras sp.
Nautilus? sp.

Just above the limestones is a calcareous sandstone from which a small fauna consisting chiefly of pelecypods was collected. Mr. Girty determined the following:

Lingula sp.
Myalina? sp.
Aviculipecten? 2 species.
Schizodus? sp.
Naticopsis sp.

Both lots are of Pennsylvanian age.

REWARD CONGLOMERATE.

In the Eureka district the "Lower Coal Measure limestone" is overlain by a series of conglomerates and sandstones having an estimated thickness of 2,000 feet, to which Hague applied the name Weber conglomerate, correlating them with the Weber quartzite of Utah. This correlation, however, is open to question. In the Inyo Range a much thinner conglomerate apparently holds the same stratigraphic position as the conglomerate in the Eureka district, but it has seemed best to give it a distinctive name, and the name Reward conglomerate is here applied to it, from the Reward mine.

The most northern observed exposure of this conglomerate is in the Inyo Range on an isolated knob about a mile northeast of Kearsarge (Citrus), although better exposures are to be had along the face of the range to the south. South of Kearsarge the conglomerate is shown in the west face of the hill just west of Coyote Spring, whence it appears at irregular intervals southward to the Ubehebe trail east of Keeler, south of which the sediments are covered by basaltic flows. Just south of the Reward mine the conglomerate stands out boldly. At the Union Wash it is faulted out. At the Estelle Mining Co.'s tunnel east of Keeler it is faulted out, but reappears a short distance farther north on the Cerro Gordo road. It is also exposed along the Saline Valley Salt Co.'s road still farther north. The conglomerate appears to have been continuous, and its absence near the Carboniferous-Triassic contact probably indicates a fault.

Hague[1] says:

> Conformably overlying the Lower Coal Measures comes the Weber conglomerate, one of the most persistent and well-defined horizons over wide areas of the Cordillera, stretching westward all the way from the Front Range in Colorado to the Eureka Mountains. It varies in the nature of the sediment with every changing condition, but it is nearly everywhere easily recognized as a siliceous formation between two great masses of Carboniferous limestone. In places it is made up of an admixture of calcareous and sandy beds; in others, of fine grits and shales; and, again, of nearly pure siliceous sediment, varying from fine to coarse grained, dependent largely upon the distance from any land area and depth of water in which it was deposited. Here at Eureka the material is exceptionally coarse, with abundant evidence of shallow water deposition and the existence of a land surface not very far removed at the time the beds were laid down.

Hague says that in the Eureka district the conglomerate is made up for the most part "of coarse material of both angular and rounded fragments of red, brown, and white grits, together with jasper, brown hornstone, and green cherty pebbles firmly held together by a siliceous cement." This description applies exactly to the Reward conglomerate. Interstratified with the conglomerate at Eureka are "occasional beds of fine yellow-white sandstone."

The coarse phase of the conglomerate is well shown along the Saline Valley Salt Co.'s road from Swansea to the summit. (See Pls. VII, *B*, and VIII, *A*.) In this exposure one boulder more than 2 feet long was seen, but most of the pebbles are small, few measuring more than 2 inches. An exposure north of Union Wash shows the contact of the conglomerate and Permian limestone and reveals another lithologic phase of the conglomerate. Some of the beds are of normal conglomerate type, with siliceous matrix; others are of white sandstone that weathers buff and brown and that is

[1] Hague, Arnold, op. cit., pp. 91–92.

from place to place more or less conglomeratic. A brownish-weathering sandstone with dark-brown patches and layers that forms the uppermost bed of the Reward in this section may be characteristic of the upper part of the Reward but may in most places have been faulted out. As measured elsewhere, the massive conglomerate apparently ranges in thickness from 100 to over 250 feet. If the sandstone is characteristic of the upper portion, 100 feet or so should be added to this total thickness. Owing to the character of the conglomerate and the obvious signs of erosion, it is evident that considerable variation in thickness and lithologic character may be expected.

Just south of the Reward mine the conglomerate at different horizons contains well-defined potholes (Pl. VIII, *B*), which penetrate the strata vertically. One is 2½ feet and another 14 inches in diameter. One hole, with an orifice of 6 to 8 inches, is 18 inches deep. The inner surface of each pothole is polished, as is the old conglomerate surface.

That the potholes are of essentially contemporaneous origin with the deposition of the conglomerate seems clear. They penetrate usually dense and resistant rock. The beds just south of the Reward mine are on the edge of the valley but have been highly tilted since the holes were formed, thus disposing of the possibility of their being due to recent stream action. Farther south potholes occur in the conglomerate several hundred feet above the valley floor. These are not the product of a peculiar type of desert erosion. Granites in the desert have many cavernous pockets, but never of this shape, with narrow mouths and expanding bodies; and, moreover, such holes were seen only at two places, although many exposures of the conglomerate were examined. Some of the holes are partly filled with a shaly conglomerate, such as forms seams between the massive beds of conglomerate. One such partly filled hole is almost entirely covered by an overlying layer of conglomerate. The shaly material filling one of these holes readily flakes off, showing the dense inner surface of the pothole underneath. The shaly material is never polished.

If it is true that these potholes were formed at the time the conglomerates were laid down, it is evident that the conglomerate is of continental origin, or at least was subjected to a stream action at different times during its deposition. The fact that the potholes occur at different levels indicates that a bed of the material was deposited, consolidated, and subjected to stream erosion for a considerable time. Then upon the stream-eroded surface another layer of conglomerate was deposited, and the process repeated.

Hague explains the variable composition and irregularities of his Weber conglomerate at Eureka as being probably due to deposition in shallow marine waters. The Reward conglomerate in the Inyo Range can be explained only as a nonmarine deposit, and the same is probably true of the conglomerate in the Eureka district. Whether the same explanation may be applied to that conglomerate, which possibly is to be correlated with these conglomerates, it is impossible to state. About the time these conglomerates were deposited there was glaciation in various parts of the world; and, though no direct evidence of glaciation in the Reward conglomerate was seen, it seems to have many of the characteristics of a tillite. It will at any rate be worth while to look for such evidence wherever this conglomerate or beds of the same age are exposed.

Whether the Reward should be called Pennsylvanian or Permian is difficult to decide. No fossils were found in the conglomerate, except a *Fusulina* in a limestone pebble. There is an unconformity between the Reward and the Owenyo (Permian), as would naturally be expected between a deposit of continental origin and an overlying marine deposit. The relations of the Reward to the Pennsylvanian deposits below are nowhere clearly shown, but because of the unconformity at its top the Reward conglomerate is here assigned to the Pennsylvanian. It may, however, contain elements of different ages. The exact age of a nonfossiliferous continental deposit lying between marine deposits is largely a matter of speculation.

PERMIAN SERIES.

OWENYO LIMESTONE.

Hague[1] describes a series of limestones 500 feet thick that overlie the Carboniferous con-

[1] Hague, Arnold, Geology of the Eureka district, Nev.: U. S. Geol. Survey Mon. 20, p. 93, 1892.

glomerate in the Eureka district. He calls this the "Upper Coal Measure limestone," and states that it attains a thickness of nearly 2,000 feet in northern and central Nevada. Lithologically these beds are in the main light bluish gray and drab compact limestones, interstratified with conglomeratic beds carrying siliceous pebbles in a calcareous matrix. One or two beds carry limestone pebbles with Pennsylvanian fossils. The fauna, as quoted by Hague, is inconclusive as regards age, but, in the opinion of Mr. Girty, a review of it in the light of recent research would change a number of the specific determinations and show the limestone to be Permian.

Permian

In the Inyo Range is a series of limestones which the writer thinks is probably to be correlated with the "Upper Coal Measure limestone" of Hague. These limestones carry a Permian fauna and, according to Mr. Girty, are probably to be correlated in part with the Park City, Phosphoria, and Embar formations of Utah, Idaho, and Wyoming. To these limestones the name Owenyo limestone is here given, from the type section about 3½ miles north of Owenyo station on the Southern Pacific, between Union Wash (the first large canyon to the north) and the Reward mine.

Only two exposures of the Owenyo limestone are known, both of which lie between the Reward mine and the Union Wash. They are too small to be shown on the geologic map. One shows the base and the other the top of the formation to advantage. Elsewhere along the range the Owenyo is either eroded or, more probably, faulted out. In most places where the Reward is shown with higher beds in contact with it, the latter are of Triassic age, and a fault contact may be demonstrated.

The Owenyo consists in the main of massive, grayish, crystalline to compact limestones. The 2-foot basal bed is a blue-gray compact limestone, fossiliferous from the contact and carrying irregular lenses and stringers of sandstone whose grains were apparently derived from the Reward below. Here and there through the Owenyo, particularly in its upper third, are layers carrying rounded chert pebbles. The higher beds are fairly massive and break down in large blocks on weathering. The limestones as a whole are bluish gray to dark in color, compact to crystalline in texture, and carry abundant fossil remains. The *Spiriferina pulchra* fauna here listed apparently ranges throughout the formation.

In the section nearest the Union Wash the Owenyo apparently has a thickness of only 125 feet. Here the contact with the underlying Reward conglomerate is shown and the measurement is carried up to the Triassic shales. There may be faulting in the section, but none is apparent. In the hill to the north (see Pl. IX, *A*) there has been some faulting and the exact relations of the formation are not clearly shown.

The fauna of the Owenyo limestone is of considerable interest. The following faunal list and comment thereon was prepared by Mr. Girty:

Stenopora? sp.
Lioclema? sp.
Spiriferina pulchra.
Productus subhorridus.
Cliothyridina? sp.
Deltopecten coreyanus?
Aviculopecten sp.
Nucula perumbonata?
Sanguinolites aff. S. costatus.
Euphemus n. sp. aff. E. subpapillosus.

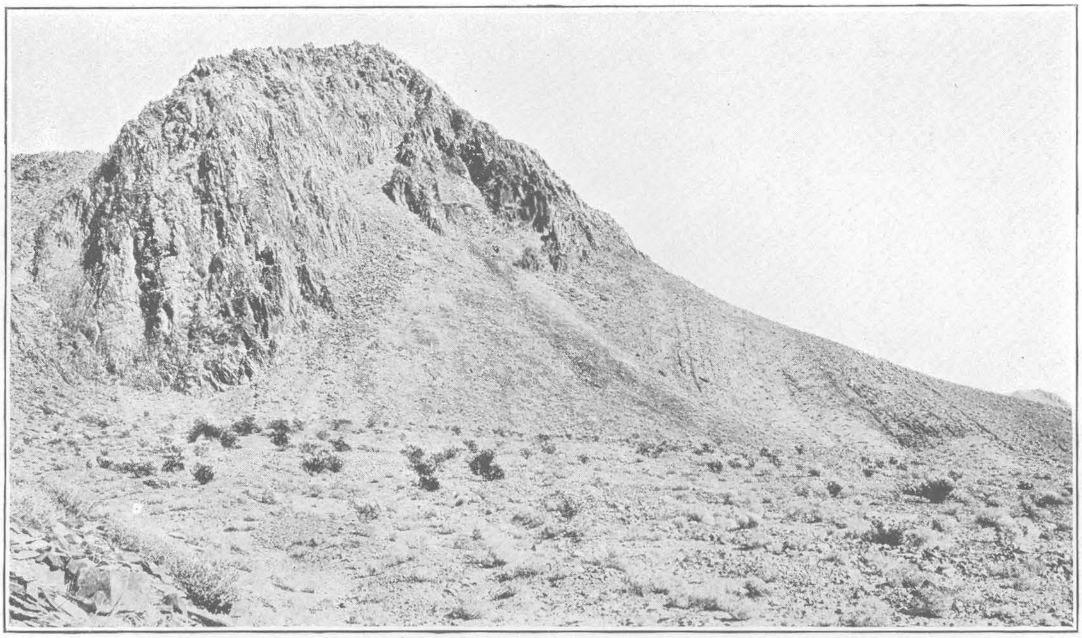
Lot C–7 especially suggests the *Spiriferina pulchra* fauna, which is best known in Utah and Idaho but which probably ranges into Nevada. I have tentatively been assigning the *Spiriferina pulchra* horizon to the Permian, but I am not sure that this is correctly done. One of the most striking features of the C–7 fauna is the abundance of a large *Euphemus* which may be an unusual form of *E. subpapillosus* or a new species related to it. It is interesting, though perhaps not significant, that the topmost Paleozoic horizon in the Alps is, I believe, called the Bellerophon limestone and that Bellerophon-bearing beds (consisting of *Euphemus subpapillosus*) form a well-marked horizon at the top of the Carboniferous in descending the Grand River.

Another lot of fossils was collected at a lower horizon, apparently about 75 feet below the top of the formation. Of these Mr. Girty identified the following forms, none of which he considers diagnostic:

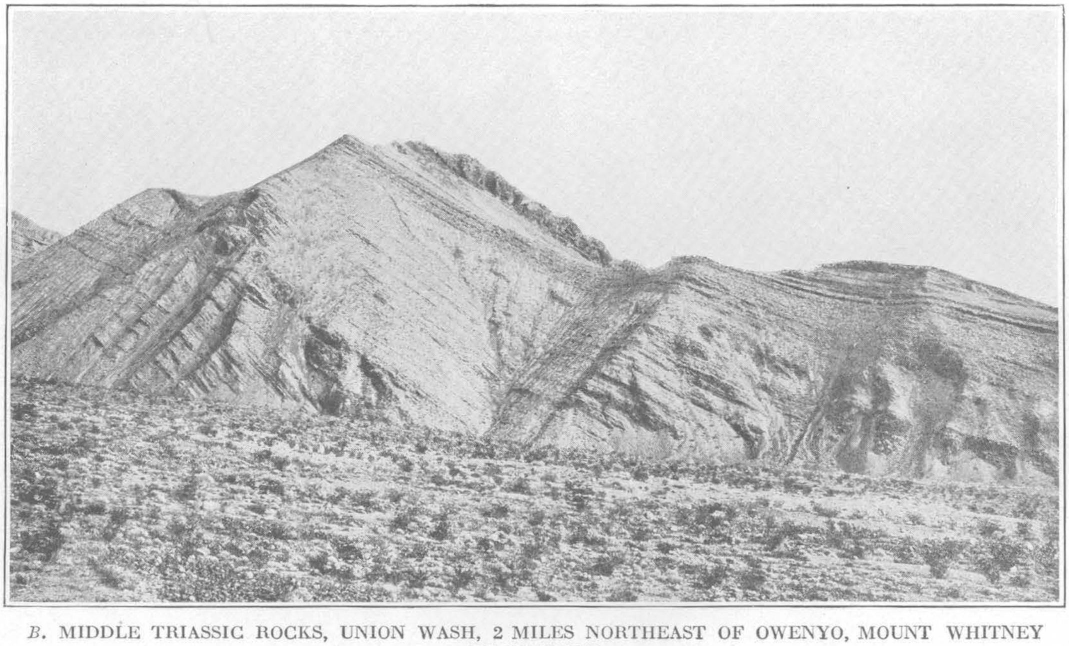
Chonetes aff. C. geinitzianus.
Marginifera? sp.
Streblopteria? sp.

Later (in 1916) Mr. Girty adds:

The *Spiriferina pulchra* fauna is more or less characteristic of the Phosphoria formation of Idaho, the Park City formation of Utah, and the Embar formation of Wyoming. The Park City formation is about equivalent to the "Upper Coal Measure limestone" of



A. PERMIAN-TRIASSIC EXPOSURE 2 MILES SOUTH OF REWARD MINE, MOUNT WHITNEY QUADRANGLE.



B. MIDDLE TRIASSIC ROCKS, UNION WASH, 2 MILES NORTHEAST OF OWENYO, MOUNT WHITNEY QUADRANGLE.

the King Survey. Compared with the Phosphoria formation it is believed to comprise the Phosphoria plus a certain thickness of the underlying Wells formation. The Phosphoria formation is regarded as Permian and the Wells as Pennsylvanian, so that the Park City is not a well-constructed formation.

Mr. Girty's general conclusion is that "you had best refer your collection to the Permian and correlate it with the Park City, Phosphoria, and Embar, though the Park City contains some Pennsylvanian and the Embar contains Pennsylvanian, Permian, and Triassic."

THE CARBONIFEROUS-TRIASSIC CONTACT.

In 1901 James Perrin Smith[1] discussed the Paleozoic and Mesozoic boundary in western North America, basing his conclusions in part on the stratigraphic relations shown in the Inyo Range, Cal., and contended that the sequence from the Carboniferous to the Triassic is unbroken. He says:

Below the Meekoceras beds of Inyo County lie several hundred feet of barren shales, and below these is siliceous limestone containing *Fusulina*. Above the *Meekoceras* beds are 800 feet of calcareous shales with impressions of ammonites, and then a few feet of black limestone with *Acrochordiceras, Hungarites, Tirolites, Ceratites, Xenodiscus*, and *Parapopanoceras*, probably belonging to the base of the Middle Trias. The entire series appears to be conformable, from the Upper Carboniferous to the Middle Trias. * * * The real transition from Paleozoic to Mesozoic must be sought in the conformable series below the *Meekoceras* beds and above the *Fusulina* limestone.

The very great importance of establishing continuity of deposition between any two systems, particularly between the Carboniferous and Triassic, is immediately obvious. Accordingly, the mutual relations of these two were studied for more than 20 miles, from a point a couple of miles south of the Reward mine to the region near the Ubehebe trail southeast of Keeler, where the sediments are covered with basalt. These studies determined the existence of a well-marked unconformity between the Carboniferous and Triassic, with no evidence of a gradual transition, either faunal or lithologic.

The Triassic sediments of the Inyo Range are greatly disturbed by masses of intrusive rocks and by numerous faults, and in order to gain even an approximate idea of the succession of the strata a large number of isolated sections must be measured and pieced together. South of Mount Whitney railway station, where the Triassic and Carboniferous are chiefly exposed, the range is synclinal in structure, and here as elsewhere is traversed by many complicated faults, some of which are of considerable magnitude. The faults that trend in general northwestward are especially troublesome to the stratigrapher, as most of them fault the Carboniferous and Triassic into contact and conceal the normal succession of beds at the boundary. (See, however, p. 46.) The fault contact may be seen very clearly on the road from Keeler to the Cerro Gordo mine, at the Estelle Mining Co.'s camp, where the mouth of the tunnel and the excavation for the powder house are both cut along it. This is on the east side of syncline. On the west side the fault contact is exposed in several of the lateral canyons opening into Owens Valley. In addition to these faults, which may be traced for a considerable distance north and south, a large transverse fault trends southeastward obliquely across the syncline from a point north of the Cerro Gordo road. Numerous smaller faults of local importance do not affect the Carboniferous and Triassic boundary.

The locality discovered by Walcott and visited by Smith lies some distance north of the area just described and is completely separated from it by great masses of igneous rocks. It has been described as lying 1½ miles east of the Union Spring near the Saline Valley trail over Union Wash and about 3 miles east of Skinner's ranch but would better be described as being on the south side of the first large canyon north of Owenyo, a station on the narrow-gage railroad and the present northern terminus of the Southern Pacific broad-gage line. A road leads up the canyon to an abandoned mining camp.

The Triassic, as shown at the locality, appears to belong to the eastern limb of the syncline, the strike of the beds having carried the remainder of the syncline outside the range. As in the area to the south, it has been faulted down against the Carboniferous. At least 500 feet of the basal Triassic and not less than 2,000 feet of the Carboniferous have been faulted out, bringing the Triassic into juxta-

[1] Smith, J. P., The border line between Paleozoic and Mesozoic in western America: Jour. Geology, vol. 9, No. 6, pp. 512-521, 1901.

position with the Diamond Peak quartzite. The fault which passes down the lateral canyon just east of the Lower Triassic fossil locality, and which probably explains the presence of the canyon, folded and disturbed the fossiliferous layer and some of the adjacent beds. Its course may be traced in the north wall of the main canyon and beyond. The faulted zone carries some low-grade ore, which has been prospected at several places. Farther north the fault cuts diagonally across the strike of the beds, passing entirely into the Triassic, and goes out into the valley.

A mile and a half or more north of Union Wash, about midway between this locality and the Reward mine, in a conspicuous hill which rises some distance from the main mountain mass, is the only certainly normal Carboniferous and Triassic contact known in the range. The Permian limestones, dipping steeply southwest, form the main mass of the hill, and the Triassic shales form a sloping ridge that merges into the general valley level. The eastern side of the hill shows evidence of faulting. A small canyon cuts the center of the hill and affords an excellent section, clearly exposing at several places the contact between the Triassic and Permian.

In most other parts of the range, wherever the Triassic and Carboniferous are shown in contact, evidence of faulting is indubitable. About 5 or 6 miles south of Keeler on the Ubehebe trail, however, the evidence is not conclusive. The Triassic here lies in contact with a massive conglomerate, apparently the Reward, and it is possible that the Permian limestones have been eroded and that the contact is undisturbed. It lies, however, at the bottom of a sharply incised ravine, and this, taken in conjunction with other structural features, suggests a fault.

The unconformity between the Permian and Triassic in the hill between Union Wash and the Reward mine, described above, is sharply defined and clearly marked. The surface of the Owenyo limestone is weathered and irregular. Resting on it and forming the basal member of the Triassic is a bed of variable composition and thickness (maximum thickness, 12 feet). In one place the bed consists of a calcareous sandstone with conglomeratic lenses and a capping layer of impure mud-cracked limestone; and a few hundred yards away it is a quartz-pebble conglomerate with a calcareous matrix. One block of yellowish-brown calcareous sandstone, found on the talus below the contact, is crowded with pelecypods, which were identified doubtfully as *Myalina* by Mr. Girty, who says that " their association and the rocks in which they are embedded strikingly recall the Lower Triassic of Idaho and Utah, the equivalent of Walcott's Grand Canyon Permian." He adds, however, that they may be Carboniferous. No similar rock was seen below the unconformity, and the block probably came from the basal bed of the Triassic.

Above the basal bed the typical Triassic shales begin sharply and, so far as exposed, are consistently green and papery. At many places near their base they contain nodules of iron. Higher in the Triassic the sediments are more arenaceous and platy and contain some bands, 2 to 5 feet thick, of thin fissile shales similar to those immediately overlying the Permian. The general talus slope, however, consists of iron-stained brownish to buff plates that tinkle under a horse's hoof. In all the section exposes at least 500 feet of Triassic shales, no part of which is represented in the section at Union Wash. Triassic fossils occur in these shales, cephalopods having been found within 100 feet of the base.

Plainly, the passage from the Paleozoic to the Mesozoic in California is abrupt, not gradual, and is marked by a well-defined unconformity. The " conformable series beneath the *Meekoceras* beds," described as occurring at Union Wash, lies stratigraphically not less than 2,000 feet beneath the top of the Carboniferous, the intervening beds being cut out by a fault which also cuts out several hundred feet of the basal Triassic.

UNDIFFERENTIATED PALEOZOIC LIMESTONE AND DOLOMITE.

Two areas mapped as undifferentiated Paleozoic lie opposite each other, on the east and west sides of the range, facing Saline Valley and on Owens Valley. The structural relations of the beds indicate that they are pre-Carboniferous, and they can not be older than Ordovician. The beds consist of limestone and dolomite, which are highly metamorphosed and in the vicinity of Swansea have been quarried for marble. No fossils were seen. It is probable from the lithologic character of the limestones that they represent the Devonian, in part at least; and it may well be that on the east side of the range, where a greater thickness of beds is exposed, the Ordovician is also present. The conclusion is, therefore, that these undifferentiated Paleozoic strata are Devonian, Ordovician, or both.

TRIASSIC SYSTEM.

DISTRIBUTION.

According to Smith,[1] both Lower and Middle Triassic faunas are present in the Inyo Range. Overlying the Triassic sediments studied by Smith there are several thousand feet of rocks, mainly volcanic. No fossils were found in these higher beds, which may be Middle or Upper Triassic and may even include rocks of Jurassic age.

From the Union Wash to the Ubehebe trail, southeast of Keeler, the Triassic sediments are prominently exposed in the trough of a broad syncline, which is flanked on either side by the more resistant Carboniferous sediments. Their base (see p. 46) is exposed between Union Wash and the Reward mine. The fossiliferous beds of Lower and Middle Triassic age are shown in only a few localities, the best section being that described by Smith, on the south side of Union Wash, where both Lower and Middle Triassic are exposed. Near the crest of the range south of New York Butte Middle and possibly Lower Triassic beds crop out in some of the faulted wedges. On the west limb of the syncline, both on the Cerro Gordo and Saline Valley Salt Co.'s roads, Lower Triassic sediments appear. A good section of the Lower Triassic, on the Ubehebe trail southeast of Keeler, affords opportunities for collecting fossils. On both the eastern and western limbs of the syncline from the Saline Valley Salt Co.'s road south, the Lower and Middle Triassic are exposed, but at most places the beds are badly disturbed and in some places are metamorphosed.

The great volcanic series is shown to best advantage along the trail from the Mount Whitney railway station to the Burgess mine, at the crest of the range just south of New York Butte, but for their detailed study the exposures along the Saline Valley Salt Co.'s road are perhaps the most convenient. These volcanic rocks are also shown on the west side of Owens Valley in the Alabama Hills, where, however, they are greatly disturbed by faulting, folding, and granitic intrusions.

Rocks supposed to be in part Triassic occur as roof pendants in the Sierra Nevada. (See pp. 62–63.)

LOWER AND MIDDLE TRIASSIC ROCKS.

Detailed stratigraphic work in the field will doubtless make it possible to separate the Lower from the Middle Triassic and reconstruct a fairly accurate section from the dissociated and fragmentary sections available, but no attempt was made to separate them in this reconnaissance. Although fossils are locally abundant in the Lower and Middle Triassic, little time was available for collecting them, and no new types were added to faunal lists made by Smith.[2]

Between Union Wash and the Reward mine, where the basal Triassic is shown, are 500 feet of arenaceous shales that are not represented in the section at Union Wash. About 75 feet above the base of these shales a cephalopod that was identified by J. P. Smith as *Danubites?* sp. was found. The section at the Union Wash is faulted and folded, especially in its lower portion. In view of these facts and of the sections on the Ubehebe trail the Lower Triassic should measure not less than 1,500 feet, and perhaps considerably more.

The thickness of the Middle Triassic can not be computed from the data at hand. Smith records a fauna which he considers of basal Middle Triassic age as occurring in a 5-foot limestone layer near the top of the Union Wash section. Higher in the section (southward along the mountain) several hundred feet of sediments of volcanic origin, whose lower beds are interstratified with marine calcareous deposits, appear to fall within the Middle Triassic. (See Pl. IX, *B*.) Still higher there are several thousand feet of strata, largely volcanic rocks of undetermined age.

[1] Smith, J. P., Comparative stratigraphy of the marine Trias of western America: California Acad. Sci. Proc., 3d ser., vol. 1, pp. 350–351, 1904.

[2] Idem, pp. 350–351, 357.

The Lower Triassic consists in the main of calcareous shales and some beds of impure limestone. The basal beds comprise 500 feet of thin-bedded arenaceous shales. The higher beds are decidedly carbonaceous and are very dark—in many places sooty black. Fossils are found chiefly in the limestone lenses, though some specimens occur in the shales. The Middle Triassic apparently consists of impure limestones and calcareous shales interstratified with sediments of volcanic origin, chiefly andesitic breccias, which carry fragments of Triassic limestone and are considerably altered.

UPPER TRIASSIC ROCKS.

Overlying the fossiliferous Middle Triassic and the andesitic breccias with interstratified Middle Triassic limestone is a great series of sediments consisting in the main of volcanic material. Along the trail from the Mount Whitney station to the Burgess mine at the crest of the Inyo Range is a mass of these beds, which is estimated from breadth of outcrop and dip to be not less than 5,000 feet thick. A similar estimate made along the Saline Valley Salt Co.'s road from Swansea to the crest of the range gave approximately the same thickness. The beds are prevailingly brilliant in color, ranging from greens to lavender and magenta. Stratified andesitic tuffs and breccias are abundant throughout the series.

Whether these beds are of Middle, Upper, or post-Triassic age could not be determined. No fossils were found in them. Stratified volcanic rocks of Middle and Upper Triassic as well as Jurassic age in other parts of California have been described, and it is of course possible that the great accumulation in the Inyo Range represents deposits of all these ages.

The igneous rocks interbedded with this series of sediments are treated at length by Mr. Knopf. (See pp. 58–59.)

TERTIARY AND QUATERNARY ROCKS OF THE REGION.

OLDER LAKE BEDS.

EAST OF ZURICH.

Along the foothills of the Inyo Range east of Zurich (or Alvord, as it was known until recently) an assemblage of beds of strikingly different aspect from the surrounding bedrock formations is exposed. The strata are brilliant white or light gray and are dissected by numerous gulches and sharp ravines, so that a sort of badland type of topography is produced. The beds consist mainly of shales, with associated sandstones, conglomerates, thin limestones, and arkose grits. All of these, except the limestones and grits, are soft and loosely coherent. They are evenly and persistently stratified in thin beds, as a rule not exceeding 2 feet in thickness. They dip westward at small angles, nowhere exceeding 6°. As the base on which they rest is nowhere visible, their thickness is not determinable, but it is at least 150 feet.

A particularly instructive section of these beds is exposed on the south side of the road to Graham Springs. In a small alcove carved in granite a series of feldspathic or arkosic grits has been laid down in massive, firmly indurated stratified beds, some of which are 6 feet thick. These beds are composed of angular grains of quartz and of fresh, clear orthoclase and plagioclase embedded in a cement of calcite. In the beds of arkose there are irregular layers composed almost wholly of unsorted, angular, or subangular granite boulders, whose longer axes invariably lie flat, in this respect differing notably from the boulders in the alluvial-cone deposits, in which the axes stand at any angle to the bedding. These strata are somewhat fossiliferous, carrying the fresh-water gastropods that are so common throughout the formation, and are manifestly littoral deposits. Certain deposits occurring along the Saline Valley road, described as shore deposits by Walcott and Trowbridge, are, however, alluvial breccias, or "fanglomerates," belonging to the overlying unconformable series of gravels.

Locally the beds, including even the conglomeratic members, are crowded with fresh-water fossils. They were therefore laid down in a lake, for which the name Waucobi was proposed by Walcott, who first described the beds.[1]

Fossils found by Walcott were identified by W. H. Dall, who reported: "Any of them

[1] Walcott, C. D., The post-Pleistocene elevation of the Inyo Range and the lake beds of Waucobi embayment, Inyo County, Cal.: Jour. Geology, vol. 5, p. 340, 1897.

might be Recent or Pliocene; my impression from the mass is that they are Pleistocene."[1] Gastropods occurring in thickly crowded masses, found in 1912, were identified by Dr. Paul Bartsch, of the United States National Museum, as *Cincinnatis cincinnatiensis* Anthony, a species characteristic of ponds, lakes, or very sluggish water.

Deposits proved by their well-stratified character and their content of fossils to be of lacustral origin extend from an altitude of 4,000 feet up to 5,200 feet, above which their extension is highly problematical, though Walcott is of the opinion that undoubted lake beds occur on the Waucoba road at an altitude of 7,000 feet. Here, in the midst of extensive alluvial breccias, are two small outcrops of crumbly white sandstone, 2½ feet thick, overlain by 6 feet of yellowish sandstone and underlain by coarse angular conglomerates. These outcrops, however, seem best explicable as pockets or lenses of finer material in the coarse, angular, unshingled, and unsorted alluvial breccias that extend continuously along the Waucoba road to the summit of the range, across the divide, and down the east flank.

The lake beds are unconformably overlain by alluvial breccias, or "fanglomerates," to use Lawson's term. At some places the unconformity is readily apparent, but at others the exact position of the surface of unconformity is difficult to find. As most of the lake beds are poorly lithified, few characteristic rock fragments derived from them occur in the overlying deposits, so that this means of determining unconformable superposition is commonly lacking. Further, the incoherent lake beds were easily reworked, and the material thus derived from them was incorporated in the overlying deposits without essential change of appearance and now forms the matrix of the gravels. In this way deposits simulating littoral phases of the lake beds were formed, and the discrimination of true lake beds from terrestrial deposits is not everywhere possible.

The unconformity between the lake beds and the overlying coarse alluvial breccias is well shown north of the Waucoba road at an altitude of 4,500 feet. At this locality the alluvial deposits are 40 feet thick instead of a few feet as is more common; they are firmly indurated, are formed of angular to subangular fragments, and contrast notably in color with the bright tints of the subjacent lake beds. Near the contact a slab of the underlying lake-bed grit, measuring 5 by 4 by 1½ feet, was found in the alluvial breccia. Moreover, it was standing vertically, a feature common enough in the alluvial deposits of Owens Valley, but nowhere observed in the lacustral deposits.

Near McMurry Spring the nature of the unconformity is not so obvious. Above the undoubted lake beds there is 20 to 30 feet of soft sandstone containing irregular pockets, lenses, and channels of coarse angular and subangular gravels. In some beds the pebbles are excellently shingled, but in others they stand at all angles to the bedding. The sandstone is further noteworthy in being speckled with numerous small particles of white rhyolite pumice. Above the sandstone are angular gravels, the top layer cemented by carbonate to a depth of 4 to 5 feet and the underlying layers uncemented, the matrix being a dusty silt. The cementation is clearly a surface effect allied to that of caliche and similar deposits common in arid regions.

At the north entrance of Devils Gate, on the Waucoba road, a prominent white stratum overlies sandstone and angular conglomerate, which are regarded by Walcott as belonging to the lake-bed series but here interpreted as belonging to the overlying unconformable deposits. The white bed is 4 feet thick, is composed largely of pumiceous rhyolite particles, and rests on an irregular surface. The irregularities, however, are small, and at a short distance the bed appears to be horizontal. The underlying yellow sandstone is speckled with rhyolite pumice particles and is similar to that at McMurry Spring. This content of rhyolite pumice, hitherto unrecognized, may possibly serve as a means of correlation; certain it is that strata of pumice breccia occur both in undoubted alluvial cones along the west flank of the Inyo Range and in deposits undoubtedly laid down in bodies of standing water.

AREA SOUTH OF BIG PINE.

Seven miles south of Big Pine, a short distance northeast of the Buckeye mine, there is

[1] Op. cit., p. 342.

a series of poorly exposed lake beds. A few openings have been made here during the recent exploitation of some interstratified diatomite deposits. The strata, which consist of evenly bedded soft sandstones and shales and some diatomite, aggregate several hundred feet in thickness. They are partly covered by a flow of olivine basalt.

The main diatomite bed, which is traceable for several hundred feet, is approximately 6 feet thick. It is overlain successively by 1 inch of rhyolite pumice tuff, by 1½ feet of diatomite, and by shaly beds and is underlain by a yellowish argillaceous stratum. Lower in the stratigraphic column there are other diatomite beds, some of them underlain by a white sandstone containing numerous small flakes of biotite.

The diatomite of the principal bed, which is of great purity, was examined by Albert Mann, who reports as follows:

> The material is an earth high in percentage of diatoms and is of strictly fresh-water origin. The forms contained are as follows in the order of their frequency:
>
> Epithemia argus (Ehrenberg) Kutzing; very common.
>
> Fragilaria construens Ehrenberg, with numerous varieties; very common.
>
> Cymbella gastroides Kutzing, especially var. minor Grunow; common.
>
> Melosira crenulata Kutzing, principally var. laevis and semilaevis Grunow; common.
>
> Gomphonema constrictum Ehrenberg, with var. capitata; common.
>
> Synedra capitata Ehrenberg, frequent.
>
> Epithemia (Rhopalodia) gibba (Ehrenberg) Kutzing var. ventricosa Grunow; rare.
>
> Cocconeis placentula Ehrenberg; rare.
>
> The quantity of fresh-water sponge spicules in this deposit is unusually small.

These beds strike N. 40° W. and dip 30° SW., a dip considerably higher than that of the late Cenozoic lake beds elsewhere in the region. The most probable interpretation of this is that they form part of a fault block that has been somewhat highly tilted.

NORTH OF OWENS RIVER.

The high bluffs on the north side of Owens River, a few miles north of Bishop, show a nearly horizontal series of white beds of rhyolitic composition. A thickness of 70 feet is exposed, but the base is not visible. The finest strata are as fine as dust; the coarsest consist of well-rounded pebbles of pumice half an inch to an inch in diameter. All are evenly and regularly bedded, single beds only 2 to 3 inches thick being traceable continuously along the face of the bluff for 200 to 300 feet. The coarse beds commonly and the fine beds rarely display cross-bedding of the foreset type; the cross layers generally dip 15° E. No fossils were found in this series of beds, but on the whole it is probable that they were deposited in a lake.

A large proportion of the white sediments is rhyolitic ash, grains of quartz, and small pebbles of white pumice and black obsidian. The pumice is generally porphyritic from the presence of relatively large phenocrysts of quartz.

The white rhyolitic beds, which are very friable, are capped by a cliff-making stratum of pinkish-gray tuff composed of rhyolitic material and carrying numerous fluxional pumice fragments, quartz particles, and angular fragments of black obsidian.

This capping stratum serves as an admirable register of the displacement that the beds have undergone by faulting. Along Fish Slough they have been broken by a major north-south fault and by a number of minor east-west faults, along which the separate fault blocks have been given a southward tilt.

NORTHEAST OF LAWS.

On the east side of Owens Valley an excavation at the mill of the Southern Belle mine, at an altitude of 4,500 feet, affords a good exposure of what are probably lake beds overlain unconformably by alluvial breccias. The supposed lake beds, consisting mainly of gravels, are rather evenly and persistently stratified and dip 14° W. The gravels are well rounded and fairly well sorted; the pebbles do not exceed 8 inches in diameter. The thinner beds consist of small, flat, generally well-rounded schist and slate fragments, and as a rule are well shingled.

The overlying alluvial breccias are sharply angular gravels composed largely of slate and schist. They are rudely layered, and, although resting on an irregular surface of erosion, they dip accordantly with the subjacent strata. It must be admitted, however, that this unconformity does not suggest an important time break. The section is shown in Plate X, *A;* the contrast between the rudely layered alluvial deposit and the well-bedded deposit below is clearly brought out, but the erosional contact is not easily distinguishable.

Similar alluvial material is exposed in one of the mine tunnels, in which the beds dip 28° to 45° W. The bedrock surface on which they rest is not a fault contact but an exceedingly rough and irregular surface of erosion. Angular blocks, 3 to 4 feet long, rest in channels cut in bedrock and are overlain by beds of subangular boulders.

The section probably represents littoral lake beds, which were exposed soon after they were deposited by a lowering of the lake waters and were covered by alluvial deposits, an explanation suggested by the late Quaternary history of Owens Lake.

SOUTH OF KEELER.

Loosely cemented sediments underlie the broad basin between the Inyo and Coso mountains, skirt the flanks of the Coso Mountains, and extend southward across the low divide between Owens Valley and Rose Spring Valley. They are particularly well exposed at the south dam of the Haiwee reservoir of the Los Angeles Aqueduct.

The general structure of the beds is that of a low anticline whose axis strikes north and south. Faults of small displacement occur in places. Along the west limb of the anticline the beds dip 10°–14° W.—that is, toward the Sierra Nevada.

The beds in the area between the Inyo and Coso mountains consist largely of loose granitic detritus, as a rule rather coarse. Stratification is not well developed, though some beds of arkose grit, 1 to 2 inches thick, are firmly enough cemented to form distinct strata. Pumiceous rhyolite tuffs are prominent toward the top of the sedimentary series, especially along the flanks of the Coso Mountains. The volcanic members are well shown east of the Haiwee reservoir. The beds here are conspicuously white and are evenly and persistently stratified. They consist of calcareous sandstones (the finer grained of which contain much flaky black mica), shales, and rhyolitic breccias and tuffs. Breccia composed of fragments of rhyolite pumice forms beds that attain a thickness of as much as 30 feet. In the thicker beds the pumice, which is a biotite rhyolite of silky luster, is present in angular fragments reaching a length of 6 inches. Some beds of conglomerate occur also, noteworthy in containing well-rounded pebbles of the rhyolite pumice. Slabs of coarsely crystalline gypsum an inch or so thick were noted but are not well enough exposed to show whether they are veins or chemical precipitates deposited contemporaneously with the sediments.

These deposits have been regarded as lake beds by the geologists who have previously examined them. No fossils had been found in them, however, until the present reconnaissance, when some were obtained from a calcareous clay or shale exposed at the south dam of the Haiwee reservoir. Those collected seem to throw some doubt on the previously accepted explanation. E. O. Ulrich, to whom the fossils were submitted, says:

> The samples submitted contain very abundant remains of minute Ostracoda. Unfortunately nearly all the specimens are crushed or distorted, and most of those that do retain approximately their original form are so greatly obscured by adhering matrix that close specific determination is difficult and for many specimens impossible.
>
> Perhaps half a dozen species are indicated. Most of them suggest *Cythere* and *Cytherideis*—marine and brackish-water genera; but the others suggest *Cypridea, Metacypris, Potamocypris,* and other more commonly fresh and brackish water genera. Satisfactory generic reference is extremely difficult.
>
> The interesting feature of these minute fossils is that they indicate marine connection for these supposed inland lakes. The age of the beds should be Tertiary or later.

Coarse gravels, mainly material composing the great alluvial cones flanking the Sierra Nevada, have been deposited on the irregular, deeply eroded surface of beds exposed at the south end of Owens Valley. This unconformity is clearly shown at different places along the Haiwee reservoir but especially at the south dam. Along the Darwin-Keeler road the beds are in places covered by sheets of basalt.

The relation of these beds to the basalt extrusions throws some light on their age, so indefinitely fixed by the paleontologic evidence. The sheets of basalt form an important element in the geologic structure of the southern end of the Inyo Range. At some time after their extravasation they were broken by faults whose vertical displacement aggregates 1,400 feet; and subsequent to this faulting deep canyons were eroded well back into the basalt plateau that forms the summit of the range. It seems reasonable, therefore, to infer that the basalts were erupted at least as far back as early Quaternary time and that the underlying sedimentary beds are early Quaternary or possibly Pliocene. Although the basalt in the area between the Inyo and Coso mountains rests directly on the brackish-water beds, in the Inyo Range it rests on angular gravels and silts that may represent littoral phases of the beds deposited farther out in deeper water.

EAST OF KEARSARGE.

Beds that are possibly of lacustral origin occur along the flank of the range east of Kearsarge, or Citrus, as it was formerly called. They dip 14°–17° W. (toward the valley). From a distance they appear to be fairly well stratified, but examination at the outcrop shows that the layering is of the rudest sort. The beds are composed of fragments of granite, limestone, chert, and quartz, firmly indurated by a calcareous cement and generally angular, unshingled, and unsorted. The lower beds, however, contain a notable amount of well-rounded pebbles, some as small as one-fourth of an inch in diameter—possibly a near-shore lacustral deposit, though its other features lend little support to this interpretation. A. C. Trowbridge[1] thinks they were laid down in a shallow lake, but this explanation can be substantiated only by finding fresh-water fossils within them.

North of Kearsarge an isolated patch of rhyolitic tuff and breccia, at most 50 feet long and 6 feet thick, rests on granite in a large canyon at an altitude of 4,800 feet. No exposure like it was found anywhere in the surrounding region, but it is closely similar to the rhyolitic beds east of the Haiwee reservoir, 40 miles to the southeast. The coarser beds are composed of angular fragments of silky pumice, crystals and fragments of quartz, and feldspar particles, all firmly embedded in a calcite cement; and the finer beds are essentially limestones. The beds are well stratified, and this fact, together with their calcareous nature, indicates that they were laid down in standing water.

CORRELATION.

The facts at hand are too few to afford a satisfactory correlation but are numerous enough to show the difficulties of the problem. The features that render difficult the deciphering of the history of the late Cenozoic deposits are the scattered distribution of the beds and the unsatisfactory or inadequate evidence furnished by their fossils. The supposed lake beds at Haiwee have yielded marine or brackish-water ostracodes; the fresh-water beds south of Big Pine have yielded diatoms, which are of no value in correlation; the lake beds east of Zurich have yielded a fresh-water fauna ranging from Pliocene to Recent; and the other supposed lake beds have yielded no organic remains.

From the geologic evidence the ostracode-bearing beds appear to be the oldest of the late Cenozoic deposits considered here, for the main faulting to which the Inyo Range owes its present relief took place, as already stated, after the sediments had been deposited and then covered in part by basaltic outflows, and subsequent to the uplift of the range deep canyons have been cut back into the high basaltic table-land. The lapse of time indicated by these events would point to a pre-Quaternary age for the deposits. It is somewhat difficult to reconcile the marine origin indicated by the ostracodes with the known facts of Californian geology; and pending the collection of more conclusive evidence, the description of the beds has been retained here under the heading of lake beds.

It is noteworthy that rhyolitic ejecta occur in nearly all the deposits under discussion. But as two or more periods of rhyolitic eruption yielded products not certainly distinguishable this does not aid much in correlation and is in fact more likely to add to the difficulty of the problem.

ALLUVIAL CONES.

The great alluvial cones that flank the mountains on both sides of Owens Valley constitute one of the most striking features of the prov-

[1] The terrestrial deposits of Owens Valley, Cal.: Jour. Geology, vol. 19, p. 732, 1911.

ince. Along the Sierra Nevada they overlap and produce an alluvial slope that extends continuously along the front of the range and merges almost imperceptibly into the valley floor. Along the Inyo Range, however, they occur only at the mouths of canyons, and thus form distinct topographic units which stand out in bold contrast to the level floor of the valley.

ALLUVIAL CONES ALONG THE SIERRA NEVADA.

General features.—The outwash apron of detritus discharged from the canyons of the Sierra Nevada forms a piedmont alluvial slope, 1 to 7 miles wide, that rises 1,000 to 2,500 feet above the valley. This slope attains its greatest dimensions between Lone Pine and the basaltic field north of Independence—that is, it is widest and highest along the base of the culminating portion of the Sierra Nevada. The coalescence of adjoining cones here has been nearly complete, resulting in a plain that, when viewed from the valley, appears to slope evenly away from the mountains, its large dimensions obliterating the inequalities in its surface and causing underestimates of the great height to which the cones rise above the floor of the valley.

In appearance the piedmont alluvial slope, sometimes called the "sagebrush slope," is dry and sterile; it is strewn with large boulders and is dotted with sagebrush, and altogether it forms an unpicturesque foreground to the magnificent range that rises behind it. Parts of it are now being reclaimed from the desert by irrigation and are being planted with apple orchards, which seem to thrive even where the boulders are too numerous to permit tilling with the plow.

The areal distribution of the outwash deposits of the Sierra Nevada is shown approximately on the geologic map (Pls. I and II, in pocket). The lower boundary roughly marks the outermost limit of coarse wash, and the upper boundary marks the limit against the mountain front, but is in places doubtful on account of the talus cones of granite sand that have spread over the alluvium. In a more detailed mapping of the region these two classes of detrital material should be carefully discriminated; and this separation will doubtless yield important results. Refined study would also lead to the discrimination and mapping of gravels of preglacial, postglacial, and possibly interglacial age, and of glacial outwash. The fact that these distinctions can be made was recognized at a number of localities, but as their systematic elaboration would have proved disproportionately time consuming, all the outwash deposits were mapped as a unit.

The average slope of the cones is between 6° and 7°. The alluvial plain exhibits marked undulation near the mountain front, where the fact that it was formed by the lateral growth of adjacent cones is readily apparent. A distinct depression marks the junction of contiguous cones, and the slope on both sides of each cone rises rather steeply toward the canyon from which the cone has been built. Toward the valley, however, this distinction between adjoining cones vanishes.

The alluvium consists predominantly of coarse granitic detritus. The large size and the great number of the boulders, even at a distance of many miles from the flank of the range, are striking features. The largest boulder noted anywhere on the alluvial piedmont slope exceeds 50 feet in length. This great granite block is partly embedded in the gravels of the alluvial cone at George Creek, about 2 miles from the mouth of the canyon. Other large boulders have traveled great distances from the mountains; some measuring 18 by 6 by 8 feet lie along the fault scarp that traverses the alluvium west of Fish Springs School, practically at the outer edge of the alluvial slope, 4 or 5 miles from the canyons from which the débris was derived. Lone Pine Creek, where it flows through the Alabama Hills, 7 miles from the Sierra Nevada, is bordered by a terrace 50 feet high, composed largely of granite boulders 3 to 4 feet in diameter.

The thickness of the gravels is at least 500 feet as determined by wells sunk by the Bureau of the Los Angeles Aqueduct. The logs of these wells, given by C. H. Lee,[1] show an alternation of coarse gravels, sands, and clays. Although the alluvial cones rise 2,000 to 2,500 feet above the valley floor, it does not necessarily follow that the gravels are 2,500 feet thick, though in some places they may well be that thick. The cone of Lone Pine Creek,

[1] U. S. Geol. Survey Water-Supply Paper 294, pl. 22, 1912.

whose apex stands at a height of 6,500 feet, consists of a thin veneer of gravels spread over a granite platform. At many places in Owens Valley knobs of bedrock project through the gravels; in fact, two very considerable groups of hills—the Alabama Hills and the Poverty Hills—rise above the alluvial slope. The bedrock floor of Owens Valley is doubtless essentially a mosaic of tilted fault blocks, the larger of which protrude through the alluvium, so that the thickness of the alluvium at any point is purely problematic.

Dissection.—The streams that flow across the piedmont alluvial slope have intrenched themselves in the gravels to depths that range from 75 to 150 feet near the range and that gradually diminish toward the valley. On some parts of the slope, notably at the apex of the cone of George Creek, they have cut through the gravels and into the underlying bedrock to a depth of 25 feet. This dissection is not ascribable to increased stream flow, for the climatic change of Recent time has been toward aridity, as is shown by the partial desiccation of the Pleistocene fresh-water predecessor of Owens Lake and by the disappearance of glacial conditions. Nor is the intrenchment of the streams wholly referable to the normal shifting of streams upon the cones, for the many abandoned channels that radiate from the apexes of the cones do not exceed 20 or 30 feet in depth. A competent cause, which the prevalence of fault scarps traversing the alluvium very naturally suggests, is a recent renewal of mountain growth, which has increased the grades of the streams and invigorated their carrying powers. Another conceivable cause is the disappearance of the glaciers, which has diminished the supply of detritus and has thereby increased the competence of the streams to cut the piedmont alluvial slope. That this is a possible explanation is shown by the occurrence on Big Pine Creek of dissected outwash gravels of the second glacial epoch. (See p. 97.) On the whole this seems the most probable explanation; but the amount of the downcutting due to orogenic movement and of that due to diminished load can not be certainly evaluated from the data at hand. However, the dissection and terracing of the gravels on Birch Creek, north of Bishop Creek, can be closely correlated with the glacial history of the region; and this fact supports the idea that the dissection of the gravels has been in the main due to climatic oscillations. Two-stage dissection is also shown on Lone Pine and on Bishop creeks, but its relation to the glacial history of the region remains unknown.

Age of the gravels.—The gravels have probably been accumulating ever since the Sierra Nevada was differentiated from the Great Basin province. The elevation of the range began in the Miocene, according to Lindgren,[1] who believes that the tilting of the western slope of the Sierra Nevada began at the close of the rhyolitic epoch. The second and major uplift took place probably at the close of the Pliocene, when the range was differentiated from the Great Basin, and the scarp facing Owens Valley was formed, the uplift imparting new erosive energy to the streams that built the great alluvial cones. The cones are therefore regarded as very probably of Quaternary age.

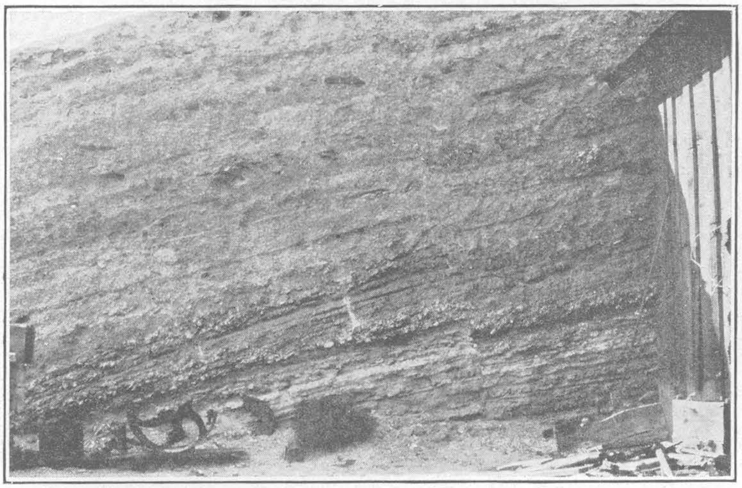
The granite boulders and detritus on the surface of the alluvial slope are essentially fresh, but those in some of the deeper stream-cuts are highly decomposed and rapidly disintegrate on exposure. This is notably true of the preglacial gravels lying beneath the basalt flow on North Fork of Oak Creek. On Birch Creek, south of Crater Mountain, where the deep gravels are excellently exposed, a large proportion of the old alluvium is thoroughly decomposed, boulders as large as 5 feet in diameter crumbling into sand when loosened from their matrix.

ALLUVIAL CONES ALONG THE INYO RANGE.

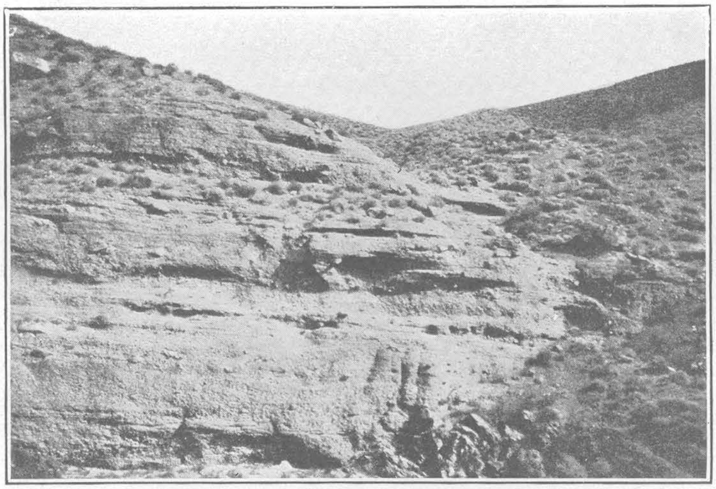
Distribution and character.—Alluvial cones of two ages have been recognized along the flanks of the Inyo Range and have been discriminated on the geologic map (Pls. I and II, in pocket). The earlier cones are especially well developed along the west slope of the range, though the later series are there also prominent. The younger cones have been derived almost wholly from the erosion and partial destruction of the older.

The most notable of the older alluvial deposits lie between Silver Canyon and Black

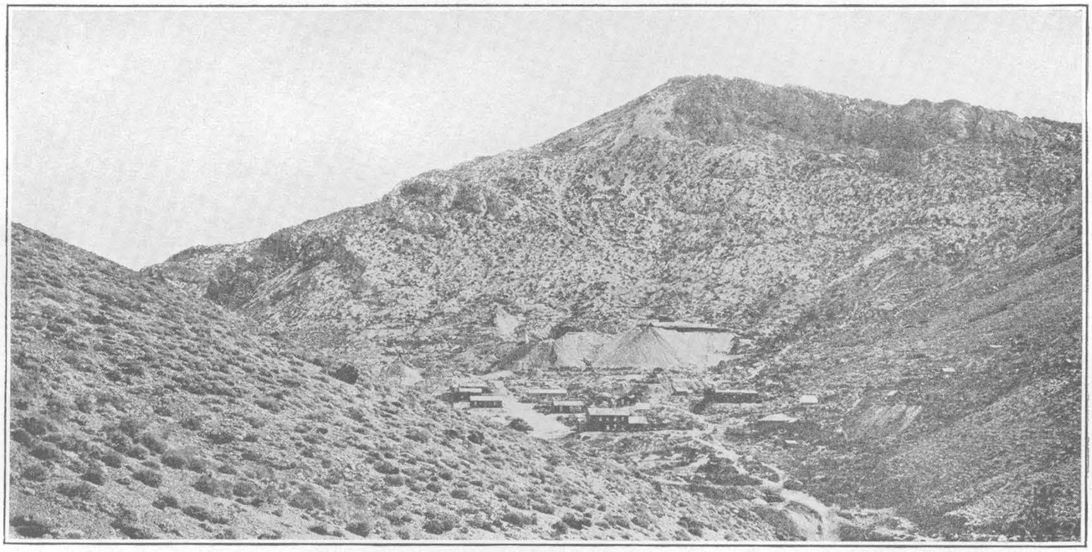
[1] Tertiary gravels of the Sierra Nevada of California: U. S. Geol. Survey Prof. Paper 73, p. 30, 1911.



A. LAKE BEDS OVERLAIN BY ALLUVIAL DEPOSITS NORTHEAST OF LAWS.



B. SECTION OF ALLUVIAL CONE IN REDDING CANYON.



C. CERRO GORDO MINE.

Canyon. The ancient gravels here form the foothills of the range and extend back into the canyons, rising to elevations as high as 6,600 feet above sea level, or 2,600 feet above the floor of Owens Valley. From a distance of a mile the alluvial deposits appear to be fairly well stratified, a feature that has led some observers to call them "lake beds," but examination of them close at hand, which alone can shake off the long-distance impressions, shows that the seemingly even stratification is at best a rough, uneven, discontinuous layering. In Plate X, *B*, the camera, by generalizing and thus emphasizing the layering of the deposit, has produced the same appearance that distance produces to the eye.

The old alluvial cone in Redding Canyon, which is one of the best developed in the range, is deeply dissected and its structure and constitution are revealed in many excellent vertical sections. It consists of angular gravels, unshingled, unsorted, and rudely layered. A noteworthy feature of the deposit is the size and number of the granite boulders, many of which are 6 feet and some 12 feet in diameter. The granite is derived from a mass that intrudes the Cambrian rocks at the head of the canyon. The deposit is semi-indurated and spalls off in great masses. "Toadstools" (pillars of gravel capped by granite boulders) are striking features here and are due to the partial cementation of the gravels. The rude layering of the deposit (it can hardly be called stratification) commonly dips 6° W. (See Pl. X, *B*.) At the mouth of this canyon, at an altitude of 4,500 feet, a breccia of white rhyolite pumice occurs as a bed 2½ feet thick, intercalated between the angular unsorted gravels forming the main mass of the alluvial cone. The pumice bed and the inclosing alluvial gravel dip 7° W., but a short distance farther west the dip steepens to 16°, and this abrupt steepening indicates that the beds have been dislocated and tilted since they were deposited.

The alluvial breccias of the older cones are excellently shown in Black Canyon. The gravels, largely dark quartzites, are only very slightly waterworn and are unsorted. The deposit, which is partly indurated, is unshingled and contains huge, promiscuously scattered boulders. In short, the sections displayed in cliffs resemble nothing so much as till. The bedding is of the rudest kind; it appears to best advantage when viewed from a distance, for on close inspection the individual beds are seen to be poorly bounded above and below, though in places the bedding is somewhat emphasized by the intercalation of short lenticular masses of finer material. Walcott,[1] however, specifically refers to these deposits as lake beds. The prevailing dip is 5° W. but ranges up to 14° W. Near the top of the cone there is a stratum containing considerable pumiceous white rhyolite, above which the layers dip a little less than do those beneath it, indicating that the ejection of the rhyolite pumice was followed by some change in the conditions under which the alluvium was deposited.

Remnants of what are probably this same series of alluvial cones lie along the west flank

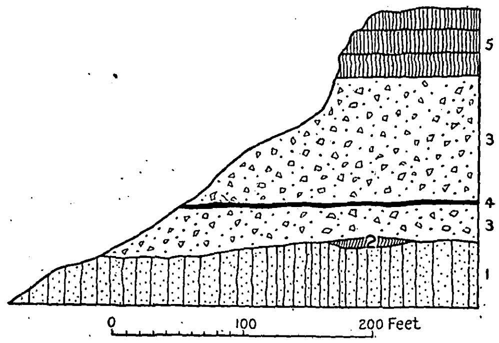


FIGURE 1.—Diagrammatic section northwest of Willow Creek, Inyo Range, Cal. 1, Quartzite; 2, basalt pumice tuff; 3, coarse, angular gravels; 4, rhyolite pumice tuff; 5, basalt.

of the range as far south as Keeler. East of Keeler, within the canyon up which the road to the Cerro Gordo mine passes, they occur in nearly complete form up to an altitude of 4,500 feet and appear as patches up to 4,700 feet. They show a rough layering, which in places dips as high as 18° W. This large westward dip indicates that the deposit has been considerably dislocated by faulting and tilting since it was laid down, for 7° appears to be the highest initial dip of the undisturbed layers in the great alluvial cones of the province.

Alluvial deposits that are probably much older than those on the western flank were laid down at a number of places on the east slope of the range. An interesting section northwest of Willow Creek, at an altitude of 3,000 feet (see fig. 1), discloses a series of quartzites, on whose upturned and irregularly eroded edges

[1] Walcott, C. D., Jour. Geology, vol. 5, p. 341, 1897.

lies 125 feet of coarse, angular, unsorted gravels, in which is intercalated a 2-foot bed of rhyolite pumice tuff. In one place a lenticular bed of tuff-breccia composed of red oxidized basaltic pumice lies beneath the gravels in a depression in the surface of the quartzite. A series of basalt flows caps the section.

An extensive body of firmly cemented ancient gravels extends 400 feet above the bottom of Marble Canyon (altitude, 6,100 feet) at the point where it is crossed by the trail to Waucoba Spring. Cliffs cut in the lowermost gravels afford 30-foot vertical sections that show typical alluvial-cone structure. The top gravels form a veneer on a rock-cut terrace. Granite boulders, some of them 5 feet in diameter, derived from the intrusive mass at Squaw Flat, constitute a noteworthy proportion of the gravels. Another remnant of this deposit occurs higher on the same canyon (at an altitude of 7,500 feet) at the point where the canyon opens out on Squaw Flat. Here gravels containing granite boulders, some of them as much as 15 feet in diameter, rest on a rock-cut terrace 50 feet high. It is manifest that the canyon was excavated to its present depth or deeper, was subsequently filled with gravels, and was later again in part excavated. At present the removal of débris seems to have ceased, if, indeed, the canyon is not again being alluviated.

At the mouth of the canyon of Willow Creek, where it opens out on Saline Valley, gravels rise 500 feet above the stream. Near the Hunter Canyon trail coarse angular gravels persist as scattered patches on the precipitous ridges between the gulches as high as 2,000 feet above the floor of Saline Valley. These patches of gravel, veneered on the flank of the Inyo Range, as it were, point unmistakably to faulting, which depressed the floor of Saline Valley at least 2,000 feet. Near the mouth of Daisy Canyon remnants of old alluvium form foothills whose greatest altitude is 2,300 feet.

History recorded in the alluvial cones.—A notable feature of the old alluvial cones is that their apexes lie well within the canyons from which they were derived. In this respect they contrast strikingly with the alluvial cones skirting the Sierra Nevada, where the gravels are sharply bounded by the front of the range. A second notable feature is the deep dissection and erosion, which has supplied the material for the cones that project so boldly into Owens Valley. The older cone in Silver Canyon is dissected to a depth of 350 feet and that in Black Canyon to a depth of at least 500 feet. During this dissection a terrace that stands about 50 feet above the present canyon bottoms was cut in the gravel, as may be seen in Silver and Black canyons and in the canyon ascended by the Deep Springs road.

The fact that the dissection of the older cones was accelerated by renewal of faulting along the west base of the range is indicated by the disturbed dips shown from place to place and more cogently by the distribution of the old alluvial cones, whose remnants occur only in reentrants in the mountain front, the parts of the cones that formerly extended into Owens Valley having been obliterated. Other evidence of faulting is seen at the mouth of Black Canyon, where a small ridge built of the older alluvium is terminated at the valley by a sharply cut triangular facet.

The upbuilding of the younger alluvial cones on the west flank of the range appears to be essentially at a standstill. Alluviation of the main canyons by the pouring in of detritus from the steep lateral tributaries is the main process now at work. Detritus is indeed carried out of the range and deposited upon the cones along the flank of the range during the cloudbursts that occur at long intervals, but the net result of erosive activity under present conditions is the alluviation of the canyons. The feeble erosion during the present régime manifestly results from the existing arid climate.

The features of the younger cones lead to an interpretation of the history recorded in the older ones. After the Inyo Range came into existence great canyons were cut into its western flank and concurrently great alluvial cones were built up along its base. Increasing aridity, however, so enfeebled the power of the streams that they dropped their loads of detritus nearer and nearer to the heads of the canyons, so that the apexes of the cones shifted upstream and great masses of gravel accumulated within the canyons. This burial of the canyons was interrupted by a renewal of faulting, and probably about the same time, as suggested by the glacial history of the Sierra Nevada on the opposite side of Owens Valley, the climate became more humid. The competence of the streams was thus increased, and the gravels were swept out of the canyons and spread as a new series of alluvial cones along the base of the range. The destruction of older cones was temporarily halted, however, by a recurrence of arid conditions, during which the terrace that stands 50 feet above present canyon bottoms was produced. More humid conditions supervened and the dissection of the older deposits was renewed, but the complete removal of the gravels was arrested by the ushering in of the existing climate.

The length of time involved in the construction and subsequent dissection of the alluvial cones can be only roughly estimated. The intervention of the faulting complicates the record and introduces a factor whose influence can not be readily evaluated, for, independent of any climatic change, it must have greatly accelerated the rate of destruction of the older cones. The first period of aridity, which followed the humid period when the lake beds in the reentrant east of Zurich were deposited, was marked by the construction of the older alluvial cones, which, as a glance at the geologic maps (Pls. I and II, in pocket) will show, were vastly larger than the later cones. The first period of aridity was therefore long, probably longer than all subsequent time. The succeeding period of increased humidity was also long. The second arid period was short as compared with the first; and the second humid period which ensued was much shorter than the earlier one. More precise comparison is not possible, for the relative degrees of humidity that prevailed during the contrasted periods can not be determined. If, for instance, the precipitation during the second period of increasing humidity was just sufficient to cause slow downcutting of the gravels, the period may have been much longer than it appears to have been. The present climatic conditions have evidently prevailed for a considerable time, for the canyons, instead of being sharply V-shaped from recent dissection, are comparatively wide floored, owing to alluviation since the arrest of downcutting.

The foregoing interpretation finds in oscillation of climatic conditions a cause adequate to account for some of the features of the alluvial cones. It is therefore of interest to compare the climatic record thus outlined with that deduced from the glacial history of the east flank of the Sierra Nevada. The two records, if correctly determined, should of course be essentially similar, and the comparison, to be of most value, should be made between records that have been determined independently of each other; unfortunately, however, the climatic history is not wholly deducible from the study of the alluvial cones of the Inyo Range, because, as already pointed out, the record is complicated by the intervention of a period of faulting between the building of the older and younger cones.

The great alluvial cones along the base of the Sierra Nevada had attained their present height before the advent of the first glacial epoch, and the period of their upbuilding probably corresponds to that of the older alluvial cones along the Inyo Range. The first glacial epoch corresponds to the older humid epoch, when the deep dissection of the cones began; the interglacial epoch corresponds to the epoch in which was built the terrace that marks the halt in the downcutting of the cones; the second glacial epoch corresponds to that of the return to more humid conditions and the consequent renewal of dissection; and postglacial time is recorded in the Inyo Range by renewed alluviation of the partly resurrected canyons. The lengths of the corresponding time subdivisions, as conjecturable from both records, appears to be of the same order of magnitude.

BEDS DEPOSITED IN THE PLEISTOCENE OWENS LAKE.

Beds deposited in the fresh-water predecessor of Owens Lake are well exposed east and southeast of Lone Pine, especially in the deep-cut banks of Owens River. Their distribution is somewhat arbitrarily shown on Plate II; they doubtless extend considerably farther northward, probably as far as Kearsarge, but outside the limits shown they are nearly completely hidden beneath a covering of soil, alluvial wash, and wind-blown sand.

Owens River along its lower course has cut a trench, about 20 feet deep and 200 yards wide, which exposes horizontally bedded ash-gray strata of silt and of fine sand, both of which are shimmery from comminuted flakes of biotite. In places fragments of pearly *Unio* shells are common in these beds. Some pebbly bands, 2 to 3 inches thick, occur locally.

The thickness of these late Pleistocene lake beds appears to be at least 300 feet. In the wells put down near Owens River fine sand and clay in alternate layers are the only materials penetrated to a depth of 300 feet, except at the north end of the Alabama Hills, where the proximity of the Pleistocene lake shore caused coarse gravels to be laid down between the finer beds.[1] A well at Lone Pine station, where the lake beds are excellently exposed at the surface, has reached a depth of 800 feet, entirely in fine sand.[2]

The beach deposits of the fresh-water lake are preserved at a number of localities, especially in the vicinity of Swansea. An artificial cut at the old smelter site southeast of Swansea reveals a 10-foot section that is highly instructive when considered in connection with the difficulty of distinguishing littoral phases of the late Cenozoic lake beds from alluvial-cone deposits. It displays the shore gravels of the beach formed when the lake level stood at approximately the 3,700-foot contour. The gravel, comprising different varieties of limestone and andesite porphyry, is well rounded, and in some of the beds, all of which are well shingled and horizontally stratified, it is accurately sorted; in others it is imperfectly sorted, but even in these the textural range is small.

The following is a list of shells collected by Edwin Kirk on the north shore of Owens Lake, on old beaches about 20 feet above the present level of the lake. The shells were determined by Dr. Paul Bartsch, of the United States National Museum:

Planorbis trivolvis Say.
Carinifex newberryi Lea.
Physa ancillaria Say.
Physa gabbi Tryon.
Sphaerium striatinum Lamarck.

SOIL AND WIND-BLOWN SAND.

The level floor of Owens Valley west of the river is formed of silt and soil representing in the main the finer detritus from the outwash slopes of the Sierra Nevada; the floor east of the river is largely formed of wind-blown sand. Areas of similar material occur in Deep Spring and Saline valleys, and certain areas in the summit region of the Sierra Nevada bear remnants of an alluvial soil that was deposited there prior to the development of the present topography.

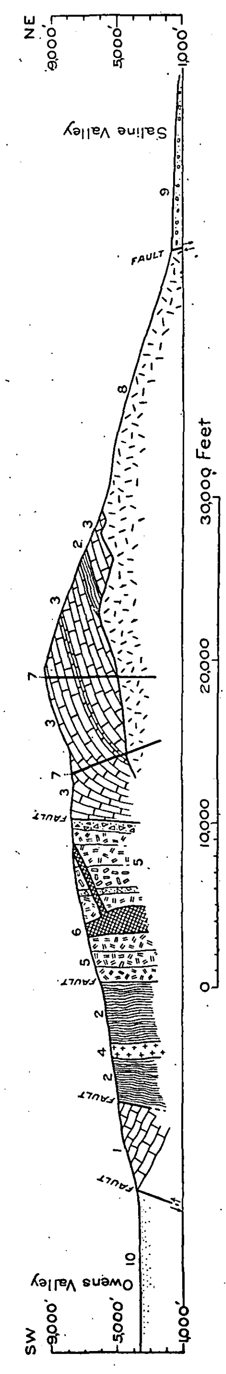


FIGURE 2.—Diagrammatic section across the Inyo Range at Swansea, Cal. 1, Undifferentiated Paleozoic limestone and dolomite; 2, Carboniferous shales; 3, Carboniferous limestones; 4, felsite; 5, Triassic andesite lavas, breccias, and tuffs; 6, aplite; 7, diorite porphyry; 8, quartz monzonite, diorite, and hornblendite; 9, alluvium; 10, lake beds.

IGNEOUS ROCKS.

TRIASSIC ANDESITES AND RHYOLITES.

INYO RANGE.

Andesites form a belt extending along the west flank of the Inyo Mountains from the Union Wash to a point near the south end of the range. They comprise a bedded series of lavas, breccias, and tuffs, but at most places thick flows of lava predominate, so that as a rule it is difficult to ascertain the internal structure of the volcanic series.

The volcanic belt is approximately 10,000 feet wide east of Swansea. The beds dip steeply, the dip on the east side of the belt, where it is clearly determinable, being 70° W. If the belt represents a closely compressed syncline, as indicated by the general structure of the range, the probable thickness of the andesitic series is 4,500 feet. (See fig. 2.) This estimate is doubtless a minimum, for both ends of the measured section are fault contacts, although the amount of faulting along them seems small.

[1] Lee, C. H., An intensive study of the water resources of a part of Owens Valley, Cal.: U. S. Geol. Survey Water-Supply Paper 294, p. 73, 1912.
[2] Idem, p. 74.

The andesites are highly porphyritic, carrying numerous large crystals of plagioclase feldspar. Under the microscope these phenocrysts prove to be oligoclase, and some chloritic pseudomorphs after hornblende and possibly after biotite become recognizable, but the primary ferromagnesian minerals appear not to have been abundant. The andesites are more or less thoroughly altered and are consequently of some subdued color, such as grayish green or dull reddish. They are well exposed on the Cerro Gordo road, in thick, conspicuously porphyritic sheets, which are reddish on weathered surfaces and bluish gray on freshly fractured surfaces. A roughly schistose or sheared structure has been impressed on the volcanic rocks, especially on the tuffs and other pyroclastic beds.

In some of the andesites exposed in the first canyon south of the Union Wash the plagioclase phenocrysts are assembled in aggregates in which they are aligned in spiral or circular patterns. The groundmass of the areas in which the phenocrysts are thus curiously grouped is especially susceptible to "desert varnishing" and weathers black, thereby emphasizing the peculiar structure.

The andesites have been invaded by granites in the area northwest of the Burgess mine by aplite in dikes and as a large mass east of Swansea (see fig. 2) and by diorite porphyry dikes at many localities.

ALABAMA HILLS AND SIERRA NEVADA.

Andesites, intruded by granite and aplite, make up the Alabama Hills. An isolated outcrop of limestone occurs west of Lone Pine, but otherwise the range seems to be composed entirely of igneous rocks. The andesites are best shown at the north end of the range, where they have been least affected by contact metamorphism and pyritization. They display considerable diversity, ranging from sparsely porphyritic rocks to those crowded with plagioclase phenocrysts an inch across. Some display flow streaking that suggests latites.

Rhyolites are associated with the andesites at the northern end of the Alabama Hills. They also comprise several varieties, ranging from dark flow breccias, crowded with quartz and orthoclase crystals and fragments, to light-colored porphyries weathering pinkish and displaying well-marked flow banding and streakiness. All are devoid of dark minerals.

The volcanic rocks make up a large proportion of the roof pendants in the Sierra Nevada, notably of those on North Fork of Oak Creek. In these the rhyolites predominate, ranging from massive rocks to white sericitic schists. They are associated with biotite schists, quartz-sericite schists, phyllites, and metamorphic limestone. They have been considerably altered by metamorphism induced by the intrusive granites—a feature that is particularly well shown by the belt of white rocks on Kearsarge Peak, which at first glance seems to consist of aplites and other differentiation products of the granites surrounding them but which proves to be largely composed of rhyolites that have been thoroughly recrystallized as a result of their invasion by the granite. The breccia structure of the pyroclastic members and the flow banding of other members have survived the metamorphism and demonstrate the rhyolitic origin of the assemblage.

AGE.

The andesitic series is probably of middle or late Triassic age. The evidence on which this determination is based was found on the ridge on the south side of Union Wash, in the Inyo Range, where the basal part of the volcanic series, consisting of andesitic breccias, interleaves with the underlying limestones of Middle Triassic age. Moreover, angular fragments derived from these limestones are common inclusions in the breccias. It is therefore certain that the andesitic series is younger than these limestones, and the most probable interpretation of the facts at hand is that Middle Triassic sedimentation in this locality was terminated by a great outburst of volcanic activity.

FELSITE.

Felsite dikes and sills were noted only in the southern part of the Inyo Range, more particularly on the lower slopes east of Swansea and Keeler. They are exceedingly fine grained rocks containing minute inconspicuous phenocrysts of feldspar and resemble dense quartzite—a resemblance not diminished by the fact that they generally lie parallel to the stratification of the inclosing rocks. Under the microscope they show small sporadic orthoclase phenocrysts embedded in an extremely fine-grained groundmass of quartz and orthoclase; but they contain no ferromagnesian minerals.

Some of the larger masses of felsite were slightly impregnated with pyrite, whose oxidation has tinted the outcrops a rusty orange. The time of these intrusions has not been established further than that they invade strata that are probably Carboniferous in age.

CRETACEOUS GRANITIC ROCKS.

GRANITIC ROCKS OF THE INYO RANGE.

DISTRIBUTION AND CHARACTER.

Granitic rocks occur in large volume in the Inyo Range. In the northern part of the range they are exposed on the east side over extensive areas, but on the west flank they occur in small areas only—for example, in Redding Canyon and east of Zürich. In the southern part of the range granite outcrops over half the surface on both sides of the range. The fact that granite underlies the remainder of the range at no great depth is shown by the occurrence of aplite intrusions at considerable distances from surface exposures of granite; by the prevalence of diorite porphyry dikes, many of which closely approach diorites in granularity; and by the occurrence of masses of garnet rocks, which are ascribable to the metamorphic effect of underlying granitic intrusions.

The average granitic rock is a quartz monzonite composed of plagioclase (andesine), orthoclase, quartz, hornblende, and biotite. This rock is the variety most widely prevalent. From this average variety the granitic rocks range on the one hand to varieties that may appropriately be termed granite (such as the mass east of Kearsarge, which is characterized by the prevalence of large porphyritic crystals of orthoclase), and on the other hand to quartz diorite, diorite, and hornblendite. The dark heavy hornblende-rich varieties are especially prevalent in Daisy Canyon (on the east flank of the range) and along the crest of the range northward from New York Butte.

A partial analysis of a coarse-grained granitoid collected in Deep Spring Valley by C. D. Walcott has been published by Turner,[1] who finds that it is composed of orthoclase, microcline, plagioclase, hornblende, titanite, apatite, and a little quartz, and designates it a hornblende syenite. The high soda (4.62 per cent) and high lime (5.94 per cent) indicate, however, that according to present usage it would be termed a monzonite.

ORIGIN AND AGE.

The intrusive character of the granites is made apparent most plainly by the extensive metamorphism that they have induced in the inclosing sedimentary rocks. This effect is displayed most notably, perhaps, in the great belt of chiastolite hornfels formed by the recrystallization of a belt of shale in the lower part of the Carboniferous section of Mazourka Canyon. This belt has a length of over 10 miles, extending from the foothills southeast of Kearsarge to beyond Santa Rita Flat, and attains a width of over a mile at Barrel Springs. The chiastolite, which is easily recognizable by its characteristic carbonaceous crosses, is present across the entire width of the belt. On the east side it occurs as a multitude of small prisms, which give the rock the appearance of a porphyritic andesite; toward the granitic contact the prisms become larger, the matrix in which they are embedded becomes increasingly granular, and locally tourmaline becomes associated with the chiastolite as another visible constituent of the hornfels.

The age of the granitic intrusions, so far as determinable in the northern part of the Inyo Range (the White Mountains), is post-Cambrian and pre-Pliocene. In the southern part of the range the intrusions are clearly post-Triassic and are older than deposits of presumably upper Miocene age. It is believed that all the intrusive masses are of essentially the same age, although this conjecture is not susceptible of proof, and that they were probably intruded contemporaneously with those of the Sierra Nevada, which forms the opposite wall of Owens Valley.

That in fact successive intrusions did take place in the southern Inyo Range was definitely determined southeast of Mount Whitney sta-

[1] Turner, H. W., Further contributions to the geology of the Sierra Nevada: U. S. Geol. Survey Seventeenth Ann. Rept., pt. 1, pp. 726–727, 1896.

tion, where a white granite, which is devoid of ferromagnesian minerals except rare flakes of biotite and is characterized by an abundance of subhedral quartz crystals, forms a prominent knob projecting into Owens Valley as a spur from the main range; and where a gray biotite-quartz monzonite forms the foothills of the main range. The two granitoids contrast strikingly. The white granite is the younger; it carries considerable plagioclase and is probably a salic differentiate of the quartz monzonite magma that is genetically coordinate with aplite and was injected shortly after the main intrusive body.

Kern Knob; Granite Hill

The granitic rocks of the Inyo Range generally show no development of schistose or gneissose textures. One important exception, however, is afforded by the mass exposed at Squaw Flat. The normal rock in the heart of this mass is a quartz monzonite carrying large porphyritic crystals of orthoclase, but along its periphery, forming a belt perhaps an eighth of a mile wide, it has been converted into well-developed augen gneiss. Aplite dikes are common along the contact and are roughly schistose. Along the southern contact the gneissic structure dips 45° S., and along the northern contact 30° NW., both under the sedimentary covering. The intrusive nature of the augen gneiss is suggested by the abundance of aplite dikes along the contact and is proved by the thermal metamorphism exerted upon the adjoining sedimentary rocks, which are highly biotitic near the contact.

No granites or granitic gneisses of pre-Cambrian age have been found in the Inyo Range. In the Silver Peak quadrangle, which touches the Bishop quadrangle on the northeast, H. W. Turner,[1] however, found a complex of granite gneiss, quartz monzonite gneiss, granite augen schists, and calcareous augen schists, which he believes are of pre-Cambrian origin.

GRANITIC ROCKS OF THE SIERRA NEVADA.

GENERAL FEATURES.

Distribution and character.—Granitic rocks form the main mass of the escarpment of the Sierra that faces Owens Valley. The great relief here—the greatest and most abrupt relief along the whole east flank of the Sierra Nevada—and the deep incisions cut into the heart of the range by the eastward-flowing streams are features that together afford unrivaled sections of the rocks down to the core of the batholithic masses composing the range. On Lone Pine Creek, which heads under Mount Whitney, there is within a horizontal distance of 5 miles a descent of 8,000 feet—from 14,501 feet on the summit of Mount Whitney to 6,500 feet at the apex of the alluvial piedmont slope.

Quartz monzonite is the prevailing granitic rock. It comprises two important varieties—one of normal granitic habit and the other containing large phenocrysts of orthoclase. These two varieties, notwithstanding their strong dissimilarity, are connected by gradual transitional phases, in which the gradation from the eugranitic quartz monzonite to the porphyritic quartz monzonite is clearly traceable in the continuous change in the orthoclase, which passes from anhedral through subhedral to euhedral development. A highly siliceous granite of later age than the quartz monzonites forms large masses.

There is also an extraordinary development of plutonic complexes of diorite and hornblende-rich rocks intersected by innumerable granitic and aplitic dikes. They are commonly associated with roof pendants or detached masses of the invaded rocks. The plutonic complexes, because of the strong contrast in black and white between the hornblendic rocks and the aplitic dikes, are easily distinguishable along the great escarpment from afar at many points in Owens Valley. West of Independence the dioritic rocks are cut by such a multiplicity of dikes of aplite that the entire escarpment, from the alluvial piedmont slope to the summit of the range, displays a persistent and prominent striping, easily visible from a distance of many miles.

Weathering.—Most of the granitic rocks of the higher parts of the range are comparatively fresh chemically but are greatly disintegrated. Sand slopes and talus cones composed largely of fine granitic detritus extend as high as 1,500 feet above the alluvial apron at the base of the range. In the lower foothills and in the Alabama Hills the granite has weathered into forms that are characteristic of arid climates, such as great spheroidal boulders perched

[1] Contribution to the geology of the Silver Peak quadrangle, Nev.: Geol. Soc. America Bull., vol. 20, p. 230, 1910.

insecurely upon pedestals, striking woolsacks, and other fantastic forms. Moreover, it has taken on a rusty orange color, which is at places more or less variegated with black desert varnish.

Crushing and foliation.—The fact that the eastern slope of the Sierra Nevada is a great fault zone led reasonably to the expectation that the granitic rocks would show crushing or gneissic foliation or other evidence of the action of the powerful orogenic forces that were formerly active here, but although the bedrock is well exposed at many places little evidence of such action was obtained. Crushing was observed at only three localities—two along the front of the range (north of Thibaut Creek and south of the debouchure of Cottonwood Canyon) and one on the upper course of Haiwee Creek, whose meridional trend of itself strongly suggests tectonic control. Though these crushed zones are several hundred feet wide, the writer could not satisfy himself that much displacement has occurred along them.

Jointing.—The granitic rocks are traversed by a number of systems of jointing, but these are not constant in strike and dip over the province as a whole nor are they equally strongly developed from place to place. Perhaps the most persistent and pronounced system of jointing is that observable near the mouth of Rawson Canyon, which is so well developed and evenly parallel as to impart to the granite the appearance of a stratified rock. This jointing trends N. 40° E. and dips 65° NW. Two other systems, not so well marked, however, traverse the rock, one striking N. 35° W. and standing vertical and the other striking N. 40° E. and dipping 25° SE.

In some of the cirques of the higher parts of the range, as that south of Army Pass, there is a horizontal sheeting which is rather closely spaced near the surface but becomes progressively more widely spaced downward. On the whole, however, the distribution of the jointing systems along the east flank of the Sierra lends no decided support to the hypothesis that the jointing is due to the development in the granite of an elastic tension arising from relief of load as the region undergoes erosion.[1]

Age.—In the part of the range that lies west of Big Pine the granitic rocks are intrusive in sedimentary rocks, which, according to Walcott, are of Cambrian age. In the Alabama Hills they invade a series of andesites and rhyolites, which, because of their similarity to the volcanic rocks on the east side of Owens Valley, are thought to be of late Triassic age.

Isolated areas of similar rhyolites and related pyroclastic equivalents occur throughout the region, but their age is not independently determinable. It is important to note, however, that in the roof pendant at Mineral King, 15 miles southwest of Mount Whitney, rhyolite (quartz porphyry) as flows, breccias, and tuffs, as well as andesitic material, is interbedded in large quantities with the sedimentary rocks.[2] This series, as determined from the fossils found in it by H. W. Turner,[3] is probably of Triassic age.

The intrusion of the granitic rocks of the culminating portion of the range can not be fixed closer, therefore, than as having occurred at some time after the Middle Triassic. The time of intrusion of some of the batholithic masses on the western flank of the range has been determined more precisely, for it has been found that there the granites penetrate late Jurassic rocks and are overlain by marine strata of Upper Cretaceous age.

ROOF PENDANTS IN THE SIERRA NEVADA.

Isolated masses of schist, quartzite, and limestone occur in the Sierra, especially in the higher parts of the range, and in deep cirques and canyons they project deep down into the intrusive granites. Similar remnants of the roof that once extended over a batholith have been aptly termed by Daly "roof pendants." The largest roof pendant in this part of the Sierra occurs between Middle and South forks of Bishop Creek. It is not only largest but it appears also to extend the deepest, projecting at least 2,500 feet downward into the granite. The remarkable attenuation of the northward extension of this roof pendant and its linear persistence despite its extreme narrowness are

[1] Lawson, A. C., Geomorphogeny of the upper Kern basin: California Univ. Dept. Geology Bull., vol. 3, No. 15, pp. 302–304, 1904.

[2] Knopf, A., and Thelen, P., Sketch of the geology of Mineral King, Cal.: California Univ. Dept. Geology Bull., vol. 4, pp. 242–254, 1905.

[3] The rocks of the Sierra Nevada: U. S. Geol. Survey Fourteenth Ann. Rept., pt. 2, p. 451, 1894.

very notable, and this and like features elsewhere in the region lend strong support to Daly's contention that batholithic invasion is not accompanied by disturbance of the tectonic axes of the invaded rocks.[1]

The rocks that compose the roof pendants have been metamorphosed by the intrusive granites to biotite schists, garnetiferous and biotitic quartzites, lime-silicate rocks (most of them white, close-grained rocks, but some showing radial tremolite), marble, and hornfels. At a few places, as at Rae Lake, there are small masses of stretched conglomerate whose matrix is biotitic. The roof pendants have not only been subjected to thermal metamorphism but have been extensively injected with granitic, aplitic, and pegmatitic dikes, and in places the schists have obviously been granitized. At Taboose Pass the schists are infiltrated with stringers that run out from large siliceous granite dikes. The stringers are folded parallel to the contorted schistosity and doubtless exemplify what Sederholm[2] calls ptygmatic folding, but this evidence of minor dynamic activity is believed not to invalidate the general evidence that the batholithic intrusion occurred without major tectonic disturbance.

The occurrence of the roof pendants in isolated areas, their thorough metamorphism, and their lack of fossils make their age conjectural. They are thought to be mainly Triassic on account of the association of somewhat similar rocks with rhyolites that occur as remnants of the batholithic roof and that are with little doubt of Triassic age. However, the rocks of the roof pendants in the headwater region of Bishop and Big Pine creeks may possibly be of Cambrian age, for the small areas of limestones and sandstone lying west of the town of Big Pine, which are intruded by granite and aplite, have been determined to be Cambrian by C. D. Walcott.[3]

The roof pendants furnish decisive evidence as to the original configuration of the upper surface of the batholithic masses, and the bearing of this evidence on the geomorphic history of the region is presented on page 83.

[1] Daly, R. A., Igneous rocks and their origin, p. 110, 1914.

[2] Sederholm, J. J., Ueber ptygmatische Faltungen: Neues Jahrb., Beilage Band 36, p. 492, 1913.

[3] Spurr, J. E., Descriptive geology of Nevada south of the fortieth parallel and adjacent portions of California: U. S. Geol. Survey Bull. 208, p. 219, 1903.

CARTOGRAPHIC REPRESENTATION.

Four units are employed on Plates I and II (in pocket) to show the distribution of the siliceous granitic rocks that occur in this part of the Sierra Nevada—quartz monzonite, porphyritic quartz monzonite, granite, and plutonic complexes. The porphyritic quartz monzonite and granite represent rocks of distinctive characters and petrographic constancy and are essentially homogeneous units; but the quartz monzonite symbol, though it represents chiefly quartz monzonite of the eugranitic variety described below, includes also rocks ranging from quartz diorite to granite. The less siliceous rocks, comprising diorite and hornblende gabbro, are shown by a single pattern. The plutonic complexes also are shown by a separate pattern. Owing to the exigencies of reconnaissance in a region of the extreme relief and ruggedness of the Sierra Nevada escarpment in the culminating portion of the range, the map must be regarded as a first approximation only, showing in a broad way the distribution of the plutonic rocks that make up the great composite batholith. The boundaries drawn in the area of the Mount Whitney quadrangle are believed to be entitled to most confidence, because the easier accessibility of this part of the region facilitated the mapping.

QUARTZ MONZONITES.

Eugranitic quartz monzonite.—Coarsely granular quartz monzonite occurs in large volume along the east flank of the Sierra Nevada. The type specimen, of which a chemical analysis was made, was obtained on Lone Pine Creek at an altitude of 6,700 feet; but rock closely similar, if in fact not identical, is found at Lake Sebrina, South Lake, Division Creek, Shephard Creek, and Muah Mountain. In other words, it occurs at numerous localities and in extensive masses along the whole length of the part of the range examined.

The quartz monzonite is essentially an even-grained aggregate of plagioclase, orthoclase, quartz, biotite, and hornblende, and contains titanite in sporadic crystals. The grain is fairly coarse, ranging in the type specimen from 5 to 10 millimeters. The biotite and hornblende occur in roughly equal amounts and make up 15 per cent of the rock. They are in general closely associated and partly intergrown; the hornblende is nearly anhedral but the biotite tends to form hexagonal plates. The orthoclase is somewhat pinkish and is easily discriminable from the white striated plagioclase. The two feldspars are present in obviously equal quantities, and the quartz-monzonitic character of the rock is therefore readily apparent megascopically. Under the microscope a few additional features appear. The fabric is hypidiomorphic granular, owing principally to the subhedral development of the plagioclase. The order in which the different minerals commenced to crystallize is not certainly determinable, but quartz was the last to finish crystallizing. It is notable that small crystals of hornblende inclosed in the plagioclase are sharply euhedral, but that otherwise the hornblende is anhedral. The plagioclase has the composition $Ab_{62}An_{38}$. The orthoclase has been in part converted to microcline, and a small quantity of the curious intergrowth termed "myrmecite" is found; both of these newly developed structures evidently point to slight pressure effects. Titanite, magnetite, apatite, and zircon comprise the accessory minerals.

The chemical analysis ana mineral composition of quartz monzonite from Lone Pine Creek is given below. In computing the mineral composition the lime, after deduction of the amount necessary for titanite and apatite, was distributed between the hornblende and plagioclase so as to produce a plagioclase of the composition $Ab_{60}An_{40}$, as indicated by the microscopic diagnosis.

Analyses of quartz monzonite from Lone Pine Creek, Cal.

Chemical composition.

[R. C. Wells, analyst.]

SiO_2	66.68	H_2O+	0.51
Al_2O_3	15.12	TiO_2	.64
Fe_2O_3	1.66	CO_2	None.
FeO	2.49	P_2O_5	.21
MgO	1.38	S	Trace.
CaO	4.09	MnO	.01
Na_2O	2.23	SrO	Trace.
K_2O	4.97		
H_2O-	.31		100.30

Specific gravity, 2.715.

Mineral composition.

Quartz	25.68
Orthoclase	25.58
Plagioclase ($Ab_{60}An_{40}$)	31.13
Biotite	7.02
Hornblende	7.38
Magnetite	1.39
Titanite	1.18
Apatite	.31
	99.67

Ferromagnesian inclosures.—The dark inclosures rich in hornblende and biotite that are common in the granitic areas of the Sierra Nevada have been noted by many geologists. Lawson[1] estimates that they average 1 cubic foot to every 4 or 5 cubic yards of granite. It seems, however, to have escaped attention that the ferromagnesian inclosures are practically restricted to the quartz monzonite and that their ubiquity and uniform distribution is one of the salient characters of the nonporphyritic facies of this rock. They are absent or extraordinarily rare in the porphyritic quartz monzonite and in the orthoclase-albite granite, and they occur only sporadically in the quartz diorites and less siliceous rocks.

The inclosures are irregular in shape but are generally rudely ovoid, distinctly angular forms being nowhere seen. Their average diameter is perhaps 6 inches, though some as large as 2½ feet in diameter have been noted. In places where they are particularly abundant there is as much as 1 cubic foot of inclusion to 1 cubic yard of quartz monzonite. The relative abundance of the inclosures seems not to be determined by their proximity to intrusive contacts, either of other granitoids or of the schist roof pendants; they are particularly abundant, for instance, at the mouth of the canyon of Lone Pine Creek, which is remote from any contact.

Most of the inclosures show an obscure porphyritic texture, which is due to the presence of subhedral crystals of plagioclase. Further, their relative richness in titanite is noteworthy, some of them being studded with numerous crystals of titanite large enough to constitute small phenocrysts. The inclosures are finer grained than the rock inclosing them. The contact between inclosure and host is abrupt, irregular, and interlocking, indicating either

[1] Lawson, A. C., California Univ. Dept. Geology Bull., vol. 3, p. 295, 1904.

simultaneous crystallization of both or solvent action of magma on exotic fragments. Under the microscope the inclosures are found to consist essentially of hornblende, biotite, and andesine; in some the hornblende surrounds cores of augite. Titanite is abnormally abundant, as is occasionally also apatite. The titanite not uncommonly incloses small crystals of andesine. Magnetite and zircon comprise the remaining accessory minerals but are not especially abundant.

The quartz monzonite inclosing the ferromagnesian clots is composed, as already mentioned, of andesine, orthoclase, quartz, biotite, and hornblende and the common accessory minerals. Orthoclase and quartz are not found in the inclosures, but the other minerals are. This suggests that the inclosures are segregations of the earlier crystallizing minerals of the quartz monzonite magma, and that this segregation was accomplished essentially in place seems indicated by the fact that some of the inclusions are surrounded by a white border consisting of quartz monzonite completely devoid of dark minerals.

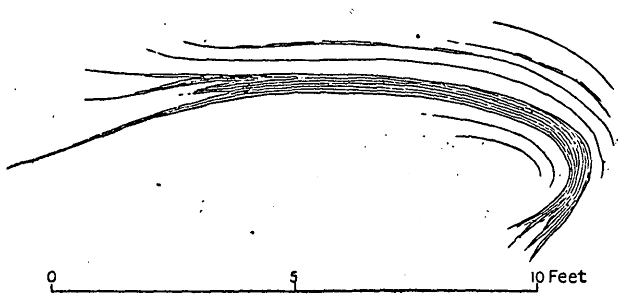


FIGURE 3.—Swirl structure in quartz monzonite, South Fork of Kings River, Cal.

Some features noted—for example, a swirl structure seen in the quartz monzonite at the head of South Fork of Kings River—seem to be related in origin to the ferromagnesian inclosures. Here, on the glaciated floor of the valley, a ferromagnesian band 6 inches wide, with blurred margins, describes nearly a half ellipse (fig. 3), whose largest diameter is 12 feet. It consists, as seen under the microscope, of hornblende, biotite, and plagioclase, subordinate quartz and orthoclase, and relatively abundant accessory titanite, magnetite, apatite, and zircon. At each end the band frays out in streamers. Other similar bands, but only three-fourths of an inch wide, parallel the main band at intervals of 4 to 6 inches. The inclosing rock is quite normal quartz monzonite, far removed from any contact.

Porphyritic quartz monzonite.—The porphyritic quartz monzonite occupies a large area in the culminating portion of the range, extending from Junction Peak on the north to near Muah Mountain on the south. Its western boundary was not determined. As exposed on Lone Pine Creek, it is at least 6,000 feet thick. It is remarkably constant in texture and mineral composition and is in fact the largest body of homogeneous granitic rock in this part of the Sierra. From Mount Whitney southward to Cirque Peak it is invaded, however, by dikes and large masses of aplite; and the broad summit of Mount Whitney is itself composed of nearly equal amounts of aplite and porphyritic quartz monzonite.

The crystals of orthoclase that at some places give the quartz monzonite its porphyritic appearance are ordinarily scattered uniformly throughout the rock, averaging perhaps one to the ordinary hand specimen, though at a few places, as locally on Diamond Mesa, where this feature was principally noted, they are so closely aggregated as to form half the rock. They are commonly somewhat pinkish and in shape are thickly tabular; their maximum length is 3 inches, but their average length is probably 1½ inches. The idiomorphism of the crystals is fairly good, though the faces are rough and uneven, owing to indentation by the other components of the quartz monzonite. In places the orthoclase is obviously perthitic. Inclusions of hornblende, biotite, and titanite are notably abundant and as a rule lie in random orientation throughout the orthoclase. A zonal arrangement of the inclosed minerals is uncommon.

The matrix in which the orthoclase phenocrysts are embedded is a coarsely granular assemblage of plagioclase, quartz, orthoclase, biotite, and hornblende, named in descending order of abundance. The plagioclase, as seen under the microscope, dominates strongly over the orthoclase; it is a zoned oligoclase ranging from $Ab_{70}An_{30}$ on the cores of the crystals to $Ab_{83}An_{17}$ on the outermost zones. Orthoclase is a very subordinate constituent. Quartz, fairly abundant, lies interstitially between the idiomorphic plagioclase but is subhedral toward the orthoclase. Biotite is present in moderate amount and hornblende in lesser quantity. Magnetite, titanite, apatite, and zircon occur as accessory minerals. Under the microscope the orthoclase phenocrysts are found to be notably microperthitic. In addition to the inclusions of hornblende, biotite, and titanite, which are visible to the unaided eye, they contain plagioclase, quartz (which is partly idiomorphic and itself holds inclusions of titanite and apatite), magnetite, apatite, and zircon—in short, all the minerals of the fully crystallized rock. This shows that the orthoclase began to crystallize after all the other constituents had begun to grow; and its porphyritic development therefore seems referable to a superior velocity of crystallization and a superior power of attracting the crystallizing molecules to a few centers of crystallization.

A chemical analysis of the porphyritic quartz monzonite from Diamond Mesa and its computed mineral composition are given on pages 66–67.

The homogeneity of the great mass of porphyritic quartz monzonite, so apparent to the unaided eye, has been verified by the examination of thin sections cut from specimens obtained at widely separated localities, such as Diaz Creek and Army Pass. Under the microscope they show features identical with those of the Diamond Mesa rock. The plagioclase feldspar is similar and averages near $Ab_{75}An_{25}$.

Interrelation of eugranitic and porphyritic quartz monzonite.—The relation of the normal quartz monzonite to the porphyritic variety is excellently displayed in the walls on the north side of Lone Pine Creek. The relation shown here proves clearly that the two varieties grade into each other. In the transition zone, which is a few hundred feet wide, the passage from porphyritic to eugranitic quartz monzonite is readily traceable in the progressive series of changes exhibited by the orthoclase. The phenocrysts of orthoclase become smaller and the crystal form becomes more and more obscure and finally inconspicuous. Concomitantly the biotite, and especially the hornblende, becomes more abundant, and wherever the rock has assumed the normal appearance of the eugranitic quartz monzonite it contains numerous characteristic ferromagnesian inclosures. A specimen that was taken from the transition zone, in megascopic appearance nearer the eugranitic than the porphyritic variety, shows its intermediate character under the microscope chiefly in the composition of the plagioclase, which is $Ab_{70}An_{30}$, and is accordingly nearer in composition to that of the feldspar in the porphyritic quartz monzonite ($Ab_{75}An_{25}$) than to that in the eugranitic quartz monzonite ($Ab_{60}An_{40}$). Megascopically this transitional rock resembles the eugranitic quartz monzonite; microscopically it resembles the porphyritic quartz monzonite.

The gradation observable on Lone Pine Creek is suggested at other localities. However, on Cottonwood Creek, where the exposures are excellent, the relations are ambiguous; there is no gradation between the two varieties and no evidence of chilling of one against the other nor other evidence of intrusion of one into the other; in fact, the phenomena point to contemporaneity of origin of the two rocks.

The chemical and mineral composition of the two varieties of quartz monzonite are contrasted in the following tables:

Analyses of quartz monzonite from the Sierra Nevada, Inyo County, Cal.

Chemical composition.

[R. C. Wells, analyst.]

	1	2
SiO_2	66.68	69.01
Al_2O_3	15.12	15.44
Fe_2O_3	1.66	1.28
FeO	2.49	1.28
MgO	1.38	.62
CaO	4.09	2.54
Na_2O	2.23	3.85
K_2O	4.97	4.52
H_2O-	.31	.33
H_2O+	.51	.56
TiO_2	.64	.49
CO_2	None.	Trace.
P_2O_5	.21	.24
S	Trace.	Trace.
MnO	.01	.01
SrO	Trace.	Trace.
	100.30	100.17

Analyses of quartz monzonite from the Sierra Nevada, Inyo County, Cal.—Continued.

Mineral composition.

	1	2
Quartz	25.68	24.66
Orthoclase	25.58	23.35
Albite (mol.)	18.34	32.49
Anorthite (mol.)	12.79	10.56
Biotite	7.02	5.76
Hornblende	7.38	......
Magnetite	1.39	1.39
Titanite	1.18	.80
Apatite	.31	.31
	99.67	99.32

1. Lone Pine Creek, altitude 6,700 feet. Specific gravity of the hand specimen, 2.715.
2. Diamond Mesa, altitude 13,000 feet. Specific gravity of the hand specimen, 2.664.

From these tabulations some interesting relations become apparent. First comes that arising from a consideration of the specific gravities: the rock occupying the higher portion of the range—the porphyritic quartz monzonite—is the lighter. The smaller specific gravity of this rock is clearly due in the main to its deficiency in ferromagnesian minerals. Even more noteworthy is the fact that the porphyritic quartz monzonite, although characterized by conspicuous phenocrysts of orthoclase, is not richer in orthoclase than the nonporphyritic quartz monzonite. This would seem to render improbable the suggestion that the porphyritic habit had been brought about during the cooling of the magma by orthoclase crystals, which had crystallized out early, rising to the upper portions of the batholithic chamber because of their inferior density. The fact that the orthoclase contains as inclusions all the minerals occurring in the completely consolidated rock also militates against the flotation hypothesis. Instead of having crystallized very early, the orthoclase phenocrysts crystallized relatively late, at a stage in which the buoyancy would probably be small, owing to the rapidly increasing viscosity of the magma. Further, the upper-lying rock is notably richer in albite, instead of in orthoclase, as would be demanded by the flotation hypothesis. If, however, the differentiation did take place by the rising of the fluid molecules under the influence of gravity, it is possible that the fluid molecules of albite, being probably lighter than those of orthoclase (as indicated by the empirical molecular weights, 263 for albite and 279 for orthoclase) tended to rise within the magma, thus bringing about part of the observed differences between the two rocks. On the other hand, the deficiency of the upper rock in hornblende may conceivably be due to the settling out of this constituent during crystallization.

In recapitulation, then, the hypsometric distribution of the two quartz monzonites appears to support the explanation that they are gravity differentiates of a single magma. The upper rock, which is characterized by a conspicuously porphyritic development of its orthoclase, does not, however, contain a larger amount of orthoclase than the lower rock. This feature, as well as the fact that the orthoclase phenocrysts inclose small crystals of all the other constituents of their matrix, indicates that the rising of orthoclase crystals to the upper levels of the magmatic chamber was not a factor in the gravity differentiation. The cause of the porphyritic development of the orthoclase remains unknown but may have been a locally increased concentration of the volatile fluxes, which tend to accumulate in the higher parts of the batholith. Finally, it should be pointed out that if the two quartz monzonites are really gravity differentiates of a primary magma their contact should lie horizontal. The boundary between them, if mapped in detail along the east flank of the Sierra, should furnish decisive evidence; but, owing to the exigencies of reconnaissance survey, such careful mapping was not attempted.

At Muah Mountain evidence was obtained, on the other hand, that seems to argue against the hypothesis of gravity differentiation. The mountain, which rises rather abruptly just beyond the southern border of the porphyritic monzonite, consists wholly of normally granular quartz monzonite, no porphyritic rock appearing above. Although this evidence appears somewhat discrepant with the broad features of the distribution of the two quartz monzonites, it should not of itself be allowed to invalidate the strong argument for their gravity differentiation.

GRANITE.

General features.—Extensive areas of a coarse light-colored granite, nearly devoid of dark minerals, occur throughout the part of the Sierra Nevada contiguous to Owens Valley. Typical exposures are those at the Kearsarge Pinnacles, at Fin Dome, west of Rae Lake, and at Rawson Canyon, southwest of Bishop. The granite of these areas is homogeneous in composition and texture and on the whole is easily mappable. It is practically barren of the ferromagnesian inclosures that are common in the quartz monzonite. In weathering it tends to assume a light orange tint.

The granite is clearly younger than the quartz monzonites. This is shown at the head of Shepard Creek, where it sends dikes into the porphyritic quartz monzonite, and near Kearsarge Peak, where it intrudes the eugranitic quartz monzonite. In certain parts of the range, as on Bishop and Baker creeks, there are large bodies of granite that both in hand specimens and in thin sections seen under the microscope, show characters intermediate between the coarse white granite and the quartz monzonite. These suggest transition between these two rocks and were so interpreted in the early part of the field season of the present investigation, but more detailed study will doubtless show that the seemingly intermediate granites are either separate intrusives or are facies of the white granite.

The typical granite is essentially a coarse aggregate of alkali feldspar and quartz, its only dark mineral being biotite, which generally constitutes about 1 per cent of the rock but in places may form 5 per cent. To signalize these features the rock might well be called alaskite.

A slight departure from the prevailing mineral make-up of the granite manifests itself on Red Mountain and Taboose creeks mainly by the sporadic occurrence of black garnet in anhedral grains which range from nearly imperceptible particles up to 0.4 inch in diameter. The quartz also differs slightly from that of the prevailing granite in that it has a faint bluish tint.

Petrography.—The granite from widely separated localities proves under the microscope to be remarkably uniform in texture and composition, confirming the impression of petrographic constancy made by the field evidence. The feldspars are found to consist of orthoclase and microcline, which are notably microperthitic, and of albite having the composition $Ab_{90}An_{10}$. The total potassium feldspar equals the albite in amount; all the feldspars are essentially anhedral. Quartz is prominent in subhedral grains. Biotite is a minor constituent; and titanite, magnetite, and apatite are accessory minerals. In mineral composition this granite is practically identical with the aplite from the summit of Mount Whitney (see p. 71) but differs markedly from it in fabric and granularity.

A specimen of the granite, which is believed to be typical of large areas of this rock, was collected on Rawson Creek at an altitude of 6,000 feet and was subjected to partial chemical analysis, with the following result:

Partial analyses of granite from Rawson Creek, Cal.

Chemical composition.

[R. C. Wells, analyst.]

SiO_2	76.28	Na_2O	4.72
CaO	.47	K_2O	4.73

Specific gravity, 2.615.

Mineral composition.

Quartz	29.76
Orthoclase	27.24
Albite (mol.)	39.82
Anorthite (mol.)	2.50
Biotite (estimated)	1.00
	100.32

Rocks of this kind are called by Iddings soda-potash granites, but it seems preferable to call this rock an orthoclase-albite granite.

If the amounts of anorthite and albite obtained in the computation are combined as plagioclase, 42.32 per cent of $Ab_{94}An_6$ is obtained; this, however, is a slightly more sodic plagioclase than is shown by the microscope to be present. The explanation of this discrepancy is mainly that the microperthitic intergrowths in the orthoclase are composed of essentially pure albite and that the plagioclase which crystallized independently is thus relatively enriched in anorthite.

An interesting feature of the mineral composition of this granite is that the proportion of quartz to orthoclase to albite—29.76:27.24:42.32—coincides closely with that computed by Vogt[1] for the ternary eutectic between these

[1] Vogt, J. H. L., Physikalische-chemische Gesetze der Krystallisationsfolge in Eruptivgesteinen: Min. pet. Mitt., vol. 25, p. 387, 1906.

three minerals, namely, 27.5:30.5:42. The granite accordingly falls into the group of rocks termed by him anchi-eutectic. So nearly complete an attainment of the ternary eutectic would seem to imply that the granite has been derived by differentiation from a parent magma that was probably richer in ferromagnesian minerals. A differentiation thus controlled by the physical-chemical laws of eutectics would therefore have been effected by the separation in the solid phase of the constituents in excess of the eutectic ratio. These constituents doubtless collected to form rocks rich in ferromagnesian minerals, and in this way it is probable some of the diorites and gabbros so common in the region originated.

Comparison of the chemical analysis of the orthoclase-albite granite with the other analyses of Sierra Nevada granites listed by Clarke[1] shows this granite to be higher in silica and lower in lime than any other that has as large a total content of alkalies comprising equal amounts of soda and potash. Lindgren[2] described and mapped an evidently similar granite in the Colfax quadrangle, which he designated a soda granite. No chemical analysis, however, was made of it. It is likely that as the range becomes better known petrographically more areas of this highly alkalic granite will be recognized.

DIORITE AND HORNBLENDE GABBRO.

Occurrence and character.—Diorite occurs in the headwater region of Big Pine Creek, where it seems to form a rather homogeneous mass. At other localities, however, it displays a considerable variety of differentiation facies, chiefly hornblende-rich rocks, and these have all been mapped under one symbol (dg in Pl. I). It is not improbable that genetically distinct rocks may have been grouped together; that is, differentiation facies of the diorite may have been grouped with basic intrusive rocks that preceded or succeeded the diorite. The range in composition extends from quartz diorite rich in hornblende and biotite, as on the lower part of the canyon of Red Mountain Creek, to rocks composed predominantly of hornblende. This range in mineral composition is in no wise related to differences in altitude in the occurrence of the different facies along the eastern escarpment of the Sierra Nevada—that is, the magmatic differentiation which originated the facies appears not to have been influenced by gravitation.

The diorite at the head of Big Pine Creek, forming the Inconsolable Range, is a moderately coarse, gray variety which is characterized by the presence of biotite and augite. Under the microscope it is found to consist essentially of andesine ($Ab_{60}An_{40}$), biotite, and augite; quartz occurs to the extent of about 5 per cent, and orthoclase and hornblende are minor constituents. Magnetite, titanite, and apatite are the accessory minerals.

The diorite from the plutonic complex west of Mount Rixford is a medium-grained dark rock distinguished by innumerable slender prisms of hornblende. Microscopically it is found to be composed of equal quantities of andesine ($Ab_{60}An_{40}$) and hornblende. Titanite is remarkably abundant, perhaps amounting to several per cent, and is molded on idiomorphic plagioclase and hornblende. Pyrrhotite, which is visible to the unaided eye as minute grains scattered evenly throughout the rock, is an important accessory mineral. Some of the grains are rimmed with magnetite, and it is clearly a pyrogenetic constituent of the diorite. Magnetite occurs also as a normal accessory mineral. and apatite occurs in minor amount.

A peculiar member of the diorite series is a hornblende-rich variety characterized by the luster mottling of its hornblende. Commonly, the hornblende individuals are large, many of them several inches in diameter, and produce a rock of extraordinarily coarse texture. These rocks are practically hornblende gabbros. They occur sporadically throughout the range, both along its foot and along the summit, in masses which, although in places attaining notable dimensions, are quantitatively insignificant compared to the enormous bodies of albite-orthoclase granite and quartz monzonite.

In a typical mass of the hornblende gabbro, which is well exposed in the hill just south of the forest ranger's station at McMurry Meadow, the hornblende forms ragged patches

[1] Clarke, F. W., Analyses of rocks and minerals from the laboratory of the U. S. Geol. Survey, 1880 to 1908: U. S. Geol. Survey Bull. 419, pp. 144–160, 1910; also in Bull. 591, pp. 175–191.

[2] Lindgren, Waldemar, U. S. Geol. Survey Geol. Atlas, Colfax folio (No. 66), p. 4, 1900.

an inch or more in diameter that poikilitically inclose plagioclase feldspar, and to this feature the rock owes its luster-mottled appearance. Extremely coarse phases of the same kind of rock occur near Kearsarge Peak. The summit of Deer Mountain in the Olancha quadrangle appears from a short distance to be capped by a basalt flow but is really capped by a richly hornblendic gabbro, of variable petrographic character, that shows the characteristic patchy poikilitic hornblende. Below it is a large mass of aplite—possibly a somewhat anomalous position if both rocks are differentiates of a common magma; and to the west of the mountain is an orthoclase-rich quartz monzonite in which the orthoclase tends to assume a porphyritic habit. Under the microscope the gabbro of Deer Mountain is seen to be composed essentially of augite and hornblende, more or less intimately intergrown, and of labradorite ($Ab_{35}An_{65}$). The feldspar is generally inclosed poikilitically in the augite or hornblende; where thus inclosed it is partly idiomorphic, but as a rule has smoothly rounded edges; where it adjoins other feldspar it is anhedral. Pyrrhotite is a minor magmatic constituent; and magnetite in lesser amount is the remaining accessory mineral.

Relation to other plutonic rocks.—The diorites and hornblende gabbro seem more closely associated areally with the albite-orthoclase granite than with the quartz monzonites. It is not improbable that they represent the complementary differentiates of a common magma; in fact, that the poverty of the granite in ferromagnesian minerals is the result of their segregation into the diorites and gabbro. The evidence as to the contact relations with the granite are somewhat conflicting. At the Big Pine Lakes the augite-biotite diorite in proximity to the granite displays notable variability. Hornblende instead of biotite is common. The diorite is patchy, streaky, and contains segregations, some of which consist almost wholly of hornblende, others of hornblende and feldspar. In places the hornblende forms large patches which poikilitically inclose small feldspar crystals. The granite, however, maintains its petrographic uniformity in the contact zone. Similar features are observable on the headwaters of Baker Creek, where the actual contact is exposed. The hornblendic facies become more siliceous and finer grained toward the contact, but the granite maintains its coarse texture and mineral composition. At the contact the two rocks are welded. Because of the great variation in the diorite toward the contact and the lack of variation of the granite the diorite appears to be the younger intrusive mass.

At other localities, as at Mount Gould and Mount Rixford, the granite is filled with angular inclusions of coarse, richly hornblendic phases of the diorite, and this complex is cut by aplite and pegmatite dikes. Here, then, the sequence of intrusion seems to be reversed. Again, on North Fork of Big Pine Creek, where a complex of dark-gray diorite and highly siliceous white granite is exposed, the granite in some places cuts the diorite and in others the diorite intrudes the granite. The phenomena suggest that the heart of the differentiation zone is here disclosed, where differentiation was followed by movement of the differentiated and partly consolidated submagmas, causing fracturing and reciprocal intrusion.

In the dioritic belt extending northwestward from Kearsarge Peak the evidence shows that the diorite is not only older than the granite but is also older than the quartz monzonite. Rounded inclusions of the diorite, with blended contacts, are contained in the quartz monzonite.

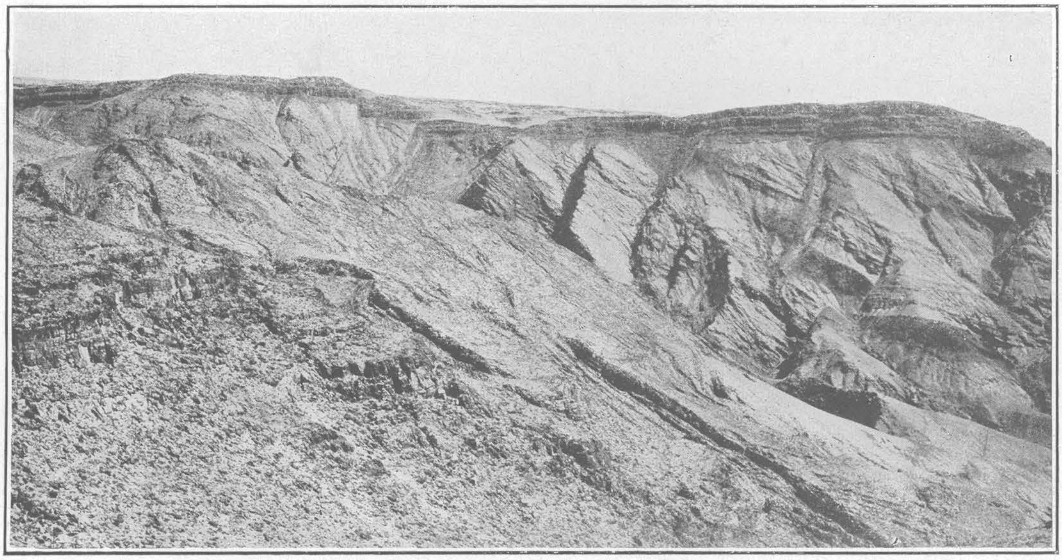
The evidence concerning the sequence of the diorite, quartz monzonite, and granite, obtained from different parts of the province, is accordingly quite conflicting. The most probable explanation of this conflict of evidence is that different diorite and gabbro masses represent genetically different intrusions, some distinct in point of time and others that have differentiated essentially in place, some from the granite magma and others from the quartz monzonite magma.

PLUTONIC COMPLEXES.

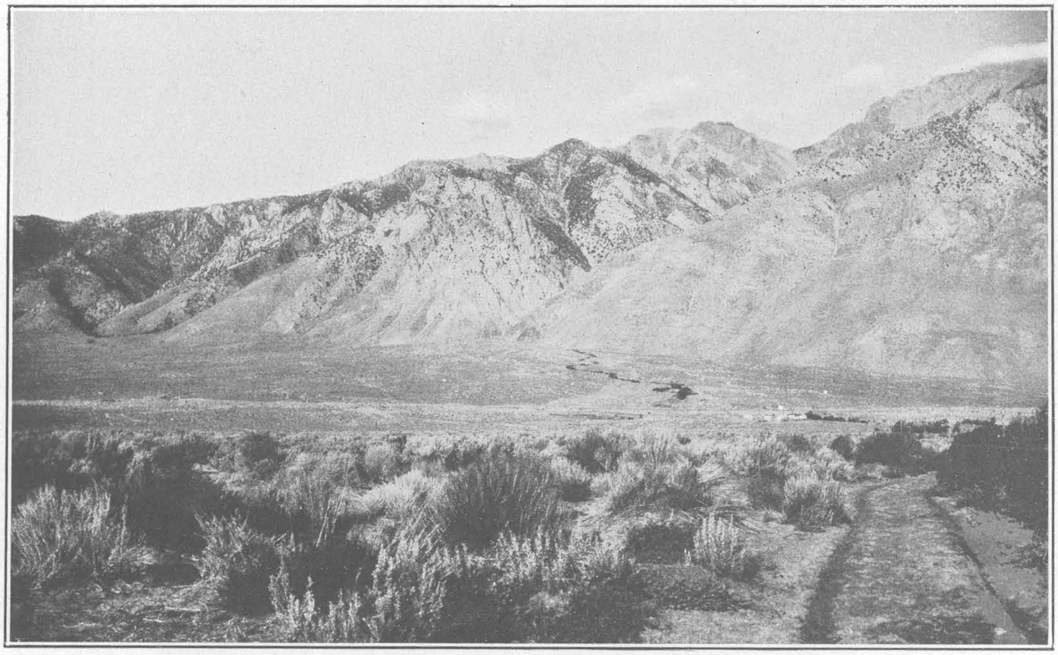
The granitic rocks of large areas in this part of the Sierra Nevada are best described as plutonic complexes, in the sense in which that term is employed by Harker,[1] and they are so designated on the geologic maps (Pls. I and II). They consist of an intricate assemblage

[1] Harker, Alfred, The natural history of igneous rocks, pp. 126–132, 1909.

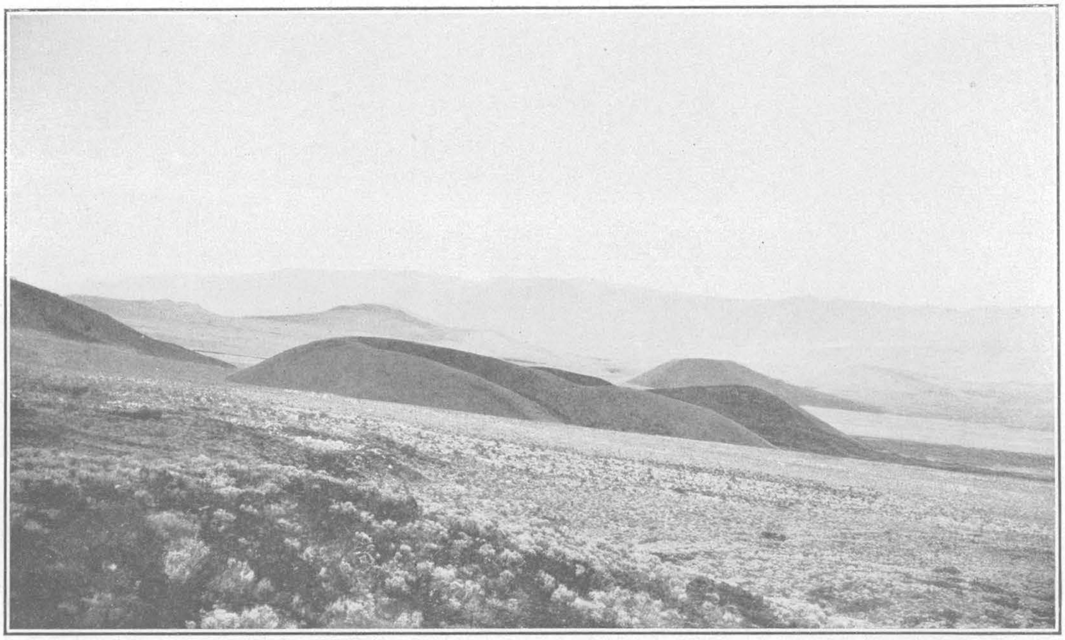
A. BASALT PLATEAU SOUTHEAST OF KEELER.



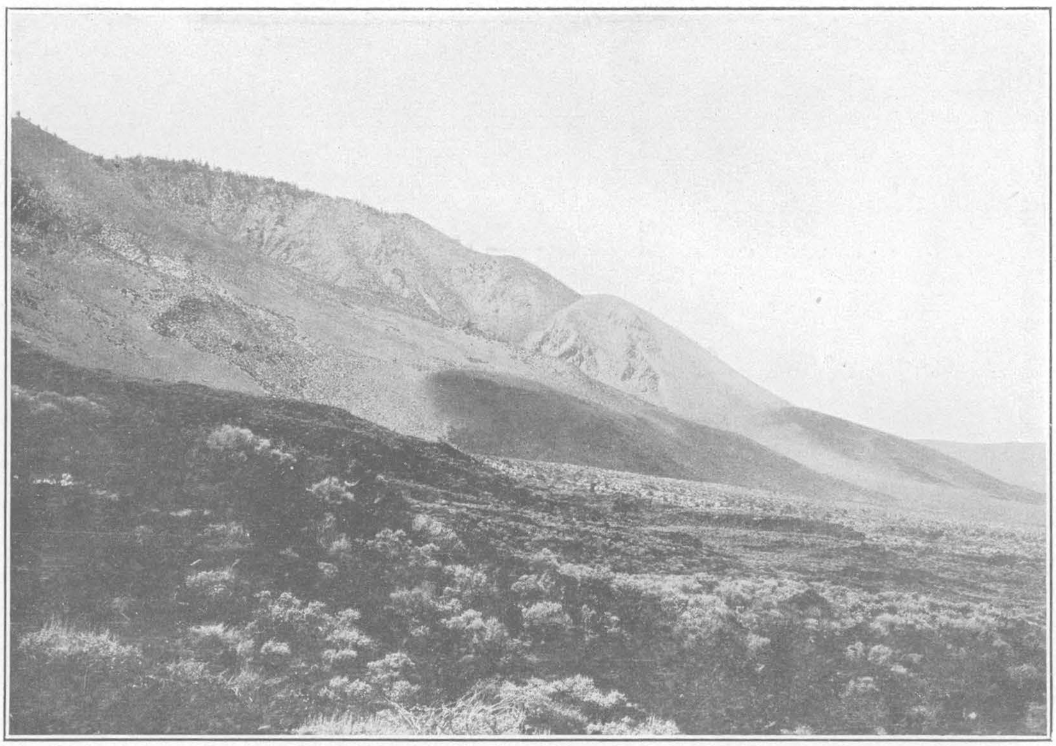
B. DETAILS OF FAULTING IN BASALT PLATEAU SOUTHEAST OF KEELER.



C. PLUTONIC BRECCIAS OF THE SIERRA NEVADA ESCARPMENT WEST OF OLANCHA.



A. VOLCANIC FIELD IN OWENS VALLEY AT THE BASE OF THE SIERRA NEVADA.



B. BASALTIC EJECTA ALONG THE BASE OF THE SIERRA NEVADA ESCARPMENT.

of hornblende gabbro, quartz diorite, porphyritic and nonporphyritic quartz monzonite, granite, aplite, and diorite porphyry dikes of lamprophyric affinities. The intrusive sequence is difficult to unravel, and complications are introduced by real or apparent gradations between different members of the series and by the production of hybrid varieties. Further, at many localities the complications are enhanced by the inclosure in the plutonic rocks of multitudes of schist fragments of both sedimentary and volcanic origin that are derived from shattered and dispersed roof pendants. In places the inclusions have been greatly modified by the imbibition of granitic matter or by the solvent action of the surrounding magma. In this way rock masses of extreme heterogeneity were produced.

The plutonic complexes occur most extensively from Olancha Peak to Haiwee Pass and southward along the range. The poikilitic hornblende gabbro is common, as at Round Mountain, Deer Mountain (p. 70), and south of Haiwee Pass. The dark gabbro, ramified by intrusions of light-colored quartz monzonite and aplite, forms a plutonic breccia on a vast scale and is a notable feature of the Sierra escarpment near the south end of Owens Lake. (See Pl. XI, *C*.) At other localities, as on the lower part of Cottonwood Creek, plutonic complexes occur, but in general they do not show so full a succession of intrusive rocks and are not so extensive as in the region south of Olancha Peak. In some of the smaller areas of plutonic complexes quartz monzonite predominates, and owing to the haste of reconnaissance work these areas have been mapped under that symbol.

MINOR INTRUSIONS.

Aplite.—Aplite is common, especially as dikes in the plutonic complexes, where their extraordinary multiplicity gives to the Sierra Nevada escarpment in many places a striped appearance. As larger masses, aplite invades the porphyritic quartz monzonite and occurs in considerable abundance along the crest of the range from Mount Whitney southward to Cirque Peak. The broad summit of Mount Whitney is composed of equal amounts of aplite and quartz monzonite.

The aplite is a fine-grained white rock carrying 1 or 2 per cent of biotite; its texture is typically panidiomorphic. A specimen from the top of Mount Whitney shows under the microscope that it is essentially an aggregate of feldspar and quartz. The feldspar consists of nearly equal parts of orthoclase and albite near $Ab_{90}An_{10}$, the orthoclase slightly exceeding the albite. Biotite, magnetite, apatite, titanite, and zircon comprise the remaining constituents. Near Cirque Peak the aplite is notably miarolitic. The cavities are surrounded by patches, many of them as much as 6 inches in diameter, of quartz and orthoclase that are much coarser grained than the surrounding normal aplite—they are in fact pegmatitic.

Aplite dikes cut all the plutonic rocks of the region. They are not common in the orthoclase-albite granite but are abundant in the other types, though by no means equally so in all parts of the region. They are notably numerous in all the masses of the poikilitic hornblende gabbro.

Pegmatite.—Pegmatite dikes are quantitatively far subordinate to the aplite dikes, although locally they are abundant. They seem to occur most commonly in or near the schist roof pendants, as, for example, at Cardinal Lake and Taboose Pass, where the schist and diorite are cut by hundreds of pegmatite and aplite dikes. The thickest measure about 20 feet, and most of them dip less than 30°. This extensive injection persists southward to Striped Mountain, whose name is obviously due to its remarkably conspicuous striping by a multitude of white dikes. The pegmatites consists of graphic intergrowth, feldspar, quartz, and long thin blades of biotite; a few carry a little tourmaline.

Diorite porphyry.—Dikes of lamprophyric affinity, though hardly rich enough in hornblende and biotite to be classified as true lamprophyres, attain some local prominence but they are vastly surpassed by the aplites in number and volume. At Taboose Pass dikes of this kind are common in both the orthoclase-albite granite and the schists of the roof pendant. They cut the aplite and pegmatite dikes. Under the microscope they show phenocrysts of andesine in a finely granular groundmass of feldspar, quartz, biotite, and hornblende and an abundance of ferromagnesian minerals to which they owe their prevailing dark color. They may accordingly be called diorite porphyry. These dikes are persistent, and some attain a thickness of 15 feet. Eastward, away from the contact of the granite and schist, they disappear.

On South Fork of Big Pine Creek, the siliceous granite is ramified by a multitude of these dikes, which are in many places broken and even separated. The fragments are angular or taper to points. At one place numerous parallel dikes are traceable for hundreds of feet and are clearly intrusive into the granite, as they show chilled margins against the granite. They appear to have been sheared and broken while the granite was still viscous enough to flow and then freeze without distinct evidence of its flowage. These observations may throw light on the origin of the peculiar belts of inclusions described by Gilbert[1] as occurring in the Kings River country of the Sierra Nevada.

SEQUENCE OF INTRUSIONS.

The sequence of intrusions, already discussed separately for the different granitic rocks, is, as a rule, in the order of increasing silicity. The hornblendic gabbros and diorites are in general oldest, and were followed by the quartz monzonite, and this by the orthoclase-albite granite. The evidence as to the relation of the more basic rocks to the others is somewhat contradictory, but that as to the interrelations of the more siliceous rocks is wholly consistent and proves that the granite is younger than the quartz monzonites.

Somewhat farther north along the crest of the range Lindgren[2] found a like conflict of evidence regarding the succession of granitic rocks. He concluded that the irruption of the granite and of the granodiorite was probably accompanied by minor intrusions of diorite, pegmatite, and aplite, and that the granite is the older rock. Under this supposition the contradictory evidence on the mutual relations of the granite and granodiorite could be reconciled. This succession of decreasing silicity is accordingly at variance with that shown in the southern Sierra Nevada.

The plutonic rocks of the major intrusions were followed by innumerable dikes of aplite and of pegmatite, and these minor intrusions were in turn followed by dikes of lamprophyric affinities (diorite porphyries rich in hornblende and biotite), which, however, are far inferior to the aplite in numbers or volume.

TERTIARY RHYOLITE.

Breccia and tuff of pumiceous rhyolite occur at many places throughout the region, but massive rhyolite and obsidian occur, so far as known, at only one locality. The rhyolite resulting from explosive outbursts is closely associated with the lacustral and alluvial deposits of late Cenozoic age and has already been described in part in the sections dealing with those deposits (pp. 54–57).

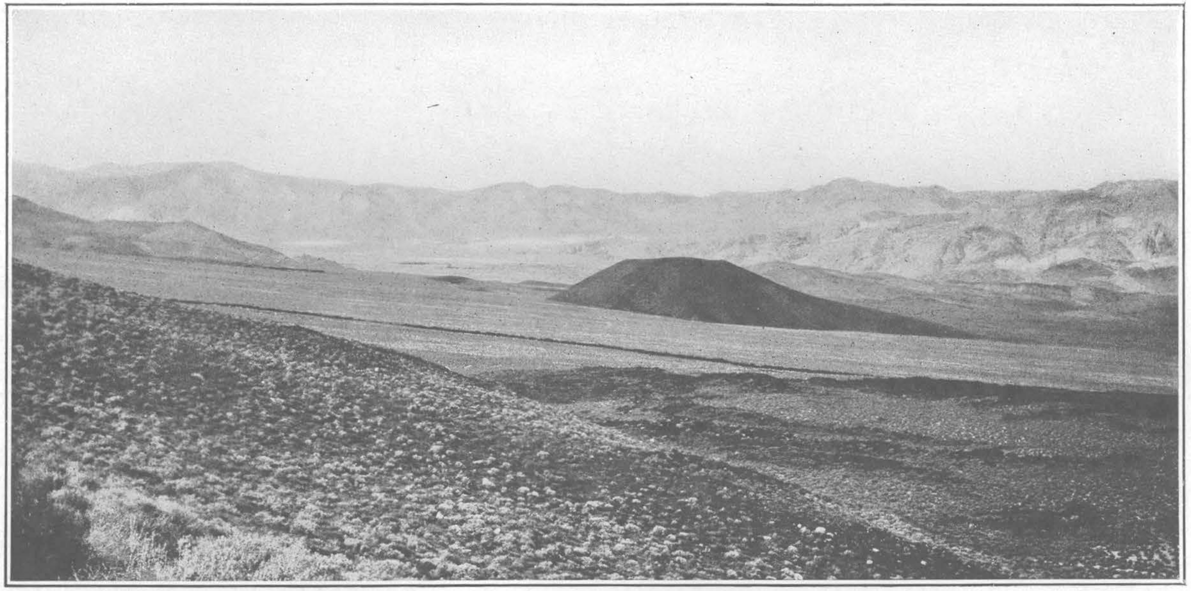
The oldest rhyolite ejection is probably that represented by the tuffs and breccias associated with the ostracode-bearing beds at Haiwee. The age of these is not satisfactorily known, but they are at least as old as early Quaternary, and they may be as old as Pliocene or even Miocene. The rhyolite composing the pyroclastic beds is a pure-white, highly vesicular glass, which is silky in appearance on fresh fracture and is characterized by phenocrysts of quartz, sanidine, and biotite. Quartz predominates; sanidine and probably other feldspars are common; but biotite is rare and is generally absent.

Rhyolite tuff occurs in places beneath the heavy basalt cappings which are widespread along the east slope of the Inyo Range, north of Deep Spring Valley. Well-worn stream gravels, in places poorly auriferous, are buried beneath the basalts, and in them the tuff is intercalated, locally forming a stratum 40 feet thick. The great revolution in the topography since the stream gravels were deposited indicates that their age and that of their associated tuff is considerable. Possibly they correspond in age to the auriferous gravels on the west flank of the Sierra Nevada. Although few channels of eastward-flowing streams of the auriferous gravel epoch have survived erosion,[3] the gravels of a Neocene river channel, capped by rhyolite breccia, lying between Lake Tahoe

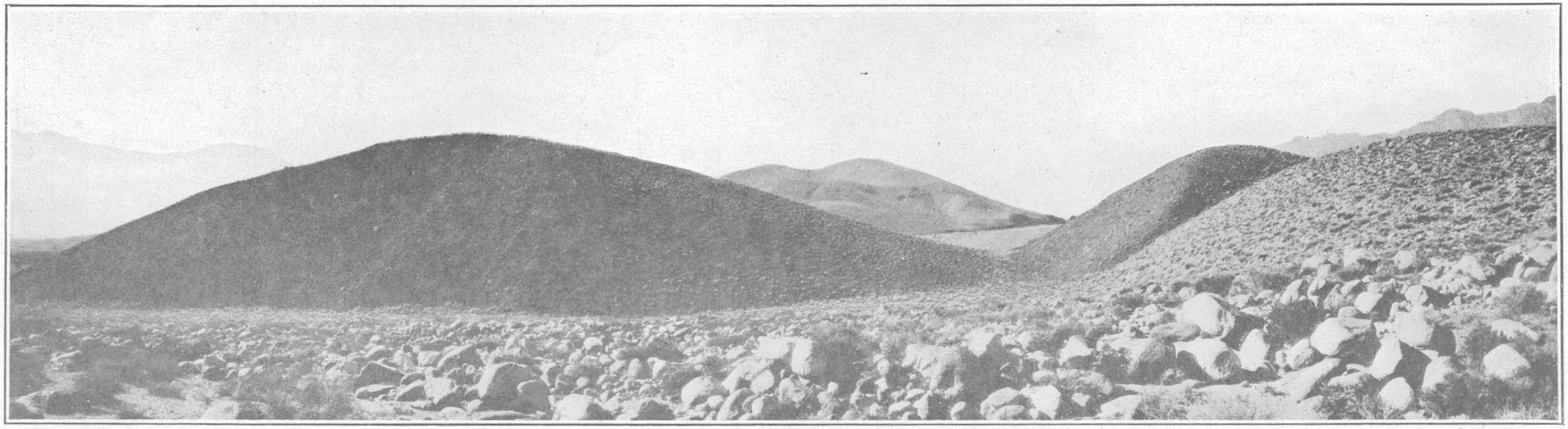
[1] Gilbert, G. K., Gravitational assemblage in granite: Geol. Soc. America Bull., vol. 17, p. 324, pl. 46, 1906.

[2] Lindgren, Waldemar, U. S. Geol. Survey Geol. Atlas, Pyramid Peak folio (No. 31), p. 3, 1896.

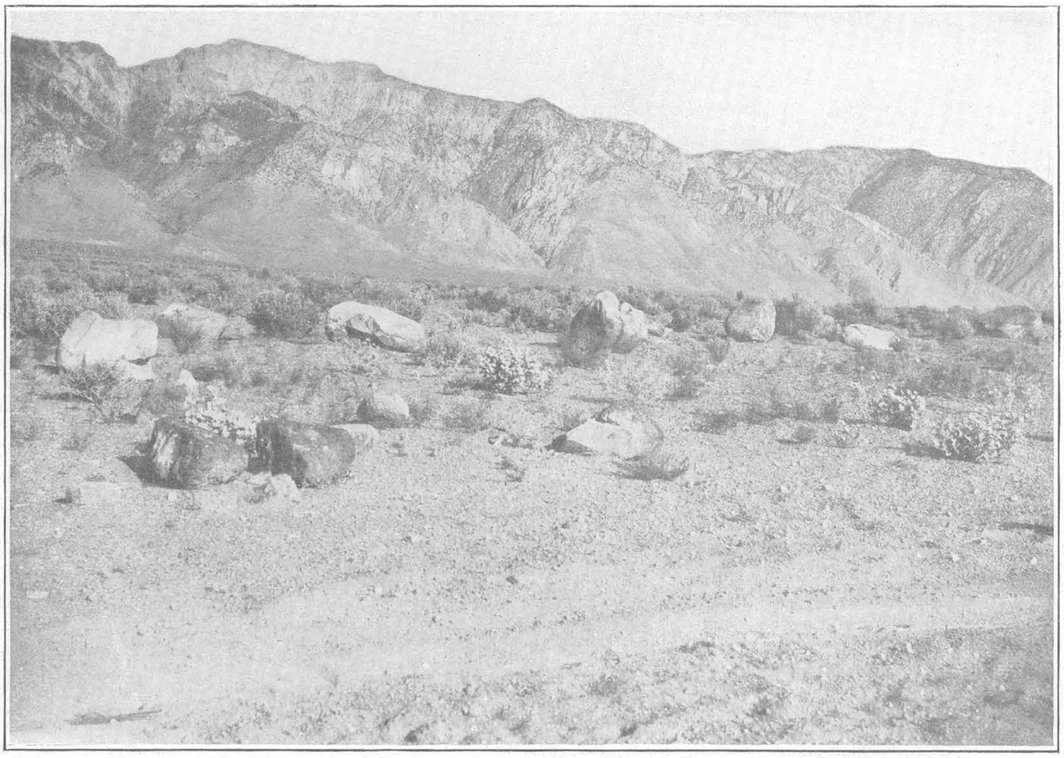
[3] Lindgren, Waldemar, Tertiary gravels of the Sierra Nevada: U. S. Geol. Survey Prof. Paper 73, p. 33, 1911.



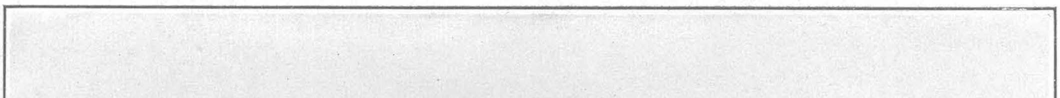
A. RED MOUNTAIN.



B. FAULTED CINDER CONE NEAR FISH SPRINGS SCHOOL, OWENS VALLEY.



A. SIERRA ESCARPMENT SOUTH OF OWENS LAKE, CAL.



B. OLANCHA PEAK FROM THE SOUTHWEST.

and Washoe Valley, have been described by Reid.[1]

The most extensive area of rhyolitic rocks forms the volcanic table-land lying north of Owens River and extending far north of the area shown on Plate I. The cliff-making stratum of pinkish-gray tuff-breccia (p. 50) contains many fragments of black obsidian; and it is noteworthy that the only occurrence of massive rhyolites found within the region includes a flow of similar obsidian. The subjacent incoherent white rhyolitic strata have already been described (p. 50).

The massive rhyolites form part of a small group of rhyolitic hills that project through the alluvial apron of the Sierra Nevada 8 miles south of Big Pine, at the junction of Fuller and Red Mountain creeks. In the lowermost parts of these hills a flow of black, somewhat dull obsidian is shown; it grades upward into a gray variety, which is markedly flow-banded and contains lithophysae; and above this are bands of flow breccia. The summits of the hills are covered with fragmental pumice and volcanic dust. The flow structure dips gently west and northwest on the east side and steeply west on the west side of the hills. The hills appear to be an erosion remnant of a formerly more extensive volcanic formation.

The greatest thickness of rhyolite tuff in the region is on the east side of the Inyo Range, on the Saline Valley road 3 miles north at Rattlesnake Cabin, where is exposed 200 feet of breccia and tuff of pumiceous rhyolite, stratified in well-defined beds dipping 10°, overlain by thick sheets of basalt.

Fragmental rhyolite is intimately associated with the alluvial deposits. It forms a distinct stratum of white pumice intercalated in the old alluvial cone of Poleta Canyon, and in that of Black Canyon, both on the west flank of the Inyo Range, and it is also embedded in the coarse angular gravels, capped by basalt sheets, on the east flank of the Inyo Range northwest of Willow Creek. Pumiceous rhyolite occurs in the sand beds or loose sandstones at McMurry Spring and forms a conspicuous white stratum in the alluvial gravels at Devils Gate on the Saline Valley road. Along this road the old alluvial gravels extend continuously to the summit of the range at an altitude of 7,500 feet and across the divide down at least to 7,300 feet. Here, as observed along the portion of the road known as the June Smith cut-off, the gravels are cemented by a white matrix composed largely of small particles of pumiceous rhyolite.

TERTIARY LATITE.

Templeton Mountain and Monachee Mountain, both west of Olancha Peak, are built of a peculiar group of lavas, provisionally termed latites, which are not elsewhere represented in the region. These mountains rise as isolated cones above broad meadows and in form closely simulate extinct volcanoes, and are, indeed, locally regarded as such. Somewhat northwest of them there are a number of basaltic cinder cones of late Pleistocene age.[2] Monachee Mountain, however, shows no evidence of having been a center of volcanic ejection, nor does Templeton Mountain, though only the south flank of this mountain was examined. The bulk of Monachee Mountain consists of a porous, bluish-gray, highly flow-banded lava carrying innumerable small plates of biotite and sporadic crystals of glassy feldspar. At Templeton Mountain a gray lava characterized by acicular hornblende is common, but highly flow-banded varicolored lavas occur also. Under the microscope the rocks of the two localities appear essentially similar. They are sparsely porphyritic flow-banded glasses, containing hornblende and biotite of deep-brown varieties, so deeply colored as to be barely translucent, and feldspar of two or more generations, the first as sporadic phenocrysts of oligoclase or andesine ($Ab_{35}An_{65}$) not exceeding 3 millimeters in length, and the others as innumerable laths embedded in the glassy groundmass. The glass ranges from clear colorless to light brown and is commonly eutaxitic. As these lavas show a combination of characters suggesting rocks high in potash they are provisionally called latites.

[1] Reid, J. A., The geomorphogeny of the Sierra Nevada northwest of Lake Tahoe: California Univ. Dept. Geology Pub., vol. 6, pp. 97–99, 1911.

[2] Lawson, A. C., The geomorphogeny of the upper Kern basin: California Univ. Dept. Geology Bull., vol. 3, pp. 320, 375, 1904.

TERTIARY AND QUATERNARY BASALTS.

Basalt was erupted during at least three separate epochs, the earliest flows, which were the most extensive, probably being erupted in late Tertiary time and the younger flows in late Quaternary time. In appearance they are all essentially similar, though the older basalt perhaps lacks the glistening freshness of some of the younger. Appearance is, however, an unreliable criterion for relative ages, and the different flows can not be correlated on mere petrographic similarity.

LATE TERTIARY BASALTS.

The basalts of the earliest epoch of eruption are prominent in the range southeast of Keeler and in fact cover its whole south end. They form a superposed succession of flows aggregating about 100 feet in thickness, which rests on a nearly horizontal surface eroded across the inclined edges of Triassic and Carboniferous strata. Highly vesicular sills of basalt, some as much as 30 feet thick, filled along their margins with angular inclusions of country rock, are inclosed in the basement rocks and possibly served as feeders to the overlying lava flows. The horizontal sheets are broken by step faults (see Pl. XI, *A* and *B*) and are of importance in deciphering the orogenic history of the range. (See p. 89.)

Basalt sheets overlie in places the supposed lake beds occupying the broad depression between the Inyo and Coso ranges and form conspicuous plateaus sloping southeastward on the east side of the Inyo Range at altitudes ranging from 10,500 to 5,500 feet. The basalts forming the plateaus are about 125 feet thick and were erupted upon a surface of gentle relief and in places have buried auriferous stream gravels.

The basalts are highly olivinitic varieties. A specimen from the head of South Fork of Crooked Creek, which is ideally well preserved, is characterized by abundant phenocrysts of olivine and of augite in irregular stellate groups; feldspars are absent from among the porphyritic constituents but occur in the groundmass, which is composed of augite, labradorite, and magnetite. The basalt from the plateau southeast of Keeler is rich in olivine, which is abundant as large crystals and is the only phenocrystic constituent. As seen under the microscope the borders of the olivine are more or less red, probably owing to the separation of ferric oxide during incipient alteration. The basalt from the 30-foot sills, previously referred to, differs from the overlying lavas in that plagioclase, phenocrysts, resting in a groundmass of plagioclase, augite, and glass predominate over those of augite and olivine.

The age of these basalts is not precisely known. They are younger than the ostracode-bearing beds at Haiwee and are older than the present Inyo Range, and are therefore probably late Tertiary.

QUATERNARY BASALT OF PREGLACIAL AGE.

GENERAL FEATURES.

Basalt erupted in the canyon of North Fork of Oak Creek in the Sierra Nevada flowed down the canyon and spread over the alluvial cone built by the stream. It was subsequently eroded and partly covered by glacial detritus of the earlier epoch of glaciation. The basalt consists of a superposed series of flows aggregating 200 feet in thickness. Petrographically the flows exhibit some diversity but consist principally of olivine-augite porphyry and augite porphyry. Like the older basalts, they show no plagioclase phenocrysts.

Basalt, probably referable to this same epoch of eruption or possibly to the earliest epoch, overlies some of the ancient alluvial cones on the east side of the Inyo Range. It appears also in a number of isolated patches on the south side of Bishop Creek, where it was erupted apparently on a surface of steep slope. Deep canyons have been eroded in it since it was erupted, indicating that it is of considerable age. It is noteworthy that fragments of basalt are conspicuous in the older moraines on Big Pine Creek, although no basalt can be found in place in its drainage basin. Some small patches of basalt west and northwest of Bishop are referred to this epoch of eruption; the basalt mass 4 miles due west of Bishop consists of fragmental material, including volcanic bombs, and is without doubt a cinder cone battered to shapelessness by the assaults of time.

COLUMNAR GRANITE.

A small knob of bedrock that projects through the alluvium on the road to Bishop

Canyon, a mile or so from the mouth of the canyon, displays marked columnar structure, which on examination is found, surprisingly enough, to be developed in granite. An irregular intrusion of basalt, in places 15 feet wide, cuts the granite, but the basalt shows no columnar jointing. The columns range from 4 to 7 feet in length and average somewhat under a foot in diameter; they are, roughly, four, five, and six sided; they are normal to the contact at the contact surface, but many of them are curved, some curving from horizontal to vertical.

The basalt is a bluish-black rock, more or less highly vesicular and containing innumerable inclusions, ranging from single grains of quartz and of feldspar up to blocks of granite several feet long. Under the microscope small phenocrysts of augite and olivine are seen embedded in a fine-grained groundmass of plagioclase and augite. Some grains of quartz and feldspar were derived from the granite; one of these—an inclusion of quartz—was found to be surrounded by a conspicuous border of brown glass filled with overlapping fanlike groups of pyroxene prisms.

The granite, as seen in a hand specimen obtained from the head of one of the columns abutting against the basalt, is a moderately coarse grained rock made up largely of feldspar and quartz. On close inspection a vesicular structure becomes apparent, owing to the presence of spherical cavities under a millimeter in diameter. Examined microscopically the granite is found to be composed essentially of orthoclase, andesine, and quartz, with rather common accessory magnetite. The former presence of some ferromagnesian mineral in small quantity is indicated by pseudomorphs consisting largely of magnetite grains. The noteworthy feature of the rock, however, is that it is permeated by small veinlets and patches of colorless and locally vesicular glass. The quartz and orthoclase adjoining the veinlets of glass show marked corrosion and embayment; and this, together with the fact that the refractive index of the glass is considerably below that of balsam, proves that the glass was formed by local fusion and reaction of the constituents of the granite. There is a suggestion that the points of contact between the orthoclase and quartz were the most favorable for the formation of glass, but this has not been established. The minerals of the granite are much shattered, especially the quartz, and are penetrated by stringers of glass—evidently local injections produced by the expansive energy of the inclosed steam. The shattered condition of the quartz and feldspar has undoubtedly been produced by the abrupt volume changes that occurred as the quartz was heated to 575° and higher.[1] In addition to the colorless glass there is locally, as for example in the vicinity of magnetite, a minute amount of clear brown glass, whose deep color is due to absorption of iron compounds during fusion.

It seems probable, then, that owing to the formation of the glass between the interstices of its mineral grains, the granite assumed a columnar structure on cooling. If no water had been present, the temperature[2] to which the granite was heated would have been about 1025°, but the vesiculation of the glass indicates that steam was developed, and that consequently the temperature was much lower.

QUATERNARY BASALT OF INTERGLACIAL AGE.

DISTRIBUTION AND CHARACTER.

A volcanic field, comprising a considerable number of finely preserved basaltic cinder cones and associated lava flows, is a notable feature of the east flank of the Sierra Nevada between Big Pine and Independence. That some of the cinder cones are situated upon fault lines and that motion has recurred along some of these fault lines as recently as 1872 are the most interesting facts in connection with the last outbreak of volcanic activity in the region.

The cinder cones are fine examples of their type and illustrate the different varieties, ranging from the symmetrical conical heaps of scoria and lapilli that were unaccompanied by the emission of flowing lava to those breached by the escape of molten rock. A portion of the volcanic field is shown in Plate XII, *A*, in which a breached cone can be seen in the foreground, and Crater Mountain, the most im-

[1] Day, A. L., Sosman, R. B., and Hostetter, J. C., The determination of mineral and rock densities at high temperature: Am. Jour. Sci., 4th ser., vol. 37, p. 34, 1914.

[2] Idem, p. 38.

posing volcanic pile of the last epoch of eruptivity, in the background. Crater Mountain attains a height of 2,000 feet above the floor of Owens Valley, but this considerable height is due in part to the fact that eruption burst forth through the top of a granite mountain that rose at least 1,400 feet above the valley floor. The volcanic accumulation consists predominantly of black basalt, but its summit is crowned by a small cinder cone, whose crater is about 100 feet deep.

Most of the cones stand upon the alluvial piedmont slope of the Sierra Nevada, but some ejection of cinders and emission of lava took place along the lower bedrock slope of the range. (See Pl. XII, *B*.) The theater of most intense volcanic activity embraces the area between Taboose and Sawmill creeks, where large flows of lava issued and spread far over the level floor of the valley. The flows consist wholly of an extremely rough and fantastic appearing mass of loose blocks of clinkery lava. The lower ends of the flows have been partly covered by alluvial wash, and owing to the original inequalities in the surface of the lava a multitude of "islands" of rough basalt project through the valley floor.

The basalt carries prominent phenocrysts of olivine and numerous less conspicuous crystals of augite. Under the microscope it is found to be porphyritic, holocrystalline, and perfectly fresh. Augite and olivine constitute the phenocrysts. The groundmass is composed of plagioclase laths, averaging 0.2 millimeter in length, disposed in fluidal arrangement and having the composition $Ab_{20}An_{80}$; of augite grains; and of magnetite granules.

The most perfect and symmetrical of the cinder cones is Red Mountain. (See Pl. XIII, *A*.) It rises 600 feet above the alluvial slope upon which it stands. An extensive flow of basalt issued from this vent, but the crater rim extends unbroken over the head of the lava flow, indicating that the final act in the life of the volcano was the ejection of fragmental material. The cone is built mainly of fragments, commonly 6 inches in diameter, of cellular lava, of a red color, from which it is named. Volcanic bombs whose ropy surfaces are spirally twisted occur sporadically, as do also "bread-crust" bombs as much as 4 feet in size. Under the microscope the red cellular basalt from the summit of Red Mountain shows sporadic phenocrysts of augite and grains of olivine embedded in a groundmass of plagioclase in small crystals ($Ab_{20}An_{80}$) and in numberless forked microlites inclosed in a deep-colored opaque glass.

Red Mountain appears extremely recent, as if it had ceased erupting only yesterday, but on close inspection its form shows a certain departure from that of the ideal cinder cone. On the west side the cone rises abruptly from the alluvium at angles ranging from 28° to 33°, whereas on the east side it rises at first very gently and steepens abruptly near the crater; in other words, only the east slope shows the distinctive profile of a normally built cinder cone. This difference is without doubt due to partial alluviation that has buried the gentle peripheral slope of the west flank and to a certain amount of erosion prior to alluviation. Erosion has slightly scarred the southwest side of the cone and has slightly exposed the edges of the rudely bedded breccias that make up the internal framework of the volcano. It is only at this scar that the slope of the cone is so steep as 33°.

The large but imperfectly shaped cinder cone at the upper edge of the alluvium between Division and Sawmill creeks is noteworthy because of the profusion of large granite boulders scattered upon its summit. These were evidently hurled from the alluvium that once underlay the site of volcanic vent.

On Sawmill Creek a flow of basalt and ejection of cinders took place in the canyon at an altitude of 7,500 feet, and the lava flowed down to the mouth of the canyon. The basalt is an olivine-bearing variety like that already described.

A large mass of basalt occurs near the base of the mountains northeast of Aberdeen in Owens Valley. The lava, which flowed out over the alluvium amassed along the front of the range, is exceedingly vesicular and scoriaceous. It is on olivine-bearing basalt whose groundmass is rather feldspathic, so that the holocrystalline form of the lava is dark gray. Ejection of cinders, resulting in the building of a number of imperfect cones, closed the eruption. This outburst on the east side of Owens Valley was in all probability contemporaneous with the outpouring of lava and the building of the cinder cones along the flank of the Sierra Nevada on the opposite side of the valley.

RELATION OF ERUPTIONS TO FAULT LINES.

Red Mountain stands at the south end of a well-defined alluvial scarp produced during the earthquake of 1872. A short distance north of Red Mountain, on this same fault scarp, is a small accumulation of basaltic cinders and scoria, representing an incomplete volcanic outburst; and on the northward prolongation of the scarp—on the extrapolated line—stands the crater of Crater Mountain. Three volcanic vents were thus situated on a single fault line.

The large cinder cone west of Fish Springs School displays the unusually interesting feature of having been cut in two by a fault of recent origin. The vertical displacement produced is 80 feet. (See Pl. XIII, *B*.) The fault scarp reveals the further fact that the periphery of the volcano had been covered by 25 to 40 feet of coarse alluvium prior to the faulting. This proof of age is confirmed by the amount of erosion discernible on the north flank, which has been sufficient in places to expose the bedding of the breccia layers. The continuation of the fault intersecting the cone can easily be traced by means of the alluvial scarp southward to the Poverty Hills, where it becomes unrecognizable. However, the west base line of the Poverty Hills bedrock mass, which projects through the alluvial floor of Owens Valley, coincides in direction with the extrapolated line of the fault scarp; and at the south end of the hills there is an accumulation of cinder, lapilli, and bombs. These facts clearly suggest that the Poverty Hills are delimited on the west by a fault along which there have been basaltic eruptions in late Quaternary time, and that the recurrence of movement along this fault in postvolcanic time has produced the prominent alluvial scarp and the dislocation of the cinder cone west of Fish Springs School.

The relation of probable fault lines to the ejected masses of cinder and scoria that occur along the upper edge of the alluvial piedmont slope and along the lower bedrock slope of the Sierra Nevada has already been described. Some of the cinder masses are shown in Plate XII, *B* (p. 71).

Although the connection between volcanic outbreaks and fracture lines is thus clearly and unmistakably illustrated along the east flank of the Sierra Nevada, yet when this connection is considered in the light of the phenomena exhibited by the basaltic eruptions of the province as a whole it seems to possess far less significance than first thought would give to it. The amount of lava erupted is relatively small; the eruptions occurred long after the great movements took place on the fault planes that determined the Sierra Nevada escarpment; and contemporaneous volcanic vents were opened upon the summit of the range, for instance, on Golden Trout Creek and South Fork of Kern River.[1] This last fact is of special interest, for the occurrence of these volcanoes shows that the magma, instead of issuing at a low altitude along one of the fault planes of the eastern escarpment, bored its way independently through the granitic core to the summit of the range, there to erupt from single isolated vents—an illustration of the independence of volcanic vents in some respects as noteworthy as the classic examples of Kilauea and Mauna Loa.

Again, the great epoch of basaltic eruption in the region was the epoch of the earliest flows, and this took place before the Inyo Range originated; in fact, as already pointed out, the basalt sheets serve as admirable registers of the dislocations by which the range was blocked out. So far as the history of the region is now known their independence of these orogenic movements does not, however, necessarily exclude their dependence upon orogenic movements accompanying the uplift of the Sierra Nevada.

AGE.

The arid climate prevailing in Owens Valley has favored the preservation of the volcanic cones, so that they have remained nearly intact. On casual inspection they appear as if built in the recent past, but, as pointed out for Red Mountain and the cinder cone near Fish Spring School, a considerably greater age than this is indicated. More precise information on this point is afforded in Sawmill Creek canyon by the flow of olivine

[1] Lawson, A. C., California Univ. Dept. Geology Bull., vol. 4, No. 15, pp. 319–320, 1904.

basalt on Sawmill Creek. This flow of lava was poured out after the canyon of Sawmill Creek had attained its present depth; the lava was subsequently covered by a great lateral moraine of the second epoch of glaciation, and the evidence (see p. 98) shows that the volcanic outburst took place in interglacial time. Of the contemporaneity of this activity and that lower upon the flank of the range there can be no reasonable doubt.

GEOMORPHOLOGY.

ORIGIN OF THE PREGLACIAL LAND FORMS.

SIERRA NEVADA.

FAULT ESCARPMENT.

That the Sierra Nevada is a great fault block, tilted to the west and bounded on the east by a fault system of large displacement, has long been recognized. Lindgren[1] has recently presented a concise description of the fault system of the portion of the range extending north of Owens Valley. The evidence of faulting, as recognized by this author, consists in the sharply descending slope, the topographic discontinuity, the oversteepening toward the foot of the escarpment, and the dislocation of gravel-filled channels and their overlying lavas. In addition, triangular faceting of the mountain spurs, another evidence of faulting whose significance has been clearly set forth by W. M. Davis, has been recognized along the west wall of Owens Valley in extraordinarily impressive development.

The great escarpment of the Sierra Nevada attains its most majestic dimensions in the vicinity of Owens Lake, where it attains not only its greatest altitude but also its greatest relief, rising from 3,600 feet on Owens Lake to 14,501 feet on Mount Whitney. From Olancha, at the south end of Owens Lake, to Independence the escarpment is steepest and the mountain base line is most sharply defined, for no foothills here break the abruptness of the descent from the crest line to the alluvial plain. In short, the eastern escarpment appears to have been produced here by dislocation mainly along a single fault.

[1] Lindgren, Waldemar, Tertiary gravels of the Sierra Nevada of California: U. S. Geol. Survey Prof. Paper 73, pp. 39–43, 1911.

The faceted spurs of the fault scarp are also strikingly shown near the south end of Owens Lake. This feature is fairly well brought out in Plate XIV, *A*, which shows Olancha Peak as seen from the southeast. The difference in altitude between the summit of Olancha Peak, whose elevation is 12,135 feet, and the apex of the alluvial cone in the central foreground is over 7,000 feet. To show the profound contrast between the rugged topography of the Sierra escarpment and the mature summit topography on the very brink of the escarpment another view of Olancha Peak, which was taken on the summit of the range southwest of the peak, is presented in Plate XIV, *B*.

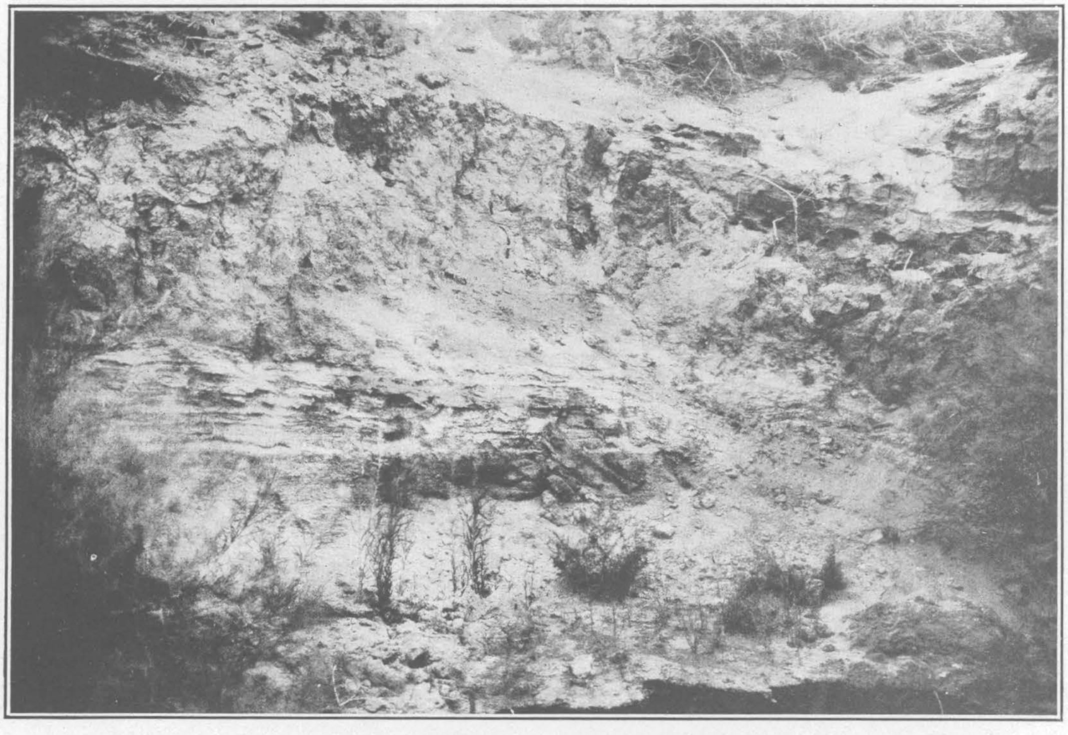
To all who behold it, the precipitous eastern slope of the Sierra Nevada seems a great granite wall rising almost vertically from Owens Valley. How illusive this impression is in point of fact is realized only after a profile of the escarpment drawn to scale is inspected. For example, when the profile of the sharply faceted spur between Ash and Braley creeks, west of Owens Lake, is drawn to scale it is found that the inclination of the fault scarp is only 25°.

The triangular faceting southwest of Independence is larger and bolder than elsewhere. The eastern slope of Mount Williamson, the dominating peak of the Sierra Nevada visible from this part of Owens Valley, is a great triangular facet, whose basal angles are at the mouths of the canyons of George and Shepard creeks. On this major facet have been cut three secondary facets, which, although deeply scored, show the characteristic triangular pattern particularly well. They rise to an altitude of 10,000 feet, the height below which all the spurs in this part of the range show a marked oversteepening.

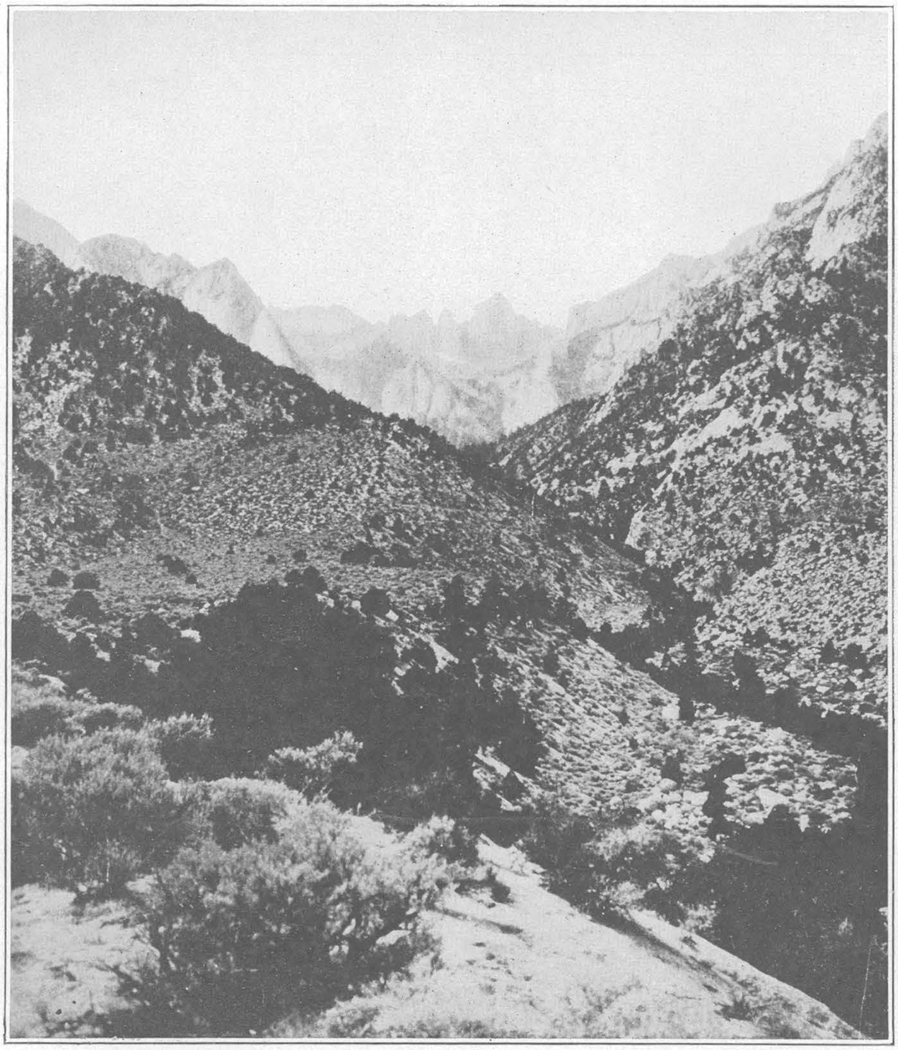
The extreme simplicity of the fault scarp west of Owens Lake disappears west of Independence. Granite foothills protrude through the alluvial slope and seem to lie against the main mass of the Sierra Nevada block along the major fault surface, suggesting a mass that has not subsided as far as that which forms the main suballuvial floor of Owens Valley.

In the vicinity of Division and Goodale creeks a number of basaltic cinder cones appear along the line where the fault trace might reasonably be expected to occur. Patches of the

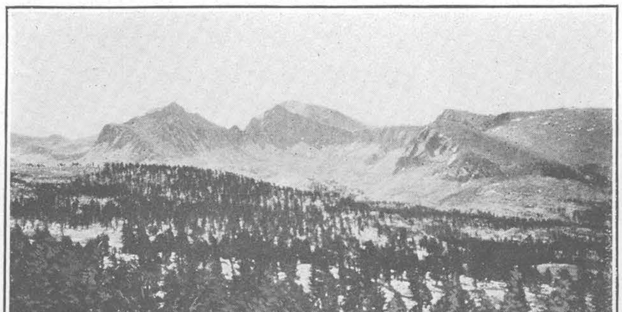
A. SIERRA FAULT SCARP WEST OF ROUND VALLEY.



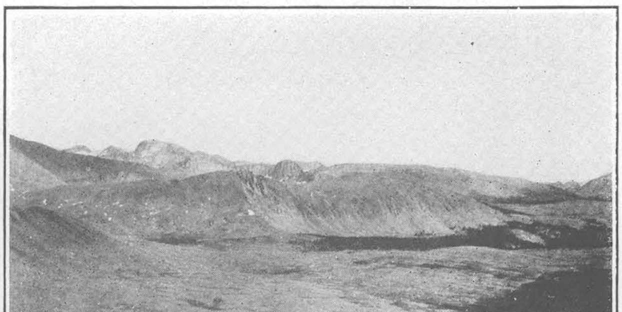
B. FAULT PRODUCED AT THE TIME OF THE OWENS VALLEY EARTHQUAKE OF 1872.



A. MOUNT WHITNEY FROM THE MOUTH OF LONE PINE CANYON.



B. MOUNT WHITNEY FROM THE NORTHWEST.



C. MOUNT WHITNEY AND THE SUBSUMMIT PLATEAU FROM DIAMOND MESA.

black basaltic ejecta are shown in Plate XII, *B*, which shows also some curious features in the profile of the spur between Goodale and Taboose creeks. These features, somewhat suggestive of the geomorphic form to which A. C. Lawson[1] gave the name "kernbut," seem to indicate a zone of distributive faulting along which there has been movement in comparatively recent time. These later movements, however, probably took place along older tectonic lines.

The ridge between Goodale and Taboose creeks is a striking example of topographic unconformity. Its lower slope, from the top of the alluvial apron up to an altitude of 8,500 feet, is a steep, rugged scarp bristling with granite ledges; surmounting this is a broad bench whose surface is smooth though hilly; and above this another steep slope to the crest line. The terrace-like form is developed on the next ridge to the north, though not so markedly. This peculiar geomorphic feature doubtless originated by differential subsidence along a subordinate fault that accompanied the main fracture.

The precipitous eastern slope of the fine peak standing between Red Mountain and Tinemaha creeks displays an ideal development of triangular faceting; the northernmost facet is large enough and is cut sharply enough to appear on the topographic map of the Bishop quadrangle. A huge talus, which extends to a great height on the flank of this peak, is traversed by a fault of recent origin, which is easily visible from a distance of several miles.

The eastern slope of the Sierra Nevada, from Olancha northward to Birch Mountain, unmistakably represents a profound break in the earth's crust, but from Birch Mountain northward to Bishop Creek the evidence is not so conclusive. Long straggling spurs extend out into the valley, and irregular foothills merge with the main mountain mass. The explanation seems to be that the dislocation was here distributed more or less equally along a number of parallel faults through a wide zone; and that subsequent erosion has been able to obscure the diastrophic origin, though it was insufficient to obscure the evidence where the movement took place entirely along a single fault surface.

In the vicinity of Bishop Creek the fault system is offset to the west about 8 miles in the manner characteristic of the Sierra Nevada farther north.[2] It is noteworthy that a few miles north of the zone of offset the Sierra Nevada escarpment shows all the abruptness and clear-cut simplicity that characterize it in its most imposing development west of Owens Lake. This is notably true of the steep wall facing Round Valley (see Pl. XV, *A*), where the topographic discordance between the mature summit topography of the range and the eastern fault face is impressed on the observer as it is nowhere else along the southern escarpment.

The fault indicated by the escarpment facing Round Valley would, if prolonged southward, coincide with the axis of the canyon of South Fork of Bishop Creek, which is noteworthy among the canyons on the east flank of the Sierra Nevada because of its meridional trend. The upper courses of Shannon and Haiwee creeks are indeed parallel to the trend of the range, but neither of these has the length and depth of South Fork of Bishop Creek. The coincidence between the trend of the fault scarp and the canyon of Bishop Creek suggests at once that the canyon is of diastrophic origin. But the fact that the old topographic surface, below which the canyon is sunk to a depth of 2,500 feet, is in hypsometric accordance on both sides of the canyon immediately indicates that the canyon, if of diastrophic origin, is a rift valley. This is the mode of origin advanced by A. C. Lawson[3] for the analogous canyon of the Kern; and the probability of this hypothesis is a matter of importance in the consideration of glacial erosion. (See pp. 102–104.) Against the probability of the rift hypothesis is the fact that the course of South Fork is somewhat sinuous, but still more convincing is the fact that the canyon of Middle Fork, which trends nearly at right angles to South Fork, is as deep as that of South Fork; in short, depth is no criterion

[1] The geomorphogeny of the upper Kern basin: California Univ. Dept. Geology Pub., vol. 3, p. 332, 1904.

[2] Lindgren, Waldemar, Tertiary gravels of the Sierra Nevada, Cal.: U. S. Geol. Survey Prof. Paper 73, p. 39, 1911.

[3] Op. cit., p. 343.

as to the diastrophic origin of the eastern Sierra Nevada canyons.

RECENT FAULT SCARPS.

A violent earthquake, comparable to the San Francisco earthquake of 1906, shook Owens Valley in 1872. It was so destructive that at the small village of Lone Pine the population was literally decimated. Some of the fault scarps produced during this earthquake, especially those in the vicinity of Lone Pine, were described by Whitney,[1] who visited the region a few months after the shock, and later by Gilbert.[2] Hobbs[3] has assembled the information concerning this earthquake and exhaustively described the earthquake faults at Lone Pine, basing his descriptions on the field work, photographs, and maps of W. D. Johnson.

The fault scarps near Lone Pine as indicated on the topographic map of the Mount Whitney quadrangle are shown in somewhat generalized form; they are shown on Plate II of this report (in pocket) as corrected from Johnson's data. The fault scarps have a general trend parallel to the front of the Alabama Hills. They range in height from a few feet up to 25 feet; as the faults traverse soft lake beds, alluvium, and soil the scarps have become somewhat softened and it is now impossible to measure within a few feet the heights properly attributable to the displacement during the earthquake. The visible geologic effects were confined to surface features until recently when a large stream of water, temporarily escaping through a break in the Los Angeles Aqueduct, cut a deep gully across the eastward-facing scarp at the north end of the Alabama Hills, revealing an excellent section that shows an actual stratigraphic discontinuity produced at the time of the earthquake. The beds exposed were deposited in the fresh-water predecessor of Owens Lake and consist of well-stratified fine gravel and sand carrying fragments of pearly *Unio*. The fault-surface dips 50° E. and the stratigraphic discontinuity produced by the dislocation is plainly visible, the overlying layer of dark soil having been faulted down against the lake beds. (See Pl. XV, *B*.)

An eastward-facing scarp produced by the earthquake fault of 1872 remains in fairly well preserved condition west of Big Pine, a town 40 miles northwest of Lone Pine. It is paralleled at one locality at least by a smaller westward-facing scarp 250 feet to the east. Both faults traverse the coarse bouldery wash of the alluvial cone of Big Pine Creek; and the larger is traceable for a considerable distance, becoming indistinguishable to the southeast, where it enters the basalt of Crater Mountain.

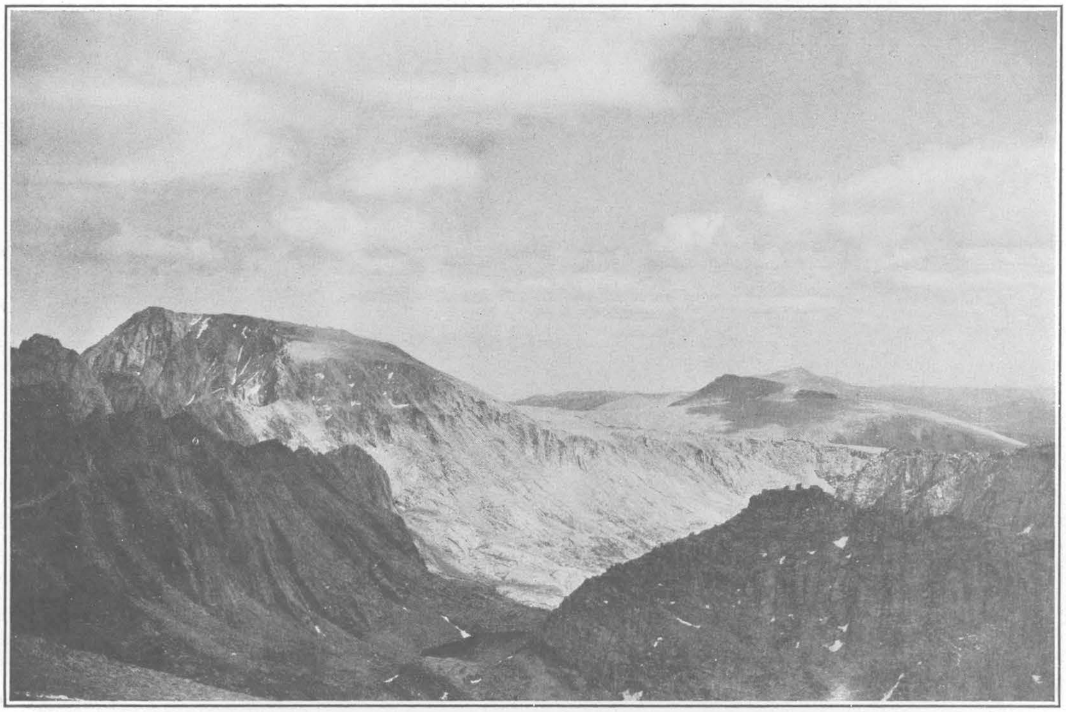
A considerable number of other fault scarps of late Quaternary origin were discovered during the present reconnaissance and, together with those near Lone Pine, were plotted upon the geologic map (Pl. II, in pocket) and the downthrown sides indicated by arrows. Most of them face eastward, but a few face westward toward the Sierra Nevada. One is reported to have been produced during the earthquake of 1872, but some of the others are obviously of earlier date. These faults occur not only at the edge of the alluvial piedmont slope, as noted by Whitney and Gilbert, but also at intervals on this slope and on the flank of the Sierra Nevada itself. Although these faults of late Quaternary age are recognized by their scarps (the results of the vertical displacements), they have also an important horizontal displacement, as was clearly pointed out both by Whitney and by Gilbert, who noted horizontal displacements measuring as much as 18 feet.

The alluvial fault scarp about 2 miles west of Fish Springs School is reported to have been formed in 1872. It is easily traceable from the southern edge of the basalt flows of Crater Mountain southward to the basaltic cinder cone known as Red Mountain. The scarp, which faces westward, is in effect a wall of granite boulders 3 to 6 feet in diameter. It averages 8 feet in height but in places is considerably higher; near Birch Creek it ranges from 16 to 18 feet. The northward prolongation of this fault passes through the crater of Crater Mountain, and the fault itself underlies a small cinder cone south of Fuller

[1] Whitney, J. D., The Owens Valley earthquake: Overland Monthly, vol. 9, pp. 130–140, 266–278, 1872. On account of its inaccessibility in this publication the description was reprinted in full in California Min. Bureau Eighth Ann. Rept., pp. 288–309, 1888.

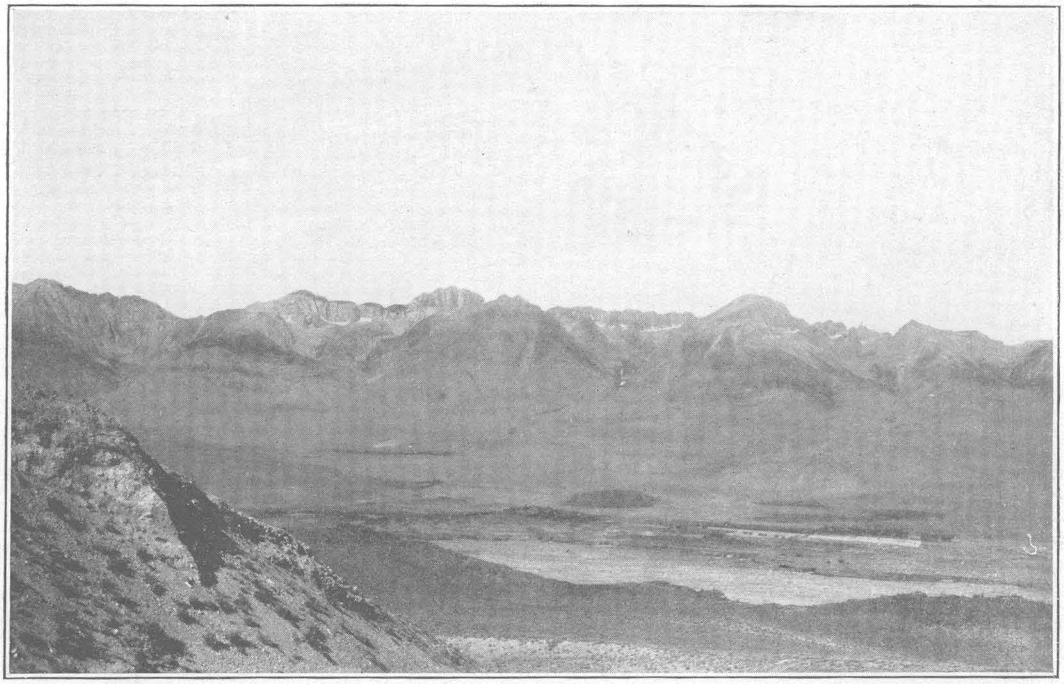
[2] Gilbert, G. K., A theory of the earthquake of the Great Basin with a practical application: Am. Jour. Sci., 3d ser., vol. 27, pp. 49–53, 1884; Lake Bonneville: U. S. Geol. Survey Mon. 1, pp. 361–362, 1890.

[3] Hobbs, W. H., The earthquake of 1872 in Owens Valley, Cal.: Beitr. Geophysik, vol. 10, pp. 352–385, 1910.

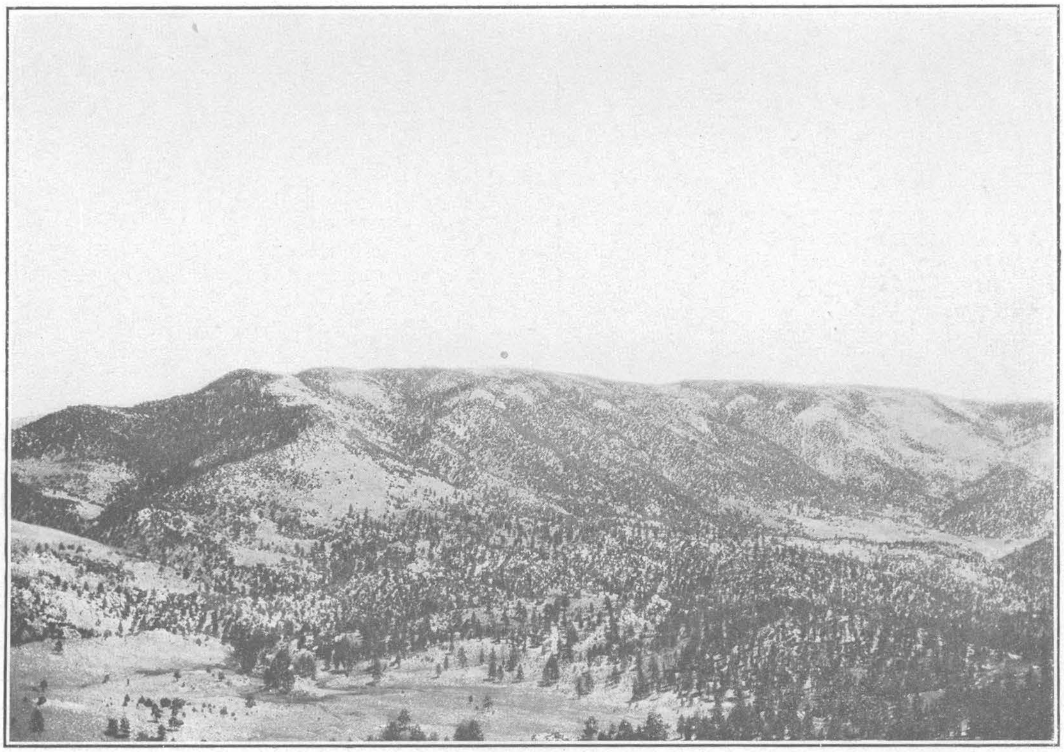


A. MOUNT LANGLEY (14,042 FEET), SHOWING A REMNANT OF THE SUMMIT UPLAND.

B. REMNANT OF SUBSUMMIT PLATEAU ON SPUR EXTENDING WEST FROM MOUNT WHITNEY.



A. BLACK SCHIST MASS APPARENTLY CAPPING THE GRANITE ALONG THE CREST OF THE SIERRA NEVADA.



B. EVEN CREST OF THE SIERRA NEVADA SOUTH OF HAIWEE PASS.

Creek and terminates at the cinder cone of Red Mountain.

The highest of the alluvial fault scarps is 1¼ miles east of that just described. It is 80 feet high, has an average slope of 30°, and faces east. The fault cut through the west side of a large basaltic cinder cone, and as a result a faulted fragment of the cinder cone shows in the scarp. The broken edges of rudely bedded volcanic scoria dipping west are displayed, and, important in another connection, the volcanic material is shown to be covered by 25 to 40 feet of alluvial wash, indicating that despite the cinder cone's extremely recent aspect considerable alluviation has taken place since its upbuilding. The southward prolongation of the fault extends along the west base of the Poverty Hills and the alluvial scarp was doubtless produced by the renewal of movement along an old fault surface.

A fault scarp, visible for many miles, traverses the talus on the flank of the peak that rises between Tinemaha and Red Mountain creeks. It trends N. 36° W., parallel to the flank of the mountain, at an altitude of 8,000 feet. Its vertical displacement is about 25 feet.

At an altitude of 6,100 feet a well-defined fault scarp crosses the alluvial cone of George Creek. It faces east, is 20 feet high, and trends N. 25° W. Along its northward continuation a granite spur, which rises here from the alluvium, clearly shows oversteepening of its basal slope. There are a number of alluvial fault scarps in the area west of Owens Lake, some of which resemble the beach cliffs produced by the fresh-water ancestor of Owens Lake but can be discriminated from them by the well-known fact that their base lines cut indifferently across the contours, as shown, for instance, by the fault traversing the alluvial cone of Cottonwood Creek.

The fault scarps described are doubtless only a few of those that will eventually be found. Those now known, however, are sufficient to show that the region is one of crustal instability, in which recent diastrophic movements have taken place along a series of parallel faults that are spaced across a zone at least 7 or 8 miles wide. The opinion has been ventured by some geologists that these renewals of crustal movement prove that the Sierra Nevada is a rising mountain range, but this view is no more inherently probable than its alternative that the floor of Owens Valley is subsiding. As A. C. Lawson[1] has shown to be probably true of the recent fault at Genoa, on the east flank of the Sierra Nevada farther north, both blocks may have moved, the mountain block up and the valley block down.

The fault scarps so far described are all on the west side of the valley. They appear to be scarce on the east side, though a notable fault produced at the time of the great earthquake in 1872 has been recognized just north of Swansea. It traverses an ancient beach of Owens Lake as a crack 1 to 3 feet wide and in places 8 feet deep. The scarp is several feet in height, the downthrown side being the mountain block east of the fault.

REMNANTS OF OLDER TOPOGRAPHIC FORMS.

SUMMIT OF THE RANGE.

The sky line of the Sierra Nevada as seen from Owens Valley, or, better still, from the Inyo Range, is in general notably even, few of the peaks rising dominatingly above the average level. In detail the crest appears to be a chaotic assemblage of precipitous peaks (see Pl. XVI, *A*) whose derivation from preexistent land forms is not apparent. Beyond the main divide, however, this condition changes, and the relation of the present summit to the earlier land surfaces begins to be apparent, especially west of Mount Whitney, and becomes increasingly apparent southward, beyond the southern limit of glaciation. The interrelation between the successive stages in the erosional history is more clearly shown in this area, which comprises the headwaters of Kern River, than elsewhere in the region. Although certain topographic remnants of earlier epochs of erosion are finely preserved north of the Kern basin, the interrelation between them has been largely obscured by the extreme glacial remodeling of the preexistent topography.

The geomorphic evolution of the headwater region of the Kern has been described in a notable paper by Lawson.[2] His obser-

[1] The recent fault scarps at Genoa, Nev.: Seismol. Soc. America Bull., vol. 2, p. 199, 1912.

[2] Lawson, A. C., Geomorphogeny of the upper Kern basin: California Univ. Dept. Geology Bull., vol. 3, pp. 292–376, 1904.

vations may be correlated with those made at other places along the range, and it will be interesting to inquire how far the geomorphic features observable on the east flank of the range support the history as determined on the region immediately west of the divide.

The upper Kern basin is characterized by three hypsometric zones, called by Lawson the High Mountain zone, the High Valley zone, and the Canyon zone. The High Mountain zone is further divided by Lawson into the Summit Upland and the Subsummit Plateau. The hypsometric relation between these subdivisions is shown in figure 4, which is a profile section extending from Mount Whitney across the canyon of the Kern. With this section may be compared the photographs of the Mount Whitney region shown in Plate XVI, *B*. Since Lawson studied the upper Kern basin the topographic surveys of the Mount Whitney and Olancha quadrangles have been completed and have proved of great value in the present investigation, especially in regard to the relative altitudes of the geomorphic subdivisions.

The summits of the highest mountains are connected by flowing transitional slopes with the next lower zone, the Subsummit Plateau. Just as the summit of Mount Whitney is typical of the Summit Upland, so the flat-topped ridge, standing at an altitude of 12,700 feet, extending west of Mount Whitney, is representative of the Subsummit Plateau. (See Pls. XVI, *C*, and XVII, *B*.) The relation between the two surfaces is diagrammatically shown in figure 4, the hypsometric data for which were obtained from the topographic map of the Mount Whitney quadrangle. The continuity of slope between these two surfaces shown in the diagram is, however, somewhat broken (see Pl. XVI, *B*, *C*) by the great glacial cirques that have been eroded into the old surfaces. On Diamond Mesa, just north of Mount Tyndall, the continuity is better preserved. Diamond Mesa is the largest remnant of the Subsummit Plateau preserved along the main divide; it is 1¼ miles long and has a broad, even top sloping continuously but with gradually increasing steepness from an altitude of 12,300 feet up to 13,200 feet. The lower, flatter part of the mesa clearly represents the Subsummit Plateau, and the steeper part is clearly the transitional slope from the Subsummit Plateau to the Summit Upland.

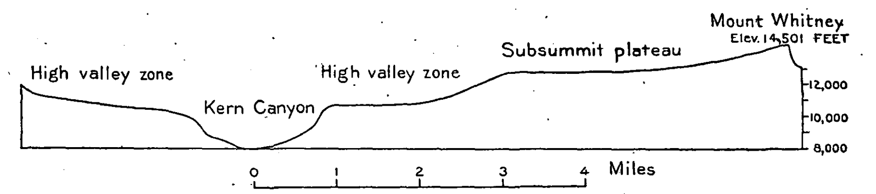


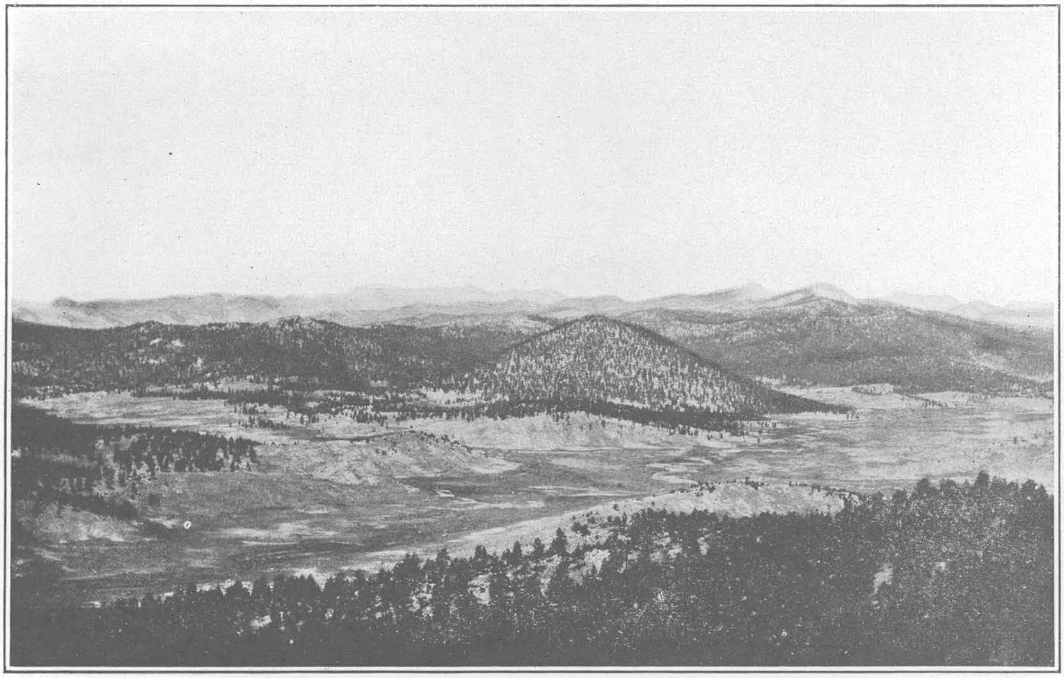
FIGURE 4.—Section across the Kern Canyon in the region of Mount Whitney, Cal.

HIGH MOUNTAIN ZONE.

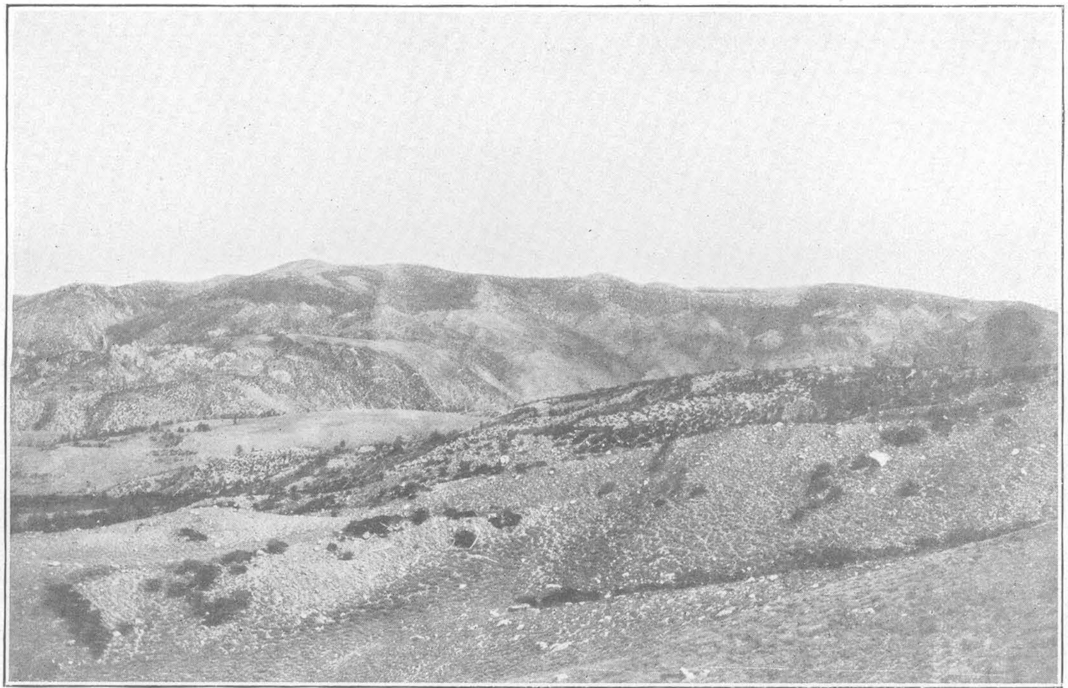
The Summit Upland is represented by the broad, gently sloping tops of the mountains overlooking Owens Valley, the portion from Mount Whitney south to Cirque Peak being cited by Lawson as typical. The summit of Mount Langley,[1] shown in Plate XVII, *A*, is a large remnant of the upland, which abuts on the edge of the great escarpment. Other examples are furnished by the summits of Mounts Whitney and Barnard. Mount Whitney, as may be seen in the illustrations, has a broad, even summit, which slopes, however, rather strongly westward; Mount Barnard shows a similar feature, though on not so large a scale.

The Subsummit Plateau is well shown west and southwest of Cirque Peak, where it has not been much dissected by glacial erosion. Farther south, south of the limit of the glaciation, it directly overlooks the eastern escarpment, as, for instance, at the head of Mulkey Creek. In other words, the Subsummit Plateau is here the upland of the summit region, and for this reason the name is infelicitous. This truncation of the Subsummit Plateau by the eastern escarpment appears to be due partly to the fact that the escarpment has here cut away the Summit Upland and partly to the fact that the divide has moved westward by stream capture from the east. (See p. 86.)

[1] This mountain, where mentioned in Lawson's bulletin, is referred to under its former name, Sheep Mountain.

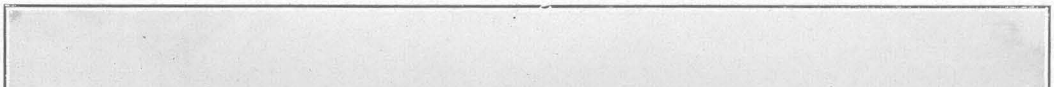


A. MONACHEE MEADOWS, A REMNANT OF THE HIGH VALLEY ZONE.



B. COYOTE RIDGE.

A. REMNANT OF SUBSUMMIT PLATEAU ON SOUTH FORK OF BISHOP CREEK.



B. DIVIDE AT THE HEAD OF CARTHAGE CREEK.

South of Mulkey Meadows the Subsummit Plateau, here literally summit upland, has an altitude of 10,700 feet; near Cirque Peak its altitude is 11,500 feet; and on the spur extending west from Mount Whitney 12,700 feet. The hypsometric range in 20 miles is accordingly 2,000 feet, and the Subsummit Plateau has therefore a pronounced southward slope.

The Summit Upland is regarded by Lawson as a surface of differential degradation that has been controlled by the gently undulating contact surface of the granite batholith with the rocks that formerly extended over it. The objection may perhaps be urged against this explanation that inasmuch as the batholith, consisting as it does of successive intrusions of diorite, gabbro, quartz monzonite, and alaskite, is of composite origin, the configuration of its contact would probably not have the simplicity postulated. More valid than this theoretical objection is that afforded by the actual mapping of the remnants of the pregranitic rocks that formed the roof of the batholith, which shows beyond question that the contact surface was characterized by extreme abruptness of relief. This evidence will now be presented.

Remnants of the batholithic roof are fairly common from Kearsarge Peak northward—that is, in the area north of the upper Kern basin. Their contact surfaces are well exposed, but these surfaces, instead of being nearly horizontal as Lawson supposed, are extraordinarily irregular, the remnants of the rock mass beneath which the magma came to place being mainly deeply projecting roof pendants. On the precipitous flanks of Mount Emerson, for instance, masses of schists can with diagrammatic clearness be seen extending 1,000 to 2,000 feet vertically downward into the granite. Even more striking are the features at Taboose Pass and Cardinal Lake. The great granite wall of the Sierra Nevada north of Taboose Pass is surmounted by a mass of black rock, which, as seen from Owens Valley, appears to be a thick flow of basalt resting on a smooth horizontal floor of granite. The pronounced color contrast makes the superposition visible 20 miles away. Close at hand, however, the black rock turns out to be a biotite schist roof pendant which projects almost vertically a thousand feet or more into the underlying granite, as may be determined at the cirque in which Cardinal Lake lies. The seemingly horizontal superposition of the black mass on the light-colored granite, as seen from Owens Valley, arises from the fact that the schist mass, which dips steeply westward, outcrops along an eastward-facing wall that trends nearly parallel to the strike of the schists, and that the trace of the contact plane is therefore an approximately horizontal line. (See Pl. XVIII, *A*.) The whole phenomenon strongly emphasizes the need of observations in three dimensions to determine the relations of roof remnants to underlying batholithic bodies.

The sedimentary roof pendant at Table Mountain, between Middle and South forks of Bishop Creek, projects at least 2,500 feet downward into the granite. But the even, gently sloping summit surface of Table Mountain extends indifferently across both granite and sedimentary rocks, and manifestly its evolution has not been controlled by differential degradation.

The foregoing facts seem to render inadmissible the hypothesis that the Summit Upland represents essentially the exhumed original upper surface of the granitic batholith of the Sierra Nevada. It is concluded, therefore, that the summits in the Mount Whitney region, which have been interpreted as remnants of a once-continuous summit upland, are merely the unreduced interstream areas of the ancient surface of erosion represented by the Subsummit Plateau; the two surface features are confluent and were formed during the same period of erosion. At Mount Whitney the confluence of the two has been broken by glacial erosion, and they seem to be separate entities, but at Diamond Mesa their unity has been preserved.

The Subsummit Plateau is correlated by Lawson with the early Tertiary peneplain of the more western part of the range; that this peneplain, however, was far from being a featureless surface of erosion has been adequately proved by Lindgren,[1] who, indeed, strongly denied that the term "peneplain" is applicable to it, even in the foothill region. Consequently a considerable relief might be expected to be shown by this surface at the crest

[1] U. S. Geol. Survey Prof. Paper 73, pp. 37-39, 1911.

of the range; but as a matter of fact the maximum—1,800 feet at Mount Whitney—is relatively small.

Reid,[1] in attempting to account for the flat summits in the vicinity of Lake Tahoe, was also forced to abandon the hypothesis of the exhumation of a batholithic contact, although many facts seemingly spoke in its favor, by the discovery that the flat surface is developed across the pregranitic schists of the Tahoe region as well as across the intrusive granite. Reid therefore adopted the view that the flat summits represent an ancient peneplain.

In the northern Sierra the ridges standing above the old Tertiary surface of erosion (the Sierra Nevada "peneplain" of most authors), are flat topped, and these flat-topped ridges, which are possibly the equivalents of the Summit Upland of the southern Sierra Nevada, are believed by Lindgren[2] to represent an earlier cycle of erosion, supposedly of Cretaceous age, but further than this their origin is not elucidated. It is with this Cretaceous surface of erosion, or peneplain, that Reid is inclined to correlate the ancient peneplain recognized by him in the region northeast of Lake Tahoe.

Flat-topped ridges, as already mentioned, occur along the main divide in the southern Sierra Nevada south of the southern limit of glaciation. South of Haiwee Pass the crest is 9,200 feet in altitude and is level topped (see Pl. XVIII, *B*), with some eminences, among which is Olancha Peak (Pl. XIV, *B*), rising above the average level. The surfaces of these flat-topped ridges are remnants of the Subsummit Plateau; no earlier surface of erosion has been recognized in this part of the southern Sierra Nevada.

HIGH VALLEY ZONE.

The most conspicuous representative of the High Valley zone as well as the most impressive geomorphic feature of the Mount Whitney region is the broad valley flanking the profound canyon of Kern River. (The steep-walled trench of the Kern, sunk 2,500 feet below the floor of the ancient valley, is the most striking example of the canyon zone.) The general topographic features of the old valley floor in the upper Kern basin are well shown on the topographic maps of the Mount Whitney and Olancha quadrangles. The area of this ancient land surface is estimated by Lawson[3] to be 100 square miles.

In places the old valley floor is connected with the Subsummit Plateau by transitional slopes, as noted by Lawson, but in other places the transition is rather abrupt; for example, in the descent from the summit of the level-topped ridge extending west from Mount Tyndall. This truncation of the spurs abutting on the old valley floor strongly suggests a glaciation anterior to the last, and this possibility should be considered in a detailed study of the area. Although in the brief time devoted to the area no evidence of more than one glaciation was found in the Kern basin, the writer is convinced that such evidence will eventually be obtained.

Many of the broad grassy meadows in the summit region south of the southern limit of glaciation are relics of the High Valley zone. Much of this region is drained by South Fork of Kern River, a stream that displays certain peculiarities demanding explanation. At Templeton Meadows South Fork meanders upon the floor of a broad valley belonging to the High Valley zone. Farther southward it enters a deep gorge several miles long, from which it emerges upon the broad Monachee Meadows, another extensive remnant of the High Valley system. (See Pl. XIX, *A*.) Farther southeast it enters a meandering vertical-walled canyon intrenched 200 to 500 feet in the floor of an old valley (a remnant of the High Valley zone), which lies 1,500 feet below the crest line south of Haiwee Pass; the canyon is so narrow that it is not distinguishable in the view of the pass shown in Plate XVIII, *B*. Farther south the stream again emerges upon broad meadows. The only reasonable explanation for this singular behavior of South Fork would seem to be that the canyons represent downcutting across zones of upwarp whose axes lie athwart the stream course. The recognition that deformation of this kind has accompanied the uplift of this part of the Sierra Nevada introduces a new ele-

[1] Reid, J. A., The geomorphogeny of the Sierra Nevada northeast of Lake Tahoe: California Univ. Dept. Geology Bull., vol. 6, pp. 109–110, 1911.

[2] Lindgren, Waldemar, Tertiary gravels of the Sierra Nevada, Cal.: U. S. Geol. Survey Prof. Paper 73, pp. 39, 44, 1911.

[3] Op. cit., p. 313.

ment of complexity in the decipherment of the physiographic history.

Representatives of the High Valley zone are rare north of the Kern drainage. A broad bench referable to this geomorphic stage occurs, however, on the headwaters of South Fork of Kings River, a short distance west of Taboose Pass. It lies at an altitude of about 10,500 feet. In it is intrenched a deep glacial canyon which bears the same relation to the floor of the old valley that Kern Canyon does to the floor of the high valley in which it is sunk—that is, the floor of the canyon gradually converges upstream toward the floor of the old valley, and in the headwater region the two coincide. The bench along South Fork of Kings River has been modified to some extent by glacial erosion, as is indicated by the sharply cut, triangular ice-worn facets that truncate the spurs projecting upon it.

Some striking remnants of older land features appear to have been "marooned" high on the east side of the Sierra Nevada divide, near the summit of the fault escarpment. They have remained essentially intact because the streams draining the escarpment have not yet eroded sufficiently headward to destroy them. Some of these remnants are practically continuous with those west of the divide, as is well shown at the head of Mulkey Creek in the Olancha quadrangle. The divide here, whose altitude is 9,500 feet, is a broad grassy meadow, the explanation of this anomalous condition, to anticipate slightly the discussion in the following pages, being that during the halt between the two uplifts of the range recognized in this region the eastward-flowing stream captured a headwater tributary of Mulkey Creek and caused the divide to shift westward. These relations afford a means to correlate the ancient topographic remnants east of the divide with those west of it and to discuss them in terms of Lawson's nomenclature. As Mulkey Creek flows upon a remnant of the High Valley zone, it is clear that the topography east of the divide was developed synchronously with that of this zone.

East of the Sierra Nevada divide, at the heads of Baker and Rawson creeks, which drain the escarpment between Bishop and Big Pine, is a broad valley named Coyote Flat, which in extent rivals many of the wide meadows of the High Valley zone south of the glacial limit on the west flank of the range. Its elevation is 10,000 feet above sea level, slightly higher than that of the previously described remnant of the High Valley zone east of the Sierra divide. The streams meander lazily through its grassy meadows, acquiring new energy only when they enter the deep gorges that gash the fault escarpment and rush turbulently down to Owens Valley, 6,000 feet below. The headwater tributaries of Rawson and Baker creeks are now just in the process of extending their canyons back into this remnant of the High Valley zone.

The mature ridge bordering Coyote Flat on the west, known as Coyote Ridge (see Pl. XIX, *B*), attains an elevation of 11,500 feet. This remnant of mature summit topography, it may be noted in passing, is developed in schist. On the west flank of Coyote Ridge, at an altitude of 11,000 feet, is preserved one of the more notable geomorphic features in the region—a remnant of an old erosion surface (see Pl. XX, *A*), in which the almost vertical canyon of South Fork of Bishop Creek is sunk to a depth of 2,500 feet. West of the canyon the old erosion surface is preserved as a fairly broad plateau, known as Table Mountain. From its relative altitude with respect to the High Valley zone of Coyote Flat the old erosion surface of Table Mountain must correspond to the Subsummit Plateau of the Kern basin.

A large remnant of a terrace occurs on the south side of Bishop Creek, below the junction of South and Middle forks, where its elevation is 9,300 feet. (See Pl. XIX, *B*.) As seen from a distance it appears to be covered by a thin sheet of basalt, which is probably of the same age as the basalt flows farther downstream on the south side of Bishop Creek. These flows rest partly on gravels which doubtless accumulated on the downstream extension of the terrace. The terrace corresponds in elevation to a point in the profile of the spur between Middle and South forks, below which a notable oversteepening occurs; and this correspondence leaves little doubt that the terrace is not of diastrophic origin, like some of the benches on the escarpment facing Owens Valley, but that it records a halt in the uplift of the Sierra Nevada or in the subsidence of the floor of Owens Valley. The important fact in regard to this terrace is that it occurs on that segment of the Sierra Nevada escarpment that faces northwest as a result of the great offset of the fault escarpment lying west of Bishop. As a consequence of its position the complementary parts of the terrace, that must have existed on the north side of the stream, have been depressed beneath the floor of Owens Valley. The development of this terrace records therefore an added detail in the history broadly outlined in the evolution of the Subsummit Plateau and the High Valley zone.

STREAM CAPTURE.

The drainage system of the Sierra Nevada escarpment is for the most part simple. It comprises a series of short streams, subequally spaced, steep of grade, that flow in profound canyons perpendicular to the trend of the range. From the glacial cirques in which they rise to the great alluvial cones at the foot of the range, they traverse a region of extraordinary ruggedness.

A few streams, however, in their headwater development exhibit features that contrast markedly with those of normal type. Two of these abnormal streams, Rawson and Baker creeks, have headwater tributaries that extend back into grassy upland meadows. The headwater tributaries of Ash Creek flow in broad grassy valleys, which have not yet been incised by the deep gorge in the fault escarpment, and they extend back into a remnant of an earlier erosion cycle probably to be correlated with that represented by Coyote Flat. Being south of the former limit of glaciation, and therefore unmodified by glacial erosion, they doubtless exemplify in a somewhat smaller way the conditions that existed on the headwaters of Cottonwood Creek prior to glaciation. This stream differs from most of the other streams of the Sierra Nevada escarpment in having a considerable headwater drainage basin, which it evidently owes to the working back of its headwaters into an extensive remnant of the ancient summit topography. Some of this topography, unmodified by ice erosion, has been preserved in the area between Cottonwood Creek and its tributary, Little Cottonwood.

The headwaters of Carthage Creek and of the branch of Cottonwood Creek heading against Mulkey Creek also drain remnants of a mature upland topography. The divide at the head of Carthage Creek at an altitude of 9,000 feet (Pl. XX, *B*) is occupied by a small marshy pond below which, toward Owens Valley, there is a considerable stretch of grassy meadow, whose lower end is just beginning to be incised by Carthage Creek, which close below falls 4,500 feet in 3 miles. The small stream heading on the north side of Olancha Peak appears to have been captured from the westward-flowing drainage. It is plain, however, that this capture must be credited to an earlier epoch of erosion, for there is no gorge at the elbow of capture.

Stream capture seems to be more clearly exemplified at the divide just north of Muah Mountain. At this locality the broad alluviated valley of Mulkey Creek, a westward-flowing stream, extends back to the brink of the steep eastern face of the range. A relatively large headwater tributary appears to have been diverted to the easterly drainage by one of the affluents of Cottonwood Creek. That the capture took place during a former epoch of erosion is evident from the fact that the profound gorge of the eastward-flowing stream does not yet extend back to the elbow of capture. It is manifest here, as at Carthage Creek, that this headward extension is progressing rapidly and that further captures are imminent.

Despite the enormous advantage of grade possessed by the eastward-flowing streams, the extent to which capture of headwater tributaries of the westward-flowing drainage has occurred is exceedingly small. This may mean either that the feebler precipitation on the eastern flank has partly counterbalanced the advantage of grade, or, what is perhaps saying the same thing in another way, that the fault escarpment was produced too recently for the eastward-flowing streams to have eroded sufficiently headward and to have effected a notable amount of stream capture. The headwaters of many streams that now drain westward will, however, in all probability ultimately be diverted to the Great Basin.

CORRELATION.

The smallness of the amount of stream capture by the drainage of the Sierra Nevada fault escarpment leads naturally to a consideration of the time that has elapsed since the formation of the eastern fault system. Lindgren sums up his views on this point as follows:[1]

Faulting has recurred irregularly along the eastern fault zone since the Cretaceous period. The subsidences along the faults are not uniform. A Cretaceous dislocation along one line may be continued by a late Tertiary fault on the extension of this line. * * * It follows from the irregularity of the subsidence which has taken place at different times that these movements can in no way have been responsible for the uniform tilting of the western slope.

The uniform tilting of the western slope was effected at the close of the rhyolitic eruptions that buried the auriferous gravels of the Tertiary drainage.[2] The streams were thus rejuvenated, and the great canyons, now trenching the western slope, which were the results of this rejuvenation, were excavated during Pliocene and Quaternary time.[3] Lindgren's interpretation appears therefore to be that the Sierra Nevada attained its present elevation at about the close of the Miocene as the result of a single uniform uplift of epeirogenic character, and that its differentiation as a topographic unit from the Great Basin was effected by the successive subsidence of fault blocks along its eastern margin.

This conception as a whole can not be reconciled with the history deducible in the portion of the range west of Owens Valley. Here the evidence shows clearly that the present altitude of the Sierra Nevada is not the result of a single uplift, but, as first established by Lawson, is the result of at least two uplifts which were separated by a protracted halt. According to Lawson,[4] however, the first elevatory movement took place at the beginning of Quaternary time and lifted the range in the Kern region 2,500 feet. The assignment of the date of the uplift to the beginning of the Quaternary is an assumption of doubtful validity; it can not, however, be proved or disproved within the Kern region by appeal to paleontologic evidence.

Baker,[5] approaching the problem from a study of the Mohave Desert region, has correlated his results with those reached in the high Sierra by Lawson. The importance of his work arises from the fact that certain events in the historical geology of the region are accurately dated by vertebrate paleontologic evidence. He shows that in the Mohave Desert the "Ricardo erosion surface," representing an unquestionable peneplain, bevels the tilted strata of the "Rosamond series," of early Pliocene age; and he seeks to correlate this surface with the Chagoopa Plateau, or High Valley system, of the upper Kern basin. It is somewhat difficult to follow this correlation, inasmuch as the Ricardo erosion surface is correlated with the summit upland represented by broad-topped mountains in the vicinity of Walker Pass, and this summit upland is in turn correlated with the high-level floor of the Kern. But the ancient floor of the Kern lies some 2,000 feet below the Subsummit Plateau and the Summit Upland, which together constitute the summit topography of the Sierra Nevada. If, despite this weakness in the chain of correlation, the development of the ancient valley of the Kern and the peneplain of the Mohave Desert were synchronous, then the High Valley zone was developed subsequent to early Pliocene time.

It is to be noted that the constitution of the "Rosamond series" itself, consisting of granitic "fanglomerate" and volcanic breccias, points to a mountain-making uplift of the southern Sierra Nevada in early Pliocene time. "The sediments of the Rosamond series were probably laid down mainly as piedmont alluvial débris and as playa deposits, under the same conditions of desert aggradation as operate in the region at the present day."[6] The uplift thus recorded in the sediments of the "Rosamond series" may be tentatively correlated with the initial uplift of the Sierra Nevada.

Now, the initial uplift of the Sierra Nevada—that is, the uplift to which it owes its present main orographic features—was correlated by Lawson with the beginning of the westward tilting of the western slope of the range. If this correlation is correct, it seems to follow from a consideration of Lindgren's

[1] Lindgren, Waldemar, The Tertiary gravels of the Sierra Nevada of California: U. S. Geol. Survey Prof. Paper 73, p. 43, 1911.

[2] Idem, p. 30.

[3] Idem, p. 28.

[4] Lawson, A. C., Geomorphogeny of the upper Kern basin: California Univ. Dept. Geology Bull., vol. 3, p. 364, 1904.

[5] Baker, C. L., Physiography and structure of the western El Paso Range and the southern Sierra Nevada: California Univ. Dept. Geology Bull., vol. 7, pp. 137–139, 1912.

[6] Baker, C. L., Notes on the later Cenozoic history of the Mohave Desert region in southeastern California: California Univ. Dept. Geology Bull., vol. 6, pp. 358–359, 1911. The "Rosamond series" was originally determined as of upper Miocene age, but is now regarded by J. C. Merriam as of early Pliocene age.

work that Lawson's assumption[1] of an early Quaternary age for the rejuvenation of the range is probably invalid, as already indicated by Baker's results. For the facts established by Lindgren in his study of the Tertiary auriferous-gravel epoch show that the drainage was rejuvenated at the close of the rhyolitic eruptions, probably late in the Miocene. This date Lindgren believes is more in harmony with the length of time indicated by the great erosional work performed since the uplift; it assuredly does less violence to our ideas concerning the length of Quaternary time than does the assignment of a post-Pliocene age to the initial uplift and to the westward tilting of the range.

SUMMARY OF OROGENIC HISTORY.

The initial disturbance to which the Sierra Nevada owes its present orographic features uplifted the range in the Mount Whitney region about 2,500 feet, as measured by the difference in elevation between the Subsummit Plateau and the ancient floor of the Kern. The date of this initial uplift is not certainly known; it may be as recent as early Pliocene or as remote as late Eocene. Following this uplift came a long period of stability, during which the streams, having trenched the peneplain of the auriferous-gravel epoch, reached grade and widened their valleys broadly, as is shown so strikingly on the upper Kern west of Mount Whitney; and certain of the streams draining the region east of the Sierra Nevada divide eroded sufficiently far headward to capture some of the headwater tributaries of certain westward-flowing streams. Although the amount of stream capture is small, the streams draining the region east of the Sierra Nevada were able to evolve a mature topography—now stranded high up on the fault escarpment—which is the correlative of the High Valley system on the west flank of the range. It is manifest that such a mature topography could not have been evolved east of the crest if the initial uplift of 2,500 feet had been accompanied by a relative subsidence of the floor of Owens Valley; the initial uplift, therefore, was of epeirogenic character, involving at least a part of the Great Basin.

[1] Lawson, A. C., op. cit., p. 364.

The second and major uplift followed. The vertical displacement in the region west of Owens Lake amounted to about 6,000 feet. This orogenic disturbance Lawson considers as having taken place in late Quaternary time, but the extensive erosional work done since the faulting took place makes its assignment to early Quaternary time more probable. To this second movement the range owes its principal orographic features—the great scarp flanking Owens Valley and the intrenchment of the canyons on both slopes of the range.

INYO RANGE.

The Inyo Range, as studied from the Owens Valley side, presents the peculiarity that its character as a dislocation range is most obvious at its two ends. At the north end the physiographic evidence points unmistakably to a fault-block origin, and at the south end the stratigraphic evidence, displayed in diagrammatic fashion on the walls of a deep canyon, shows the actual dislocations that have given the range its relief.

The southern part of the range southeast of Keeler is almost completely covered by a superposed succession of basalt lavas. The floor on which these flows were erupted—a nearly horizontal surface whose altitude is 6,200 feet—is fortunately, however, well exposed (see Pl. XI, *A*, *B*, p. 70), and the evidence thus revealed makes clear an important chapter in the orogenic history of the range. Beneath the flows of lava as exposed here is a 10-foot stratum of tuff, composed of fragments of oxidized, pumiceous basalt; and the tuff itself rests on gravel deposited unconformably on the eroded edges of Triassic and Carboniferous strata. The horizontal lava sheets are broken by step faults, of which two of the smaller are shown in Plate XI, *B* (p. 70). The descent from the Summit Plateau to the valley is accomplished mainly by two step faults, each involving a drop of about 600 feet. In the canyon forming the north edge of the basalt plateau shown in Plate XI, *B*, the basalt of the lowermost fault segment rests on gravels 50 feet thick, which are faulted against bedrock, the fault surface dipping 45° W.

A short distance farther north a basalt-capped mesa rising to an altitude of 5,000 feet discloses some interesting features. The basalt overlies a series of angular gravels and silts, probably of terrestrial origin, lying horizontal, and at least 100 feet thick. Along a gulch eroded back parallel to the east edge of the mesa (the edge facing the crest of the range) the gravels have been abruptly upturned, causing the stratification to dip 31° W. Besides this upturning, which was evidently due to dragging along the longitudinal fault, there is equally clear evidence of transverse faulting. A cliff, 25 feet high, reveals a remarkably fine slickensided wall standing vertical and trending S. 55° W. Upon it strong horizontal corrugations are scored and upon these corrugations are superposed striae that dip 30° E. Dissimilar gravels have been brought into juxtaposition and the demarkation between them is, in places, exceedingly sharp. Some of the basalt-covered fault blocks were partly rotated during or after their subsidence. (See Pl. XI, *A*, p. 70.) The evidence of transverse faulting found in the underlying gravels is doubtless the internal expression of relative movements of this kind between the broken fractions of single large fault blocks.

The basalt covering the extreme south end of the range simulates a great lava flow that descends from the summit plateau to the level of the broad depression between the Inyo and Coso mountains; but this effect has undoubtedly been produced by dislocations along a large number of small step faults whose scarps are now obscured by talus slopes.

In the southern portion of the Inyo Range, then, the evidence demonstrates conclusively a fault-block origin for at least this portion of the range.

Along the northern portion of the range (north of the area considered in this report) the spurs facing Owens Valley are terminated by remarkably large clean-cut triangular facets, whose sharp edges and geometric perfection make them extraordinarily fine illustrations of this salient geomorphic feature of recently uplifted dislocation ranges. Southward, however, the triangular faceting is less conspicuous, perhaps because the faulting is distributive, as is strongly suggested by the distributive faulting that is actually revealed southeast of Keeler in the fractured and dislocated basalt plateau.

Northward from the Montezuma mine triangular facets, sharply cut but much smaller than those at the north end of the range, appear on the truncated spurs abutting on the valley. Corroborative evidence of the faulting thus indicated is furnished by the fact that the ravines incised in the fault face are youthful and are obviously eroding headward into a more mature topography. (See Pl. I, in pocket.) Southward from the mine, the plane of faceting appears to run obliquely into the main mass of the range, gradually becoming obscure, and to coincide with the prolongation of the fault that was detected between the Ordovician and Carboniferous rocks by the application of stratigraphic criteria. The features of the range front, from the mouth of Waucoba Canyon to the Montezuma mine and southward, display in an unusually clear way the complications that render difficult the decipherment of the orogenic history from physiographic criteria alone. The dislocations that determined the relief of the range took place along a series of faults many of which have a tendency to coincide with the base line of the range for some distance and then to run at a narrow angle into the mass of the range.

Other evidence of the fault-block origin of the range consists in the straightness of its western front and its independence of bedrock control. The general course of the base line is oblique to the trend of the rock belts; in places it actually cuts at right angles across the axes of highly folded Cambrian strata.

Walcott[1] has advanced the view that the range was uplifted 3,000 feet along its eastern margin and tilted westward in post-Pleistocene time, basing his opinion largely on the examination of the lake beds east of Big Pine. But (see p. 55) he did not adequately discriminate the lake beds from the alluvial gravels deposited unconformably on them; and the views entertained concerning these deposits closely affect the interpretation of the orogenic history of the range. According to Walcott the lake beds are exposed continuously along the Saline Valley road in Waucoba Canyon up to an altitude of 3,000 feet above Owens Valley and the rise of the canyon bottom is nearly coincident with that of the lake beds, which have an average dip of 3° to 5° W. This westward dip is thought to be largely

[1] Walcott, C. D., The post-Pleistocene elevation of the Inyo Range, and the lake beds of the Waucobi embayment, Inyo County, Cal.: Jour. Geology, vol. 5, pp. 340–348, 1897.

due to the westward tilting of the range. Unfortunately for this explanation the highest lake bed in the canyon, if indeed it be a lake bed, dips southeast (9° SE.) instead of southwest as demanded by Walcott's explanation. In view of this discrepancy, of the failure to discriminate accurately between lacustral and alluvial deposits, and of the indubitable stratigraphic and physiographic evidence concerning the fault-block origin of the range it is certain that Walcott's explanation needs considerable modification.

The eastern border of the Inyo Range is not a long, continuous straight line, such as characterizes the western face. But at many localities the geomorphic features bear decisive witness of extensive faulting. The evidence is perhaps most plain in the deep elliptical depression known as Saline Valley, whose floor lies 2,500 feet lower than that of Owens Valley. The flank of the Inyo Range is here exceedingly steep and rugged, in fact comparable to the great escarpment of the Sierra Nevada. That faulting has taken place here has been previously recognized by Fairbanks[1] and Walcott.[2] It is interesting to note that Walcott tacitly assumed that this faulting proved that the range had been uplifted along its eastern edge and tilted to the west. An alternative assumption, which is inherently as probable, is that the bottom of Saline Valley has been subsiding. The further fact that some of the streams flow eastward from broad flats that extend to the brink of the escarpment facing Owens Valley and the pronounced easterly inclination of the basalt plateaus north of Deep Spring Valley indicate that in places at least the range received an easterly tilt when it was blocked out.

The escarpment of the Inyo Range facing Saline Valley displays a remarkable development of triangular facets, so recently formed that the new talus cones are just starting to accumulate along the base of the precipitous slope. (See Pl. XXI.) The canyons in the eastern flank are acutely V-shaped in their lower courses and at their mouths are mere slits in the bedrock. For example, Hunter Canyon narrows at its mouth to a bedrock gorge 20 or 30 feet wide with walls that rise sheer for several hundred feet, the south wall being in fact actually vertical. From an altitude of 1,500 feet up to 5,000 feet the canyon is a narrow, impassable rock sluice, but above 5,000 feet it is relatively open.

A noteworthy feature of the geology of the escarpment facing Saline Valley is the severely crushed condition of the rocks. The granite at the mouth of Willow Creek crumbles easily under slight pressure of the hand and is so unlike normal granite that it is unrecognizable as such at a distance, resembling rather the soft deposits of white Tertiary lake beds. Profoundly brecciated rocks occur also near Hunter Canyon. Similar crushing and shattering were noted by Fairbanks[3] along the west flank of the Panamint Range, another Great Basin range, which lies east of the Inyo Mountains. The topographic forms resulting from the weathering of the crushed crystalline rocks resemble those produced by the erosion of unconsolidated deposits.

OWENS VALLEY.

All the evidence points to the conclusion that Owens Valley is a great tectonic trough, whose floor has subsided along a series of parallel faults. The subsidence has been neither uniform nor equal, and partial rotation has affected the block comprising the bedrock floor of the valley. An epitome of the geologic and structural features of the valley is shown in figure 5, which is drawn without vertical exaggeration. The profile, extending from the summit of Mount Whitney northeastward across Owens Valley to the summit of the Inyo Range, illustrates the character of the valley where its troughlike form is most pronounced. Furthermore, the great triangular facet terminating the spur between Lone Pine and Hogback creeks slopes at an angle of 28° and is steeper than any other in the valley with the possible exception of the wall west of Round Valley.

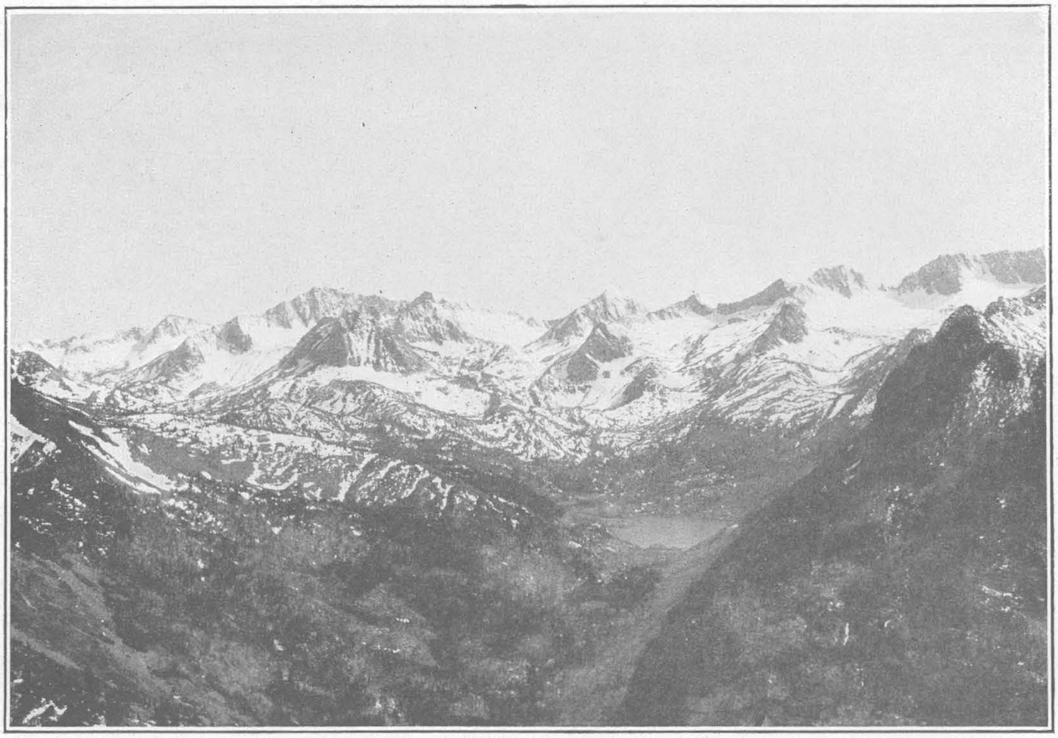
The positions of the faults along the bases of the confining mountain ranges are conjectural, but the positions of the two west of Owens River are indicated in the field by alluvial scarps. The line of the profile crosses the Alabama Hills, the prominent range of hills

[1] Fairbanks, H. W., Notes on the geology of eastern California: Am. Geologist, vol. 17, p. 66, 1896.

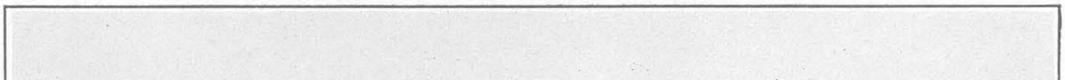
[2] Walcott, C. D., op. cit., p. 346.

[3] Idem, p. 67.

EAST FAULT SCARP OF THE INYO RANGE, FACING SALINE VALLEY.



A. CIRQUES AT HEAD OF SOUTH FORK OF BISHOP CREEK.



B. HEAD OF NORTH FORK OF BISHOP CREEK.

lying west of Lone Pine, and effectively brings out their insignificance compared to the main mass of the Sierra Nevada. The opinion prevalent in Owens Valley that the Alabama Hills are the "oldest hills in the world" is in no respect tenable, either as to the age of the rocks composing the hills or as to the age of their uplift as a range. This opinion is probably fostered by the peculiar and fantastic weathering of the granite that makes up a large part of the hills, because this weathering lends them an ancient appearance in contrast to the Sierra Nevada. The fact that Lone Pine Creek flows across the range, which appears to have risen athwart its course, and the recent fault scarps that parallel its eastern front indicate that the Alabama Hills are of recent origin.

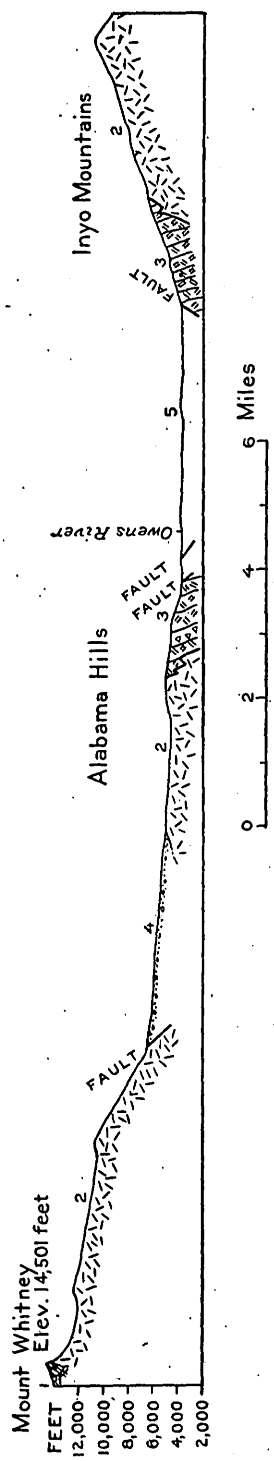


FIGURE 5.—Diagrammatic section across Owens Valley, from the summit of Mount Whitney to the summit of the Inyo Range, Cal. 1, Aplite; 2, quartz monzonite; 3, Triassic andesites and rhyolites; 4, alluvial wash; 5, lake beds.

OWENS LAKE

TECTONIC ORIGIN OF THE BASIN.

The origin of the depression in which Owens Lake rests is a problem of some interest. The explanation most strongly suggested by the unequal subsidence and partial rotation of the fault blocks that make up the bedrock floor of Owens Valley and by the repeated movements along the faults is that the lake basin is of tectonic origin. In direct support of this explanation is the fact that along the west side of the lake the basal slopes of the spurs of the Sierra Nevada escarpment, notably those between Ash and Braley creeks, are oversteepened very conspicuously and to unusually great heights. So recent has been the faulting to which this oversteepening is due that talus cones of granite sand have hardly begun to accumulate, in which respect the part of the escarpment west of Owens Lake contrasts strongly with other parts farther north, as near Division Creek, where the talus cones extend up the flank of the range for 1,500 feet above the stream alluvium. In conformity with the recent faulting indicated along the west side is the fact that the axis of greatest depth of the lake lies close to the west shore, as shown by the contours of the lake bottom.[1] This is the more noteworthy, as the great alluvial cones building out from the Sierra Nevada must tend to encroach rapidly upon the lake from that side.

THE OLD BEACH LINES.

Owens Lake is surrounded by old beaches, which are locally well defined. They are best developed near Swansea, east and southeast of Keeler, south of the lake, and along the front of the Alabama Hills. The remnants of the higher strand lines are only small fractions of their former perimeters. The highest of the old shore lines is also the most conspicuous because of its prominent shore cliffs. The altitude of the highest beach east of Keeler, as determined by aneroid measurements by the writer, is 3,800 feet. The old shore line is marked by alluvial scarps 30 feet high, which represent sea cliffs whose steepness has been much modified by slumping. In altitude this beach responds well within the limits of the accuracy of the measurement to the well-marked beach along the front of the Alabama Hills, whose altitude has been precisely determined as 3,790 feet,[2] or 220 feet above the level of Owens Lake, in

[1] Gale, H. S., Salines in the Owens, Searles, and Panamint basins, southeastern California: U. S. Geol. Survey Bull. 580, pl. 6, 1914.

[2] Lee, C. H., U. S. Geol. Survey Water-Supply Paper 294, p. 73, 1913.

February, 1913. Remnants of another beach, 100 feet below the highest beach east of Keeler, are marked by a much-softened sea cliff 30 to 40 feet high. The altitude of this beach—3,700 feet—corresponds with that observed at the old smelter site southeast of Swansea. (See p. 58.) The rapid outward growth of the alluvial cone that followed upon the recession of the water of the lake has nearly obliterated the 3,700-foot beach. A finely developed beach terrace occurs about 30 feet below the 3,700-foot water level, as determined near Swansea by Gale.[1]

Some lower beaches can also be recognized, but they seem to record very minor stands of the old water level, especially as compared to the two highest beaches, at 3,700 and 3,800 feet.

In connection with the tracing of the old beach lines it is probable that a strand line may have different altitudes on the east and west sides of Owens Valley on account of faulting that has taken place since the lowering of the lake waters, the intensity of which may be gaged by the 25-foot high scarps produced during the earthquake of 1872.

The southern rim of the lake at the time of its maximum expansion was the broad alluvial divide between Owens Valley and Rose Valley on the south. The alluvium, consisting of coarse bouldery granite wash derived mainly from the Sierra Nevada on the west, is spread over the irregularly eroded edges of the lake beds, which here consist of soft gray shales and of rhyolite pumice in beds, some of which are 30 feet thick. The lake overflowed the alluvial barrier and cut a well-defined channel, which shows a terrace near the north dam of the Haiwee reservoir. The altitude of the divide in the floor of the channel is 3,760 feet, 30 feet below the highest level of the old lake. That the overflow was of considerable duration is indicated by the deep channel that the stream cut into an andesite (or latite) flow extending across the valley south of the divide. The surplus waters from Owens Lake emptied into a system of lakes that filled Searles and Panamint basins and probably overflowed into Death Valley. The details of this interesting history and their bearing on the accumulation of saline deposits have recently been described by Gale.[2]

The petrographic character of the rocks that formed the bedrock dam of Owens Lake at its maximum expansion has some bearing on the probable length of time since the lake last ceased to overflow. From the amount of sodium and chlorine accumulated in the lake Gale[3] has estimated this to be about 4,000 years. This computation rests on the tacit assumption that the bedrock basin of the lake is and has been water-tight and that evaporation alone has balanced the inflow.

Porous tuffs and breccias of rhyolite pumice formed, however, an important part of the bedrock dam of the ancient lake, and these, unless naturally puddled by silt carried in suspension, would probably permit a considerable subsurface flow. That this is no unreasonable supposition was proved when the Haiwee reservoir began to fill in 1913. The east abutment of the south dam, composed as it was of rhyolitic strata, leaked freely and copious springs issued along its base. If at the time of the lake's expansion such a subsurface flow took place, it is probable that the estimate of 4,000 years for the latest stage in the lake's history is a minimum.

One other point must be referred to. Although the study of the glaciation of the adjacent Sierra Nevada has established the occurrence of two glacial epochs, no evidence has been found to show that Owens Lake underwent two expansions, as seems demanded by the close parallelism between the glacial and lacustral history of the Great Basin. Possibly the evidence of the earlier expansion has been destroyed, or, on the other hand, the lake, which fills a shallow depression produced by the displacement of a fault block, may not have been in existence during the earlier glaciation.

GLACIATION.

DISTRIBUTION.

The canyons in the eastern slope of the Sierra Nevada have been heavily glaciated. No evidence of ice action has been found in

[1] Gale, H. S., Salines in the Owens, Searles, and Panamint basins, southeastern California: U. S. Geol. Survey Bull. 580, p. 256, 1914.

[2] Idem, pp. 251–323.

[3] Idem, p. 264.

the southern part of the Inyo Range, though traces of glaciation occur on the east side of its extreme north end.[1]

SIERRA NEVADA.

GENERAL GLACIAL FEATURES.

Two epochs of glaciation are recognized on the Sierra Nevada escarpment. The earlier of these was much the greater; its ice streams were much thicker, and, as shown by its extensive moraines, it endured much longer. Moreover, its glaciers reached lower altitudes than those of the second glaciation, some certainly having descended to an altitude of 5,000 feet and probably to 4,500 feet. Some of those that descended lowest reached the mouths of the canyons and probably deployed to some extent on the alluvial cones flanking the range.

Many glaciers, however, did not reach the mouths of their canyons, and in consequence many canyons show profound contrasts between their glaciated upper portions and their unglaciated lower portions. The lower stretches of the great canyons are deep clefts that are no wider at their bottoms than the streams incising them, whereas the glaciated upper portions are wide floored, with grassy parks or lakelets on the treads of the "giant stairways" by which the glacial canyons, bordered by sheer walls, descend from the summit of the range. The situation of the canyons on the great escarpment has emphasized in a remarkable way the contrast between the qualitative effects of glacial and stream erosion.

The study of the glaciation of the east slope of the Sierra Nevada insistently calls for criteria by which alluvial-cone deposits can be discriminated from morainal or other glacial deposits. Deposits of the two types are in juxtaposition at many localities along the front of the range, and in places they even overlap. Field work shows that along the eastern flank of the Sierra Nevada the two types are extraordinarily alike and that the only unimpeachable evidence of the glacial origin of any particular deposit is the presence of striated and faceted pebbles. As the morainal deposits consist predominantly of granitic rocks, which soon lose glacial polish and striae, striated pebbles are scarce and the difficulty of discriminating the deposit is much enhanced. Curiously enough it was found that the presence of well-rounded waterworn cobbles and pebbles scattered sporadically through angular, unsorted, unshingled, bouldery accumulations often served as a clue, if not a proof, of glacial derivation. Such isolated waterworn cobbles, evidently the products of fluvioglacial streams, were seen at many localities, as noted in the local descriptions in the following pages.

[1] Turner, H. W., The Pleistocene geology of the south-central Sierra Nevada, with especial reference to the origin of Yosemite Valley: California Acad. Sci. Proc., vol. 1, 3d ser., No. 9, p. 274, 1900.

EVIDENCES OF GLACIATION.

BISHOP CREEK.

Older glaciation.—A large area lying between Bishop Creek and Birch Creek (in the Mount Goddard quadrangle), extending from the mouth of Bishop Canyon at an altitude of 5,000 feet up to 9,700 feet, is underlain by coarse gravels of the older epoch of glaciation. Good sections of these gravels are exposed along Bishop Creek and in the numerous excavations for the pipe lines of the hydroelectric power company using the water of Bishop Creek. The material is an unsorted and unstratified accumulation of angular boulders of granite, with some quartzite, schist, and basalt. The general topographic aspect of this deposit is that of smooth, rounded ridges, but a view from a commanding point between Bishop and Birch creeks, north of power station 3, leaves no doubt as to the morainal character of the deposit, for it shows the original series of curved, parallel morainal ridges, still fairly preserved, owing to the arid climate of the lower slopes of the range.

The gravel sheet once extended continuously across Birch Creek, as shown by the long, narrow remnant on the north side of that stream. As Birch Creek is intrenched in the gravels to a depth of 200 to 500 feet, its canyon affords a rough measure of the time that has elapsed since the older glaciation. The intrenchment, however, was interrupted by a pronounced halt, shown by a well-defined terrace approximately 75 feet high and 75 feet wide that extends for a mile along the south side of Birch Creek at an elevation of about 6,000 feet above sea level. The development of this terrace is ascribed to the second epoch of glaciation. This part of Birch Creek was far below the limit of the second ice advance, the thick undissected moraines of which extend down to an altitude of 8,400 feet only. Below these moraines a narrow outwash apron extends down to 7,600 feet, beyond which the stream is deeply intrenched, having cut not only through the older glacial gravels but also a bedrock gorge nearly 100 feet deep.

After the maximum stage of the first glacial epoch the stream proceeded to sink its channel in the glacial gravels and excavated a valley at least 125 feet deep. At this stage the second glacial epoch supervened; the stream became heavily loaded, and even overloaded, as shown by the deposition of the outwash plain, and at the lower limit of the outwash plain it began to meander and to widen its valley. This widening continued until the close of the second glacial epoch, when the stream, becoming underloaded, again began to dissect its valley and to cut a trench now approximately 75 feet deep.

According to this interpretation, the excavation of the older valley above the terrace platform affords a rough measure of the duration of interglacial time; the development of the terrace platform a measure of the second glacial epoch; and the incision of the present canyon a measure of postglacial time. If the relative amounts of downcutting during interglacial and postglacial time are compared, from the rough data at hand and on the assumptions that the distance across the top of the older valley coincides with the original surface of the moraine (which seems a fair assumption), that no important aggradation or degradation except the widening of the valley took place during the second glacial epoch, and that the average rates of erosion during interglacial and postglacial time were equal, it appears that interglacial time was three to five times as long as postglacial time.

Later glaciation.—At about 6,400 feet (power station 3), the valley of Bishop Creek changes abruptly, becoming rounded and troughlike and less steep. Glaciated bedrock makes its appearance; embankments, which are obviously lateral moraines, flank its sides, and small recessional moraines occur at intervals.

The younger lateral moraines on the north side of the canyon are best developed, the main one forming a nearly continuous embankment 700 feet high. Its crest is narrow and is strewn with boulders. A moraine of the same height occurs discontinuously on the south side of the stream and extends up South Fork. It has in places caused high-level alluviation behind it, a geomorphic feature sufficiently pronounced to show on the topographic map. Some of this alluviation, however, may have taken place during the first epoch of glaciation; indeed, the considerable drainage modification on the south side seems more likely to be correlatable with the older glaciation.

The main lateral moraine on the north side of the canyon slopes down abruptly at power station 3 (altitude 6,400 feet), but the terminal moraine here is almost insignificant. Well-defined moraines lie on the flank several hundred feet below the crest of the main moraine, sloping down and looping across the canyon to form a number of recessional moraines—at 7,500, 8,000, and 8,400 feet. It is therefore evident that the glacier did not retreat continuously but made a number of sustained halts. Moreover, it persisted longer in Middle Fork than in South Fork, for the lateral moraine on the south side of Middle Fork extends across the mouth of South Fork. This longer persistence of the ice stream in the canyon of Middle Fork is manifestly in consonance with the fact that the Middle Fork glacier had the greater number of tributaries, most of which headed against the main divide, and which thereby provided Middle Fork with the larger alimentation.

The moraines referred to the second glacial epoch differ most obviously from the older morainal deposits against which they lie in being clearly the work of a recently vanished glaciation of alpine character. Their form and position stamp them at once as of glacial origin, and their perfect preservation and the intact character of their constituent boulders attest their recent origin.

Headwater region.—The canyon of South Fork of Bishop Creek is a splendid **U** trough, 2,500 feet deep. Its general trend is meridional, although slightly sinuous. It much resembles the Kern Canyon, although lacking the notable straightness of that canyon, but like Kern Canyon it is a great trench sunk 2,500 feet into a remnant of the high valley zone. South Lake (see Pl. XXII, *A*) is near its head.

The insignificant moraines on South Fork—small lateral moraines only—contrast strongly with the extensive moraines on the lower course of Bishop Creek. Yet all the evidence points to intense glacial erosion on South Fork and to relatively little on Bishop Creek. Facts of this kind enforce the conclusion that moraines in U canyons are chance products of glacial erosion, dependent for their construction and preservation on the rare simultaneous occurrence of many favoring circumstances.

At the head of North Fork is Piute Pass, through which a trail crosses over to the westward-flowing waters of the San Joaquin. This pass (see Pl. XXII, *B*) is a striking example of a deep gap that has been cut through the main divide by the headward erosion of two ice streams until the wall separating their cirques was completely obliterated.

BAKER CREEK.

Moraines deposited by glaciers originating in the headwater tributaries of Baker Creek can not be certainly identified below 9,400 feet. Below this altitude the deep rugged canyon of Baker Creek bears no evidence of having ever been occupied by an ice stream. The thick sheet of old morainal gravels forming a mantle on the divide between Baker Creek and Big Pine Creek to the south seems to have been brought mainly by the great glacier that came down Big Pine Creek.

In places the base of these morainal gravels is 1,000 feet above the bottom of the canyon of Baker Creek; downstream the base approaches nearer to the stream until, near the mouth of the canyon, it rests on a bedrock bench 450 feet above the creek. From here the morainal gravels gradually merge with the alluvial cones on the flank of the range.

These gravels, which occur only on the south side of the creek, overlook the brink of a canyon whose wall slopes 30°. They consist of an unsorted and unstratified deposit of angular blocks 6 to 8 feet long, mainly of coarse white granite and biotite-augite diorite, scattered through which is a small but striking proportion of thoroughly waterworn cobbles.

Moraines positively referable to glaciers from the cirques at the head of Baker Creek do not extend below an altitude of 9,400 feet. On the north side of Baker Creek a broad moraine of the earlier glaciation, 300 feet high, extends as a free embankment from 9,500 up to 10,500 feet. It has an extremely smooth even top, evidently due to the considerable disintegration of its component boulders. The blocks of white granite, commonly 6 feet in diameter, are almost wholly embedded in granite sand, projecting as a rule only a few inches above the surface. Corresponding moraines occur on the south side of Baker Creek and on the south side of the south tributary of Baker Creek. Here the contrast between the older and younger moraines is particularly impressive. The younger moraine is superposed on the older, from which it is easily distinguished, as the older contains a large amount of biotite-augite diorite and of white granite which has been rendered inconspicuous by the products of its own disintegration, and the younger is composed wholly of white granite which as a rule is brilliantly fresh.

The lateral moraine of the second epoch of glaciation is excellently defined on the south side of Baker Creek, extending down to an altitude of 9,400 feet and looping across the valley as a terminal moraine. Behind this is a small pond, and in front a small steep outwash apron, below which begins the deep bedrock gorge of Baker Creek—features indicative of the youthfulness of the topography produced by the second glaciation.

The glacier of the second epoch occupied nearly the whole width of the valley between the morainal ridges of the earlier epoch for a short time only, as indicated by the small lateral moraines along the side of the older. It then shrunk to a far narrower stream and in this condition persisted much longer, as indicated by the comparative sizes of the moraines. During its final retreat it was subject to numerous halts and minor readvances, as shown by a complex and rather confused system of small moraines.

The total amount of morainal material laid down during the second glacial epoch is small in comparison to that deposited during the first. From this may be drawn the deduction that though the morainal ridges of the earlier glacial epoch can not be traced lower than 9,400 feet (to which level the later glacial advance also extended) they probably really extended considerably lower. It seems the more reasonable to suppose this from the fact that the glaciers of the earlier epoch are known definitely to have descended to considerably lower altitudes on Bishop and Big Pine creeks than did the glaciers of the later epoch. The great sheet of morainal gravels covering the divide between Baker and Big Pine creeks may therefore be in part the deposit of a glacier from Baker Creek.

If the deduction is valid that the earlier glacier extended down the canyon of Baker Creek it follows from the great revolution in the topography, from the complete destruction of all other evidence of this ice advance, and from the replacement of the characteristic U-shaped valley by the present sharp V-shaped gorge, that the age of the earlier glaciation is very considerable. This is in consonance with the evidence offered by the advanced disintegration of the older moraines, but in the opinion of the writer it is far more convincing.

CIRQUES NORTHWEST OF BAKER CREEK.

A number of small cirques, notable for their symmetry, indent the upland surface northwest of Baker Creek. They are well shown on the map of the Mount Goddard quadrangle. Although these cirques are very small compared to others in the region the moraines associated with them are disproportionately large. In fact, the moraines appear to be roughly equal to the volumetric capacity of the cirques. This equivalence is manifestly due to favoring topographic conditions. The cirques open on a broad plain and this has evidently caused the small glaciers that deployed upon this plain to deposit most of their detritus and has prevented its removal by glacial streams.

These moraines show that relatively large moraines may be produced by the erosion of small cirques, that a favorable locus of deposition is necessary for the formation of moraines, and that the volume of a moraine does not necessarily give quantitative data on the amount of glacial erosion.

BIG PINE CREEK.

Older moraines.—The most extensive of the older moraines are on Big Pine Creek. The glacier of the earlier epoch here descended, as shown by evidence of the most emphatic kind, to an altitude of 5,000 feet, the lowest descent so far discovered on the east flank of the Sierra Nevada. Probably it flowed down to 4,500 feet, though the evidence for this is not unequivocal, and it may have even extended somewhat lower.

A thick sheet of morainal gravels mantles the divide between Big Pine and Baker creeks and extends continuously from 10,500 down to 4,500 feet, where it merges with the alluvial cone flanking the range, as already partly described. A thickness of 600 feet is indicated in places.

The morainal gravels of the older epoch, as exposed between 4,500 and 5,000 feet, near their juncture with the alluvial cone, are unsorted and unstratified and contain numerous boulders of rotted granite, the largest 5 feet in diameter. Some poorly striated pebbles were found, without which it would be impossible to decide as to the alluvial-cone origin or glacial derivation of the gravels. At an altitude of about 5,000 feet, just below the bridge over Big Pine Creek, unimpeachable evidence of former glaciation was found on a large outcrop of granite cut by aplite dikes, which projects through the gravels. The granite, although much affected by exfoliation and disintegration, still retains a broad, finely polished surface, and the aplite shows polished surfaces abundantly striated. These polished and striated surfaces are the only ones found along the east flank of the Sierra that are referable to the earlier epoch of glaciation, and their preservation at this locality is undoubtedly due to the recency with which they have been uncovered by erosion and subjected to weathering.

The gravels consist mainly of granitic material, with some basalt of vesicular, augitic, and olivinitic facies. The basalt fragments are of peculiar importance in deciphering the glacial history of the region, for they are practically the only kind found in the moraines that retain glacial striae. No basalt occurs in the moraines of the later glacial epoch, and no basalt can be found in place within the drainage basin of Big Pine Creek, indicating that possibly the intense glacial activity of the earlier epoch completely covered or removed all basalt flows of preglacial age.

Granite blocks, at least 25 feet long and 15 feet thick, occur in the gravels, but those 6 feet in diameter are most common. Many of the large granite blocks lying on the surface of the moraines have been disrupted by insolation and show an astonishing evenness of fracture planes. In size and in evenness of fracture they compare with those from the Ethiopian Range described by Walther.[1]

Sorted or rounded gravels are not conspicuous, but sporadic water-worn pebbles and cobbles are associated with the angular material that makes up the bulk of the moraine.

The gravels have lost the topographic aspect of moraines. They have, moreover, been considerably dissected by erosion, as is best shown in the foothills between Big Pine and Baker creeks. Gulches, several hundred feet deep, have here cut back into them and afford fine sections of the deeper lying gravels. These cuts show in an impressive way the marked disintegration of the constituent boulders of the moraine, the extent of which would not be fully appreciated from examination of the general surface features of the old moraine. Many boulders, as much as 5 feet in diameter, are so disintegrated that they crumble under the fingers. They are, as it were, mere disintegration pseudomorphs after the original boulders. In composition they are granitic, but fortunately sporadic pebbles of basalt are associated with them, some of which retain glacial striae, thus establishing beyond doubt the morainal character of the gravels.

Later glacial records.—Two lateral moraines referable to the later glaciation lie on Big Pine Creek on the north side of Sage Flat. The crest of the lower is 400 feet above the flat, as measured at the upper end, and the higher is 550 feet. The upper moraine, which is particularly well marked, consists of large angular granite boulders, and contrasts strongly with the older moraines, upon which it rests to the north. Boulders of the same granites in the older moraine have neither the sharp angularity nor the brilliant freshness that distinguish the boulders on the lower moraines; they have taken on an orange tint and are not uncommonly pitted with irregular cavities, and in other respects are notably different. The older morainal sheet here extends to a height of 1,100 feet above Big Pine Creek, just double the height of the lateral moraines of the later glaciation.

From an altitude of 6,800 feet, the lowest limit of the later glaciation, a broad alluvial terrace extends downstream. Apparently a thick mass of outwash gravel was laid down beyond the front of the glacier, and into this deposit postglacial erosion has caused the present stream to sink its channel to a depth of 75 feet.

Toward the head of Big Pine Creek the glacial character of the canyon is more and more pronounced. The series of six stepped tarns on the headwaters of North Fork afford a fine illustration of the peculiarities of ice erosion. The lake basins, each lying behind its rock barrier, are clearly, as John Muir phrases it, eroded from the solid. They also show, in a highly convincing way, the strong local control that is exercised on glacial sculpture by jointing.

The headwater basin of North Fork, with its encircling ridges, suggests a huge relatively shallow cirque, below the general level of whose floor are sunk deep glacial troughs, each stepped with rock-rimmed tarns and each heading in its own cirque. This peculiar relation suggests that the large cirque has resulted from the erosive work of the earlier glaciation, and that the entrenchment of the relatively narrow troughs and the cirques in which they head is the work of the later glaciation. The hypsometric position of the earlier moraine—that is, the fact that its up-valley end lies 1,500 feet above the present valley floor—also seems more in harmony with this supposition, which carries with it the conclusion that this moraine was deposited by a glacier occupying a channel whose floor was considerably higher than that of the present valley.

BIRCH CREEK.

On Birch Creek,[2] the next large stream south of Big Pine Creek, the contrast between the older and younger moraines is well shown. The gravels of the earlier glaciation extend down to 7,000 feet; those of the later down to 7,500 feet. A series of thick moraines lying

[1] Walther, Johannes, Das Gesetz der Wüstenbildung, 2d ed., pp. 132, 133, 1912.

[2] There are two Birch creeks in the Bishop quadrangle. This is the southern.

within the lateral moraines marking the farthest advance of the last glaciation gives evidence that the retreat was interrupted by distinct halts.

RED MOUNTAIN AND TABOOSE CREEKS.

Well-defined moraines, which, owing to their undissected condition are referred to the later glaciation, do not extend below an altitude of 7,500 feet on Red Mountain Creek. But at the mouth of the canyon a deposit of coarse glacial gravels, extending down to 6,500 feet, seems referable to the earlier glaciation. It is noteworthy, as affording some measure of the time that has elapsed since the earlier glaciation, that the stretch of canyon between the upper and lower deposits of morainal gravels retains no evidence of having ever been occupied by ice.

At the mouth of the canyon of Taboose Creek a deposit of gravels that extends out upon the great piedmont alluvial cone down to an altitude of 5,700 feet seems referable, like that at the mouth of Red Mountain Creek, to the earlier glacial epoch. The lowest altitude at which unequivocal evidence of ice action was found, in the shape of polished bedrock, is 6,200 feet.

SAWMILL CREEK.

The glacial features on Sawmill Creek are unusually interesting in that a portion of the glacial history can here be linked with a chapter in the volcanic history of the region. And, furthermore, among all the profound canyons incised in the great escarpment of the Sierra Nevada, none shows in more impressive fashion the striking contrast between its glaciated and unglaciated portions.

A flow of basalt, accompanied by some cinders, was emitted in the canyon at an altitude of 7,800 feet and flowed down to its mouth at 5,000 feet. The basalt and cinders partly cover an old lateral moraine, probably of the earlier glacial epoch. Farther downstream the lava flow is itself covered by the superb lateral moraine that is so prominent on the north side of this part of the canyon, and that, from its ideal preservation, is obviously a product of the later glaciation. It extends down to an altitude of 6,500 feet. The contact with the underlying basalt is in places well exposed, and where examined unexpectedly showed that the scoriaceous crust of the lava sheet had neither been smoothed nor striated.

In the stretch of canyon below the moraine the basalt flow has been largely removed by erosion, but in places some of it still remains welded to the canyon walls. (See fig. 6 and Pl. XXIII, *A*). The flow, which was about

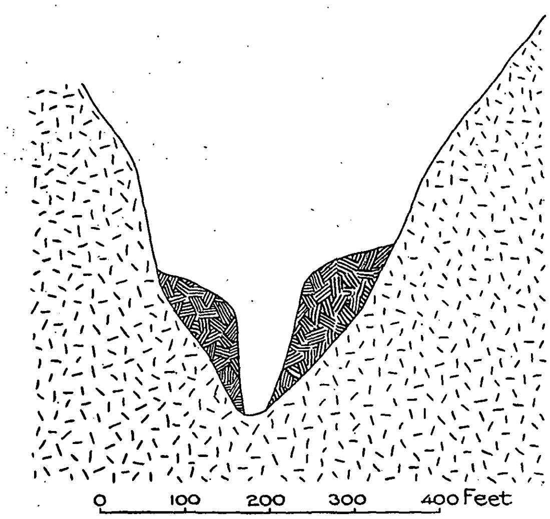
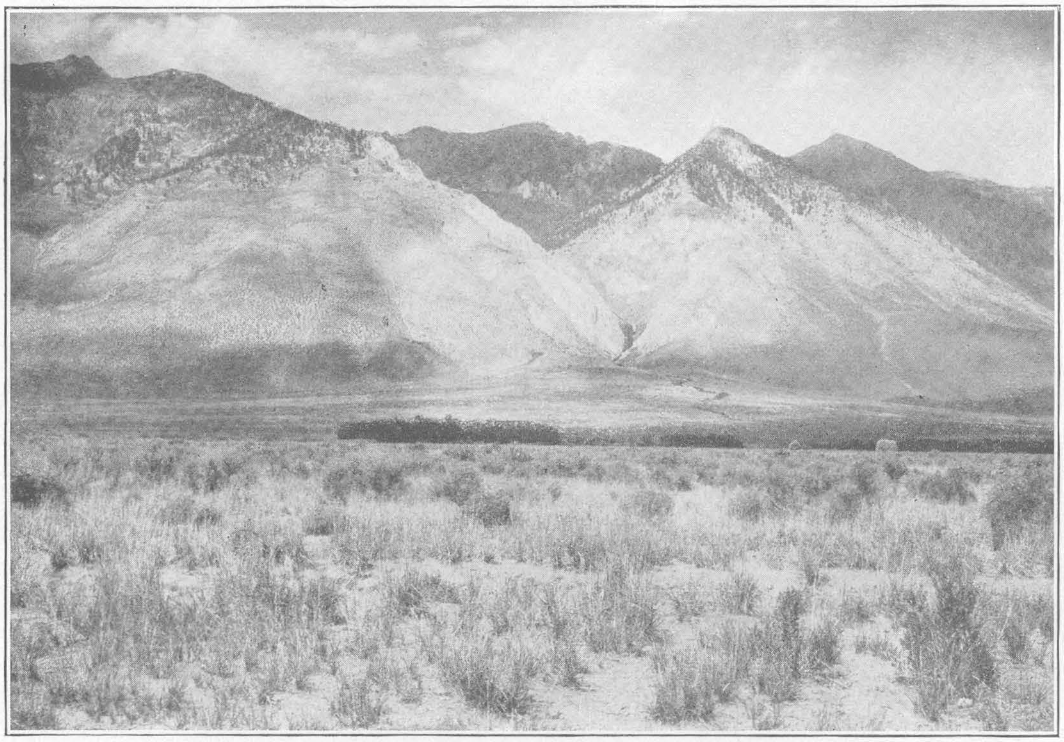


FIGURE 6.—Dissected flow of basalt in the bottom of Sawmill Canyon, Cal.

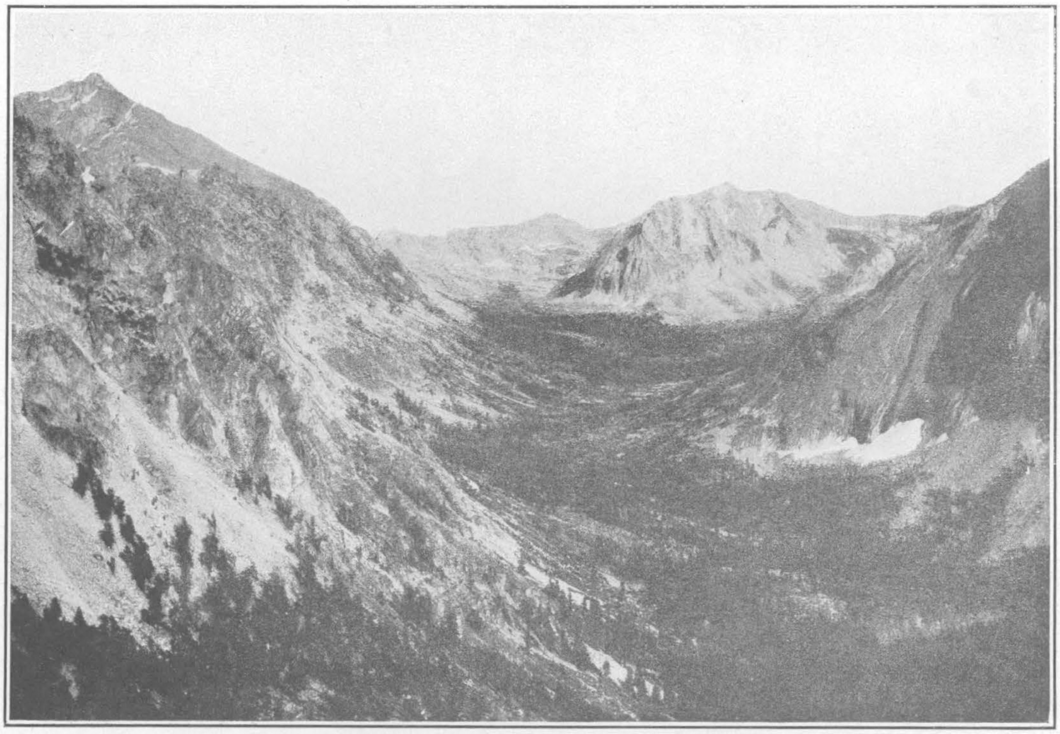
200 feet thick, has been completely cut through. The eruption of the basalt flow and the slight ejection of the cinders was, in the nature of things, a paroxysmal event and occupied only a brief geologic moment, probably during interglacial time. The dissection and nearly complete removal of its 200 feet of thickness required, however, a considerable lapse of time since eruption, though it must be conceded that the flow, filling the bottom of a profound canyon, occupied a site of most intense erosive activity.

OAK CREEK.

Patches of old moraine belonging to the earlier glacial epoch rest upon the basalt that occurs on the south side of North Fork. The basalt is therefore older than that on Sawmill Creek, which is probably of interglacial age, and is to be correlated with that on the south side of Bishop Creek and that represented by the large quantities of débris in the old moraines on Bishop and Big Pine creeks. The basalt of North Fork flowed out over the allu-



A. BASALT FLOW IN BOTTOM OF SAWMILL CANYON.



B. BUBBS CANYON, MOUNT WHITNEY QUADRANGLE.

vial cone, and thus recorded the fact that the cone had attained essentially its present dimensions in prebasalt time and consequently in preglacial time. As the alluvial cone was almost wholly built in preglacial time, its material was not furnished by glacial erosion. Trowbridge,[1] on theoretic grounds, had regarded the upbuilding of the alluvial cones as due largely to rapid supply of débris furnished by glacial erosion.

The largest remnant of morainal gravel of the earlier glaciation caps the basalt ridge at an altitude of 7,200 feet, about 500 feet above the present stream.

The well-preserved lateral moraines of the later glaciation descend on North Fork to 6,500 feet. The breaching of these moraines caused the deposition of gravels and boulders in the valley cut in the alluvial cone.

Both sides of the north branch of South Fork are flanked by fine moraines which terminate downstream at an altitude of 7,300 feet. A remnant of an older moraine extending farther downstream is found here also.

INDEPENDENCE CREEK.

Well-developed lateral moraines, which from their degree of disintegration seem referable to the earlier epoch of glaciation, extend down to the mouth of the canyon of Independence Creek at an altitude of 6,400 feet. Two miles below the end of the moraines, at an altitude of 5,200 feet, a puzzling feature appears. A knob of felsitic porphyries and breccias, which projects through the alluvial cone to a height of about 100 feet, bears, perched well up on its side, erratic granite boulders, some of which are 15 feet in diameter and are comparatively well preserved. If they were carried there by ice, which, indeed, seems the simplest explanation of their anomalous position, the glacier must have descended 2 miles upon the piedmont alluvial slope. Of this advance, however, no other evidence was obtained, and the problem suggested by this discovery must await a more detailed study.

LONE PINE CREEK.

From 8,000 feet up, the canyon of Lone Pine Creek is an open U trough, whose floor is stepped by a number of "cyclopean treads"; below 8,000 feet, to the mouth of the canyon at 6,500 feet, the canyon is a deep, narrow gorge.

Fine lateral moraines, 300 feet high, belonging to the last epoch of glaciation, extend down to about 7,500 feet. Although the stretch of canyon below this fails to show, either by glacial scorings or by its configuration, any clear evidence of having been occupied by ice, nevertheless morainal material extends along its sides down to its debouchure on the piedmont slope. These older gravels are best preserved on the south side of the canyon, for only small remnants are left perched on the precipitous walls of the north side. They consist largely of coarse angular blocks of the porphyritic variety of quartz monzonite—that is, studded with large crystals of orthoclase—and are much disintegrated. Coarse angular unsorted material, consisting of blocks as much as 10 feet in diameter, makes up the bulk of the gravels, but, like other morainic material in the region, they contain sporadic small well-rounded pebbles.

The height attained by the gravels, at the very mouth of the canyon, is 500 feet above the present stream, a fact from which some noteworthy inferences can be drawn. The glacier, having had so considerable a thickness at the mouth of the canyon, probably extended some distance out on the alluvial cone; and, it seems reasonable to infer, would have built itself a terminal moraine commensurate in size with the lateral moraines. But no vestige of one now remains.

Lone Pine Creek has cut a bedrock sluice 100 feet deep into what appears to have been the general level of the floor of the canyon in early glacial time. The depth of this incision may possibly afford a measure of the time that has elapsed since the early glaciation,[2] but as channels incised in canyon floors by subglacial streams are common in the Sierra Nevada it is not always possible to evaluate accurately the amount of downcutting ascribable to postglacial erosion.

DIAZ CREEK.

Evidence of only the later epoch of glaciation was obtained on Diaz Creek. The cirques

[1] Trowbridge, A. C., Terrestrial deposits of Owens Valley, Cal.: Jour. Geology, vol. 19, p. 745, 1911.

[2] Knopf, Adolph, Sketch of the geology of Mineral King: California Univ. Dept. Geology Bull., vol. 4, p. 234, 1905.

are well developed. The moraines, which are relatively large in view of the small gathering grounds, terminate downstream at an altitude of 8,400 feet. The lack of evidence of the older glaciation seems to be due to the fact that in such short, steep canyons as that of Diaz Creek the intense erosive activity soon obliterates all records of glacial occupancy, carrying away even the moraines that had been deposited along the steep sides of the narrow canyon.

COTTONWOOD CREEK.

Great symmetrical cirques and strings of glacial tarns—the Cottonwood Lakes—distinguish the headwaters of Cottonwood Creek. The main ice stream, despite its considerable gathering ground, descended to an altitude of 9,000 feet only. Extensive morainal deposits, well shown on the trail to Cottonwood Pass, were spread out.

On the south side of Horseshoe Meadow is a moraine—the southernmost in the range—which because of its deeply disintegrated condition is referable to the earlier glacial epoch.

Twelve miles farther south, on the north flank of Olancha Peak, a small cirque, at an altitude of 10,500 feet, has a form that is characteristic of glacial origin, but whether it is really such was not investigated. This theater-like indentation near the summit of Olancha Peak marks the southernmost point in the range at which any evidence whatever that points to former glacial conditions has been found.

EVIDENCE OF GLACIAL EROSION.

It is purposed to assemble here some of the evidence that is afforded by this part of the Sierra Nevada on the problem of glacial erosion. Evidence in regard to the destruction of mountain crests by cirque sapping, which is displayed on an extraordinarily grand scale along the main divide, has been so ably marshaled by Lawson[1] that further discussion of this phase of the problem is unnecessary.

STEPPED CHARACTER OF THE GLACIATED CANYONS.

The most notable feature of the glacial sculpture of the region—a feature that the ascent of any of the canyons in the great escarpment of the Sierra Nevada impresses forcibly upon the observer—is the strong contrast between the lower unglaciated stretches of the canyons and the upper glaciated portions. Such contrasts are displayed in especially impressive fashion on Sawmill and Shepard creeks.

The glacial remodeling of a canyon on the eastern Sierra Nevada flank has transformed it from a deep, narrow gorge into a wide-floored valley of gentle grade, and this contrast is extraordinarily augmented by great transverse cliffs 500 to 800 feet high that rise at intervals almost vertically athwart the valley, each seemingly forming the valley head. By these abrupt rises the floor of the valley is given a stepped character; it has been converted, to use Russell's phrase, into a "cyclopean stairway"—a rather rough hewn stairway, it is true, but nevertheless so manifestly a stairway that the characterization is in general strikingly apposite.

The radical change from the normal profile of the canyon floors to the stepped condition of the glaciated canyons indicates that a large amount of glacial erosion has taken place. Fortunately the region furnishes examples both of glaciated and unglaciated canyons, so that a basis for determining the amount of this erosion is available. The longitudinal profiles of unglaciated canyons are steep but are unbroken by falls; they are, in fact, fairly smooth curves that steepen rapidly headward.

This erosion is nowhere more clearly shown than at Onion Valley on Independence Creek. The cross wall at the head of the valley marks the abrupt rise of the valley floor to the tread above; two lateral valleys, whose floors are hung high above that of Onion Valley, enter diagonally from opposite sides, the trend of each making an equal angle with the axis of the main canyon. The oblique junctions of the two valleys with the main canyon appear to preclude the possibility that the step-up of the floor of the main canyon and the hanging condition of the lateral canyons are due to faulting and strengthen the evidence of glacial erosion afforded by the cross wall.

GLACIAL CAPTURE.

Glacial capture has been discussed theoretically by W. M. Davis,[2] who credits the recog-

[1] Lawson, A. C., Geomorphogeny of the upper Kern basin: California Univ. Dept. Geology Bull., vol. 3, pp. 345–362, 1904.

[2] Geographical essays, p. 663, 1909.

nition of the process to Stanislas Meunier.[1] The possibility of glacial capture was pointed out by Meunier, but no example was described either by him or by Davis. It appears to have been first recognized in the field in the Big Horn Mountains by F. E. Matthes,[2] who briefly refers to an example mapped by him.

Glacial capture is exemplified in this part of the Sierra Nevada. An especially fine example near Bullfrog Lake, west of Kearsarge Pass, excellently illustrates the process and clearly shows the amount of erosion accomplished by the ice after the capture. Westward from Kearsarge Pass a broad glacial valley extends, to all appearance, continuously westward. At Bullfrog Lake, however, it is found that the south wall of this seemingly continuous valley has been widely breached, and that the drainage, instead of flowing westward (as would appear from Kearsarge Pass to be its normal course), escapes precipitously through this breach to Bubbs Creek, 1,100 feet below. (See Pl. XXIII, *B*.) The lower part of the beheaded valley is drained by Charlotte Creek, and to ascend this stream is to gain an even more striking impression of the glacial capture of its upper part. For at the "elbow of capture" the valley floor descends abruptly to the level of Bullfrog Lake, and this downstepping of the valley floor upstream is of course in remarkable contrast to the normally stepped character of glacial valleys. The scarp facing upstream thus produced is about 100 feet high at the axis of the valley. It follows, therefore, that after the diversion of the upper drainage of Charlotte Creek into Bubbs Creek, glacial erosion has lowered the floor of the valley at the elbow of capture 100 feet below that of the lower valley at the point of beheadment.

The cause of this glacial capture is difficult to find. The flowing of two glaciers in parallel channels, one of which was much larger and occupied a much deeper channel than the other, was of course conducive; but the cause that determined the point of attack on the wall separating the two glaciers is uncertain. This wall was relatively narrow at the place where it was finally breached, and it may have been there traversed by an uncommonly closely spaced system of joints; indeed, the narrowness of the wall may have facilitated the development of jointing. Throughout this area local differences in the intensity of jointing are marked. Somewhat below the point where the stream draining Lake Bullfrog enters Bubbs Creek—above the mouth of Charlotte Creek—magnificent cliffs of monolithic granite rise sheer to heights of 2,500 feet; but elsewhere the granite is jointed, and this may well have been the condition at the point of breaching.

[1] Compt. Rend., vol. 124, p. 1043, 1897.

[2] Glacial sculpture of the Bighorn Mountains: U. S. Geol. Survey Twenty-first Ann. Rept., pt. 2, p. 178, 1900.

INFLUENCE OF JOINTING.

The influence of jointing on glacial erosion is most strikingly shown by the peculiar upper perimeter of the cirque south of Army Pass. This cirque has been cut back from the east into a relatively flat and unglaciated upland, so that it is possible to walk along the upper edge of its sheer walls. The numerous large and small reentrants that make up the detailed pattern of the upper perimeter of the cirque are shown in part in figure 7. The granite is traversed by three systems of jointing—two vertical and one horizontal—and the walls of the cirque are prevailingly parallel to a well-developed joint system trending N. 80° E. and dipping 80° S. Single joint planes commonly form the faces of cliffs several hundred feet high. The complex system of deep reentrants seems to prove that the plucking of joint blocks was the dominant factor in the formation of this cirque.

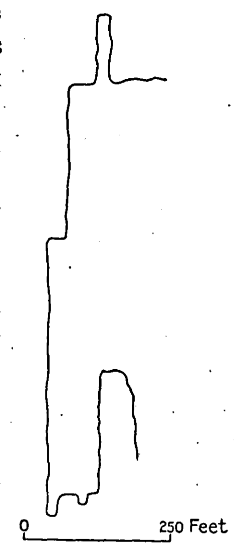


FIGURE 7.—Detail of a part of the upper perimeter of the cirque south of Army Pass, Cal.

The control exerted by jointing is also well displayed at the Big Pine Lakes—a string of six rock-rimmed tarns at the head of Big Pine Creek. At the third lake a vertical jointage trending N. 45° W. has markedly controlled the course of glacial erosion, vertical cliffs over 100 feet high having been produced parallel to the joint system and long, narrow trenches, bounded by vertical joint faces and as much as 6 feet deep; clearly indicative of ice plucking, having been excavated on the summits of roche moutonnée ridges. The rock barrier between the second and third lakes is composed of granite of nearly monolithic character, being traversed by a very widely spaced system of jointing, which strikes N. 40° E. Glacial action availed itself of this system and eroded out a number of long, narrow troughs, one of which now forms the outlet of the lake. The rock dam is rounded and smoothed, with well-developed roche moutonnée forms, on whose backs are perched various erratic blocks.

On the whole, the conclusion seems justified from a study of this part of the Sierra Nevada that ice erosion has taken place mainly by the plucking and removal of joint blocks, and that therefore jointage has greatly facilitated the process. On the other hand, however, it appears that the systems of jointage have exerted no great directive control on the geomorphic evolution of the region and have determined the pattern of only minor sculptural features, such as outlets and troughs across the rock barriers of the glacial tarns.

HANGING VALLEYS.

According to Lawson, the canyon of the Kern, distinguished by its great depth, meridional trend, and remarkable straightness, is an erosional trough developed along a rift valley. "Probably only a minor proportion of the cross section of the canyon," he says, "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."[1] The canyon is thus explained as essentially a stream-wrought valley whose remarkably straight course was determined by tectonic control.

During late Pleistocene time the canyon of the Kern was occupied by a trunk glacier 24 miles long that extended down to an altitude of 6,500 feet. The extent to which glacial erosion enlarged the canyon is of importance in considering the origin of equally profound canyons, such as those of Bubbs Creek and South Fork of Bishop Creek, in this part of the Sierra Nevada.

Lawson concludes that the glacial widening of the canyon is negligible. He assumes that the material shed upon the surface of the glacier would all accumulate in the terminal moraine, and from the volume of the moraine he deduced that the glacial widening amounts to only a few inches.

The argument based on the incommensurate size of moraines is much favored by those denying great erosive power to ice streams.[2] They who use it, however, seem unaware of the inconsistencies in which they become involved. Russell, for example, believes in the glacial origin of cirques and rock basins but disbelieves in that of U canyons. Moraines, he says, are too small to account for the U canyons. But, he admits, "it is difficult to draw a definite line between a glacial cirque and the canyon leading to it."[3] Here, then, are a number of inconsistencies that it is hardly necessary to enumerate. Lawson, after graphically describing the glacial reduction of mountain crests to the extent of 1,000 feet or more and the obliteration of large plateau surfaces by cirque sapping, notes "that in general the alpine glaciers of these mountains seem to have developed but feeble terminal moraines." This discrepancy between the amount of glacial erosion indicated and the size of the terminal moraines is left unexplained.

It seems to the writer, from field experience in Alaska, that the argument based on the size of moraines, if not indeed fallacious, is at least to be used with utmost caution. The great glaciers of Alaska as a rule show no large terminal moraines. The streams emerging from the glaciers have built extended flood plains, 1 mile to 3 miles wide, over which they flow in a complexly braided system of channels. They are laden with silt and move great quantities of coarse detritus; in the afternoons—the period of diurnal high water—the boulders can be heard bumping downstream. The conclusion is obvious that the glaciers are furnishing large amounts of débris, that the streams are able to transport this material

[1] Lawson, A. C., The geomorphogeny of the upper Kern basin: California Univ. Dept. Geology Bull., vol. 3, p. 343, 1904.

[2] Russell, I. C., Quaternary history of Mono Valley, Cal.: U. S. Geol. Survey Eighth Ann. Rept., pt. 1, p. 350, 1889.

[3] Idem, p. 354.

away from the ice edge, and that although the glaciers are active agents of erosion, no important terminal moraines are being formed.

Some specific examples may be cited. The Kennicott Glacier, a large ice stream on the southern slope of the Wrangell Mountains, has remarkably little moraine around its edges; although the terminus of the glacier is covered with detritus the streams remove this as fast as it is dropped by the ice and in many places are cutting into the glacier itself.[1] Even more striking are conditions at the great Kahiltna Glacier on the southern flank of the Alaska Range,[2] which, as shown by its relation to timber and vegetation, has been stationary at its present position for some time. This glacier is discharging detritus from its surface so actively that it is dangerous to walk near its edge, despite which it is building no terminal moraine, the glacier-born streams being able to carry off all the detritus as rapidly as it is furnished.

These Alaskan glaciers terminate in broad valleys of comparatively low gradients. Where, however, glaciers that, like those of the Sierra Nevada, terminate in profound U troughs with gradients of 200 to 500 feet a mile, the conditions must be far more effective for exporting glacial detritus. Such canyons form natural sluices, through which the glacial detritus must inevitably be swept. Under these conditions the accumulation of a moraine is essentially adventitious.

The scale of the glacial erosion on the western slope of the Sierra Nevada is immensely greater than on the eastern slope. This is most strikingly exemplified in the region of Taboose Pass. West of the pass is the great wide cirque-scalloped basin of South Fork of Kings River, formerly occupied by an ice stream 1,300 feet thick; downstream the glacial channel becomes narrower and deeper until it becomes one of the great canyons of the range. But despite the grand scale of this glaciation moraines are absent or insignificant. So, also, on Bubbs Creek, the south branch of South Fork of Kings River, whose canyon is even more profound than that of the Kern, moraines are absent. On the other hand, moraines are much more common and are of larger size on the east flank of the range, especially where, as west of Bishop, the glaciers extended out upon the piedmont slope. In other words, morainal accumulations in glacial canyons are in nowise proportional to the amount of glacial erosion.

From convergent lines of evidence, then, the conclusion is driven home that the volume of a terminal or other moraine does not necessarily measure quantitatively the amount of the glacial erosion of the canyons and cirques from which it was derived.

To return to the problem of Kern Canyon: Although Lawson decides that the widening of this canyon by glacial erosion is negligible, he leaves in abeyance its deepening by that process. It seems a fair inference, however, from the nature of the argument he uses in deducing the amount of glacial widening, that he considers the deepening also negligible. This conclusion, however, is irresistibly opposed by the evidence afforded by the hanging condition of the lateral valleys. The Kern, as shown by Lawson, is essentially a stream-wrought valley; and the hanging valleys along it are therefore not of diastrophic origin. Nor is their hanging character due to faster downcutting of the master stream, for the tributary streams, below the glacial limit, have cut down to its bottom.[3] Little Kern River, for example, enters at grade; like the main Kern, it is bordered by high hanging valleys along its upper course, but below the lower limit of glaciation all its tributaries enter at grade.[4]

It is necessary, then, to conclude that the hanging character of the upper tributary valleys of the Kern is due to glacial erosion. The Kern-Kaweah River is hung up several hundred feet and Tyndall Creek and other affluents from the east a thousand feet or more. The discordance in the height of the tributaries seems roughly proportional to the probable size of the ice streams that occupied them.

Similar features occur in other canyons of the region. Bubbs Canyon, somewhat deeper than that of the Kern, can not, because of its sinuous course, be explained as a rift valley or as a valley eroded along a rift zone. Those of

[1] Moffit, F. H., and Capps, S. R., Geology and mineral resources of the Nizina district, Alaska: U. S. Geol. Survey Bull. 448, p. 48, 1911.

[2] Capps, S. R., The Yentna district, Alaska: U. S. Geol. Survey Bull. 534, pls. 3, 10, 1913.

[3] Lawson, A. C., op. cit., pl. 35, B.

[4] Knopf, Adolph, and Thelen, Paul, Sketch of the geology of Mineral King: California Univ. Dept. Geology Bull., vol. 4, p. 232, 1905.

its tributaries (East Fork, for instance) that supported ice streams equal in size to those of the main stream enter at grade; but smaller affluents join discordantly; Charlotte Creek, for example, is hung up nearly 2,000 feet. The canyons of South Fork and Middle Fork of Bishop Creek, having essentially equal catchment areas, unite at grade, but North Fork, which is considerably smaller, enters Middle Fork 500 feet above grade. The hanging valleys of this part of the Sierra Nevada therefore point strongly to the efficacy of glacial erosion.

CORRELATION OF GLACIAL EPOCHS.

Evidence of more than one epoch of glaciation on the western slope of the Sierra Nevada has not been generally recognized. Turner,[1] however, describes on the upper Stanislaus River moraines that he believes were laid down during two widely separated glacial epochs. Lindgren,[2] in describing the western slope of the range, says: "While it is probable that the glaciers receded and advanced several times, it can not be said that decisive evidence has been found in favor of two or more definite divisions of the period."

Russell[3] had previously recorded his belief that two epochs of glaciation are indicated on the eastern slope of the range, but his evidence is weakened by not being assembled in one place in the text, and, when critically examined, is not wholly convincing. His main conclusion[4] is that "the two best-defined advances of the Sierra Nevada glaciers and the two high-water stages of the Quaternary lake at Mono Valley are believed to correspond in time with the two high-water stages of Lakes Bonneville and Lahontan."

Gilbert has carefully discussed the interrelation of the glacial history of the Wasatch Range and the Sierra Nevada with the lacustral history of Lakes Bonneville, Lahontan, and Mono. He states, from first-hand observations, that although proof of two high-water stages of Mono Lake had not been satisfactorily established he is decidedly inclined to regard the maximum flood of the Mono basin as the equivalent and contemporary of the maximum flood in the basins of Lakes Bonneville and Lahontan.[5] As a result of his inquiry into the glacial and lacustral history of the Great Basin province he concludes that the glaciation and the expansion of the three lakes were coordinate and synchronous results of the same climatic changes and that "it follows as a corollary that the glacial period of the Sierra Nevada, the Wasatch, and other mountains of the western United States was divided into two epochs separated by an interglacial epoch, and this has not been independently shown."[6]

The evidence gathered during the present reconnaissance of the east flank of the range from Bishop south to Owens Lake seems to leave little doubt that two epochs of glaciation are represented. Also, in the vicinity of Bridgeport, north of Mono Lake, W. D. Johnson has found evidence of two epochs of glaciation, but his observations have not been published. The results of both these investigations therefore confirm Russell's conclusion that two distinct glacial epochs can be recognized on the east flank of the Sierra Nevada. Further corroboration of the results reached on the east slope of the range is found in the highly important recognition by Calkins and Matthes[7] of two epochs of glaciation in the Yosemite National Park.

It can therefore be said that Gilbert's corollary, so far as it applies to the Sierra Nevada, has now received independent confirmation from the recent investigations in the range. It has previously been confirmed for the Wasatch Mountains by Atwood.[8]

The correlation of the lake history with the glacial history, as determined in the Sierra Nevada, can now be carried somewhat further. The duration of interglacial time was found to be considerably longer than that of postglacial time, a conclusion that accords with Gilbert's determination that "the inter-Bonneville epoch of low water was of greater duration than the time that has elapsed since the

[1] Turner, H. W., U. S. Geol. Survey Geol. Atlas, Big Trees folio (No. 51), p. 5, 1898.

[2] Lindgren, Waldemar, U. S. Geol. Survey Geol. Atlas, Colfax folio (No. 66), p. 7, 1900.

[3] Russell, I. C., Quaternary history of Mono Valley, Cal.: U. S. Geol. Survey Eighth Ann. Rept., pt. 1, pp. 339, 341, 346, 369, 1889.

[4] Idem, p. 371.

[5] Gilbert, G. K., Lake Bonneville: U. S. Geol. Survey Mon. 1, p. 306, 1890.

[6] Idem, p. 315.

[7] Oral communication.

[8] Atwood, W. W., Glaciation of the Uinta and Wasatch mountains: U. S. Geol. Survey Prof. Paper 61, pp. 91–92, 1909.

final desiccation."[1] Of the two epochs of high water, the first lasted at least five times as long as the second. This is paralleled by the glacial record. The extensive moraines of the first epoch of glaciation clearly indicate that its duration was far greater than that of the second—probably at least five times as great. In one respect, however, the glacial and lacustral histories seem not to run parallel. The glaciers of the first epoch not only persisted far longer than those of the second epoch but also descended to considerably lower altitudes: the first epoch was the epoch of maximum glacial expansion. Of the two epochs of lake expansion, however, the second, although the shorter, showed the greater effect, for in it the waters rose sufficiently to cause Lake Bonneville to overflow.

SUMMARY OF GLACIAL HISTORY.

After the great alluvial cones flanking the Sierra Nevada escarpment had attained essentially their present size glaciers commenced to flow from the recesses of the range. It is probable, therefore, that the beginning of this, the earliest epoch of glaciation recognized, corresponds in time to the first expansion of Lake Bonneville, which, as shown by Gilbert,[2] occurred after the building of the great alluvial cones of the Wasatch escarpment. This is but another fact pointing to the close parallelism between the glacial and lacustral history of the Great Basin.

Some of the glaciers on the east slope of the Sierra Nevada descended to the mouths of the canyons and probably deployed to an unknown extent upon the piedmont alluvial slope. The lowest altitude to which it is certainly known that they descended is 5,000 feet. Where the glaciers emerged from the confining canyons into more open country, as they did on Bishop and Big Pine creeks, they deposited extensive moraines.

An epoch of milder climatic conditions, during which the ice probably disappeared, then intervened, to be followed by a renewal of glaciation. That the interval between the first and second epochs was long is indicated by the advanced disintegration of the boulders in the older moraines, by the pronounced modification of the form of the older moraines, and more especially by their deep dissection. As to its duration, some data of a roughly quantitative character are obtainable on Birch Creek, north of Bishop Creek, where it is estimated interglacial time was three to five times as long as postglacial time. During the interval between the two epochs of glaciation a flow of olivine basalt, accompanied by an ejection of cinders, was emitted on Sawmill Creek.

The ice streams of the second glacial epoch were much shorter lived than those of the first epoch and did not reach as low altitudes. The perfect preservation of the moraines they built attest the recency of their retreat. So recent or so slow has been this retreat that a number of small glaciers still linger in the heads of the cirques on the upper waters of Big Pine Creek. These residuary ice masses have been considered the most southerly in the United States, but the small glacier in latitude 36° 35′, near Mount Whitney, now seems to be the farthest south.

[1] Gilbert, G. K., U. S. Geol. Survey Mon. 1, p. 316, 1890.
[2] Idem, p. 221.

MINERAL RESOURCES.

CHARACTER.

The mineral resources of the region occur chiefly in the Inyo Range. They comprise argentiferous galena, zinc carbonate, gold, and copper. The Cerro Gordo mine, in the southern part of this range, has yielded more silver-bearing lead ore than any other mine or district in California, and still maintains its premier position. Marble is the only nonmetallic resource of commercial importance, but in late years the quarries have not been worked; possibly the recently improved railroad facilities may revive this industry.

Mining along the eastern slope of the southern Sierra Nevada was practically limited in 1913 to work at the Bishop Creek gold mine.[3]

HISTORICAL NOTE.

Mining began in the region in 1861, when the Russ mining district was established in the Inyo Range east of Independence. From 1869 to 1877 the industry was very active, for it was then that Cerro Gordo was yielding

[3] Since this was written large deposits of contact-metamorphic tungsten ore have been found west of Bishop and have been energetically developed. (See Knopf, Adolph, Tungsten deposits of northwestern Inyo County, Cal.: U. S. Geol. Survey Bull. 640, pp. 229–249, 1917.)

its large output of base bullion. The completion of the Colorado & Carson Railroad to Keeler in the early eighties stimulated mining to some extent, although not so much as was expected, and the region never regained the prominence it held during the first years of Cerro Gordo. About 1907 interest in the mineral deposits of the Inyo Range revived, the most notable result of which has been the development of zinc ore at the Cerro Gordo mine. In recent years this mine has yielded practically the entire output of metal in the region—zinc, lead, and silver.

In the sixties considerable excitement was aroused by the discovery of rich silver ore in the Kearsarge district high on the slopes of the Sierra Nevada west of Independence. A number of mills were built on Independence Creek, but these have long ago fallen into ruins, and little work in excess of the annual assessment requirements has been done in the district during the last decades.

INYO RANGE.[1]

ORE DEPOSITS.

The ore deposits occur most abundantly in the southern part of the Inyo Range, from which comes the main part of the metallic output of the region. This distribution coincides with that of the intrusive granite, which, as already pointed out, is far more abundant in the southern than in the northern part of the range. The zinc, lead, silver, and copper deposits as a rule are in limestone, but the gold deposits seem closely linked to the granite, occurring chiefly in the marginal zone of the granite masses or in the immediately adjacent country rock. Ore deposits have not been found in the central portions of the larger granitic areas.

LEAD-SILVER, SILICEOUS SILVER, AND ZINC ORES.

GENERAL CHARACTER.

Argentiferous galena ores occur at several localities in the region, but only at Cerro Gordo and vicinity have they yielded a notable production. All the important ore bodies are irregular lenticular masses inclosed in limestone.

Oxidation has partly altered the galena to the carbonate, cerusite, and if the ore originally contained zinc blende, zinc carbonate ores may possibly have been formed during the process of alteration.

Siliceous silver ores are also found in the Inyo Range, principally in the Belmont district 3 miles southeast of Cerro Gordo, where they occur as narrow quartz veins in monzonite porphyry. A considerable number of mines were worked here about 1870, as described by Goodyear[2] from notes taken by him in that year. The Belmont was then the most important mine and was yielding each month 100 tons of first-class ore, which averaged about 165 ounces of silver to the ton. In 1913 the Newsboy was the only mine in operation in the Belmont district and was furnishing a high-grade siliceous silver ore valued at $100 a ton.

Zinc ore composed predominantly of the carbonate, smithsonite, occurs at Cerro Gordo; in fact, it was the discovery of this ore, whose presence was previously unsuspected, that led to the recent revival of mining at that camp. It has been found nowhere else in the Inyo Range. The zinc ore forms pipes and irregular masses principally in the limestone footwall of the old galena stopes; it occurs immediately below the lead-ore bodies formerly worked and extends in places as far as 100 feet laterally from them.

ORIGIN OF THE ZINC ORE.

The primary ore bodies as a rule have been extensively oxidized. During this process sulphates of lead, zinc, iron, and copper were formed, together with sulphuric acid, which, acting on shale or porphyry, took alumina and silica into solution. The lead sulphate, being insoluble, remained in place and was later transformed into cerusite; the copper also did not travel far but was precipitated as chrysocolla or as a basic sulphate. Thus in the first stage the zinc and iron were separated from the other metals and, being contained in a solution moving under the influence of gravity, naturally tended to sink into the footwall of

[1] The main part of this description appeared in Knopf, Adolph, Mineral resources of the Inyo and White mountains, Cal.: U. S. Geol. Survey Bull. 540, pp. 81–120, 1914.

[2] Goodyear, W. A., California Min. Bureau Eighth Ann. Rept., pp. 250–254, 1888.

the lead ore bodies. Here the solution came into contact with the calcitic wall rock and a further separation took place. The free sulphuric acid present was immediately neutralized and the ferric iron was precipitated as hydroxide according to the equation

$$Fe_2(SO)_4)_3+3CaCO_3+3H_2O= 2Fe(OH)_3+3CaSO_4+3CO_2$$

This reaction has been experimentally studied by Meigen, who finds that ferric iron is, even at 15° C., rapidly and completely precipitated as hydroxide from its solutions by calcite.[1] He finds further that ferrous iron and zinc are precipitated more slowly. According, then, to the extent that the iron contained in the solution was in the ferric state, the zinc, which is later precipitated as carbonate, will be proportionately free from iron.

At Cerro Gordo the zinc ore is as a rule remarkably free from iron, indicating, as one possibility, that the iron in the downward-percolating solutions was mainly in the ferric condition. This would be so if during oxidation there had been available an excess of oxygen—a condition likely to arise, among others, owing to the comparatively small amount of pyrite that underwent oxidation in the primary deposits.

After the precipitation of the ferric iron the ferrous iron and the zinc would be precipitated as carbonates. At Wiesloch, Baden, for example, ferrous carbonate is mingled with zinc carbonate in all proportions up to 50 per cent, although the main ore bodies are relatively pure zinc carbonate.[2] By subsequent oxidation the ferrous carbonate may be converted to limonite, and in this way iron-stained zinc carbonate ores would be produced. The separation of the zinc from ferrous iron would be determined by two factors—the concentration of the solutions in zinc and ferrous iron and the relative precipitability of the carbonates of zinc and ferrous iron. The solubility of zinc carbonates and of ferrous carbonate,[3] measured in gram equivalents per liter, is respectively 1.7×10^{-4} and 6.2×10^{-5}. From these figures it can be inferred that the iron is more easily precipitable and that this favors the segregation of the zinc from the iron. When, however, the concentration of the zinc becomes high relatively to the iron, both metals must come down together. No experimental data are available concerning the fractional precipitation of a mixture of sulphates of zinc and ferrous iron by means of calcium carbonate, but the geologic evidence seems to show that the fractionation as carried out in nature is very complete, provided, as already pointed out, that the thorough separation of the zinc and iron is not due to the previous complete precipitation of the iron as ferric hydroxide.

One of the most striking features of the ore deposits of Cerro Gordo is the localization of the zinc as carbonate in high-grade bodies in comparison with the small proportion of zinc blende contained in the primary ore. The zinc carbonate, as shown in the preceding paragraphs, was derived from the blende by a process involving oxidation, solution, migration, and precipitation; nevertheless the proportion of blende in the unoxidized lead ore now found in the mine is extremely small, ranging perhaps from 1 to 2 per cent. The lead ore bodies formerly worked may have carried more sphalerite than any ore now visible, but this seems unlikely, because in no account hitherto published concerning Cerro Gordo is the presence of sphalerite recorded. It is believed, therefore, that the primary ore found now is an index of the primary ore occurring formerly in the mine. In the shoot of primary ore recently uncovered at the surface the galena contains only a small quantity of sphalerite; nevertheless the galena is bordered by a layer of smithsonite several feet thick. From a consideration of the foregoing facts it would appear that the zinc, sparsely distributed throughout the primary lead ore, was effectively segregated and concentrated to a remarkable extent during the formation of the secondary ore.

Practical deductions.—Some deductions of practical importance follow almost obviously from a recognition of the principles governing the formation and origin of the zinc carbonate ore bodies. Certain of these deductions had been recognized at Cerro Gordo as criteria

[1] Meigen, W., Beiträge zur Kenntnis des Kohlensauren Kalkes: Naturf. Gesell. Freiburg Ber., vol. 13, p. 76, 1903.

[2] Schmidt, A., Die Zinkerz-Lagerstätten von Wiesloch, Baden: Naturhist.-Med. Ver. Heidelberg Verh., neue Folge, vol. 2, p. 399, 1880.

[3] Data supplied by R. C. Wells, U. S. Geological Survey.

for the search for undiscovered bodies of ore, although the theoretic foundations on which they were based were not known. These deductions are, stated summarily:

1. The zinc carbonate bodies can occur only in the marble, most likely in the footwall zones of primary lead ore deposits. The largest zinc deposits will therefore be found most probably in the footwall country rock of the old lead stopes.

2. Zinc ore is especially likely to occur below bodies of hydrated iron oxide along the periphery of the primary ore masses—the iron oxide bodies marking the heads of the channels along which the sulphate solutions commenced to migrate into the limestone wall rock. The zinc ore does not necessarily lie vertically below these masses of iron oxide; it may occur diagonally below it, or otherwise, according to the structural features of the wall rock.

3. Conversely, bodies of lead ore, if not already mined out, may be found on the upward extension of zinc ore deposits, above the iron oxide masses.

4. Zinc ore is likely to be found as far down as the zone of oxidation extends, the bottom of which has not yet been reached.

The discovery of zinc carbonate ore at Cerro Gordo is another striking illustration of what has been happening in recent years at many of the other silver-lead mining camps in the Western States. Oxidized zinc ores were formerly unsought or were thrown over the dumps unrecognized; only in recent years have they been recognized or their value appreciated. At Leadville the zinc carbonate ores were long unrecognized, but Leadville is now the largest producer of oxidized zinc ore in Colorado. The same is true for the Kelly or Magdalena district, in New Mexico; for Yellow Pine, in Nevada; and for Cerro Gordo, in California; and it may prove true for Tintic, in Utah, where the abundance of zinc ore in the old stopes is proving a surprise to operators.

These facts render it highly probable that other valuable deposits of zinc carbonate will be discovered in limestone in association with galena ore bodies that were formerly worked for their lead and silver. As shown by the occurrence of zinc ore at Cerro Gordo, a fact pointed out in the discussion of the origin of the ore, the primary ore bodies need not have contained a large proportion of sphalerite to have given rise to commercially important deposits of zinc carbonate.

MINES AND PROSPECTS.

CERRO GORDO MINE.

Location.—The property now known as the Cerro Gordo mine is a consolidation of the Union and Santa Maria mines, the two mines that furnished the bulk of the output of argentiferous lead ore to which Cerro Gordo owes its fame. The Cerro Gordo has been the only notable producer of silver-lead ore in the State of California; its resuscitation, however, was due mainly to the discovery of bodies of zinc carbonate ore, which occur in the footwall of the lead ore bodies formerly worked.

The mine is near the summit of the Inyo Range, east of Owens Lake. At the Belshaw, or principal shaft, the altitude is 8,500 feet—nearly 5,000 feet above Keeler, the terminus of the Nevada & California Railroad. In an air line the mine is 5½ miles northeast of Keeler; by wagon road it is 8 miles, and the grade from the valley is steep. The mine lies immediately below the bold scarp on the west flank of the peak called Cerro Gordo, which rises to an elevation of 9,217 feet and is a prominent landmark as seen from Owens Valley.

History.—The ore bodies at Cerro Gordo, according to Loew,[1] who visited the mines in 1875, were discovered in 1866 by Mexicans—Pablo Flores and his companions. By others the date of discovery is given as 1861. Be that as it may, the deposits were worked by the Mexicans on a small scale only, the ores being smelted in galemadores (inclined reverberatory furnaces) and the district did not become notably productive until its mines were taken over by Americans in 1869, when four furnaces were built. The Union mines came into the possession of M. W. Belshaw and V. Beaudry, and the Santa Maria and allied properties were shortly afterward acquired by the Owens Lake Silver Mining & Smelting Co., of New York. The ores were smelted at three reduction works. Those from the Union mine were treated at Belshaw & Judson's furnaces, above the portal of the Omega tunnel, and at Beaudry's furnace,

[1] Loew, Oscar, U. S. Geog. Surveys W. 100th Mer., p. 62, 1876.

just west of Cerro Gordo camp; those from the Santa Maria mine were smelted at the Owens Lake Silver Mining & Smelting Co.'s furnaces at Swansea, near the shore of Owens Lake.

Scarcity of water, scarcity of fuel, and high transportation charges made mining and reduction costs large. Water was pumped to Cerro Gordo from 11 miles away and 1,875 feet below; charcoal burned from piñon and mountain mahogany, which grow in scattered stands in the higher portions of the Inyo Range, cost at the furnaces at Cerro Gordo 32½ cents a bushel; all freight had to be hauled across the desert from Los Angeles, a distance of 275 miles, at a cost of 3 to 6 cents a pound. Despite these handicaps the period from 1869 to 1876 was one of great activity.

In 1871 the production of the district was $300,000, with a recovery of only 50 to 55 per cent of the lead. In 1872, 3,220 tons of base bullion carrying 140 to 150 ounces of silver a ton, was produced, which, with silver at $1.2929 an ounce and lead at 6 cents a pound, aggregated $977,255 in value, or approximately $303 a ton.[1] A. Eilers, who visited Cerro Gordo in 1872 and described the metallurgic processes in use there, estimated that the ore of the Union mine, whose average content was not precisely ascertained at the works, contained about 34 per cent of lead and that the slag carried 15 per cent of lead. Quartzose silver ores, obtained from the Ignacio, Belmont, and other mines in the vicinage of the Cerro Gordo, were added in small quantity to the furnace charge to concentrate their silver in the lead. Economy of fuel was obtained by means of "an almost unprecedented loss of lead." Eilers concluded that "the whole management of the works is rather calculated to create the suspicion that the proper composition of the charge is not understood. It is certain that either by an addition of iron oxide to the present charge or by omitting the addition of the quartzose silver ores altogether far better results might be obtained than at present."[2]

These suggestions seem to have borne some fruit, for the old slag dumps, as sampled by the present management of the Cerro Gordo. show a content of not over $5 a ton in silver and lead; only by sorting out material containing unfused lumps of ore it is possible to obtain a product averaging $15 a ton. The more deeply buried slags have recently been uncovered and were found to be much richer; they were a source of considerable profit in 1916 and 1917.

It is recounted that $2,000,000 worth of bullion was corded up at one time in 1873 on the shores of Owens Lake awaiting transportation out of the valley, and bars of base bullion were even used to construct cabins as temporary shelter for the miners.

Litigation commenced at this time. The San Felipe Co., most of whose stock was owned by the Owens Lake Silver Mining & Smelting Co., claimed discovery title to the Union mine, and a verdict was rendered in its favor. The case was then appealed to the United States Supreme Court, where it lay for several years.

The maximum annual output—5,600 tons of base bullion—was made in 1874. From December 1, 1873, to November 1, 1874, the Union mine produced 12,171 tons of ore of an average assay content of 47 per cent of lead and 87 ounces of silver to the ton.

According to M. W. Belshaw,[3] the total cost per ton for mining and reduction for the period February 1 to October 1, 1876, was $19.96; the quantity of ore treated was 9,950 tons; the lead produced was 1,325 tons. The recovery was 64 per cent of the lead assay and 90 per cent of the silver assay. According to these figures the ore as mined carried 21 per cent of lead, and was therefore of considerably lower grade than that mined a few years earlier.

It is impossible to give accurate figures for the total output of the Cerro Gordo during its most prosperous years. The figures now current in Owens Valley range around $20,000,000, but these estimates surely show the generous influence of time and tradition. The estimates given in contemporary or nearly contemporary reports range from $6,500,000 to $15,000,000. The total output of base bullion from 1869 to 1876, inclusive, obtained by summing up the yearly production given in Raymond's annual statistics of mines and mining in the States and Territories west of the Rocky Mountains,[4] is approximately 22,500 tons. On

[1] Statistics of mines and mining in the States and Territories west of the Rocky Mountains for 1872, p. 21, 1873.

[2] Idem, pp. 355–356.

[3] California Min. Bur. Fourth Ann. Rept., p. 225, 1884.

[4] The production for 1876 is obtained, however, from the statement by Belshaw, previously cited.

the assumption that the average value was $300 a ton, as in 1872, the value of the total output of the Cerro Gordo during its most prosperous period was $6,750,000, or in round numbers, $7,000,000.

The mines, although consolidated after the settlement of the litigation, were shut down about 1877, mainly, it would appear, because the large bonanza bodies of argentiferous galena had been worked out. In the early eighties the Carson & Colorado Railroad, a narrow-gage line which connected with the Central Pacific Railway at Reno, was completed to Keeler and was expected to revive the mining industry at the Cerro Gordo. The mine, however, was worked spasmodically by lessees until it was acquired by the Great Western Ore Purchasing Co. in 1905. A small production was made by this corporation in 1907. Subsequently the property was taken over by the Four Metals Mining Co., which erected a 200-ton smelter just east of Keeler and connected it with the mine by an aerial tramway. This company attempted to smelt the old slags from the Cerro Gordo and to work the mine but went into insolvency. L. D. Gordon and associates, who had obtained from the Four Metals Mining Co. a lease to extract the zinc ore of the mine, then took over the property by purchase of the bonds of the insolvent corporation. During 1912 the property was in litigation, and in April, 1913, it was sold by marshal's sale under foreclosure of mortgage. It was bought by L. D. Gordon and associates, but in 1914 in order to obviate any further litigation a reorganization was effected and the Cerro Gordo Mines Co., which now operates the mine, was incorporated.

To whom belongs the credit of recognizing the zinc ores at Cerro Gordo is not certainly known. Its discovery in important quantities and its profitable exploitation are due to L. D. Gordon. The first shipment of zinc ore under the management of L. D. Gordon was made in May, 1911; previously, however, the Great Western Co. had made a shipment of two cars but at a loss of $800.

During the mining of the oxidized zinc ore exploration was carried on in search of silver-lead ore, and in 1914 important bodies of lead ore high in silver were discovered. The output in 1915 was 4,440,666 pounds of zinc, 121,510 pounds of copper, 748,952 pounds of lead, 126 ounces of gold, and 112,541 ounces of silver.

Developments.—The underground workings are said to aggregate 20 miles in length. The Belshaw shaft, from which five levels have been driven, is 900 feet deep, and from the 900-foot level a winze extends down to the 1,150-foot level.

An aerial tram connects the mine with the smelter half a mile east of Keeler. The nominal capacity of the tram is 50 tons a day, but this is frequently lowered by breakdowns. The difference in elevation between the terminals is approximately 4,500 feet, but nevertheless the cable must be driven by a steam engine. Crude oil is at present employed as fuel in the operation of the hoist and the tram, but if developments warrant it electric power will be obtained from one of the hydroelectric power companies that are operating in Owens Valley.[1]

Despite the considerable depth of the mine, water level has not been reached. In the lower levels there was (in September, 1912) a slow trickling or "sweating" from the walls of the drifts.

Geologic features.—The mine is at the foot of the scarp forming the western face of Cerro Gordo Peak. (See Pl. X, *C*, p. 54.) This scarp shows a broad band of white marble surmounted by dark-gray limestone forming the summit of Cerro Gordo Peak. The white marble—the principal repository of the ore—plainly wedges out southeastward owing to its plunging anticlinal structure, and northwestward it is cut off by a zone of faulting. With the marble, which is the prevailing rock at the mine, are associated some interstratified slate and a number of dikes of monzonite porphyry and quartz diorite porphyry.

The rocks at the mine are part of a Carboniferous formation of limestone, with some interstratified shale or slate and quartzite, that is extensively developed in the surrounding area. A belt of shale, probably 300 feet thick, lies northwest of the mine and is underlain by fine-grained white quartzite, 100 feet thick. The strike is N. 30° W. and the dip 45° W. The shale is in places highly fossiliferous,

[1] The tram has since been reconstructed, and in January, 1917, a high-tension transmission line was completed from Keeler to Cerro Gordo.

carrying *Derbya*, *Goniatites*, pelecypods, and other forms. These fossils fix its age as Carboniferous.

In the vicinity of the mine the strata dip steeply westward, but a short distance east of the ore-bearing zone they dip gently eastward, as may be determined on the north slope of Cerro Gordo Peak from the altitude of some thinly bedded dark-gray limestones. A rough schistosity trending N. 20° W. and dipping 75° W., superposed on the stratification, is the structure most commonly seen in surface exposures, and unless "end" views of the strata are seen is likely to lead to erroneous conclusions. The strata at Cerro Gordo are, it therefore appears, flexed into a highly asymmetric anticline whose axis lies just east of the ore-bearing zone. The anticlinal axis plunges steeply southward, causing the white marble belt to disappear abruptly a short distance south of the mine. Northwestward the marble is cut off by a fault zone.

The shale and quartzite strata register the displacement and show that complex faulting has taken place just northwest of the mine, where the 100-foot quartzite member is cut out by a fault trending northeastward. The displacement of the fault is considerable, but its details are obscured by talus. The fault zone appears to be made up of a number of diversely oriented blocks. For example, some 600 feet north of the shaft house an outcrop of gray crinoidal limestones interbedded with quartzitic strata strikes east and dips 50° S.; but 50 feet farther southwest the rocks strike N. 15° W. and dip vertically. Other similarly discrepant measurements can be obtained, all of which indicate that the fault zone is probably made up of a mosaic of small blocks.

East of the mine, as already mentioned, the limestones dip eastward, averaging 45° E. on Cerro Gordo and flattening eastward and being practically horizontal near the Newtown mine. At this locality is shown a fine example of a fault breccia lying parallel to the stratification. The breccia, which is locally 4 feet thick, lies between two beds of limestone and consists of long slabs of dark-gray limestone and of a light-buff variety held in a matrix of very coarse white calc spar, individuals of which show cleavage surfaces 6 to 8 inches broad. On the face of the cliff southwest of the Newton shaft house a reverse fault of 10 feet displacement is well shown. The value of quartzite beds as indicators of faulting is illustrated effectively on the slopes behind the Newtown mine, where within a length of a few hundred feet the rocks are intersected by four faults, marked by fault breccias, with displacements, as measured on the interstratified beds of quartzite, that range from a few feet to 75 feet. One of these fault breccias carries numerous fragments of gossany iron oxide.

The examination of the geologic structure around Cerro Gordo therefore shows that the rocks have been subjected to severe faulting. Some of this faulting took place prior to the formation of the ore bodies and some after they had been formed, but the postmineral faults are probably of much smaller magnitude than the premineral. Underground examination in the Cerro Gordo mine is confirmatory of the indications of the surface geology, for many faults are exposed in the workings. Elucidation of the faulting may prove to be of the highest practical importance, for valuable ore bodies may have been cut off by faults and their continuations not found by the early operators. In determining the character and amount of dislocation along the faults, the diorite porphyry and other dikes should prove easily identifiable registers of displacement.

Three kinds of igneous rock occur in the mine—monzonite porphyry, quartz diorite porphyry, and diabase. The porphyries are the more abundant, but the diabase, of which there is a single narrow dike, is of especial interest, for one of the principal shoots of silver-lead ore recently found is a replacement of a sheared portion of it. The dikes occurring in the mine have been successively altered by metamorphism of three distinct kinds—alteration by shearing, alteration accompanying the primary mineralization, and alteration by oxidation and by the downward percolation of sulphate solutions. Any one of the alterations produced by these processes might be sufficient to obliterate the original features of the dikes; it follows, therefore, that the precise identification of some dikes is impossible; in fact, certain narrow dikes, which are considerably sheared, are difficult to distinguish from slate. The intrusive rocks near the mine admit of readier petrographic identification because of their freedom from alterations.

Monzonite porphyry forms a small mass intrusive into the surrounding shale northwest of Cerro Gordo. The porphyry is characterized by an abundance of feldspar phenocrysts and hornblende prisms, the phenocrysts being in certain parts of the mass so closely crowded as to give the rock a granitic appearance. The specimen, when examined microscopically, was found to show essentially these features. Plagioclase ($Ab_{62}An_{38}$) forms the predominant phenocrysts and is associated with phenocrysts of orthoclase and hornblende; the porphyritic constituents are inclosed in a groundmass which is composed of orthoclase and quartz and forms only a small proportion of the whole rock. Titanite (which is rather abundant), apatite, and magnetite are the accessory minerals. A small body of similar porphyry intrusive into limestone found southeast of the mine is noteworthy from containing masses of garnet rock whose boundaries are blurred, owing to garnetization of the inclosing porphyry. Garnet rock carrying a small amount of specularite occurs locally along the edge of the porphyry intrusion. Monzonite porphyry also forms a large body in the Belmont district a few miles southeast of Cerro Gordo.

These intrusive masses of monzonite porphyry are in all probability the partly uncovered tops of great bodies of granitic rock that underlie the Inyo Range at no great depth. Although granite does not appear along the crest of the range within 10 miles north of Cerro Gordo, yet toward the east, where the range drops off abruptly to Saline Valley 7,000 feet below, great quantities of granitic rock are exposed. Furthermore, lime-silicate rock, an aphanitic rock resembling a dense quartzite and consisting of one-third diopside and the remainder of quartz, calcite, and feldspar, occurs on the hillside a few hundred feet northwest of the mine, and masses of garnetized limestone are found at several mines and prospects west and southwest of Cerro Gordo, as at the Ignacio, Ventura, and others, a fact which indicates that the rocks at Cerro Gordo at the time of the intrusion of a granitic mass, now unexposed, were situated near the outermost limit of the zone of metamorphism produced by the invasion.

One of the most prominent dikes in the mine appears to have been originally similar to the monzonite porphyry northwest of Cerro Gordo. It is exposed in the Union tunnel, in the footwall crosscut of the Santa Maria pit, where it is 50 feet wide, and in the Zero level. The dike apparently conforms in the main with the strike and dip of the bedding of the inclosing rocks. (See fig. 8.) In the Union tunnel the contacts are considerably shattered; the west contact strikes N. 15° W. and the east contact N. 35° W., both being nearly vertical. The dike is overlain by a shale belt 105 feet wide and is underlain by massive white marble. In the Zero level, which is several hundred feet south of the Union tunnel, the dike lies within the shale belt, and therefore probably cuts across the trend of the formation at a narrow angle. The dike is of conspicuously porphyritic appearance, owing to the prevalence of large tabular feldspar crystals, and is considerably sheared and deeply stained by oxides of iron and manganese. Specimens from this dike are

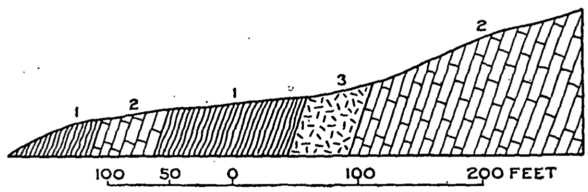


FIGURE 8.—Diagrammatic section along the line of the Union tunnel, Cerro Gordo, Cal. 1, Slate; 2, marble; 3, monzonite porphyry.

unsuitable for precise determination; and some material, which at least is not affected by oxidation, taken from the 400-foot level near the intersection of the San Felipe quartz vein, was found to be much altered by the development of dolomite, sericite, and pyrite.

The quartz diorite porphyry dikes differ considerably in appearance from the monzonite porphyry. A number of these dikes were noted in the underground workings, but only one was exposed at the surface near the mine—near the Buena Vista tunnel. A similar dike cuts across the stratification of the limestone at the south end of the east scarp of Cerro Gordo Peak; it ranges from 6 to 12 feet in thickness and is somewhat better preserved than the dikes in the mine. The dikes noted underground range in thickness from those 4 feet to those 25 feet. They are greenish-gray porphyries carrying innumerable small black prisms of hornblende, obscure plagioclase phenocrysts, and corroded quartz crystals. The quartz phenocrysts, although as a rule widely scattered and easily overlooked on casual inspection, are nevertheless peculiarly distinctive of the rock; and they are readily distinguishable even where the hornblende and plagioclase have been obliterated by mineralization. The dike cut on the 400-foot level is one of the best preserved in the mine, although locally considerably sheared, as in drift 404–1. It is about 18 feet wide and trends N. 70° W., cutting obliquely across the strike of the strata. Under the microscope the dikes prove to be highly altered, consisting of epidote, chlorite, feldspar, and sericite. On the 900-foot level a quartz diorite porphyry dike intersects the monzonite porphyry dike.

A single dike of diabase, disclosed by the mine workings, is of especial interest, for it contains the most important silver-lead ore shoot discovered since the rehabilitation of the mine. In the ore-bearing portion it is so strongly sheared and the primary minerals are so completely destroyed that its recognition and identification as an igneous rock would remain uncertain were it not that fairly well preserved material is obtainable on its southeast extension in the face of the Buena Vista tunnel. It is about 5 feet thick and lies conformable to the strike and dip of the inclosing marble. Both contacts are shattered. As here exposed it is a fine-grained grayish-green rock, which, under the microscope, is seen to have a typical diabasic texture, though the plagioclase is largely sericitized and the augite that occupied the triangular spaces between the plagioclase laths is wholly chloritized. Profoundly altered equivalents in which the diabasic texture is almost completely obliterated were collected from the 700 and 900 foot levels.

Lead ore bodies.—The lead ore bodies of Cerro Gordo consist of lenticular masses distributed through a zone 1,500 feet long and several hundred feet wide. The predominant rock of the ore-bearing zone is a white, finely saccharoidal marble, essentially a pure calcite rock, which on freshly fractured surfaces shows a slight bluish tint. Slate and igneous rock (dikes of quartz diorite porphyry and monzonite porphyry) occur also within the ore-bearing zone, but the ore bodies with one notable exception are inclosed in the marble. Certain of the larger ore bodies that were formerly worked (for example, that of the Santa Maria pit) rested on a footwall of slate.

The rocks of the ore-bearing zone strike north to northwest and dip on the average 70° SW.; the ore bodies conform to the trend of the inclosing rocks. To cite an example, the Jefferson stope—the stope farthest southeast—strikes N. 35° W. and dips 75° SW.

The lead ore bodies extracted during the early history of the mine attained in places a thickness of as much as 40 feet. The Jefferson stope is from 3 to 20 feet wide and averaged 70 feet in length; the Union stope, from which $3,000,000 worth of silver and lead is supposed to have been extracted, extended down to the 500-foot level. According to Raymond,[1]

The Union, the highest on the mountain side, has undergone considerable development during the past year. On the surface the ore body strikes about S. 30° E. and dips steeply to the southwest, but at the level of the main working tunnel, which strikes the Union at a depth of about 175 feet from the surface, the ore body begins to stand nearly perpendicularly and continues so for a depth below this level of 165 feet, the lowest point reached in September, 1872. At a depth of 200 feet below the tunnel a branch leaves the main ore body toward the west. Its dip is very flat, and it has been followed over 100 feet, always in very excellent ore, the greater part of which is galena. This branch is about 3 feet thick. It is thought and hoped by the owners of the Union that it will eventually run into the Santa Maria; and, as the Union has the older title, the independent existence of the Santa Maria would in that case be endangered. The longest level on the vein in the whole mine is the one driven at a depth of 200 feet below the tunnel, and even this one is little over 100 feet long. But the ore deposit, as developed by this level and the work done in the 65 feet below, is of extraordinary extent, being in many places 40 feet wide and nowhere less than 15. At the same time the ore is very solid, being either reddish-yellow carbonate or pure gray carbonate, lying in great blodges in the former. The masses of the latter kind have frequently a diameter of from 3 to 6 feet, and always show a concentric arrangement—that is, every mass of this kind which has been cut through by the excavations shows concentric rings around an interior nucleus (generally a small lump of unaltered galena), the rings being somewhat darker than the main mass. This arrangement presents a beautiful aspect, and, though common with gray carbonate of lead when

[1] Raymond, R. W., Statistics of mines and mining in the States and Territories west of the Rocky Mountains for 1872, pp. 18–19, 1873.

lying in a ferruginous gangue, it is not often seen on as large a scale as exposed in the Union. The carbonate ores of the Union, on account of their friability termed "fuse ores" by the miners, average, as delivered to the furnace, about 25 ounces of silver per ton and the galena from 50 to 80 ounces.

Many of the old stopes are no longer accessible, having either caved or been filled with waste by the many different lessees who labored in the old workings prior to the rehabilitation of the mine. The west wall rock of the Union (or China) stope is distinctive and is locally known as "altered lime." Instead of the dense white marble or limestone that generally incloses the ore bodies, the wall rock consists of a moderately coarse grained curved dolomite spar more or less stained with manganese. In places, owing to the development of the dolomite in distinct crystals, it resembles a porphyry closely crowded with white feldspar phenocrysts. The dolomite contains a few limonite pseudomorphs after pyrite. Similar dolomite rock is found in the storehouse drift on the 400-foot level. This dolomitization of the marble wall rock evidently accompanied the primary mineralization. In an exploratory crosscut driven on the 700-foot level some coarsely dolomitic rock heavily charged with pyrite was found; and it is not improbable that such dolomitized rock may serve as a guide in the search for bodies of argentiferous galena.

Some shoots of lead ore were recently discovered at the surface in the marble several hundred feet east of the shaft—that is, in the footwall portion of the ore-bearing zone, though it should be borne in mind that no definite footwall has yet been found. These ore bodies were covered by 5 to 6 feet of slide rock, which probably accounts for their nondiscovery by the former operators. One of the shoots recently uncovered at the surface, averaging a foot or so in width, consists predominantly of galena but contains also some tetrahedrite, sphalerite, and pyrite. The galena has a distinct sheared structure, which wraps around the sphalerite and tetrahedrite. This structure was evidently produced by the crushing of galena into small, flat, parallel lenticles. Oxidation products, among which bindheimite is the most notable, are to a small extent associated with the primary lead ore, though not so abundantly as in places in the deeper levels. Completeness of oxidation in the Cerro Gordo was obviously not determined by depth, but was dependent largely on the perviousness of individual ore shoots to oxidizing solutions. Adjoining the lead ore zinc carbonate has replaced the marble wall rock through a thickness of several feet.

The most important shoot of argentiferous lead ore mined in late years occurs in a much-sheared portion of the diabase dike previously described. This shoot, at the time of visit in 1913, had been developed from the 1,025-foot level to 170 feet above the 700-foot level. Its average dip is about 68° and it pitches southeast. Its length is 17 to 20 feet and its maximum thickness 5 feet, but its high silver content makes it an especially valuable ore body. The ore occurs in the footwall portion of the dike, which here ranges in thickness from 5 to 8 feet, probably as a replacement, although the evidence of this has been obscured by the prevalent oxidized condition of the ore. Rarely does the ore extend into the marble foot or hanging wall; and this limitation of the ore to the diabase dike is rather mysterious, for in the rest of the mine the ore is a replacement of marble of the same kind. The ore consists largely of galena but contains some tetrahedrite, zinc blende, and pyrite. Galena is intimately intergrown with the tetrahedrite. Cerusite, anglesite, and bindheimite (the hydrous antimonate of lead) are the most common oxidation products; linarite (the deep azure-blue sulphate of lead and copper), caledonite (the pale-green sulphate of lead and copper), and chrysocolla are present in smaller quantity.

The minerals in the ore shoots described are typical of the mine as a whole. The predominant primary mineral is galena and the subordinate constituents are zinc blende, tetrahedrite, and pyrite. The zinc blende, although subordinate, is of much importance in connection with the origin of the zinc carbonate ore. By oxidation the sulphides have yielded a multitude of secondary minerals, such as cerusite, anglesite, bindheimite, smithsonite, calamine, hydrozincite, aurichalcite, chrysocolla, linarite, brochantite, caledonite, and limonite. Cerusite and smithsonite are of economic importance, the others are of mineralogic interest only. Linarite, a rare mineral for which Cerro Gordo is well known, deserves mention because of its striking beauty. Aurichalcite, another comparatively rare mineral, is also noteworthy because it occurs locally in some abundance in small veinlets traversing zinciferous limonite; it is of a delicate blue and bluish-green color, though fading on continued exposure to light, and characteristically forms rosettes and fanlike groups of pearly luster.[1]

The San Felipe vein cuts diagonally across the silver-lead ore-bearing zone, traversing both marble and monzonite porphyry. It trends N. 45° W., dips 70°–80° SW., and ranges from a fraction of an inch to 18 inches in thickness. The main ore mineral is tetrahedrite, with which occur its oxidation products, azurite and malachite, inclosed in a gangue of quartz and barite. The vein is well exposed in the Zero level, where a drift shows it to be 12 inches wide and quartzose, carrying considerable galena, partly converted to carbonate, and a minor quantity of tetrahedrite, but locally no barite. It is noteworthy that the dense marble in proximity to the vein was not converted to coarsely crystalline calcite. The vein is frozen to the hard white marble walls, and the ore is therefore expensive to break out and to separate from the waste rock broken with it. The sorted ore is said to carry $100 a ton in silver.

Zinc ore bodies.—The zinc ore forms irregular masses and pipes in the limestone walls of the old lead stopes, principally in the footwall. The form of the ore bodies is determined partly by structural features such as stratification, jointing, and the fracturing that took place after the formation of the lead ore masses. The zinc ore is frozen to the limestone but does not grade into it, although the ore originated clearly by replacement of the limestone.

The first zinc ore taken out was that found in the footwall of the old Union stope; from this body 5,000 tons were extracted. On the 400-foot level a pipe 5 feet in diameter and 150 feet long averaged more than 40 per cent in metallic zinc. As the zinc mineral in the ore is mainly smithsonite, whose theoretic percentage of zinc is 52, the ore is very pure, and considerable quantities have actually contained as much as 50 per cent. The pipe headed toward the Union stope and, with increasing proximity to it, showed a notable increase in limonite and halloysite. Near the head of the pipe extensive masses of limonite, including bodies of pure white halloysite as much as 4 feet thick, were found. The same phenomenon occurs throughout the mine, the zinc ore becoming, by progressive disappearance of the iron, increasingly purer with increasing distance from the old lead ore bodies. Bodies of zinc ore extend in places at least 100 feet laterally from the lead ore.

The halloysite is a white amorphous substance of somewhat waxy appearance. In composition it resembles kaolin, a mineral with which the writer was at first inclined to identify it, but it contains more water. Its identity as halloysite was established by a quantitative analysis made in the laboratory of the United States Geological Survey.

Analysis of halloysite from Cerro Gordo, Cal.

[Chase Palmer, analyst.]

SiO_2	43.11
Al_2O_3	38.60
H_2O (ignition)	17.52
	99.23

The analysis shows that the material is an almost ideally pure hydrous aluminum silicate whose composition agrees closely with that given by Dana for halloysite. Under the microscope the halloysite is found to be isotropic; its refractive index, as determined by the immersion method, is 1.55.

The zinc ore consists essentially of the carbonate, smithsonite, with limonite and calcite as impurities. The ore is fine grained in texture and dead white in color, and hence is known as "dry bone." Much of it is characteristically banded or laminated; the laminae range from mere films to half an inch thick. The lamination is curiously convoluted and the patterns produced by the convoluted laminae are not uncommonly irregular-shaped closed ellipses. The occurrence of patterns of this kind proves that the lamination did not result from the replacement of a bedding structure in the marble nor from a sort of photographic "development" by the replacement of a bedding structure that was previously impercepti-

[1] In mineralogic publications many minerals are described as occurring at "Cerro Gordo," but the contexts show that the distinction between Cerro Gordo "mine" and Cerro Gordo "district" is not always made.

ble. The lamination strongly suggests that it originated by the rhythmic precipitation of the zinc carbonate by the calcite of the marble. Vugs are common in the fine-grained smithsonite, and some are lined with more coarsely crystalline smithsonite and with calamine. Calamine occurs also to some extent in laminae, which have a radial fibrous structure. Hydrozincite is rare, occurring for the most part as small botryoidal groups implanted on smithsonite.

The ore as shipped in 1913 averaged 35 per cent of zinc, about 10 per cent of ferric oxide, and 2 per cent of calcium carbonate. It carries only a trace of lead as a rule and no silver nor gold. The total production of zinc ore to January 1, 1917, was 24,000 tons.

GIBRALTAR PROSPECT.

The Gibraltar prospect, 3 miles north of Antelope Spring, in Deep Spring Valley, was located in 1886. Ten tons of ore carrying $34 to the ton in lead and silver is said to have been sent from it to the Selby smelter a number of years ago. The country rock is a tremolite-bearing white fine-grained marble. The lode trends N. 85° E. and stands vertical. A large open cut on the property exposes a zone about 4 feet wide carrying the small irregular stringers of ore. One hundred feet above this is a short tunnel in which the lode ranges from 6 inches to 1 foot in thickness. The ore consists of galena, sphalerite, and tetrahedrite. The oxidized ore shows a little azurite stain.

MONTEZUMA MINE.

The Montezuma Mining & Smelting Co.'s property lies near the foot of the Inyo Range, 9 miles by road southeast of Big Pine. The Montezuma is one of the old mines of the region. As described in the report of the Director of the Mint for 1883 a large amount of argentiferous galena lying almost horizontal and containing 30 ounces of silver to the ton and 38 per cent of lead was exposed at or near the surface. A smelter, since abandoned, had been built on the railroad at Elna and the ore was hauled there for treatment. The ore is difficult to treat on account of its low grade and considerable admixture of zinc blende. The mine was idle during 1912.

Buff-weathering and gray-weathering limestones of dense texture, which on fresh fracture are white with a bluish cast, constitute the prevailing country rock in the vicinity of the upper tunnel. As seen within the tunnel the rocks are intensely shattered and broken, and in one drift a porphyry dike, which seems to have been originally a diorite porphyry, was, because of the intensity of dynamic disturbance, kneaded to a putty-like mass and powerfully slickensided. The ore seen on the dump carries finely disseminated galena, sphalerite, and pyrite, and a few coarse particles of tetrahedrite; the galena and sphalerite occur in approximately equal amounts and are in part intimately intergrown. The gangue consists largely of dolomite with some associated quartz. The oxidized ore shows azurite, lead carbonate, and iron oxide.

ESTELLE MINING CO.'S CLAIMS.

The Estelle Mining Co., organized in August, 1902, owns 29 claims south and southwest of the Cerro Gordo mine. During the four years preceding 1912 the energies of the company were devoted to driving a crosscut tunnel (4,400 feet long, in 1912) to undercut the iron oxide cropping on the Morning Star claim, 1,700 feet above the portal of the tunnel. The tunnel, known as the Dellaphene, traverses Carboniferous rocks, mainly limestones, and intersects a considerable number of fault zones, the most extensive of which is 200 feet in width. At 3,750 feet from the portal drifts have been turned off both north and south for several hundred feet along one of these fault zones, which is traversed by a number of quartz veins of irregular size and description. Locally the quartz contains tetrahedrite, galena, sphalerite, and pyrite in amounts in the order named. The ore is said to carry 20 ounces to the ton in silver.

The outcrop on the Morning Star claim, which the Dellaphene tunnel is projected to undercut, is said to assay $14 in gold and 17 ounces in silver to the ton across a width of 45 feet. The developments on the Morning Star claim consist of a tunnel 420 feet long, from which a winze has been sunk 225 feet, giving a total depth of 500 feet below the apex. From this winze levels have been run at depths of 35, 70, 120, and 220 feet. A crosscut tunnel traverses what may be called the ore-bearing zone, exposing 35 feet of hydrous iron oxide and limestone, 60 feet of limestone, and 20 feet more of limestone stained with iron oxide. The iron oxide contains a few small lumps of galena.

VENTURA MINE.

The Ventura Mining Co. owns nine claims situated a short distance below Cerro Gordo. Development work in a small way was in progress in 1913, and a 6-horsepower gasoline hoist was installed for deepening an old shaft that former owners had sunk to a depth of 150 feet. Some ore was taken out in drifting along a number of the many short tunnels on the property.

In the vicinity of the workings a small mass of intrusive diorite appears at the surface, evidently the top of a body much larger in depth. It has exerted a large amount of contact metamorphism and has converted an extensive body of Carboniferous limestones into garnet and other dense fine-grained lime-silicate rocks. In places these rocks are netted with quartz stringers inclosing small quantities of galena. The mineralization of economic interest took place, however, along a number of shear zones, some of which are 30 feet wide, that traverse the metamorphic area. Galena ore, largely converted into carbonate, occurs in bunches along these zones and carries an ounce of silver to the unit of lead.

Some work has been done also on a narrow argentiferous quartz vein that outcrops near the main road below the principal workings. This vein carries tetrahedrite and galena and shows a little blue staining due to linarite.

NEWSBOY MINE.

The Newsboy mine, owned by the Cerro Gordo Mining Co., lies in the Belmont district a few miles southeast of Cerro Gordo at an altitude of 7,500 feet. It is opened by a tunnel which cuts the lode 275 feet below the outcrop. The best ore is obtained from winzes and drifts below the tunnel level; at the time of visit in 1913 a rich shoot was being exploited 50 feet below the tunnel level.

The country rock in which the veins of the Belmont district are inclosed is a homogeneous mass of monzonite porphyry, which is intrusive into limestones of Carboniferous age. The porphyry consists of crystals of andesine, orthoclase, and hornblende in a groundmass which is so scanty as to be barely perceptible to the unaided eye but which under the microscope is found to be composed of quartz, orthoclase, and plagioclase.

The ore of the Newsboy mine is a coarse white rather vuggy quartz that carries considerable galena, subordinate tetrahedrite, and rarely chalcopyrite and pyrite. Cerusite and a bright-yellow ocher, bindheimite, are common; iron oxide is present; and linarite in places is excellently crystallized in needles. The ocher is rich in precious metals, assays showing 508 ounces of silver and 3.4 ounces of gold to the ton. The ore that was being mined at the time of visit was sorted to yield a product carrying $100 a ton, mainly in silver; the rejected material has a value of $25 a ton, but the cost of mining and of freighting the ore by pack train to Cerro Gordo makes the loss of this material unavoidable.

PERSEVERANCE MINE.

The Perseverance mine is on the east flank of the Inyo Range, about 1½ miles from Cerro Gordo. The ore body is a well-defined quartz vein averaging several feet in width, which is inclosed in limestone and dips 45° E. The metalliferous minerals, which are present in small amount, are tetrahedrite, sphalerite, and galena, partly oxidized to cerusite, azurite, and bindheimite. The quartz gangue contains some tabular barite. By rigorous sorting, in which all material not showing metalliferous minerals was rejected, the present lessees obtained a product carrying $20 to $40 a ton in silver. The large proportion of waste, however, rendered operation unremunerative.

MONSTER MINE.

The Monster mine, discovered in 1907, is on the east flank of the Inyo Range northwest of Saline Valley. It is reached either by a trail over the summit of the mountains from Mazourka Canyon or by the Saline Valley road from Zurich. The principal developments consist of two tunnels and a number of open cuts.

The general country rock consists of a stratified series of limestones, probably of Ordovician age, striking N. 75° E. and dipping steeply north. Several hundred yards south of the mine dark knotted schists represent thermally metamorphosed argillaceous sediments intruded by granite.

The ore body at the point of discovery was an irregular lens of nearly solid galena 3½ feet wide and approximately 40 feet long. The general trend of the body of ore as seen in the upper tunnel, which is 75 feet long, is northwest. The galena has been almost completely removed, but at the far end of the tunnel some is found embedded in quartz veinlets that reticulate through the limestone. The ore makes in bunches in the limestone but is everywhere associated with quartz, although the galena tends to segregate and form pure masses. A new tunnel driven below the upper tunnel is approximately 150 feet long but did not cut much ore. The country rock is a mottled blackish limestone transfixed by tremolite fibers at the portal of the lower tunnel, and is coarsely brecciated throughout its length. The limestone in the ore-bearing zone is a severely brecciated buff-weathering variety which is white with a slight yellowish cast on fresh fracture.

The ore seen on the dumps consists almost entirely of galena, a very subordinate proportion of pyrite, and even less tetrahedrite, which is to be found only on close search. No sphalerite or other zinc mineral was noted. The oxidized ore consists largely of cerusite, in places finely crystallized, but shows also a little chrysocolla and the blue and green basic sulphates of lead and copper—linarite and caledonite.

The ore was taken on pack animals over the Inyo Range to Mazourka Canyon, whence it was hauled by team to the railroad at Kearsarge (Citrus). It was carefully sorted and is reported to have carried $100 a ton in silver and lead. The property was not worked in 1912.

GOLD ORES.

CHARACTER AND OCCURRENCE.

The gold deposits of the Inyo Range are mainly small, narrow quartz veins. The greatest depth attained on any of the veins, so far as known to the writer, is 300 feet. The surface ores are thoroughly oxidized and are of comparatively high grade, ranging from a few dollars up to $100 a ton. The mineralogic features are simple; the primary ores carry a small amount of sulphides, commonly pyrite or galena, with subordinate sphalerite and chalcopyrite, in a coarse white quartz gangue. Primary barite was noted in one ore.

The veins occur either in the borders of the granite intrusions or in the surrounding country rock at no great distance from the granite. This is so uniformly true that it suggests strongly a genetic connection between the veins and the granite.

A large number of veins have been found and developed, have contributed their quota to the output of the region, and are now exhausted. At the time of visit, in 1912, opportunities were not favorable for the study of deposits of this class, and an extended treatment of them here is not advisable; details concerning the accessible mines and prospects must be sought under the special descriptions.

Many of the deposits were discovered in the sixties by Mexicans, who for many years worked them by means of arrastres. The most important gold-producing area was probably the Beveridge district, on the summit of the Inyo Range northeast of Lone Pine. The Keynote, situated at an altitude of 10,000 feet and accessible only by a mule trail, was the most productive mine, yielding for a time more than $10,000 a month.[1] Much ore was taken out of other mines, but no records of their production are available.

As a whole the veins have not given rise to a steady gold-quartz mining industry, and during 1912 their exploitation was nearly at a standstill. The Reward, the largest gold-quartz mine in the range, was idle during the year, pending change of ownership.

Placers, especially those of Mazourka Canyon, were formerly of some importance.[2] The gold was separated by passing the gravel through dry washers. The best ground has been exhausted, and in 1912 a few men working on the rims of the auriferous channels and at the heads of the gullies were able to make only bare wages by dry washing.

[1] Director of the Mint Rept. for 1883, p. 159, 1884.

[2] California State Mineralogist Thirteenth Ann. Rept., p. 182, 1896.

MINES AND PROSPECTS.

GOLDEN SIREN PROSPECT.

The Golden Siren prospect is in the White Mountains at an altitude of 10,500 feet, near the head of North Fork of Crooked Creek. Its main shaft is reported to be 90 feet deep and to intersect the vein at 45 feet. The country rock is a white Cambrian marble, which is intruded by granite that outcrops a few hundred feet east of the shaft. The ore is of two kinds—quartz and iron oxide. The vein sampled over a width of 5 feet is said to average $14 to $18 a ton in gold.

BLIZZARD EXTENSION PROSPECT.

The Blizzard Extension prospect is a scant 3 miles south of the Golden Siren on the north flank of Mount Blanco at an altitude of 10,800 feet. The developments consist of a few small open cuts, an incline 60 feet long, from which a drift 26 feet long was driven at a depth of 45 feet. The geologic features are essentially like those at the Golden Siren. The country rock is a white marble of Cambrian age, and a large mass of intrusive granite lies a few hundred yards north of the property. The vein strikes N. 80° E. and dips steeply south. It consists at the surface of 3 to 6 inches of quartz carrying oxidized sulphides, but it is said to be 2 feet wide and to average $13 a ton in gold in the drift. On the dump considerable gossany iron oxide has accumulated, much of which was doubtless formed by the reaction of iron-bearing solutions (derived from the oxidation of the primary sulphides originally inclosed in the quartz) on the limestone wall rocks.

During 1912 a road 5 miles long was being constructed to Roberts's ranch, on Wyman Creek, at an altitude of 8,200 feet. Here a small stamp-milling outfit, to be driven by an overshot wheel, was being installed.

WATERFALL PROSPECT.

The geologic features at the Waterfall prospect are unlike those seen anywhere else in the Inyo Range. This prospect, located in 1906, is at an altitude of 7,400 feet 3 miles north of Antelope Spring, in Deep Spring Valley. The general limestone country rock lies within the zone of contact metamorphism of the nearby intrusive mass of granite, and as a result has been considerably altered, chiefly by marmarization and the development of tremolite and other minerals. The gold-bearing deposit, as shown in open-cut workings, consists of a north-south belt of tremolitic white marble 10 to 12 feet thick, traversed by fluoritic veinlets, which range from a fraction of an inch to several inches in thickness. The larger veinlets are quartzose and contain coarse orthoclase, muscovite, and fluorite, and are therefore pegmatitic in composition and appearance. The hanging wall of the belt is a black micaceous hornfels. The fluorite, which is of a pronounced purple color and imparts to the gold ore an unusual and striking appearance, is said to assay $18 a ton in gold, though neither gold nor other metallic mineral, except rare specks of pyrite, is visible in it. The proportion of fluoritic veinlets to the whole mass of limestone traversed by them is small, and at one point only are the veinlets possibly numerous enough to bring the whole mass up to ore grade.

GRAY EAGLE PROSPECT.

The Gray Eagle prospect is on the south side of Redding Canyon, on the west flank of the Inyo Range, at an altitude of 7,000 feet. The vein, which occurs at the contact of the granite and limestone, lies nearly horizontal and has a maximum thickness of 8 inches. The quartz carries considerable iron oxide; the sulphide ore shows some chalcopyrite and pyrite, associated with iron oxide in a quartz gangue. At the immediate contact a small mass of oxidized ore carrying some galena was found. In the underground workings massive garnet rock is found at the contact, and also rock showing columnar epidote several inches long. These contact rocks are traversed by small quartz stringers carrying a minor quantity of chalcopyrite.

GOLDEN MIRAGE PROSPECT.

The Golden Mirage prospect, which lies west of the Gray Eagle at an altitude of 6,450 feet, comprises a number of workings on a quartz vein in granite. At the lower open cut 2½ feet of solid milk-white quartz strikes N. 20° E.

and dips 40° E. Leached cavities in the quartz indicate the presence of former sulphides, principally of large cubic crystals of iron pyrite. The vein is rather irregular in thickness; 2½ feet is the maximum and 1 foot is probably a generous average. The gold content is spotted and is generally highest in the honeycombed rock; it is reported to average perhaps $5 a ton for the whole vein.

X-RAY MINE.

The X-Ray mine is an old property worked by the Mexicans in the sixties, which was obtained by its present owners by relocation after its abandonment by the former owners. It is on the west side of Redding Canyon, near the Gray Eagle and Golden Mirage prospects, all of which are now under the same ownership. The vein is in granite. On the south end, near the contact of granite and sandstone, it ranges from a fraction of an inch to 8 inches in thickness. In the incline driven on the vein it dips 16° N. and trends N. 70° E. Toward the north end the vein is a foot thick, but 3 inches is probably the average. The walls are well defined. In view of its narrowness, the vein is remarkably persistent and continuous. The shoot of ore on the south end is said to be nearly 600 feet long. During 1912 five carloads of ore were shipped from this and the other two claims under the same ownership.

EUREKA MINE.

The Eureka mine is on the Nevada & California Railroad (Southern Pacific system), on the east side of Owens Valley at the foot of the Inyo Range, 9 miles northeast of Independence. The property consists of four patented claims, which were located in 1862. About 1864 a 20-stamp mill was erected near the property on Owens River, which was dammed and a water wheel set up; but within a year the mill burned down. The settlement was known as Chrysopolis, but it has long been obliterated.

The principal developments at the Eureka mine consist of a shaft and a tunnel undercutting the deposit at a depth of 100 feet. The prevailing country rock is a massive, fairly coarse hornblende-biotite granite intersected by a number of dikes of dark fine-grained diorite porphyry, which as a rule are highly schistose. The dike intersected in the tunnel is 15 feet wide, is roughly schistose, and cuts inclosing granite that is somewhat sheared along the contacts. The dikes in general consist of black fine-grained rock which, owing to the presence of small white feldspars, exhibits an obscure porphyritic texture. Under the microscope the porphyritic feldspars are found to consist of plagioclase and the groundmass to be made up of a fine intergrowth of feldspar, finely flaky biotite, and sericite. A specimen of granite, or, more precisely, quartz monzonite, taken from the bottom of the winze at a depth of 140 feet, was determined microscopically to be composed of plagioclase, microcline, quartz, and biotite, with considerable associated secondary epidote and calcite.

The ore body consists of a mass of granite interlaced with quartz stringers lying between two dikes of diorite porphyry, which converge at a narrow angle toward the south. The surface ore is highly oxidized, containing much red and brown iron oxide and showing in places some of the blue copper silicate, chrysocolla. Coarse gold is not uncommon and is readily panned from the oxidized ore. The ore is sorted and shipped to the smelter, and in recent shipments is reported to have averaged $77 a ton in gold.

Necessarily on the present small scale of working the richer ore alone is taken out. Single stringers are followed, and because of their irregular and discontinuous character mining is expensive. Investigations to determine the practicability of mining the whole mass of granite and its included quartz stringers are reported to have been undertaken.

BLACK EAGLE MINE.

The Black Eagle mine is on the west flank of the Inyo Range at an altitude of 8,300 feet, 4 miles in an air line east of Kearsarge (Citrus). The developments consist of a shaft 310 feet deep and a number of levels. The ore body is a narrow quartz vein at the contact of granite and limestone but inclosed principally in the granite. The vein trends N. 70° E. and dips very slightly to the south. On the third level its total exposed length is 400 feet.

The vein material is quartzose, though carrying a little barite which is intergrown with the quartz and is undoubtedly of primary origin. Pyrite is the only sulphide noted, and its oxidation has given rise to earthy hematite, limonite, and ferruginous jasper. The ore is usually of high grade and by sorting will yield a product that carries $100 a ton in gold. During the operation of the mine the ore was packed by mules at a cost of $4 a ton to a small steam-driven stamp mill at Willow Springs, 2,800 feet lower on the flank of the range.

REWARD AND BROWN MONSTER MINES.

The Reward and Brown Monster mines, usually spoken of together as the Reward mine, are the property of the Reward Consolidated Gold Mining Co.

The Brown Monster was formerly known as the Eclipse, and the Eclipse mill of six stamps was built in 1870. After change of ownership a 30-stamp mill was erected, which was driven by water power generated by water diverted from Owens River. The mill is reported to have produced $200,000, when the property became involved and was sold under an execution.[1] Subsequently this mill was dismantled and the present mill of 20 stamps was built near the mine openings, with which it is connected by a gravity tram. In 1911 the mine and plant were overhauled and an electric transmission line 4½ miles long was constructed across Owens Valley to furnish power. After a short run the mine was closed in the spring of 1912, pending change of ownership.

The Reward mine is favorably situated on the east side of Owens Valley less than 2 miles from Manzanar station on the Nevada & California Railroad.

The working tunnel of the Reward mine, which opens on Reward Gulch, intersects the vein 750 feet from the portal. From the intersection the seventh or lowest level follows the vein for 300 feet. Above the seventh level are six others, ranging in length from 300 to 500 feet. All the workings on the Reward vein are south of Reward Gulch; those on the Brown Monster vein are on the north side, and a short drift driven northward connects them with the main working tunnel of the Reward mine. The Brown Monster vein is developed by an incline on the vein several hundred feet long and by several short drifts to the north.

The country rock in the vicinity of the Reward mine consists of a stratified series of limestones of Carboniferous age, but to the southwest there are Triassic rocks, which form the low hills that project through the alluvium of Owens Valley. The strata strike generally northwest, but as they have been intensely folded the dips are extremely variable. The folding is displayed in diagrammatic perfection on the north side of Reward Gulch; in the bottom of the gulch the strata stand vertical, and near the level of the Brown Monster outcrop they are sharply bent and dip west at a low angle.

A few hundred yards east of the mine, at an altitude of 5,000 feet, is exposed intrusive diorite which is part of the great granitic mass making up the western flank of the Inyo Range for a considerable distance to the north. In consequence of the intrusion the limestones in the vicinity of the mine have been considerably metamorphosed and are either tremolite-bearing marbles or dense-textured lime-silicate hornstones. Dikes and sills have been injected, one of which, 10 feet thick and approximately 50 feet above the vein, is particularly noteworthy because, being easily traceable on the surface, it furnishes an index of the character and amount of the faulting that the Reward vein has undergone. A limestone bed a foot thick, lying above the diorite sill, has as a result of metamorphism been recrystallized to a coarse-grained aggregate of diopside, tremolite, and calcite.

The Reward vein conforms approximately to the bedding of the inclosing rocks. The hanging wall, as seen above the outcrop, is a stratum of dark-blue siliceous limestone 5 feet thick, which locally is considerably brecciated. The vein can be traced south of the gulch for 400 feet, beyond which it forks and the branches pinch out abruptly. Near the surface the vein lies nearly flat, but at the face of the lowermost drift it dips 40° NE. and strikes N. 40° W. The vein swells and pinches abruptly, ranging from a few inches to 10 feet in thickness with an average thickness of 4 feet.

The ore is a coarse white quartz generally devoid of sulphides. On some of the levels

[1] Director of the Mint Rept. for 1883, p. 160, 1884.

the Reward vein shows large solid bunches of coarsely crystalline galena and some pyrite, chalcopyrite, and sphalerite. These last, however, are extremely rare, and the total quantity of sulphides is only a small fraction of 1 per cent of the ore. Oxidation products occur to some extent—limonite, ferruginous jasper, chrysocolla, cerusite, anglesite, the deep azure-blue linarite, and the bluish-green caledonite, the last two of which are rare basic sulphates of lead and copper.

The Brown Monster vein can be traced more or less continuously for 1,000 feet northwestward from Reward Gulch. In the underground workings it displays the same general features that it shows along the outcrop, being in places a solid and well-defined quartz vein and in others mixed with country rock. In the upper levels the vein dips 25° E., but in depth it steepens and near the bottom of the incline the dip increases abruptly to 50°. The vertical depth attained on the vein is 200 feet.

The ore is a quartz practically barren of sulphides. Locally, it carries blebs of pyrite and, rarely, chalcopyrite, galena, and sphalerite. Minerals resulting from the oxidation of sulphides originally present are limonite, which is by far the most abundant, and calamine, chrysocolla, and wulfenite in small amounts. Well-formed crystals of orange-yellow wulfenite occur in vugs in the quartz at the north incline. In the face of the fifth level the secondary minerals are well shown as replacement products of country rock inclosed in the vein. They comprise calamine in fine radial groups, some of which are half an inch in diameter, hydrous iron oxides, ferruginous jasper, chrysocolla, and wulfenite.

The underground workings of the Reward and Brown Monster mines are dry. Oxidation has extended down to the lowest levels, although some larger masses of sulphides on the upper levels, such as the bunches of galena in the Reward vein, have escaped alteration.

Considerable ore is exposed in the workings of the Reward mine and is stated to average $12 a ton in gold and silver.

Reward Gulch is eroded along a shear zone 40 to 50 feet wide, whose crushed and broken character is excellently shown in the main working tunnel of the Reward mine. It is therefore a matter of importance whether the Reward and Brown Monster veins are two distinct veins or are the faulted segments of a single vein displaced about 200 feet horizontally along the line of Reward Gulch. The limestone strata or groups of strata match on opposite sides of the gulch, and the diorite sill previously mentioned, which serves as a more easily recognizable indicator than the limestones, crosses the gulch without essential displacement. The powerfully slickensided country rock in the Reward tunnel is therefore the product of oscillatory movement, and as a further consequence it follows that the Reward and Brown Monster veins are two distinct and independent veins. Faults along which displacement has occurred have, however, dislocated the veins from 1 foot to 6 feet, as shown along the outcrop of the Brown Monster vein and in the workings of the Reward vein. The faulted blocks have been invariably downthrown on the south side. On the north side of Reward Gulch the diorite sill is cut by two faults, both of which displace the sill 15 feet vertically and produce a fault segment 20 feet long.

Several hundred feet stratigraphically above the Reward vein is a bedded quartz vein 2 feet thick; the hanging wall is limestone and the footwall is a diorite sill. The vein carries a moderate quantity of galena and some chrysocolla. In the main mass of diorite near its contact with the invaded limestone is a quartz ledge 6 inches thick carrying galena. The ore is similar to that of the Reward vein and is of interest as establishing the fact that the mineralization took place after the intrusion of the diorite.

BURGESS MINE.

The Burgess mine is on the summit of the Inyo Range at an altitude of 9,200 feet. It is reached by a trail from Mount Whitney station and by wagon road from Swansea, but supplies are usually brought in by pack train over the trail. In the mine the rocks strike N. 30° W. and dip 65° W. The vein conforms in strike and dip with the inclosing rocks, which are mainly limestones of Triassic age, containing crushed specimens of ammonites north of the shaft. Dikes of diorite porphyry are common in the vicinity of the mine.

The ore is a milky-white quartz carrying galena; by sorting, a product high in gold is obtained. The developments consist of two shallow inclines, the principal one of which was operated by a gasoline hoist. During 1912, however, the mine was idle.

COPPER ORES.

OCCURRENCE AND CHARACTER.

Cupriferous contact-metamorphic rock occurs in limestone at a number of places where the limestone abuts upon the margin of the intrusive granite west of Mazourka Canyon. In the unoxidized condition this material consists essentially of garnet carrying a small quantity of chalcopyrite, but in its prevalent oxidized state the copper is present mainly as films and thin veinlets of chrysocolla. As the garnetized rock is not abundant and as it contains trivial quantities of copper, most of the deposits of this type in this region are not of economic importance.

GREEN MONSTER MINE.

The most notable deposit of contact-metamorphic copper ore is that exploited at the Green Monster mine, 1½ miles north of Kearsarge (Citrus). The total production of this property, it is reported, is 300 tons of 12 per cent copper ore, carrying $4.50 a ton in gold and silver. In 1912 the property changed ownership, and it was the intention of the new owners to develop it systematically. The developments so far made (1912) consist of open cuts, short tunnels, and drifts.

Geologically the mine is situated at the contact of intrusive aplite and limestone that is probably of Carboniferous age. The aplite, which is a white, even-grained, fine-textured rock composed of feldspar and quartz, penetrates the limestone irregularly and has produced considerable metamorphism in the invaded rock, as shown by the formation of garnet masses. At the upper workings of the mine the buckled arch of an anticline is exposed; the west limb, which is the more regular, strikes N. 10° E. and dips 30° W.; the east limb stands vertical.

The copper ore occurs in the garnetized zone. It is highly oxidized, so that the facts concerning its origin and distribution are much obscured. It is associated with iron oxides and occurs in such a form that its presence must be determined by chemical means. Chrysocolla, which is found subordinately, is the only copper mineral definitely recognizable. In the outcrop there is much yellowish-green mineral, to which prevalence the mine doubtless owes its designation. This mineral is in part earthy in texture and in part shows a fibrous, woody structure. Some of this fibrous material was investigated chemically by W. T. Schaller and proved to be a hydrous ferric silicate analogous to chloropal.

MARBLE.

Marble quarries have been opened on the west front of the Inyo Range, on the Nevada & California Railroad, a mile northwest of Swansea and 4 miles northwest of the railroad terminus at Keeler. Sidings from the railroad extend to the quarry faces. Stone from these quarries was used in the construction of the Mills Building, one of the first modern office buildings in San Francisco, which was erected by D. O. Mills, who was largely instrumental in the construction of the Carson & Colorado Railroad, the predecessor of the Nevada & California. In recent years the quarries have lain idle, but the improved transportation facilities provided by the Mohave-Owenyo branch of the Southern Pacific system, which gives access to Los Angeles, 250 miles away, may result in their being reopened or in the development of new quarries along the southeastern extension of the marble belt.

Quarries have been opened at two closely adjoining places upon a series of stratified dolomites of unknown but possibly Ordovician age, which stand at high angles. The dolomite beds are much jointed and fractured, and it is obvious that to get out sound blocks of marble much accompanying waste rock had to be removed. It does not seem likely that these defects will disappear in depth. The product obtained was mainly a pure white marble of rather fine grain, but it included some fancy varieties. Merrill[1] has described these marbles, and concludes that "the Inyo marbles are perhaps among the most promising the West has as yet produced." An analysis of the marble yielded 54.25 per cent of calcium carbonate,

[1] Merrill, G. P., Stones for building and decoration, pp. 206–207, 1903.

44.45 per cent of magnesium carbonate, and 0.6 per cent of iron and silica.[1]

The southeast extension of the belt, mapped as "undifferentiated Paleozoic" (see Pl. I), has been covered with building-stone claims. Hill[2] says that half a mile southeast of Swansea there is "a magnificent vertical stratum of pure white dolomite marble, estimated to be over 100 feet thick." He believes that the quantity of marble is ample for development.

SIERRA NEVADA.

ORE DEPOSITS.

Large deposits of tungsten ore, consisting of scheelite in contact-metamorphic garnet rock, were found west of Bishop in the later part of 1913. They remained practically unknown until the spring of 1916, when two mills, having a total daily capacity of 400 tons, were completed and put in active operation.[3] The intrusive granitic contacts shown on Plate I (in pocket) are favorable places to prospect for other similar ore bodies. Favorable conditions persist also north of the area mapped, as shown by recent discoveries of large contact-metamorphic tungsten deposits on Pine Creek, northwest of Bishop.

The only gold mining in progress in recent years in the Sierra Nevada west of Owens Valley is that at the Bishop Creek mine on the Middle Fork of Bishop Creek. The ore body under exploration consists of a quartzite band carrying auriferous pyrrhotite and arsenopyrite and forms part of a sedimentary roof pendant projecting deeply into the batholithic masses of the range.

The veins of the Kearsarge district are high on the east and north flanks of Kearsarge Peak. The Rex Montis mine, said to have been the most important in the district, is 11,600 feet above the sea or 8,000 feet above the floor of Owens Valley. It was opened by a number of adits, but these are now caved or filled with snow and ice. The vein, which is apparently a few feet wide at most, is inclosed in quartz monzonite in proximity to a schist belt that is extensively penetrated by quartz monzonite and aplite dikes. The gangue is a comby milk-white quartz devoid of metallic minerals. In early days the mines of the district yielded ores extremely rich in gold and silver.[4]

A large number of small gold veins have been worked at Fish Spring Hill, 6 miles south of Big Pine. At this locality quartz monzonite projects through the basalt that makes up the extinct volcano known as Crater Mountain. The veins traverse the quartz monzonite; the ore carries chalcopyrite in a quartz gangue; and the sorted product averages about $50 in gold to the ton. The output has in part been milled in arrastres on Birch Creek.

MINES AND PROSPECTS.

The Bishop Creek Mining Co. has been developing during recent years a gold mine on Middle Fork of Bishop Creek at an altitude of 8,500 feet. A 10-stamp mill has been built and during 1913 a cyanide plant was erected. The company owns 12 patented claims and 80 or more unpatented claims along a belt of highly metamorphosed quartzites and schists surrounded by granite. The mine is opened by a shaft, the first level of which is at a depth of 188 feet and the second at 288 feet.

The rocks in the immediate vicinity of the shaft are quartzitic strata striking N. 50° W. and dipping 60° NE. They are intersected by numerous dikes of aplite, which cut across the stratification. The quartzites are a coarse vitreous variety that contains a small amount of accessory garnet and finely disseminated pyrrhotite. Under the microscope they show in addition small quantities of pyroxene and titanite. They have obviously been highly affected by thermal metamorphism. The shaft of the mine seems to be at about the middle of the belt of quartzite strata, although this can not be precisely determined on account of the presence of much morainal material on the slopes behind the mine. This belt of quartzites continues northwestward as a quite narrow band, but toward the southeast it widens abruptly. The granitic rock west of the mine is a quartz monzonite comparatively rich in hornblende and biotite. The contact with the quartzite belt is excellently exposed in a glacial knob in the center of the valley. At the con-

[1] California Min. Bureau Tenth Ann. Rept., p. 218, 1890.

[2] Hill, R. T., Marble deposits of the Inyo Mountains: Min. and Sci. Press, vol. 105, pp. 86–87, 1912.

[3] Knopf, Adolph, Tungsten deposits of northwestern Inyo County, Cal.: U. S. Geol. Survey Bull. 640, pp. 229–249, 1917.

[4] Goodyear, W. A., Inyo County: California Min. Bureau. Eighth Ann. Rept., pp. 232–233, 1888.

tact, which is welded, the granite shows no mineralogic change, but the sedimentary rock is either coarsely recrystallized or granitized. In addition to the quartzites and aplite seen in the surface exposures a narrow dike of pyroxene lamprophyre has been cut on the first level of the mine.

The ore body, which is said to have no walls, is 4 to 8 feet wide, its width being determined by assay findings. The ore consists of quartzite carrying disseminated sulphides, among which pyrrhotite and arsenopyrite predominate, and sphalerite, chalcopyrite, pyrite, and molybdenite occur. Pyrrhotite is by far the most common and widely disseminated sulphide. The ore on the dump is reported to average $10 to the ton in gold and the heavy sulphides $50 to the ton in gold.

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