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GEOLOGY AND WATER RESOURCES

OF

OWENS VALLEY, CALIFORNIA

BY

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GEOLOGY AND WATER RESOURCES OF OWENS VALLEY, CALIFORNIA.

By WILLIS T. LEE.

INTRODUCTION.

This report is the result of field studies made during the season of 1904 under the direction of Mr. N. H. Darton. The region considered includes Owens Valley, part of Mono Lake and Salt Wells valleys, and the slopes of the adjoining mountain ranges. A description of the geologic formations and structure is presented, with special reference to their bearing on the prospects for underground water. A general account of the surface waters also is given, with a discussion of the conditions likely to influence the storage of water in a region of recent seismic disturbances. Economic products in the nature of building materials are briefly described, and the effect of the present irrigation on the total water supply of Owens Valley is pointed out.

GEOGRAPHY.

TOPOGRAPHY.

General relations.—Owens Valley is located in east-central California, between the Sierra Nevada on the west and the White Mountains or Inyo Range on the east (see Pl. I), and includes the area drained by Owens River and its tributaries. It contains two smaller topographic depressions, Long and Round valleys. Owens Valley is the westernmost of the desiccated valleys of the Great Basin region and differs from the others in that it has an abundant water supply, derived mainly from the melting snows on the high mountains to the west. It is an undrained basin, the lowest part of which is occupied by a large salt lake.

Altitudes and slopes.—The floor to the valley has an average elevation of 3,700 feet, with a uniform gradient between Keeler and Bishop of 7 feet to the mile. The altitude, according to railway surveys, is 3,607 feet at Keeler, 3,661 feet at Lone Pine, 3,721 feet at Independence, and 4,107 feet at Bishop. North of Bishop the grade of the river is much steeper. Mono Lake is 55 miles from Bishop and the difference in elevation is 2,623 feet. The general altitude of the Sierra Nevada west of Owens Valley is about 12,500 feet, but several peaks of the range rise to elevations varying from 12,500 to nearly 15,000 feet; these are Mounts Whitney (see Pl. II, *B*), Williamson, Ritter, Lyell (see Pl. VI, *A*), and others. The rugged character of the range is illustrated in Pl. II, *A*. Between Owens Lake, the lowest point in the valley, and Mount Whitney, the highest peak of the Sierra Nevada, the difference in altitude is about 11,300 feet, but there are other places much nearer together where differences nearly as great occur.

The maximum elevation of the White Mountains is reached in White Mountain Peak, which is 11,321 feet high. To the south the average altitude is about 10,000 feet. The western side of the White Mountains, which faces Owens Valley, is a steep though regular slope, as shown in Pl. III, *B*, but it is much less deeply dissected by erosion than the eastern face of the Sierra Nevada. The Coso Mountains comprise the southern part of the White Mountains, but they are separated from the Mountains on the north by a low pass east of Owens Lake.

DRAINAGE.

Owens River.—The principal drainage in this region is into Owens River, a main stream with a large number of important tributaries entering mainly from the west, those from the east being intermittent. The waters of Owens River empty into Owens Lake, from which they escape only by evaporation. There is a heavy precipitation on the western side of Owens Valley, resulting from the great elevation of the Sierra Nevada. The moisture-laden winds from the west lose much of their moisture in passing over this high range, and as a consequence the rainfall is very light in the main part of Owens Valley and the districts farther east. From the headwaters of Owens River, at Mount Lyell, southward to Mount Whitney, numerous streams enter the valley from the Sierra Nevada, as shown in Pl. I. The largest of these are South Branch, Rock, Pine, Bishop, Coyote, Big Pine, Tinemaha, Taboose, Oak, Shepherd, and Lone Pine creeks. South of Mount Whitney the tributaries are smaller and intermittent, because of the small amount of snow on the summit of the range. Owing to the steepness of the mountain slopes on the west, the streams are torrential in character, flowing through deep, narrow gorges on the higher slopes and emerging lower down onto detrital cones which they have deposited. Some of the smaller streams sink in the detrital material and the larger ones reach the river with greatly diminished volume.

The present form of the Owens River system (see Pl. I) is due largely to the change of climate in recent geologic time. Throughout a part at least of Quaternary time Owens River flowed southward through Salt Wells Valley, and the portion of Owens Valley north of Bishop probably contained a flowing stream. During the changes toward greater aridity of climate which took place later, the water supply was cut off from the upper part of Owens River and one of its main tributaries was left as the head of the stream. At the time evaporation in the valley equaled or exceeded the inflow, that part of the river south of Owens Lake ceased to flow, and the tributaries from the White Mountains became dry from lack of sufficient rainfall, if, indeed, they ever had been permanent streams. The result is a river system of considerable size truncated at both ends and modified on the east side, with only its middle portion still active.

Mono Lake drainage.—There are several short mountain streams in the northern part of the district which empty into Mono Lake. Rush Creek, the largest of these, is a stream of considerable size. It derives its waters principally from melting snows high on the slopes of the Sierra Nevada near Mount Lyell. (See Pl. VI, *A*). Mono Lake is similar to Owens Lake both in its physical character and in the chemical composition of its waters. The two lakes are nearly the same in size, Mono having an area of about 85 square miles and Owens about 75 square miles. Both are located at the eastern base of the Sierra Nevada and, although about 125 miles apart, both derive their water supply from the vicinity of Mount Lyell. Mono Lake, however, lies at an elevation about 3,000 feet higher than Owens Lake. Neither lake has an outlet.

GEOLOGY.

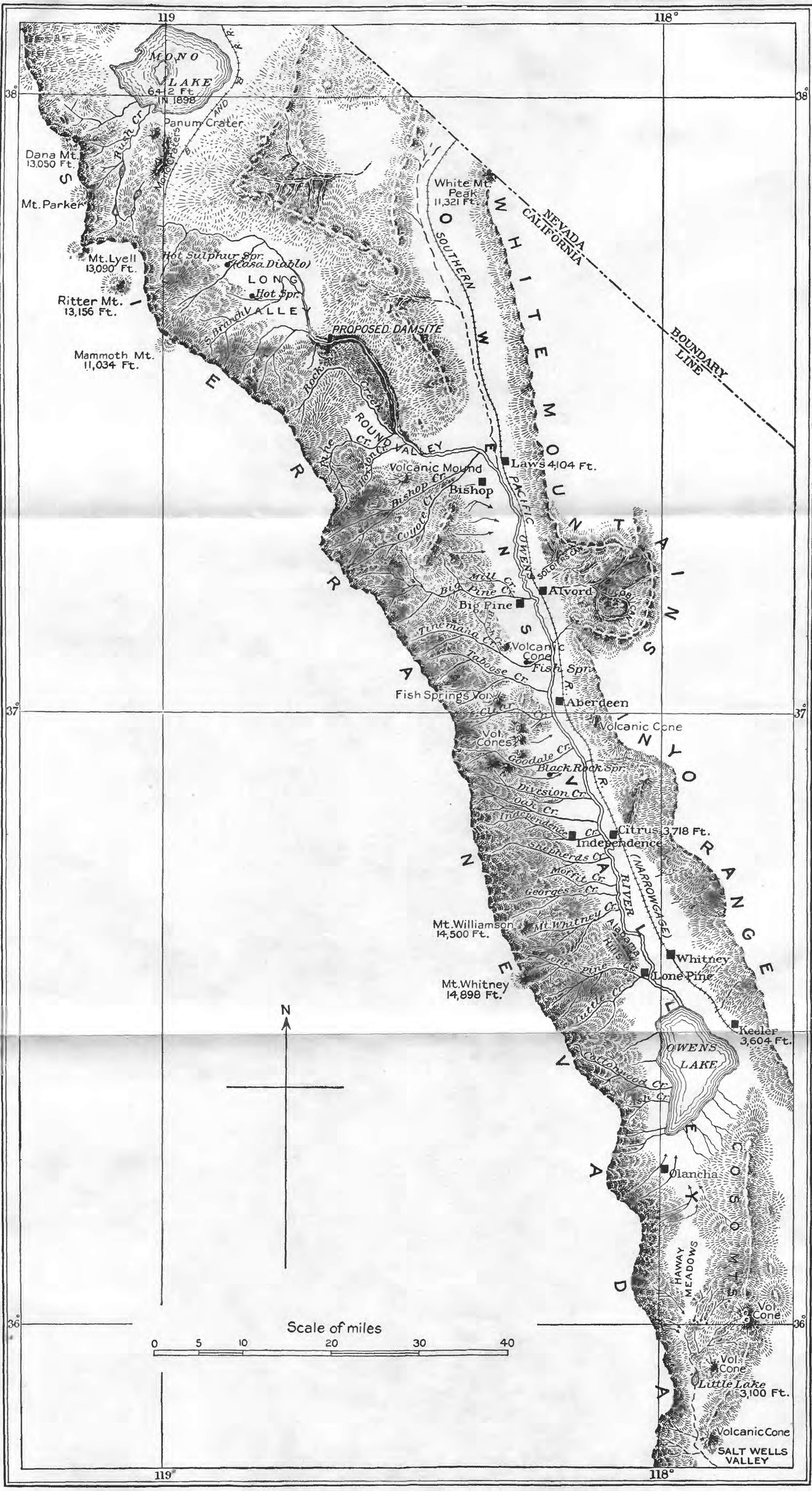
STRATIGRAPHY.

PRE-TERTIARY ROCKS.

The older rocks appearing at the surface in the Owens Valley region consist of granite and more or less metamorphosed sediments, which are of Algonkian, Paleozoic, and Mesozoic age. The rocks are nearly impervious and, as they outcrop in a region of practically no rainfall, they probably do not contain much water. They form an impervious basin, however, for the water-bearing sands and gravels.

TERTIARY SEDIMENTS.

Deposits of sand, gravel, and clay of supposed Tertiary age occur at two localities in the Owens Valley region, one south of Owens Lake, between the Coso Mountains and the Sierra Nevada, and the other in the Waucobi embayment east of Alvord. In the area south of



MAP OF OWENS VALLEY, CALIFORNIA.

Owens Lake the beds consist of partly consolidated deposits of sand, gravel, and clay, which attain a thickness of at least 1,500 feet and possibly more. These deposits have been referred to the Miocene by Fairbanks[a]. Near Haway Meadows, where at least 500 feet of this formation have been removed by erosion, a boring 1,028 feet deep did not pass through it.

The so-called Tertiary deposits occurring in the Waucobi embayment, east of Alvord, extend westward into Owens Valley, passing beneath the late Quaternary deposits of the valley floor. The strata consist of fine limy, sandy, and clayey beds with layers of conglomerate, the whole series being covered by wash brought down from the mountains. Near the mountains the deposits consist of coarse material which changes toward the valley to finer sediments. This formation has been described by Walcott[b] as a lake deposit of late Pliocene or Quaternary age, and the fresh-water shells, abundant in some beds, are considered by W. H. Dall[c] to be of Pleistocene age.

QUATERNARY SEDIMENTS.

The Quaternary deposits in Owens Valley consist mainly of clay, volcanic ash, sand, and gravel laid down in successive layers which have a thickness of at least 465 feet beneath the lake level, as is shown by the record of the well at Keeler, near the eastern edge of Owens Lake. Material similar to that penetrated by the Keeler boring is found in terraces at an elevation of about 250 feet above the lake. These terraces, having the same elevation as the southern outlet of the valley, undoubtedly mark the level of the lake when it drained southward through Salt Wells Valley. At that time the lake probably extended northward as far as Bishop. In these terraces and in the material penetrated by the Keeler well fresh-water shells occur in considerable abundance. *Carinifex newberryi* Lea and *Odonta* sp. are the principal forms. These were identified by W. H. Dall, who believes that the species were denizens of Owens Lake and of other lakes extending over a wide range west of the Rockies. The desiccation of the lakes, with concentration of the alkaline salts in their waters, rendered them unsuitable for molluscan life, and the species were left only in streams and such lakes as remained fresh, where they are found at the present time in greatly diminished numbers.

Along the base of the mountains on either side of Owens Valley are detrital cones, which were brought down in late Quaternary time and are still in process of accumulation. Those at the base of the Sierra Nevada have a maximum elevation of about 2,000 feet above the river and are connected with each other, forming a continuous slope, while along the base of the White Mountains they are smaller and more isolated, and their outlines are better preserved. The material in the cones on the White Mountain side of the valley consists largely of detritus from sedimentary rocks; along the Sierra Nevada it is composed of granitic fragments. Many of the granite blocks are 10 to 15 feet in diameter, and some of them occur as far as 5 to 6 miles from the base of the mountains.

VOLCANIC FEATURES.

The volcanic features of the Owens Valley region consist of crater cones, lava flows, hot springs, and mud geysers. The occurrence of the hot springs and mud geysers in this connection is probably significant. The volcanic deposits are found principally in three districts.

Coso district.—In the Coso Mountains, southeast of Owens Lake, extensive volcanic action has taken place and the effects of two distinct periods of eruption are apparent. The older flows have been deeply dissected by erosion, while the more recent lavas are not dissected, but still retain their original form. These lavas are mainly beyond the border of Owens Valley and no special study was made of them.

[a] Fairbanks, H. F., Notes on the geology of eastern California: Am. Geologist, vol. 17, 1896, p. 67.
[b] Walcott, C. D., The post-Pliocene elevation of the Inyo Range: Jour. Geol., vol. 5, No. 4, 1897, pp. 340–348.
[c] Ibid, p. 342.

Big Pine district.—There is a volcanic region near the center of Owens Valley, between Independence and Big Pine. The flows of basalt are evidently of very recent origin, overlying late Quaternary deposits and giving little evidence of weathering. Scoriaceous lava occurs in the irregular forms in which it cooled from the molten state, and numerous cinder cones contain craters which are more or less perfect. The lava once extended across the valley and for a considerable distance up the side of the White Mountains. In the floor of Owens Valley the lava sheet is now considerably eroded by the river and covered to some extent by alluvium. In the vicinity of Aberdeen the lavas occur near a group of granitic hills, which extend for some distance into the lower portion of the valley. (See Pl. I.) Flows of volcanic rock extend southward along the base of the Sierra Nevada to a point a few miles north of Independence. The extinct volcanic cone known as "Fish Spring Volcano" (see Pl. II, *A*) lies west of Aberdeen and is the largest and possibly the oldest volcanic cone in the region. It rises about 2,000 feet above Owens Valley and has a well-defined crater about 100 feet deep. At the base of the Sierra Nevada, west of Bishop, occur the northernmost cinder cones of this district.

Long Valley district.—The largest district of volcanic rocks within the area described in this report extends from the upper end of Round Valley to Mono Lake. In the southern part of the district the rock is dark colored and consists mainly of andesitic tuffs and breccias, which are well exposed in the bluffs of Owens River and Rock Creek, where they form bold, cavernous cliffs and rugged slopes. In some places large masses of material are almost wholly unconsolidated, while in others the tuff is solidified into resistant rock. The canyons which are cut through the andesite by Owens River and the smaller streams, such as Crooked Creek (Pl. V, *B*), are 200 to 300 feet deep, a fact indicative of considerable age. In that portion of the district which lies north of Long Valley the surface is more or less covered with volcanic products that are believed to be more recent than those farther south. They consist of obsidian, pumice, and unconsolidated ash, and are described in detail by Russell [a] in his paper on the Mono Lake region. Beds of ash and scoriaceous rock of this younger series were observed as far south as Casa Diablo. Panum Crater (Pl. V, *A*) is probably one of the best illustrations of the younger volcanic cones. Russell described this crater as follows: "The rough crags piled in the center of the bowl of lapilli are not of the nature of a cone of eruption, as might be supposed from our knowledge of Vesuvius and other similar volcanoes, but are ejections of a molten rock of the same character as the neighboring lava flows. They are in fact incipient coulées which were congealed before a definite flow in any direction had been established."

The central core of Panum Crater is completely surrounded by a sharp, V-shaped depression, the outer rim of which is a circular ridge composed of the volcanic cinders that form the outer part of the cone. The core rises to an elevation considerably higher than the cinder rim and is composed of scoria and black volcanic glass. The sides of the core are steep, craggy, and more or less broken, giving unmistakable evidence that it was thrust out en masse after the formation of the cinder rim and at a time when the material was in a semiplastic condition and yet resistant enough in general to hold the form given to it by the throat of the crater. Some of the blocks from the side of the core are elongated, some are warped or contorted, and many are scored and grooved on the sides, so that a differential motion is plainly indicated.

Hot springs.—Along the zone in which extinct volcanoes occur there is a series of hot springs. Although the temperature of the water in these springs is not necessarily due to volcanic heat, their close association with the old volcanoes suggests that the heat may be derived from that source. Several of the springs are grouped near the west end of Long Valley, where they form a stream of considerable size, known as Hot Creek. One of these springs is said to have been an active geyser until a few years ago, when the creek changed its course in such a way as to flow over the mouth of the geyser and destroy its intermittent action. Hot springs were observed in Owens Valley as far south as the group of volcanic cones between Independence and Big Pine.

[a] Russell, I. C., Quaternary history of Mono Valley, California: Eighth Ann. Rept. U. S. Geol. Survey, pt. 1, 1889, pp. 377-389.

A. VIEW OF OWENS VALLEY AND THE SIERRA NEVADA NEAR BIG PINE.

Showing a volcanic cone ("Fish Spring" volcano) in the middle-ground and the Sierra Nevada in the distance.

B. EASTERN FACE OF MOUNT WHITNEY.

Cliffs in the center are about 3,000 feet high. Western slope of Sierra Nevada is seen in upper left-hand corner and a remnant of Tertiary slope at the right in the distance.

Mud geysers.—There is a small mud geyser at Casa Diablo, near the west end of Long Valley, which is in continuous and violent action. At a number of places in its immediate vicinity the steam escapes in small quantities and for a considerable distance from the geyser the rock is more or less heated. This suggests either very recent volcanic activity or the beginning of future volcanic action. No vent showing signs of recent eruption was found near this place, and it is possible that the heat accompanies some initial rather than closing stage of volcanic activity. On the other hand, the heat may be due to friction or crushing caused by faulting. Casa Diablo is near the fault zone at the base of the Sierra Nevada, along which in other places there has been recent movement.

STRUCTURAL GEOLOGY.

Owens Valley is a V-shaped trough, extending in a nearly straight line from Salt Wells Valley northward into Nevada east of Mono Lake. The western side of the trough is the granitic escarpment of the Sierra Nevada, a general view of which is given in Pl. II, *A*. The eastern side is the less steep face of the White Mountains (see Pl. III, *A*), composed principally of sedimentary rocks. The bottom of the trough is filled to an unknown depth with Tertiary and Quaternary deposits. From Owens Lake to Bishop, a distance of more than 70 miles, the trough, measured from crest to crest of the adjoining mountain ranges, is 12 to 25 miles wide. North of Bishop it is much wider.

The geologic structure of the Owens Valley region has been described in part by several geologists, mainly in connection with discussions of certain features of the Sierra Nevada. Briefly stated, it is assumed that this range is a large block of the earth's crust which in comparatively recent geologic time has been faulted and elevated at its eastern margin, with westward tilting of its surface. Although no conclusive proof has been presented that the eastern face or escarpment of the Sierra Nevada is due to faulting, confirmatory evidence has been discovered in a number of places. It has been shown by Gilbert[a] and Diller[b] that the western slope of the Sierra Nevada is a tilted peneplain and that the escarpment on the east is presumably due to faulting which accompanied the uplift and tilting of the great block. This faulting is indicated by the displacement of gravel deposits at the north end of the range as described by Diller,[b] also by similar movements of gravels near Mono Lake, of lava sheets north of Honey Lake, of gravels near Genoa, and of various rocks along the base of the Sierra Nevada in Owens Valley, as described by Russell,[c] Diller,[d] Lindgren,[e] and Whitney,[f] respectively.

Evidence of faulting and block tilting similar to that which affected the Sierra Nevada has been found in the White Mountains. Walcott[g] has shown that the strata of these mountains were contorted and strongly folded in comparatively early geologic time, but later the range, like the Sierra Nevada, moved as a large crust block. It has also been suggested by Walcott[h] that the steep eastern escarpment of the White Mountains may be due to faulting, while the westward inclination of the lake beds in the Waucobi embayment may be due to a tilting of the White Mountain block.

To these indications of faulting in the Owens Valley region may be added those observed by the writer. In the White Mountain face east of Lone Pine strata of Triassic age pass beneath the floor of Owens Valley, with a dip of about 50°. In the Alabama Hills west of Lone Pine the same formation is found in a shattered condition and associated with granitic rock in a manner clearly indicating displacement by faulting. Southwest of Bishop a small

[a] Gilbert, G. K., Science, vol. 1, 1883, pp. 194-195.
[b] Diller, J. S., Tertiary revolution in topography of Pacific coast: Fourteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1894, pp. 408, 432.
[c] Russell, I. C., Quaternary history of Moses Valley, California: Eighth Ann. Rep. U. S. Geol. Survey, pt. 1, 1889, p. 322.
[d] Diller, J. S., Geology of Lassen Peak district: Eighth Ann. Rept. U. S. Geol. Survey, pt. 1, 1889, p. 429.
[e] Lindgren, W., Age of the auriferous gravels of the Sierra Nevada: Jour. Geol., vol. 4, 1896, p. 902.
[f] Whitney, J. D., The Owens Valley earthquake: Overland Monthly, June, 1872.
[g] Walcott, C. D., The Appalachian type of folding in the White Mountain Range of Inyo County, Cal.: Am. Jour. Sci., 3d ser., vol. 49, 1895, pp. 169-174.
[h] Walcott, C. D., The post-Pleistocene elevation of the Inyo Range: Jour. Geol., vol. 5, 1897, pp. 340-348.

exposure of marble occurs, apparently a displaced remnant of the extensive marble and limestone formation in the White Mountains, which passes beneath the floor of the valley at Independence, with a dip of 80°. There is evidence near Little Lake not only of displacement by faulting, but also of the rate at which displacement took place. At Little Lake, which has an altitude of 3,000 feet, the granite extends across the valley, and at Haway Meadows, at an altitude of 3,782 feet, a well bored to a depth of 1,028 feet was still in Tertiary sediments. The basin formed by the older rocks is therefore at least 246 feet deeper than the granite which forms the lowest part of its rim. How much deeper the basin is remains unknown. Its ascertained depth of 246 feet is clearly due to subsidence and not to erosion and indicates that the subsidence was more rapid than the down cutting of the river. The Tertiary strata at Haway Meadows dip westward at an angle of about 15° and terminate somewhat abruptly against the granite base of the Sierra Nevada, but it was not determined whether they were displaced there by a fault or otherwise.

HISTORY OF THE ORIGIN AND DEVELOPMENT OF THE VALLEY.

GENERAL STATEMENT.

As stated in the introduction, one of the purposes of the present investigation was to determine the prospects of successful water storage in this region of recent seismic disturbances. If Owens Valley has resulted from the formation and movements of crust blocks, accompanied by faulting, the time at which these movements occurred and the prospects of their recurrence must be considered in connection with a project for water storage in this valley. In case the crustal disturbances occurred only in ages long past, a stable condition of the surface might reasonably be expected; but, on the other hand, if movements have taken place recently an unstable condition may exist and earthquakes more or less disastrous to an irrigation system are to be expected. For these reasons the following brief history of the crustal movements in the Owens Valley region is given.

Disturbances of great magnitude are known to have occurred in both the Sierra Nevada and the White Mountain regions in pre-Tertiary time, resulting in the formation of mountain ranges. These movements obviously were too ancient to affect seriously the question here discussed and therefore need not be treated at length. Some time during the Tertiary period, however, a series of events began which do affect these questions. The peneplain of the western slope of the Sierra Nevada, first recognized by Gilbert,[a] has been further described by Diller,[b] who shows that the planation was probably accomplished during Miocene time. Gravels deposited upon this peneplain have been elevated, faulted, and tilted. Diller found them showing a vertical displacement of about 3,000 feet along the eastern face of the range at its north end. Similar displacements were found by Russell[c] near Mono Lake and by Turner[d] near Tower Peak. At the latter place gravel-covered plateaus occur near the summit of the range, close to the escarpment, which Turner explains as parts of the old peneplain raised to its present position after the deposition of the gravels. Parts of the peneplain are well preserved at Mammoth Mountain, and its relation to the eastern face of the Sierra Nevada is clearly shown in Pl. VI, *B*.

POST-TERTIARY UPLIFT.

Since the time of King's survey,[e] observers of the Sierra Nevada region, with few exceptions, have assigned the main uplift to post-Tertiary time. Le Conte,[f] in a paper describing the geology of the western slope of the Sierra Nevada places the elevation of the moun-

[a] Gilbert, G. K., Science, vol. 1, 1883, pp. 194-195.
[b] Diller, J. S., Tertiary revolution in topography of Pacific coast: Fourteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1894, pp. 404-411.
[c] Russell, I. C., Quarternary history of Mono Valley, California: Eighth Ann. Rept. U. S. Geol. Survey, pt. 1, 1889, p. 322.
[d] Turner, H. W., Rocks of Sierra Nevada: Fourteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1894, p. 442.
[e] King, Clarence, Rept. U. S. Geol. Explor. 40th Par., vol. 1, 1878, p. 744.
[f] Le Conte, Joseph, A post-Tertiary elevation of the Sierra Nevada, shown by the river beds: Am. Jour. Sci., 3d ser., vol. 32, 1886, pp. 167-181.

A. WESTERN FACE OF THE WHITE MOUNTAINS NEAR ALVORD STATION.

Level valley floor in the foreground, and transition slope in the middle-ground. Photograph by C. D. Walcott.

B. GRANITE BOWLDERS OF THE ALLUVIAL SLOPE AT THE BASE OF THE SIERRA NEVADA, NEAR BIG PINE.

Photograph by C. D. Walcott.

tains at the close of the Tertiary and suggests that their rise may have been coincident with an increasing aridity of climate in the Basin region and with the beginning of deposition of the Quatenary beds which occupy so large an area east of the range, including Owens Valley.

The assignment of the uplift to post-Tertiary time has recently been confirmed by certain observations of Turner. [a] From a study of the Tertiary gravels and lavas on the western face of the Sierra Nevada along Tuolumne River, he concludes that the Sierra block has been tilted to a notable extent since the close of the Tertiary period. He shows that the grade represented by the Neocene gravels averages 142 feet per mile, while the grade of the Tuolumne River is 92 feet per mile. He also points out that the Neocene stream was more mature than the present one and presumably flowed at a lower grade. He concludes: "Assuming that the Neocene Tuolumne had originally a grade as low as that of the modern stream, which is evidently yet a young stream, it is clear that the present grade of the Neocene channel must have been brought about by the differential uplift on the east, resulting in a tilting of the range westward."

It is probable that some of the phenomena observed by the present writer are to be explained by the post-Tertiary uplift. At certain places, especially in the vicinity of Mount Whitney, isolated and inclined table-lands terminated by nearly perpendicular cliffs, interrupt the continuity of the general slope of the mountains. Some of these table-lands have concave and others convex surfaces. One with a concave surface appears in the distance at the right in Pl. II, *B*. They are found in considerable numbers near Mount Whitney at an elevation of over 10,000 feet and they do not occur, so far as observed, below that elevation.

The rock floors of the gorges and cirques separating the table-lands give abundant evidence of glaciation. Polished and grooved surfaces and glacial lakes are numerous. Pl. IV is a view from " the meadow " on the Mount Whitney trail in one of these gorges. The cliff is the side of one of the table-lands. In this case the table is a concave surface of considerable extent and slopes steeply to the east.

The ancient slope represented by these table-lands is not in harmony with the general steep eastern face of the Sierra Nevada, and obviously it was formed before these mountains attained their present elevation. On the other hand, the deep gorges and wide cirques separating the table-lands give evidence of extensive erosion after the development of this ancient surface. They also indicate glaciation near the close of this period of erosion.

The succession of events, as inferred from the phenomena above described, is as follows: Previous to the last great uplift of the Sierra Nevada the land surface in the vicinity of Mount Whitney was one of low relief and gentle slopes. The uplift of the mountains, presumably at the close of the Tertiary, was followed by a period of rapid erosion of the now precipitous eastern face of the range. Near the close of this period the newly formed valleys (Pl. IV) were occupied by glaciers. How long they were thus occupied and whether the glaciers were major or minor factors in excavating the valleys are questions to which no answer is here offered.

LATE QUATERNARY MOVEMENTS.

A movement of recent date in the White Mountains (Inyo Range) has been described by Walcott [b], who shows that a difference in elevation of about 3,000 feet has been effected within the range in comparatively recent geologic time. The lake beds of the Waucobi embayment, which are of late Pliocene or Quaternary age, have been tilted until at their eastern border they are 3,000 feet higher than at their western border in Owens Valley. Walcott suggests that the movement which tilted these beds occurred in late Quaternary time. This opinion is based mainly on the occurrence of a recently formed fault scarp, the truncation of spurs, and the presence of large springs along the line of the fault, and the formation of pools and bogs on land formerly crossed by wagon roads. Lindgren [c] has described a recent fault at the base of the Sierra Nevada, near Genoa, where Quaternary deposits have been

[a] Turner, H. W., Post-Tertiary elevation of the Sierra Nevada: Bull. Geol. Soc. America, vol. 13, 1903, pp. 540-541.

[b] Walcott, C. D., The post-Pleistocene elevation of the Inyo Range: Jour. Geol., vol. 5, 1897, pp. 340-348.

[c] Lindgren, W., Age of the auriferous gravels of the Sierra Nevada: Jour. Geol., vol. 4, 1896, p. 902.

displaced 40 feet, and evidences of still more recent faulting are found in Owens Valley. During the earthquake of 1872, described by Whitney[a] and later by Gilbert, Russell, and others, faulting occurred throughout the valley along the base of the Sierra Nevada.

EFFECTS OF OWENS VALLEY EARTHQUAKE.

The more important geologic effects of the earthquake described by Whitney[a] are fissures in the soil or rock, alterations of level of the different parts of the valley, either temporary or permanent, changes in the water courses, and accumulations of water in depressions formed by the earthquake. The author says:

> From Haway Meadows to Big Pine Creek we met frequent cracks in the earth, areas of sunken ground, depressions partly filled with water, and regions where motions of the surface soil had taken place either in a vertical or horizontal direction. The direction of these fissures is almost always nearly parallel with that of the base of the mountains, although in a few instances they run diagonally across the valley. . . . Near Big Pine . . . there is a series of extensive fissures, which may be traced uninterruptedly for several miles. In one place an area of ground 200 or 300 feet wide has sunk to the depth of 20 or 30 feet in places, leaving vertical walls on each side, and these depressions have become partly filled with water, so that ponds have been formed of no inconsiderable size. One noticed was fully one-third of a mile in length, and would have been much larger had not the depression been so situated as to afford partial drainage of the area at one end, so that the basin could not be entirely filled. . . . There are several places in the valley where fissures in the ground have crossed roads, ditches, and lines of fences, and where evidence has been left of an actual moving of the ground horizontally as well as vertically. One of these instances of horizontal motion is seen on the road from Bend City to Independence, about 3 miles east of the latter place. Here, according to a careful diagram of the locality drawn by Captain Scoones, it appears that the road running east and west has been cut off by a fissure 12 feet wide and the westerly portion of it carried 18 feet to the south. The same thing was noticed by us at Lone Pine and Big Pine with regard to fences and ditches, the horizontal distance through which the ground had been moved varying from 3 to 12 feet.

The distribution of volcanic vents and hot springs along the supposed fault line at the base of the Sierra Nevada escarpment is suggestive of movement along that line in comparatively recent time. To judge from Walcott's description of the Waucobi region, Lindgren's description of the Genoa region, and Whitney's description of Owens Valley, it is not unlikely that movements may still be in progress. According to Whitney the earthquake of 1872 was the most severe and disastrous that had been known on the Pacific coast. The shock was felt over the greater part of California and Nevada and southward far into Mexico. The area of greatest disturbance and greatest destruction of life and property was in Owens Valley along a line parallel with the face of the Seirra Nevada.

UNDERGROUND WATERS.

ARTESIAN CONDITIONS.

GENERAL STATEMENT.

From the descriptions of the geology and structure it is evident that Owens Valley is a well-defined structural basin formed by the older rocks and partly filled with younger sediments. These sediments, which were accumulated both as lake deposits and as débris from near-by mountain slopes, vary greatly in physical character. Lenticular deposits of sand, clay, and gravel occur in the valley fill, and at the sides wedge-shaped masses of coarse mountain wash are probably interbedded with the finer lake deposits. The extent and distribution of the various kinds of material composing the valley fill can only be conjectured, since the well data obtained are insufficient to establish definite relations between them.

The outline of the basin, together with such indications of the structure of the fill as could be obtained, indicates that the valley is a well-defined artesian basin; but whether the underground conditions are such as to produce flowing wells over a considerable portion of the basin can not be stated. A number of wells have been sunk in the valley to moderate depths

[a] Whitney, J. D., The Owens Valley earthquake: Overland Monthly, June, 1872.

VIEW FROM "THE MEADOW" ON THE EASTERN SLOPE OF MOUNT WHITNEY

Showing precipitous cliffs and the glaciated character of the bottom of the gorge.

and some of them yield flows. No definite records of these wells have been preserved, and all the available well data are insufficient to furnish a thorough knowledge of the underground conditions.

WELL RECORDS.

Inyo Development Company.—A well at Keeler owned by the Inyo Development Company is the only one in Owens Valley having a strong artesian flow. It was drilled in 1902, is 465 feet deep, and penetrates 7 gravel layers, all of which contain water under strong pressure. For the upper 190 feet the well is cased with 6-inch pipe, inside of which there is a 4-inch pipe extending from the surface to the bottom. The first flow was found at a depth of 85 feet. The water flowing from the outer casing enters the bottom of the pipe at a depth of 190 feet and is under sufficient pressure to rise 20 feet above the surface. It is too saline for use, as it contains large quantities of "alkali," common salt, calcium carbonate, hydrogen sulphide, etc. The water from the 465-foot level is much better, but it is not used for domestic purposes on account of its large content of hydrogen sulphide. It seems, however, to be comparatively free from "alkali," salt, and lime, as it has been used satisfactorily for two years in the boilers of the soda works. The pressure from the lower horizon lifts the water in a pipe 35 feet above the surface. Nothing was learned regarding the five other water-bearing horizons which were encountered. The well flows about 550 gallons per minute, and since the casings are not perforated this amount enters only at the bottoms of the two pipes. It is evident that a much greater supply could be obtained by using perforated casings, so as to admit water from the other five artesian horizons. Both horizons furnishing water contain natural gas, which escapes with the water at the surface. A preliminary test indicated that the well yields about 1 cubic foot of gas per second. It has satisfactory illuminating properties and might be used to advantage if obtained in sufficiently large quantities.

Olanche.—A well near Olanche 80 feet deep failed to obtain artesian water. The material penetrated in this boring was largely granite wash and sand.

Dodge Brothers' well.—The Dodge Brothers have made three attempts to obtain artesian water near Lone Pine. The deepest boring went down 160 feet. In each case the attempt failed, probably in large measure on account of the use of unsuitable machinery.

Spear's well.—A well at Lone Pine, owned by Mr. R. C. Spear, has a depth of 184 feet No coarse gravel or bowlders were found, and the boring was stopped by hard rock which the drill could not penetrate. No water was struck under pressure sufficient to yield a flow.

Wrinkle's well.—About 6 miles north of Lone Pine a well on Wrinkle's ranch, 80 feet deep, yields a slight flow.

Roeper's well.—Mr. J. C. Roeper has a 7-inch well 250 feet deep on his farm in sec. 30, T. 14 S., R. 36 E. Several horizons were encountered with water under sufficient pressure to cause a slight flow. Since its construction the well has practically ceased to flow and now yields scarcely enough water for domestic use.

Well near Black Rock Spring.—A well about 10 miles north of Independence was bored to a depth of 180 feet. Nothing except detrital material was encountered. Water was found from a depth of 5 feet downward, but it was not under hydrostatic pressure.

Coe's wells.—Three wells have been bored by Mr. J. H. Coe. The first, in sec. 3, T. 9 S., R. 34 E., is a 5-inch well, 160 feet deep. Three water-bearing strata were found, separated by layers of blue clay, but no water was obtained under pressure sufficient to produce a flow. The second well, in sec. 4, T. 9 S., R. 34 E., is 175 feet deep. In this well several gravel strata were encountered containing water under some pressure, but yielding no flow. The third well, in sec. 26, T. 9 S., R. 34 E., is 180 feet deep. The material penetrated consists of alternating layers of gravel and clay. Water rose a short distance in this well.

Bishop.—There are two small flowing wells at Bishop, but no record of them could be obtained. They are drilled wells and are said to be about 200 feet in depth. The yield is only a few gallons per minute and the pressure is less than 3 pounds. Had the location been on ground a few feet higher the water would not have flowed. On the other hand, a well on lower ground might strike a larger flow.

Longley's well.—Mr. A. W. Longley has a well about 6 miles west of Bishop, in Round Valley. It is 401 feet deep and is nonflowing, but it supplies by pumping all the water desired.

Minor wells.—In addition to the wells already described there are several places in the valley where pipes driven 20 to 30 feet yield flowing water. While the water in these wells, as well as in those at Bishop, is under more or less hydrostatic pressure, this pressure is so slight that the wells are of small value.

FLOWING AREA.

From a consideration of the wells just described it is evident that the only place within Owens Valley where conditions of flow worthy of note are now known to exist is at Keeler.[a] Considered as a whole, however, the valley is an artesian basin in the sense that underground water exists in it under more or less hydrostatic pressure; but the basin is small and the catchment area is practically limited to the space between the confining mountains. No considerable volume of artesian water from a catchment area outside of the valley proper enters Owens Valley. The outcrops of sedimentary formations to the east are of small extent and in a desert region, while the granite to the west precludes all possibility of any notable underflow from that direction. The underground supply therefore is derived mainly from the water entering the valley as streams from the Sierra Nevada, which finds its way downward through the gravels. Hence any artesian conditions which may exist are confined to the narrow limits of the valley floor.

The flowing wells at Bishop and Keeler, situated, as they are, near the opposite extremities of the valley, might suggest that the conditions are favorable for flowing wells throughout the valley, but several wells between these two localities have penetrated at least to the level of the upper horizon at Keeler without obtaining flows. It is worthy of note in this connection that in the Keeler well the lower flow has a greater pressure than the upper, the water from the 190-foot level rising 20 feet and that from the 465-foot level 35 feet above the surface. It is possible that wells deeper than those which have failed might find flowing water throughout the valley.

There are two possible structures of the valley fill to be considered in connection with the subject of artesian conditions. On the one hand it may consist of comparatively uniform and continuous layers of alternating pervious and impervious material with moderately regular successions throughout the valley. In this case a flowing well at one point, as at Keeler, would indicate a reasonable possibility of procuring flowing water at other localities similarly situated. On the other hand, the distribution of the pervious and impervious material may be irregular, in which case isolated bodies of water-bearing sands may occur, yielding flowing wells, while a few miles distant very different conditions may prevail.

NONFLOWING AREA.

A large amount of water under no hydrostatic pressure occurs throughout Owens Valley. All the shallow wells encounter it within a few feet of the surface, and the bored wells, with the exception of the few just described, show water without hydrostatic pressure to a depth of nearly 200 feet. These wells penetrate layers of sand and gravel separated by layers of clay. The absence of hydrostatic pressure, however, indicates that the porous beds may be so intimately connected that they virtually form one body of sediment through which the water has free communication.

UTILIZATION OF UNDERGROUND WATERS.

PUMPING PLANTS.

Pumping water for irrigation has received but little attention thus far in Owens Valley. No pump, so far as could be learned, has ever been given a trial in the valley, and as there

[a] It is possible that the strong flow at Keeler is due in some measure to the pressure of the natural gas. The gas escaping with the water lightens the column in the well and helps to raise the water, a principle utilized in wells using the "air lift."

are no experiments from which inference may be drawn the subject must be considered entirely from surface indications.

Since the valley fill is composed largely of loose detrital material, it has a large capacity for holding water, and since the valley is an inclosed basin, with the granite extending continuously across it south of Owens Lake, there is little opportunity for water to escape through underground passages. As there is a continuous inflow, amounting to about 395,000 acre-feet per year, and as this inflow passes over loose detrital matter, there is large opportunity for water to pass underground. All things considered, Owens Valley presents ideal conditions for the accumulation of underground water. Some of the observed facts bearing on this subject are as follows:

There are many places throughout the bottom lands where small swamps and lowlands producing swamp vegetation indicate that water is near the surface. The wells throughout the valley contain water within a few feet of the surface. The water table on the Sierra Nevada side is somewhat steeply inclined, owing to the numerous streams entering the valley from those mountains. Cellars were observed with water a foot or more in depth and having a distinct current toward the lowlands, which indicates a somewhat rapid rate of underflow. There are wells into which water flows in streams from the sides near the top and from which it escapes at a lower level. Streams from the mountains diminish in volume to a notable extent as they flow over the detrital matter, the smaller ones passing completely beneath the surface. In the lava fields north of Independence water becomes confined beneath the sheets of lava and issues as large springs. Black Rock spring is a good example and is said to yield about 3,500 gallons per minute. Soldier spring, a few miles farther north, yields about 2,500 gallons per minute.

A comparison of the coarse detritus, large water supply, and closed condition of the basin of Owens Valley with the conditions in other regions where the underground waters have been developed indicates that the pumping of water for irrigation in this valley might be made very successful. At present much land is being injured by the misuse of water. Small swamps are being developed in many places, especially in the vicinity of Bishop, by the diversion of too much water. Lands which were formerly part of the unproductive desert have been changed into unhealthy swamps. A system of pumps might be so arranged as not only to utilize the underground waters, but to drain the land wherever necessary.

POWER PLANTS.

Many of the streams entering Owens Valley from the higher portions of the Sierra Nevada are of sufficient volume and gradient to produce a large amount of power. These streams are all mountain torrents, and numerous places are available for the establishment of power plants at no great distance from the lowlands of the valley. There is no lack of available power and no obvious reason why it should not be employed in raising the underground waters of the valley for irrigation or used in any other manner desired.

RESERVOIR SITE.

Preliminary surveys of Long Valley have been made by the Reclamation Service to determine the practicability of converting this depression into a storage reservoir. The dam site for this project is at the lower end of Long Valley, where Owens River cuts a narrow gorge in the recent volcanic rocks. The surplus water of Owens River impounded in this reservoir would be used in reclaiming the desert lands of the lower part of Owens Valley.

Long Valley is a shallow depression about 15 miles long and 8 miles wide nearly surrounded by volcanic rocks. It may be due in some measure to local subsidence, but is more probably due to the deposition of volcanic material as a dam across a portion of an older valley. This created a lake in Long Valley, in which were deposited the Quaternary sediments shown on a geologic map of this region by Spurr.[a] This lake was evi-

[a] Spurr, J. E., Bull. U. S. Geol. Survey No. 208, 1903.

dently of short duration, for the beach lines are not continuous and are nowhere prominent, and the delta deposits formed by the streams which entered the lake are comparatively small.

There was at first some doubt concerning the ability of the tuff to hold the water of the reservoir, for it is of a soft, spongy nature, easily crushed, though not easily fractured. Subsequent tests have shown, however, that the rock is very resistant and sufficiently impervious for all required purposes.

EFFECT OF SEISMIC DISTURBANCES.

In the west end of Long Valley the largest hot springs of the region are found. The mud geyser described on page 9 is also in this vicinity. The most recent volcanic craters of the region, of which Panum Crater (Pl. V, *A*) is an example, occur a few miles to the north of the springs, and the zone of faulting believed to be at the foot of the Sierra Nevada passes near if not actually through Long Valley. It is believed by many geologists that a slipping in this fault zone caused the earthquake of 1872, described by Whitney in the article previously quoted (p. 12). There is no reason to suppose that disturbances of this kind are at an end and that an earthquake similar to the one of 1872, which has been recognized as one of the most severe shocks ever experienced in America, should not be repeated at any time.[a] A consideration of the surface movements, both temporary and permanent, which caused that shock and of the fact that the proposed reservoir location is near the line of faulting, indicates the possibility that future earthquakes may bring serious consequences to any system of water storage in Owens Valley. On the other hand, more than a quarter of a century has passed without notable disturbance of the region.

STRUCTURAL MATERIALS.

BUILDING STONE.

Granite of excellent quality for building purposes is found throughout the Sierra Nevada west of Owens Valley. An exposure of this rock occurs within a few miles of the site of the proposed dam. The andesitic tuff is also used to some extent in this region as a building stone. It is so soft that it may be hewn with an ax, but it is surprisingly resistant to strain and to the influence of the weather. Exposed cliffs 50 to 150 feet high maintain rugged and sharp outlines. The material often changes within short distances from a soft ash to a well-consolidated tuff.

MATERIAL FOR CEMENT.

When the investigation of the Owens River project was undertaken by the United States Reclamation Service, it was suggested by J. B. Lippincott, engineer in charge, that the volcanic ash known to exist in the vicinity of the reservoir site might be mixed with Portland cement for use in the construction of the proposed dam and that this might greatly reduce the cost of construction. During the course of the investigation, however, it was discovered that limestone, clay, and a natural cement material also occur in abundance in Owens Valley.

It was found that the volcanic rocks in the vicinity of Long Valley (see p. 8) are, so far as observed, fairly uniform in character. Samples were taken, therefore, at the site of the proposed dam, in order that tests might be made to gain some knowledge of the strength of the abutments and of the cement-making qualities of the tuff. At the dam site the rock is more resistant and more uniformly consolidated than in some other localities, but does not differ in other respects from the less consolidated portions. The tuff has not yet been tested for cement making, but some of its physical properties, as ascertained by the division of physical and chemical research of the United States Geological Survey, are as follows:[b]

[a] The San Francisco earthquake occurred after the above paragraph was written.
[b] Data furnished by J. C. Clausen, engineer of the United States Reclamation Service.

A. PANUM CRATER, NEAR MONO LAKE.

The rim of the crater is composed of loose volcanic cinders and the central core of somewhat scoriaceous obsidian.

B. CROOKED CREEK NEAR LONG VALLEY DAM SITE.

A gorge carved in the volcanic tuffs south of Long Valley.

Physical properties of tuff from Long Valley, California.

Specific gravity, dry		1.53
Specific gravity, saturated with water		1.91
Gain in weight after saturating with water	per cent..	24
Weight per cubic foot dry	pounds..	95.62
Weight per cubic foot, saturated with water	do....	119.37

The Bureau of Ordnance, Department of the Navy, reports on the crushing strength of this rock as follows: Test No. 1 crushed at 2,056 pounds per square inch; test No. 2 crushed at 1,725 pounds per square inch. Edward Duryee, of the United States Reclamation Service, reports the specific gravity of the same kind of rock as 2.19.

Limestones and marble are abundant in Owens Valley, especially on the flanks of the White Mountains. Clay is found in the valley floor and in the form of shale and slate on the mountain slopes. It is thought that these materials may be found suitable for the manufacture of cement.

In the western bluff of Owens Lake, near the mouth of Cottonwood Creek, occurs a stratum of fine material about 8 feet thick, which seems to be composed of a mixture of fine volcanic ash and clay. J. F. Holloway, who owns a ranch near this point, has taken some interest in this deposit in the hope that it may prove of value in the construction of canals. At his request the material was examined by Mr. Cooper, formerly State mineralogist of California, who states that "with the addition of lime the material would make a good Portland cement." The material was also examined for fineness by E. C. Preble of Chicago. Of two samples tested by him, 11.9 per cent and 22 per cent, respectively, were left on a 100-mesh sieve. He suggests that with the addition of proper quantities of lime a good cement could be manufactured. A deposit of this material is shown in Pl. V, *A*. Where the blocks fallen from the cliff have been acted on by the lake water, the material has been distinctly hardened, owing to the deposition of carbonate of lime, and is notably changed in chemical composition. Samples of both the original and the altered material were collected, and have been analyzed by Edward Duryee, of the United States Reclamation Service, as follows:

Analysis of cement rock from Owens Lake.

	Unaltered material.	Altered material.
Silica	71.50	14
Oxide of iron and alumina	22.02	5.64
Carbonate of lime	2	74.98
Carbonate of magnesia	2.40	4.37

Commenting on these analyses, Mr. Duryee says: "The analysis of No. 2 [the altered material] indicates that the material is suitable for making Portland cement by burning it at the proper temperature. If further examination shows the deposit to be extensive and uniform in composition and free from insoluble sand, it is a Portland cement rock."

CLIMATE.

RAINFALL.

Owens Valley is cut off from the supply of moisture on the east and south by a long stretch of desert and on the west by high mountains. As previously stated the moisture-laden winds from the Pacific Ocean lose much of their moisture in passing over the Sierra Nevada before reaching the Owens Valley region. The result of these conditions is the heavy precipitation near the top of the range, while desert conditions prevail in the valley only a few miles to the east. The available information regarding the rainfall in the valley is contained in the following tables:

Record of precipitation at Bishop Creek, Inyo County, Cal. [a]

[Lat., 37° 21′; long., 118° 22′; elevation, 4,450 feet. Authority, Southern Pacific Railroad.]

Year.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Total.
1883-84	0.12	0.11	0	0.38	0.62	0.64	0.94	0.05	0	0	0	0	2.86
1884-85	0	0	0	1	0	0	.67	.14	0	0	0	0	1.81
1885-86	0	.02	0.35	0	1.03	0	.50	.38	0	0	0	0	2.28
1886-87	0	0	0	.20	.65	1.58	0	.35	0.55	0.35	0	0	3.68
1887-88	.15	.15	.05	1.10	1.37	.47	.05	0	0	.35	0.20	0	3.89
1888-89	0	0	1.72	.40	.10	.50	1.46	.12	.30	0	0	0	4.60
1889-90	0	.03	.35	1.20	4.75	.30	0	0	0	0	0	0.50	7.13
1890-91	.69	0	0	1	0	3.70	.28	0	2.90	0	0	.03	8.60
1891-92	.19	0	0	3.52	.10	.70	1.10	0	.25	T.	0	0	5.86
1892-93	0	.20	1.42	2.27	1.22	1.12	.15	0	0	0	1.05	T.	7.43
1893-94	.19	0	.10	.49	.30	.75	.09	.05	T.	.35	T.	.23	2.55
1894-95	T.	0	0	1.18	1.10	.50	.22	.29	.15	.11	.21	.07	3.83
1895-96	T.	.16	.15	T.	1.07	0	.60	.05	.03	0	.57	.06	2.69
1896-97	.05	T.	T.	.16	.32	1.67	1.75	0	.12	T.	.01	.05	4.13
1897-98	.09	.39	T.	.49	.05	.13	T.	.21	.27	T.	T.	.06	1.69
1898-99	.41	0	.21	.11	1.65	0	T.	.64	.02	0	0	.05	3.09
1899-1900	0	.14	.05	1.05	.49	.01	.54	.60	.34	.12	T.	0	3.34
1900-1901	.39	.03	2.69	.17	4.89	1.01	T.	.50	1.29	T.	0	.93	11.90
1901-2	0	.81	.61	.12	.07	.55	1.53	.61	.06	0	T.	.12	4.48
19-year mean	......	......	......	......	......	......	......	......	......	......	......	......	4.52

[a] Water-Sup. and Irr. Paper No. 81, U. S. Geol. Survey, 1903, p. 426.

Record of precipitation at Keeler, Inyo County, Cal. [a]

[Lat., 36° 35′; long., 117° 50′; elevation, 3,622 feet. Authority, Southern Pacific Railroad.]

Year.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June	July.	Aug.	Total.
1883-84	......	......	......	......	......	......	......	0.20	1.60	0.80	0	0.20	[b] 2.80
1884-85	0	0	0	0.70	0	0	0.12	.82	0	.08	0	.11	1.83
1885-86	0	0.25	0.65	.36	0.49	0.14	.60	.40	0	0	.14	.08	3.11
1886-87	0	.01	.08	0	T.	.93	0	1.14	.04	T.	.52	0	2.72
1887-88	1.08	.84	.01	.48	.70	1.21	.30	.12	.30	.20	.17	.10	5.51
1888-89	.06	0	1.68	.82	.04	T.	.52	.12	.06	.01	0	T.	3.31
1889-90	.08	.56	.05	.56	.42	.01	T.	.10	.20	0	T.	1.71	3.69
1890-91	.93	.03	.12	.22	0	1	2.01	0	.37	.30	.06	.02	5.06
1891-92	.19	.04	0	.31	.26	.19	.32	0	.56	T.	0	0	1.87
1892-93	T.	.81	.11	.54	.71	.75	1.50	0	T.	0	1.41	T.	5.83
1893-94	T.	T.	.03	1.48	T.	.29	.01	T.	T.	T.	.11	0	1.92
1894-95	0	0	0	1.05	.35	1.15	T.	.25	T.	T.	T.	T.	2.80
1895-96	T.	0	0	T.	.45	0	T.	T.	.15	T.	.25	1.42	2.27
1896-97	.50	T.	0	.25	.10	.27	.13	0	T.	0	0	.19	1.44
1897-98	.14	.15	T.	T.	0	0	0	.05	0	0	0	0	.34
1898-99	T.	0	T.	.30	.40	.45	0	.01	T.	.50	T.	T.	1.66
1899-1900	0	T.	1.75	T.	T.	0	.16	1.25	.23	T.	.10	T.	3.49
1900-1901	.35	.09	.45	0	.75	.25	0	T.	.40	0	0	.90	3.19
1901-2	0	.50	0	0	T.	.25	1.25	0	0	0	T.	T.	2
18-year mean	......	......	......	......	......	......	......	......	......	......	......	......	2.89

[a] Water-Sup. and Irr. Paper No. 81, U. S. Geol. Survey, 1903, p. 427.
[b] Year incomplete.

Record of precipitation at Camp Independence, Inyo County, Cal.[a]

[Lat., 36° 50′; long., 118° 10′; elevation, 4,598 feet. Authority, United States War Department.]

Year.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Total.
1865-66	......	......	0	0.65	2.42	0	0	0.16	......	......	......	......	[b]3.23
1866-67	0	0.32	0	2.27	0	1.63	4.76	.53	0.76	0	0.01	1.15	11.43
1867-68	0.07	.32	0.21	12.19	5.46	0	0	.40	.71	0	.10	0	19.46
1868-69	0	.74	.44	1.17	.16	0	.32	.11	.36	0	.03	0	3.33
1869-70	0	0	.14	0	.20	1.36	0	.21	.27	0	.35	.10	2.63
1870-71	0	1.10	0	1	0	1.28	0	0	0	.30	0	0	3.68
1871-72	0	0	.65	4.70	0	.30	.28	.55	.18	0	.28	.12	7.06
1872-73	0	0	0	1.18	0	.40	0	0	0	0	0	.05	1.63
1873-74	.10	0	0	3.40	2.40	1	0	0	0	.01	.15	0	7.06
1874-75	.40	.80	.40	0	1.73	0	0	0	0	0	0	0	3.33
1875-76	.01	0	.66	.62	1.51	.70	.87	0	0	.15	.19	.56	5.27
1876-77	.16	.26	0	0	.76	0	0	.59	.69	0	0	0	2.46
1891-92	......	......	......	......	......	......	.62	......	.96	.07	T.	T.	[b]1.65
1892-93	0	.35	.23	1.61	1.51	2.91	.98	.02	T.	0	.77	T.	8.38
1893-94	T.	0	.10	.75	.12	.42	.09	.02	.10	.11	.12	.51	2.34
1894-95	T.	0	0	1.89	1.24	1.18	.12	T.	.01	T.	T.	.04	4.48
1895-96	T.	.83	.67	.08	......	......	......	......	......	......	......	......	[b]1.58
1897-98	......	......	......	......	......	......	0	.16	.23	T.	T.	.11	[b].50
1898-99	.20	0	.10	.20	.54	T.	.01	.02	.03	.37	.01	.06	1.54
1899-1900	T.	.30	.85	.56	.31	.05	.67	.62	.22	.04	.08	T.	3.70
1900-1901	.75	.01	1.34	.13	2.81	.64	.05	T.	.36	0	.10	.32	6.51
1901-2	0	.65	.22	.06	.04	1.69	1.05	.17	.04	.01	.17	.13	4.23
18-year mean	......	......	......	......	......	......	......	......	......	......	......	......	5.47

[a] Water-Sup. and Irr. Paper No. 81, U. S. Geol. Survey, 1903, p. 427.
[b] Year incomplete

These tables show that the precipitation is not only slight but exceedingly variable, the yearly totals ranging from a maximum of 19.46 inches to a minimum of 0.34 inch, while the average is 4.14 inches.

No records are available for the Sierra Nevada region, but the annual precipitation is about 50 inches.[a] The amount of rainfall in the mountainous district is much greater than in the valley. This fact is indicated by the condition of the vegetation in the two districts. The mountains are covered with a luxuriant forest, characteristic of a well-watered region, while in the valley outside of the immediate influence of the streams there is only a scant and stunted growth of plants characteristic of the desert region of the Great Basin.

EVAPORATION.

Rate at Owens Lake.—The waters entering Owens Lake have no means of escape except by evaporation, but these waters have been disappearing for several years and the lake itself has greatly decreased in volume. During the last ten years the surface of the lake has lowered 16 feet and in 1904 it lowered 2.5 feet. According to measurements furnished by J. C. Clausen, of the United States Reclamation Service, the volume of water entering the valley during one year, August, 1903, to July, 1904, was about 395,000 acre-feet, of which 297,000 were diverted for irrigation and 64,000 entered Owens Lake, leaving 34,000 which presumably joined the underflow.[b] Furthermore, a large though unknown propor-

[a] See map, Water-Sup. and Irr. Paper No. 81, U. S. Geol. Survey, 1903, p. 12.
[b] The total includes the waters of 18 of the tributary streams, of which occasional measurements were made and the discharge estimated. The error is not great, as the discharge of these streams is small compared with that of Owens River. The measurements so far as they are available are to be found in the reports of progress of stream measurements, Water-Sup. and Irr. Papers Nos. 100, 134, and 177, U. S. Geol. Survey.

tion of the water diverted for irrigation must have found its way beneath the surface. This water moves slowly toward the lowest part of the basin, where it is eventually lost by evaporation either from the land surface to which it is brought by capillary action or from the lake.

Based on the loss from the lake in 1904, the annual rate of evaporation is 30 inches more than the total inflow. The 64,000 acre-feet of water entering the lake and lost from its 75 square miles of evaporating surface add about 16 inches to the annual rate of evaporation. Several small streams whose waters were not measured enter the lake and the volume entering as underflow, although unknown, must be large. A rate of evaporation sufficient to dispose of these unmeasured waters must be added, which makes an annual evaporation of considerably more than 46 inches from the surface of the lake.

Rate at Bishop.—During 1904 evaporation measurements were carried on at Bishop, Cal., by the engineers of the United States Reclamation Service, with the following result:

Evaporation at Bishop, Cal.

[Data furnished by R. J. Taylor.]

	Inches.		Inches.
January 5-31, 1904	4.09	September	3.83
February	2.21	October	2.82
March	4.48	November	1.73
April	6.41	December	3.21
May	11.02	January 1-4, 1905 [a]	.26
June	7.88		
July	6.95		60.13
August	5.24		

TEMPERATURE.

The temperature of Owens Valley is subject to great and sudden changes, owing to the wide differences of altitude within the region. The average temperature is moderate, as is shown by the accompanying table of mean temperatures. It is not uncommon for killing frosts to occur late in the spring, nor is it unusual, on the other hand, for the temperature to reach 100° or more during the summer months.

Monthly mean temperature at Independence, Cal.

[Data by J. J. McLean, observer, U. S. Weather Bureau.]

Years	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1894	......	......	......	......	......	......	......	......	......	......	......	38.4	......
1895	37.8	45.5	49.2	57.3	65.6	71.6	78	76	68.3	60	48.3	37.8	58
1896	43.2	47.2	44	......	......	......	......	......	......	......	......	......	......
1897 [a]	......	......	......	......	......	......	......	......	......	......	......	......	......
1898	......	......	......	62	62.1	74.2	80.4	80.1	72	60	48.2	39.7	......
1899	40.2	46.5	50.5	59.4	60	74.2	80.4	72.6	74.6	55.4	49.4	43.1	58.8
1900	46.6	48.1	54.9	52	65.8	75.4	79.4	72.4	63.5	58.8	50.4	43.4	59.2
Mean	42	46.8	49.6	57.7	63.4	73.8	79.6	75.3	69.6	58.6	49.1	40.5	58.7

[a] Station closed.

UNDRAINED LAKES AS REGISTERS OF CLIMATE.

OWENS LAKE.

Physical character.—Owens Lake was originally described[b] as having an area of about 110 square miles, with an average depth of 9 feet 10 inches and a density of 1.051. The only

[a] The total for January, 1905, is 2.05; in order to make the table cover a complete year four thirty-firsts of that amount is included with the 1904 measurements.

[b] Loew, Oscar, Ann. Rept. U. S. Geog. Surv. W. 100th Mer., 1876, p. 189. Goodyear, W. A., Eighth Ann. Rept. State Mineralogist California, 1888, p. 227.

known forms of animal life inhabiting the water were infusoria, alkali shrimps (*Artemia salina*), and the larvæ of the alkali flies (*Ephydra*). which developed in great numbers. Some of the conditions described by former writers have materially changed in recent years. At Keeler, on the eastern shore of Owens Lake, the Inyo Development Company has an extensive plant for the extraction of soda from the waters of the lake. This plant has been in operation for about twenty years and the lake has been observed from a commercial standpoint during that time. Mr. N. Wrinkle, the superintendent of the soda works, has kindly furnished the following information.[a]

The density of the water has increased to a point where bicarbonate of soda precipitates during the winter months without concentration by evaporation. During the past three years—1902 to 1904—the surface of the lake has lowered at the rate of 2.5 feet per year, and it has lowered 16 feet since 1894. Throughout the ten years previous to this date the lake surface remained practically stationary. Formerly alkali flies developed in myriads, as described by various writers, but during the present season (1904), although the larvæ are as numerous as usual, the flies have failed to appear.

It has been assumed that the failure of the larvæ to develop is due to the increasing density of the water. This suggestion is strengthened by the fact that at Mono Lake these flies appeared in as great numbers as usual, and were seen by the writer literally blackening the sands at the water's edge. The water of Mono Lake is much less saline than that of Owens Lake, although it is otherwise similar, as a comparison of the analyses will show.

It is evident from Goodyear's description[b] that the decrease in volume of Owens Lake had a comparatively recent beginning. He writes concerning his visit in 1870: "It is certain that the water at the time of our visit was higher by at least several feet than it had been for some time previously, for at one or two points along the margin of the lake I saw in the shallow water near the shore the dead sagebrush still standing where it grew, but entirely covered by water."

Chemical character.—The water of Owens Lake is strongly charged with common salt, sodium carbonate, borax, and minor quantities of other salts. Several analyses of the water have been made.[c]

The earliest analysis, so far as known, was by Professor Phillips, of England, the exact date, however, being unknown. It is as follows:[d]

Analysis of the water of Owens Lake, California.

	Parts per million.		Parts per million.
Sodium (Na)	43,395	Silicate radicle (SiO_3)	908
Potassium (K)	3,378	Organic matter	242
Chlorine (Cl)	25,478		
Sulphate radicle (SO_4)	12,929		103,605
Carbonate radicle (CO_3)	17,275		

The following analysis was made by Oscar Loew for the Wheeler Survey.[e]

Analysis of the water of Owens Lake, California (1876).

[Specific gravity 1.051.]

	Parts per million.		Parts per million.
Sodium (Na)	21,550	Magnesium (Mg)	Trace.
Potassium (K)	2,753	Aluminum (Al)	Trace.
Chlorine (Cl)	13,496	Borate radicle (B_4O_7)	Trace.
Sulphate radicle (SO_4)	9,363	Phosphate radicle (PO_4)	Trace.
Carbonate radicle (CO_3)	13,240	Nitrate radicle (NO_3)	Trace.
Silica (SiO_2)	163	Organic matter	Trace.
Lithium (Li)	Trace.		
Calcium (Ca)	Trace.		60,565

[a] Personal communication.
[b] Goodyear, W. A., Eighth Ann. Rept. State Mineralogist California, 1888, p. 241.
[c] The values are given in various units in the original reports, but have been reduced to parts per million and to round numbers in order that comparison may be made more readily. Correction is also made for specific gravity.
[d] Bailey, Gilbert E., Saline deposits of California: Bull. California State Mining Bureau No. 24, 1902, p 95.
[e] Ann. Rept. U. S. Geog. Survey W. 100th Mer., 1876, p. 190. See also Eighth Ann. Rept. U. S. Geol. Survey, pt. 1, 1889, p. 295.

Ten years later another analysis was made by T. M. Chatard, of the United States Geological Survey. The sample was taken September 17, 1886.[a]

Analysis of the water of Owens Lake, California (1886).

[Specific gravity, 1.062 at 25°.]

	Per cent.	Parts per million.		Per cent.	Parts per million.
Silica (SiO_2)	0.28	208	Sulphate radicle (SO_4)	9.73	7,080
Potassium (K)	2.13	1,551	Borate radicle (B_4O_7)	.49	346
Sodium (Na)	36.96	26,887	Carbonate radicle (CO_3)	25.16	18,300
Calcium (Ca)	.02	13	Chlorine (Cl)	25.09	18,250
Magnesium (Mg)		5	Hydrogen (H)	.10	60
Iron (Fe)	.02	9			
Aluminum (Al)	.03	12		100.01	72,721

Recently a partial analysis of the water of Owens Lake was made by N. Wrinkle, manager of the Inyo Development Company's soda works at Keeler. The sample was taken in July, 1904. Mr. Wrinkle found the specific gravity to be 1.186 and the percentage of contained salts correspondingly great.

In August, 1905, at the writer's request a complete analysis was made by C. H. Stone, of the United States Reclamation Service, as follows:

Analysis of water from Owens Lake, California (1905).

[Sample taken August 21.[b] Specific gravity, 1.195.]

	Parts per million by weight.		Parts per million by weight.
Silica (SiO_2)	298	Phosphate radicle (PO_4)	238
Iron and aluminum (FeAl calculated as Al)	48	Borate radicle (B_4O_7)	296
Calcium (Ca)	34	H (in HCO_3, Na_2HPO_4, and $CaH_4(PO_4)_2$).	130
Magnesium (Mg)	15	As_2O_3	111
Potassium (K)	3,448	NO_3	948
Sodium (Na)	81,176	Rb	Trace.
Lithium (Li)	57	Cs	Trace.
Sulphate radicle (SO_4)	21,174	Total solids (by addition)	213,197
Chlorine (Cl)	52,898	Total solids determined	213,661
Carbonate radicle (CO_3)	52,326		

For convenience of comparison the total solids and densities given in the foregoing analyses are tabulated below. The first analysis, that of Phillips, does not accord with the later ones. The increase in density shown by the others is largely, if not wholly, due to the decrease in the volume of the lake caused by rapid evaporation.

Increase in salinity of Owens Lake, California.

Date of analysis.	Authority.	Total solids (parts per million).	Specific gravity.	Remarks.
(?)	Phillips	103,605		
1876	Loew	60,565	1.051	
1886	Chatard	72,721	1.062	Volume constant since 1876.
1904	Wrinkle		1.186	Volume decreasing since 1894.
1905	Stone	213,660	1.195	Volume of lake constant for 1 year previous to sampling.

[a] Bull. U. S. Geol. Survey No. 60, 1890, p. 58.
[b] For about one year previous to this date the surface of the lake had remained stationary.

MONO LAKE.

Physical character.—Mono Lake and its environs have been described by Russell,[a] who shows that the lake had been increasing in volume for twenty-five years previous to the time of his examination, the surface having risen from 15 to 20 feet during that time. To aid in future determinations of changes of level a permanent bench mark was placed at the water's edge on one of the islands in the lake, the water level at that time (November 5, 1883) being 6,380 feet above sea level, as determined by vertical angles from Mount Conness.

During the writer's visit to the lake in the summer of 1904 abundant evidence was found of a recent rise of the water surface. Dead trees and shrubs of varieties that grow only on dry land were seen standing in several feet of water, and a road at the west end of the lake, said to have been used only a few years ago, was covered with water about 4 feet deep. The island on which the bench mark described by Russell was established was not visited by the writer, but at his request William Farrington, a young man living near the lake, later visited this island and found that the bench mark had been submerged, and no measurement was taken.

According to determinations of altitude by the United States Geological Survey[b] the surface of Mono Lake had an altitude of 6,412 feet on July 27, 1898. In making these determinations it was found that the altitude as previously determined was 13 feet too high. According to the later determinations, therefore, the lake surface was 19 feet higher in 1898 than it was in 1883.

Chemical character.—The water of Mono Lake is similar in composition to that of Owens Lake, as is indicated by the following analysis:

Analysis of the water of Mono Lake (1882).[c]

[Specific gravity, 1.0456 at 15.5°.]

	Per cent of total solids.	Parts per million.		Per cent of total solids.	Parts per million.
Silica (SiO_2)	0.130	67	Sulphate radicle (SO_4)	12.480	6,319
Calcium (Ca)	.037	20	Chlorine (Cl)	22.630	11,638
Magnesium (Mg)	.103	53	Borate radicle (B_4O_7)	.300	154
Potassium (K)	1.795	924	Carbonate radicle (CO_3)	23.350	13,163
Sodium (Na)	36.810	19,312	Bicarbonate radicle (HCO_3)	.360	4
Alumina (Al_2O_3), Ferric oxide (Fe_2O_3)	.005	3		98	51,657

DISCUSSION.

The statement is sometimes made that a decrease in volume of an undrained lake indicates a change of climate toward aridity and vice versa. In discussing the fluctuations of level of the basin lakes, Mono and Owens lakes among others, King[d] states that the influence of irrigation is too slight to be considered. This opinion seems to have been too generally accepted, and in the case of Owens Lake it will certainly not hold good. According to the measurements previously given (p. 19), 297,000 acre-feet of water were spread over about 40,000 acres of land during one year (1903–4), or enough to make an average depth of nearly 7.5 feet. Since the annual evaporation from a free water surface is about 60 inches, it follows that about one-third of the water sinks into the ground. The rate of evaporation from irrigated land is not known. Were this rate the same as

[a] Russell, I. C., Quaternary history of Mono Valley, California: Eighth Ann. Rept. U. S. Geol. Survey, pt. 1, 1889, pp. 269–394.
[b] Gannett, Henry, Dictionary of altitudes: Bull. U. S. Geol. Survey No. 274, 1906, p. 110.
[c] Chatard, T. M. Bull. U. S. Geol. Survey No. 60, 1890, p. 53; Am. Jour. Sci., 3d ser., vol. 36, 1888, p. 149. Russell, I. C., Eighth Ann. Rept. U. S. Geol. Survey, pt. 1, 1889, p. 293.
[d] King, Clarence, Rept. U. S. Geol. Explor. 40th Par., vol. 1, 1878, p. 525.

from a water surface, about 200,000 acre-feet of water would have been lost by evaporation from the irrigated land. Of the total quantity of water entering the valley during the year 1904 (395,000 acre-feet), 75 per cent was diverted for irrigation and 16 per cent entered Owens Lake as surface flow, leaving 9 per cent unaccounted for. If the rate of evaporation from irrigated land were the same as that from a water surface, 200,000 acre-feet, or 50 per cent of the total inflow, would have been lost from the land, leaving 50 per cent to be divided between surface flow and underflow, of which 16 per cent is known to have been surface flow.

The misuse of water in Owens Valley makes the loss by evaporation much greater than it would be from properly irrigated land. Not all the water diverted for irrigation purposes is used, but a portion is allowed to spread over uncultivated land. For this reason evaporation from the irrigated district is greater than it would otherwise be. The area of irrigated land, about 40,000 acres, is comparable in size to that of the lake, about 48,000 acres. It is evident from the facts stated that the rate of evaporation from the land is high and may be little, if any, less than that from a water surface, and that the volume lost from the land is comparable to that lost from the lake.

During 1903–4, when careful measurements were made of all the water entering Owens Valley, as described on page 19, there was a loss by evaporation of not only all this water (395,000 acre-feet), but an additional amount from the lake represented by a depth of 2.5 feet over 75 square miles, or 48,000 acres—that is, 120,000-acre-feet. Since the valley is an undrained basin and water can escape only by evaporation, it is evident that this loss during the year was 515,000 acre-feet. Had the natural flow of the streams entered the lake the rate of evaporation (disregarding evaporation along the stream courses) in order to lower the surface of the lake 2.5 feet would have been about 128 inches, for in that case the loss would have been from the lake surface alone. Since the actual rate of evaporation has been found to be only 60.13 inches at Bishop, the rate of 128 inches from the surface of Owens Lake is improbable.

Again, if only the measured volume of water, 395,000 acre-feet, which would naturally have entered the lake be considered, a rate of evaporation of about 98 inches from the lake surface would be required in order that the surface might remain stationary. Even this rate is greater than can reasonably be assumed, and it follows that the undisturbed flow of the streams entering Owens Valley would probably increase the present volume of the lake and restore it to its original size, if it would not actually increase that size.

CONCLUSION.

Since Mono and Owens lakes are comparable in size, location, and chemical composition, and derive their water supply from the same mountain range, it is natural to suppose that a change of climate would affect both alike, yet Mono Lake is increasing in volume, while Owens Lake is decreasing. The drainage into Mono Lake has never been disturbed to any appreciable extent by artificial means, such as irrigation. If a rise or fall of the water level of an undrained lake is an adequate indication of climatic change, Mono Lake might show such a change, for natural conditions are there practically undisturbed. In this case, however, the rise of the water level apparently indicates that the climate has become more humid during the last few years.

The glacier at the summit of Mount Lyell (Pl. VI, *A*) gives confirmatory evidence that an increase rather than a decrease in humidity has occurred in recent years in this vicinity. This glacier is the largest of the numerous bodies of snow and ice near the headwaters of Owens River and Rush Creek. It drains westward away from Owens Valley, but is at the summit of the main drainage area of the Owens Valley region. Its form and size have been definitely known for about twenty-two years.[a] The writer[b] has previously shown the

[a] See Russell, I. C., Existing glaciers of the United States: Fifth Ann. Rept. U. S. Geol. Survey, 1885, p. 315; Quaternary history of Mono Valley, California: Eighth Ann. Rept. U. S. Geol. Survey, pt. 1, 1889, Pls. XXVII, XXVIII.

[b] Lee, W. T., Note on the glacier of Mount Lyell, California: Jour. Geol., vol. 13, 1905, pp. 358-362.

A. WESTERN LOBE OF LYELL GLACIER.

This glacier is the largest of the numerous bodies of snow and ice near the headwaters of Owens River.

B. CREST OF THE HIGH SIERRA AT MAMMOTH MOUNTAIN.

Showing the precipitous eastern face at the left and parts of the gentler western slope at the right. Photograph by J. B. Lippincott.

during this time no permanent diminution in the volume of the ice has occurred and that the large amounts of snow on the glacier, shown in Pl. VI, *A*, indicate a possible increase in humidity.

From the preceding discussion it is evident that the evaporation from irrigated lands in Owens Valley is very large and that the decrease in volume of water of Owens Lake is due mainly to this cause. The measurements given indicate that if the waters of Owens Valley were allowed to flow naturally into Owens Lake that lake would probably be increasing instead of diminishing in volume, just as Mono Lake is increasing. To judge from present knowledge of the two lakes and of Mount Lyell Glacier, it is evident that the popular belief in a diminution of rainfall in the vicinity of Owens Valley for the last ten years is not supported by the facts, and that if any change of climate is in progress it is toward a more humid rather than a more arid climate.

RÉSUMÉ.

Owens Valley is a long, narrow, -shaped trough formed mainly by the deformation of pre-Tertiary rocks and partly filled with unconsolidated Tertiary and Quaternary sediments originating as lake deposits, river deposits, and mountain wash. The deformation is assumed to have occurred in the form of crust-block tilting, Owens Valley representing the V-shaped depression between the Sierra Nevada and White Mountain blocks. This assumption is based on the following facts: A succession of lava flows and volcanic craters of recent origin occur along the eastern base of the Sierra Nevada throughout the length of Owens Valley. Hot springs occur in the same zone from the midst of Owens Valley to Mono Lake, and a mud geyser is found at Casa Diablo. Faulting and associated phenomena have been observed in many places along the eastern margin of the Sierra Nevada and also east of the White Mountains. Confirmatory evidence is found in such topographic forms as the inclined peneplain of the western slope of the Sierra Nevada, the cliff-like eastern face, the steep escarpment east of the White Mountains, and the less steep western face.

Owens Valley is a barren desert except where it is reclaimed by the use of water entering as mountain streams. Abundant rainfall occurs in the Sierra Nevada, yielding for this valley an annual water supply of about 400,000 acre-feet. As the streams enter the valley they pass over unconsolidated detritus, into which much of the water sinks.

Flowing wells occur in Owens Valley, but the limits of the district in which such wells are obtainable are undetermined.

A large amount of underground water exists without hydrostatic pressure sufficient to produce flowing wells, but power for pumping this water can be produced from the mountain streams and transmitted to the valley at moderate cost.

Owens Lake has been decreasing in volume for several years, with a corresponding increase in the density of its water. The salinity has reached a point at which the more insoluble salts precipitate. The change is probably due to the loss by evaporation of water diverted for irrigation and not to an increase in the aridity of the climate, as originally supposed.

Faulting and crustal movements of considerable magnitude, accompanied by earthquake shocks, have taken place in Owens Valley within historic time, and there is no evidence that disturbances of this kind are at an end

The proposed Owens Valley reservoir, being located in the fault zone at the base of the Sierra Nevada, would be especially liable to injury from crustal movements.

INDEX.

CLASSIFICATION OF THE PUBLICATIONS OF THE UNITED STATES GEOLOGICAL SURVEY.

[Water-Supply Paper No. 181.]

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Most of the above publications may be obtained or consulted in the following ways:

1. A limited number are delivered to the Director of the Survey, from whom they may be obtained, free of charge (except classes 2, 7, and 8), on application.
2. A certain number are delivered to Senators and Representatives in Congress for distribution.
3. Other copies are deposited with the Superintendent of Documents, Washington, D. C., from whom they may be had at practically cost.
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