THE LAKES OF CALIFORNIA

By WILLIAM MORRIS DAVIS *

OUTLINE OF REPORT

EXPLANATION OF PLATE V

LOCATION MAP OF CALIFORNIAN LAKES

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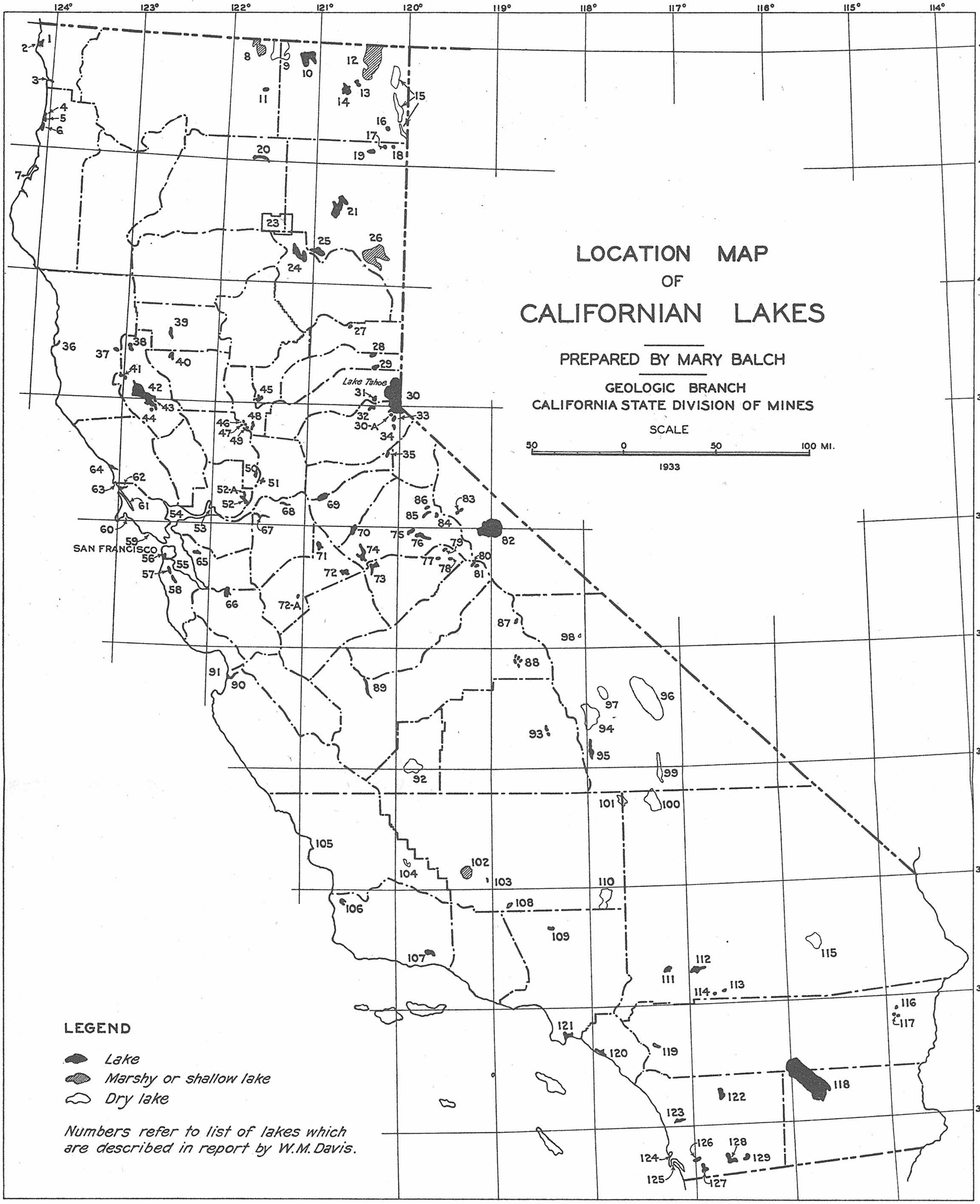
LOCATION MAP
OF
CALIFORNIAN LAKES
PREPARED BY MARY BALCH
GEOLOGIC BRANCH
CALIFORNIA STATE DIVISION OF MINES
SCALE
50 0 50 100 MI.
1933
Lake Tahoe
SAN FRANCISCO
LEGEND
Lake
Marshy or shallow lake
Dry lake
Numbers refer to list of lakes which are described in report by W.M. Davis.

Part I. THE ORIGIN OF LAKES

The Forms of the Lands

The forms of the lands are determined in the main by the slow interaction of two antagonistic processes. One process, of interior origin and unsolved explanation, slowly deforms the earth's crust and

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makes its surface uneven. Associated with this deforming process in being of interior origin and of difficult explanation, but apparently acting independently of it, are volcanic eruptions which build up cones and domes and pour out lava flows of smaller or larger extent.

The other process, of exterior origin and simpler explanation, includes all the agencies which tend either to wear down the land surface and reduce the uneven highlands to smooth lowlands or to fill up depressed basins and convert them into smooth plains. Chief among these agencies are weathering and streaming; that is, the ordinary agencies by which rocks are distintegrated, by which valleys are deepened and widened, and by which the irregular slopes of the deformed crust are graded down or graded up to regular slopes and eventually smoothed out as plains. Associated with these familiar agencies are certain more special agencies, such as the glaciers of high mountains and the ice sheets of the Arctic and Antarctic regions; also wind action in deserts, solvent action in limestones, and wave and current action on sea and lake shores.

The fact that many unevennesses, such as mountains and highlands, exist today does not mean that the earth's history is so short that its primitive unevennesses have not yet been worn down, for all unevennesses of ancient origin were worn down ages ago. Existing mountains and highlands are of later upheaval; and although they are vastly more ancient than human history, they are young as the earth measures time; so young that they have not yet been worn down, although the agencies of weathering and streaming have very generally made good progress in carving valleys of continuous descent down their slopes. Hence it may be said in a general way that the highest mountains of today are high because they are geologically young; they represent, although already much dissected by deep-cut valleys, the latest great upheavals that the earth's crust has suffered. It should be understood, however, that geologically young mountains are historically so ancient that they antedate all human records.

The Antagonism of Lakes and Rivers

Inasmuch as rivers carve valleys of continuous down grade from head to mouth, they tend to destroy lakes; for the floor of every lake basin must have an up-grade from its deepest part to the lake outlet. The occurrence of lakes therefore suggests an imperfection or an incompleteness in the down-grading action of rivers, and hence a study of lakes must involve a search for the origin of such imperfection or incompleteness. Such study shows that basin-like depressions, large or small, have been produced in the surface of the lands by irregular deformation of the earth's crust. If the deformation is slow, the resulting basin may be filled with inwashed detritus while the deformation is in progress, and no lake will be formed; but if the deformation is more rapid, the basin will be only in part filled with detritus during its deformation, and a lake will occupy the unfilled part. Where the climate is moist such basins are water-filled to overflowing; where it is dry the basin is only in part water-filled and there is no overflow. In this case the area of the non-overflowing lake comes to be such that evaporation from its surface disposes of the inflow from the entire drainage basin: in the other case the overflow will equal the inflow minus the evaporation from the lake surface.

The study of lakes also shows that some of them occur where the land surface has been unevenly worn down by ancient glaciers, or where it has been unevenly up-built by volcanic eruptions. Moreover, certain desert regions, in the broad basins of which lakes are now small or wanting, are shown by the shore-line terraces still preserved on the basin slopes to have possessed large lakes during a moister and cooler climatic period of the geologically recent past, presumably contemporaneous with the period in which the ancient mountain glaciers and the great ice-sheets of certain continental areas attained their vast extension. All these possible causes of lake production must be investigated.

The study of lakes shows further that, whenever and wherever they are produced, the action of weathering and streaming tends, as above intimated, to destroy them, either by slowly filling their basins with inwashed detritus or by gradually cutting down their outlets and draining off their waters. Thus Lake Geneva, at the northwestern margin of the Swiss Alps, is now somewhat encroached upon by the delta that the inflowing Rhone is building at the lake head; eventually, the delta may replace the entire lake. Likewise, Lake Erie is fated to be drained away in the distant future when Niagara Falls and the rapids upstream from them are worn back sufficiently to lower the lake outlet to the level of its basin floor, which will then be laid bare as a smooth plain.

Lake basins should therefore be considered as resembling, in a smaller way, the greater unevenness of the earth's surface, because they also very generally exhibit the interaction of antagonistic processes: One set of processes producing the lake-holding basin, the other set tending to destroy the basin-holding lake. In other words, the quicker-acting but less enduring processes of lake production are, in time, overcome by the slower acting but longer enduring processes of lake destruction. Lakes are therefore, as a rule, what our old Mother Earth would consider short-lived features of her land surfaces. A few examples of these general principles may be here presented.

Divers Methods of Lake Production

Warped-Valley Lakes

A slight bending or breaking of the earth's crust will affect the slope of river basins and their valleys. If a valley slope is thus increased, its river will run faster and erode its valley deeper; but if a valley slope is decreased even to the point of reversing its direction, a lake may be formed in the depressed part of the valley. A peculiar lake in equatorial Africa illustrates this method of lake-production to perfection. The headwater area of a region drained by the Kafu and Katonga rivers has been slightly down-warped, so that their valleys now slope eastward instead of westward as formerly. The branching Kafu headwaters have thus been transformed, Fig. 1, into the branching Lake Kyoga, 150 miles in length. The Katonga headwaters are more completely submerged in the broad Lake Victoria, of similar measure in diameter. Parts of both rivers now flow backwards into their lakes.

Lake Victoria is the chief source of the Nile, which flows northward from it into Kyoga Lake by one of its branches and out by another. The little eroded Ripon Falls, next north of Lake Victoria, and the extremely narrow gorge below Murchison Falls, northwest of Lake Kyoga, testify to the recency of the time when the lakes were formed and the present course of the Nile was assumed.

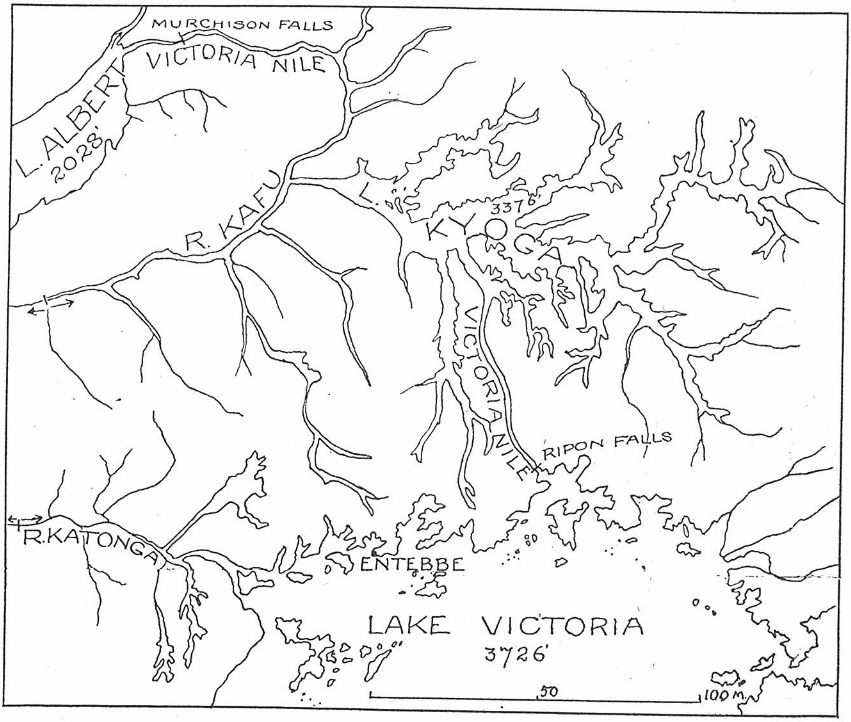

FIG. 1. Lakes Kyoga and Victoria, central Africa; reduced from map in report of E. J. Wayland, director, Uganda Geological Survey.

Fault-Basin Lakes

Certain lakes occupy depressions in the land surface which result from the breaking and tilting of huge blocks of previously nearly level earth-crust, as in Fig. 2. The deep fractures on which such blocks are displaced are known to geologists as faults, and the displaced blocks are called fault-blocks. When some of the blocks are raised to mountainous heights, as in the background of Fig. 2, the depression between them may be called an intermont trough or basin. Some such basins are of so recent a geological date of formation that they have not as yet been much filled by detritus washed down from the adjoining highlands, and rather deep lakes may then occupy a considerable part of their cavities. Central Africa again affords a typical example of this kind in the long and deep Lake Tanganyika; and the exceptionally long and deep Lake Baikal of north-central Asia may be of similar origin.

Other fault basins of more ancient origin are now largely filled with evenly spread layers of inwashed detritus, coarser and steeper-sloping near the base of the enclosing highlands, finer and more nearly level near the basin center. The basins are thus converted into flat, intermont plains, while the uplifted blocks are carved into rugged mountainous forms. Such basins are said to be aggraded, while the mountain blocks are dissected or degraded. Shallow lakes may then occupy the least filled parts of the plains, as in the foreground of Fig. 2.

It must not be imagined that the faulting or flexing of such crustal blocks took place suddenly or that the resulting troughs or basins immediately became filled with great bodies of water. The displacements were probably accomplished by many small movements separated by quiet pauses of years or centuries; and it is to be supposed that a considerable quantity of detritus was washed into the cavities from the enclosing highlands while the displacements were in slow progress. The displacements may have been, in some cases, so slow that the larger rivers of the deformed region held their courses, by cutting deep gorges through the uplifted blocks and filling the depressed areas with detritus. In all cases any lakes that were thus formed occupy merely such parts of the basins as are not otherwise filled. All such lakes may therefore be roughly classified with respect to the proportion that their water volume and area bear to the volume and area of the basin of deformation.

Intermont lakes will overflow if the climate is humid, but not if the climate is arid; for in the latter case evaporation from the lake surface disposes of all the water that the lake receives from rainfall and from inflowing streams and springs. Lakes without outlets are commonly saline, because as told above the minute amount of dissolved saline minerals brought in by their streams accumulates in them. If these lakes lie on the plains of smoothly aggraded intermont depressions, they may be so shallow even during the wetter part of the year that they evaporate in the drier part, leaving a smooth plain of silt in their place. Plains of this kind are called playas and the thin water sheets that temporarily cover them are known as playa lakes.

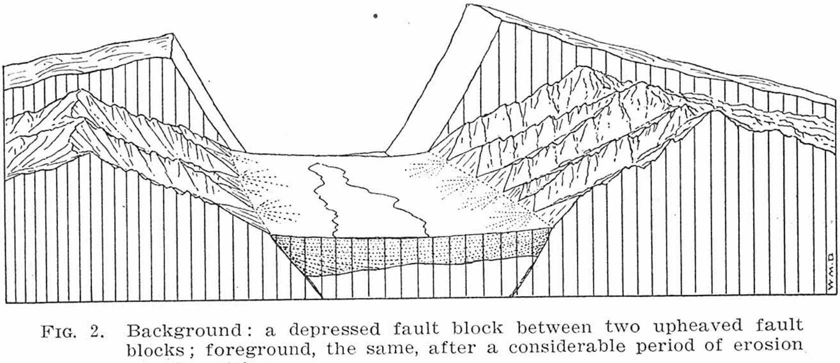

FIG. 2. Background: a depressed fault block between two upheaved fault blocks; foreground, the same, after a considerable period of erosion and deposition.

Nevada, Arizona and southern California, of arid climate, possess a good number of intermont depressions of earlier or later origin, the depth of which has been more or less diminished by deposits of inwashed detritus. Hence, besides some good-sized and rather deep lakes in the younger and less filled depressions of western Nevada, the flat, aggraded floors of many other depressions of the two states contain only dry lake beds or playas, mostly of moderate or small area. These are flooded, if at all, only after winter rains or summer downpours, and even then only by very shallow water sheets. But many of these heavily aggraded basins held much larger perennial lakes during the cooler and moister Glacial Period of modern geological times.

Landslide lakes

It sometimes happens that a steep-sided, stream-eroded canyon is blocked by a landslide, upstream from which a lake then rises, as in Fig. 3. A famous example of this kind occurred in a deep and steep-sided valley of the Ganges headwaters in the Himalaya Mountains of India in September, 1893. The slide descended some 4000 feet, leaving a great bare scar at its source, and forming a barrier in the valley two miles long and from 800 to 900 feet high. A lake gradually rose behind it and gained a length of over three miles. Then overflowing some eight months later, the outrushing flood rapidly cut a gash a mile long and nearly 400 feet deep through the barrier. The

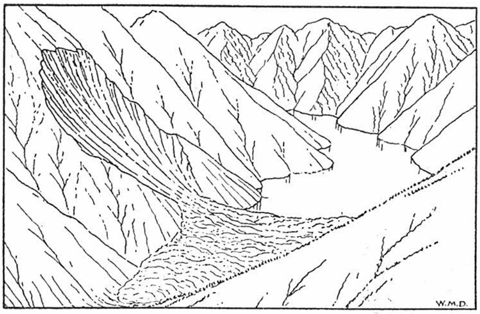

FIG. 3. Diagram of a landslide lake in a mountain valley.

lake fell 25 feet in the first hour after its overflow began and 300 feet in the second hour. The resulting flood rose 160 feet 20 miles down the valley and from 50 to 60 feet 70 miles down. Yet such were the precautions taken and so well was the coming of the flood announced by telegraph to the villages down the valley that, although all houses and bridges were swept away, live stock was driven up the valley sides to safety and only one human life was lost, that of a religious devotee who insisted on living at the base of the slide. He was never found after the overflow took place.[1]

If the obstruction produced by a landslide does not block a valley to a great depth, the outlet of the resulting lake will, on overflowing, cut down its course gradually and the lake will be slowly lowered. A great, prehistoric landslide, descending a slanting course of several miles on the Washington side, blocked the Columbia River about midway in its gorge through the Cascade Mountains and pushed the river toward the Oregon side; there the great river now has a cascading

[1] Holland, T. H., The Landslip at Gohna, Garwhal. Rec. Geol. Survey, India, vol. 27, pp. 55-64, 1894.
Strachey, The Landslip at Gohna. Geog. Jour., vol. 4, pp. 162–170, 1894.
Lubbock, F., The Gohna Lake. Geog. Jour., vol. 4, p. 457, 1894.

course among giant boulders and is striving to reestablish an even current and drain away its lake-like expansion that still remains next upstream from the obstruction; but as it has not yet succeeded in doing so, the slide must be of recent geological date. The name of the mountains through which the river has cut its deep gorge has been taken from the cascades of the river among the huge boulders of the slide.

Glacial Lakes

The great glaciers, which were formed on certain mountain ranges during the geologically recent, cooler and moister Glacial Period above referred to, scoured the bed rock of the highland valleys along which they crept, slowly and heavily, from higher to lower ground, and where the scouring was uneven, rock basins were excavated. Since the glaciers disappeared in the warmer and drier climate of the present, the basins that they excavated are occupied by lakes. Many Californian lakes are of this kind.

The modification of mountain forms produced by glacial erosion and the intimate association of lake basins with that extraordinary process may be made clearer by reference to Fig. 4. On the extreme left is shown the Preglacial form of a mountain range as produced by the prolonged action of ordinary weathering and streaming on an uplifted highland; not that all mountains had such forms in Preglacial time but that many of them had. The timber line was then at a high level, appropriate to the mild Preglacial climate. The dome-like summits give forth rounded, branching ridges and spurs, which separated correspondingly branching valleys; and down the continuously descending floors of the valleys, slender and nimble water streams ran in winding channels on the narrow valley floors.

In the left center, where the timber-line is lower by reason of a colder climate, a glacial system, consisting of several short branches heading in broad reservoirs and uniting in a long trunk, has taken possession of the upper part of a valley system and has reshaped the valleys to the satisfaction of the heavy and sluggish ice-streams. Each branch glacier has a concave surface in its gathering reservoir, but the trunk glacier assumes a convex surface as it sluggishly creeps down its course. Large as it is, all of its slow-moving volume is drained away by the slender ice-water stream that issues from a terminal ice cave. The several head glaciers have excavated great quarry-like cavities, known as cirques, in the valley heads, thus reducing the rounded mounts and ridges that enclose them to sharpened peaks and serrated crests; but unconsumed remnants of Preglacial dome-tops survive here and there. Each branch glacier preserves its individuality in the trunk; for ice streams do not mix their currents as water streams do. Hence the detritus dragged along from the narrowed spurs between the head reservoirs is seen in long "medial moraines" on the surface of the trunk glacier. That great glacier has transformed a narrow-floored, Preglacial valley into a strongly deepened and broadly opened but still steep-sided trough. The large size of the trough or ice-channel below the higher valley-side slopes is appropriate to the sluggish movement of the glacier, just as the small size of a valley-bottom stream channel is appropriate to the nimble flow of the water-stream.

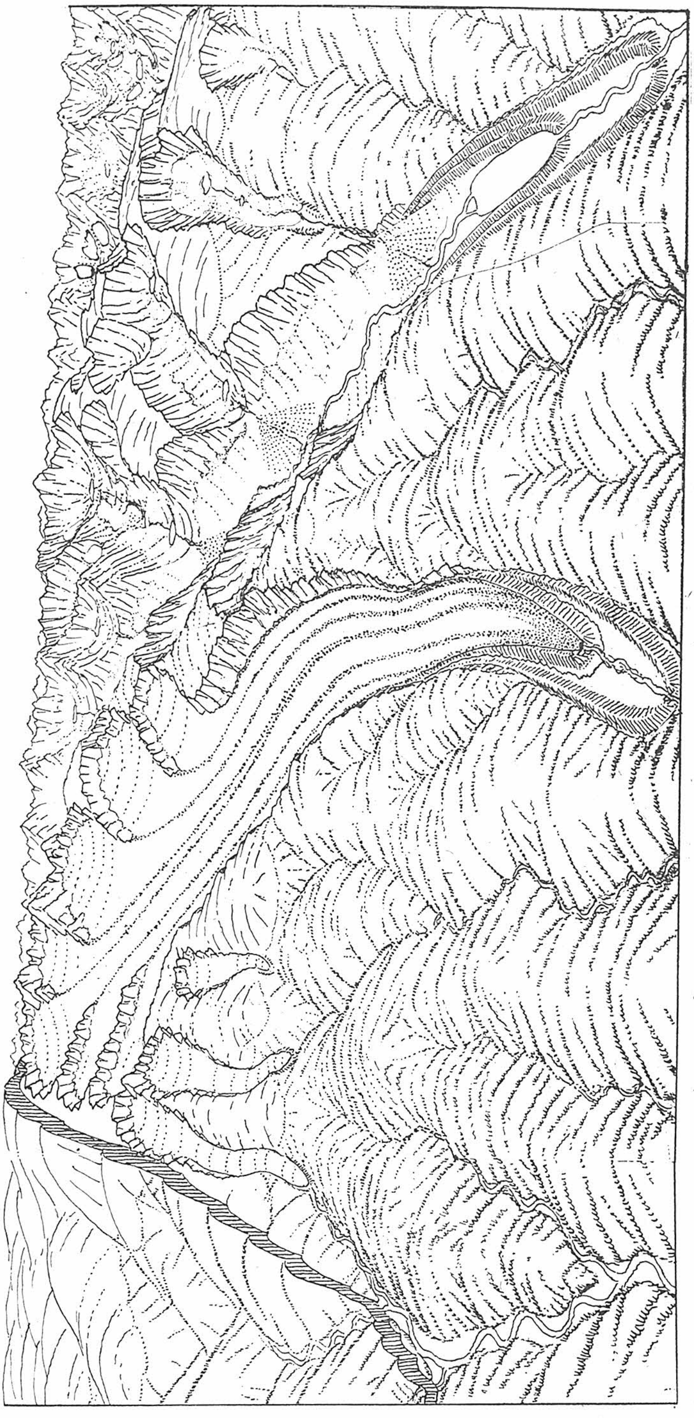

FIG. 4. Three-stage diagram, illustrating the glacial sculpture of mountains. On the extreme left, a non-glaciated mountain mass, with rounded spurs and narrow valleys, the work of ordinary erosional processes, chiefly weathering and streaming. Across the middle, same kind of mountains after they have been well modified by the glaciers which still occupy their valleys. On the right, the same, after the glaciers have disappeared, so that the cirques and troughs which they have excavated are exposed to view. Many small lakes are there seen, although no lakes existed in the mountains on the extreme left.

A small share of the detritus removed by the plucking and scouring action of the heavy, slow-creeping ice from the walls and floors of the cirques and troughs, as well as of that washed down upon the ice from the higher, ice-free surfaces, is deposited in a terminal moraine which loops around the end of the glacier in ridge-like form; but most of the removed detritus is carried away by the ice-water stream. The occurrence of a larger exterior terminal moraine indicates the presence at an earlier time of a larger glacier by which part of the cirque and trough excavation must have been done.

While these changes are going on, the parts of the range not occupied by glaciers are worn down lower by ordinary weathering and streaming without significantly changing their shape, to some such measure as is shown by the vertical face between the extreme left and the left center of the diagram.

The right half of the diagram exhibits the mountains as they appear after the glaciers have melted away in the milder climate of Postglacial time. The timber line is at a higher level again. The rock floors of the cirques are often scoured out in shallow basins, holding lakelets or tarns. Talus from the steep rock walls encroaches more or less upon the floors of the cirques and troughs. It is noticeable that the short side troughs which head in lateral cirques 'hang' above the much deeper floor of each great main trough. Streams, cascading down into the main trough, cut clefts and chasms in the lips of the hanging troughs, or hanging valleys as they may now be called, and build detrital fans below. The fans push the main trough stream toward the opposite side of the trough.

Small lakes may occupy shallow basins in the trough floor down stream from the cirques for a time after the disappearance of the glaciers; but many of them have been filled by stream-washed detritus which has built up or aggraded parts of the over-deepened floor in smooth flood plains or 'meadows.' The largest lake of the glacial system occupies the terminal part of the over-deepened floor, where the terminal moraine may aid in holding back its waters. The head of such a lake is partly filled in by the delta extension of the trough-floor flood plain.

Inasmuch as no great amount of talus has yet accumulated in the cirques, as the clefts cut in the lips of the hanging side valleys have not yet gained great depth, and as the terminal lake has not yet been completely filled by its growing delta, it must be inferred that the time since the disappearance of the latest glacial system is short compared to the time during which the valleys were occupied by that system as shown in the left-center of the figure, and shorter still compared to the time during which the mountain valleys, shown at the left end of the figure, were carved by ordinary weathering and streaming to the form they had before their occupation by ice.

The importance of glaciation in the production of lakes may be judged by the number and the size of such lakes in various parts of the world. For example, Okanagon, Arrow, Slocan and Kootenay in British Columbia, 60, 95, 23, and 68 miles in length, and the 65-mile Lake Chelan in Washington, all in valleys of the Columbia River system, occupy basins of glacial excavation. The same is true of the piedmont lakes of the Alps, including Annecy, Geneva, Thun-Brienz, Lucerne, Zurich, Constance, Ammer, Würm, and Chiem on the north, and Maggiore, Lugano, Como, Iseo and Garda on the south. Some of these lakes are over 1000 feet deep. They are all surrounded by beautiful mountain scenery, but the European examples have the additional and very picturesque attraction of long-established human occupation, while the

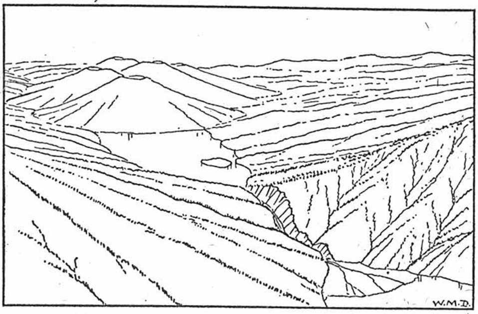

FIG. 5. A lake in a valley-head, above a group of volcanoes; the lake outlet has cut a notch in the divide at the head of the valley.

American examples are for the most part in mountain wildernesses, scantily inhabited.

The great North American lakes, from those of the St. Lawrence system northwestward 2000 miles toward the Arctic Ocean, are all associated with the scouring action of the vast ice-sheets which covered northeastern North America in the Glacial Period, although it should not be asserted that they are wholly due to the excavation of their basins by ice action. Lake-basin production there may have been aided by warping of the earth's crust and by morainic obstruction of Preglacial river courses.

Volcanic Lakes

Volcanic cones or lava flows may obstruct valleys and produce lakes. Again an example may be taken from Africa: Lake Kivu, north of Tanganyika, is of this kind: its basin was apparently drained by a northward valley to the Nile before a group of great volcanoes barred the valley and turned its overflow southward via Tanganyika to the Congo, somewhat as in Fig. 5. The craters of extinct volcanoes may hold lakes. Among the most famous is Crater Lake in southern Oregon, 6 miles in diameter, 6240 feet in altitude and 2000 feet deep. It is surmounted by the 1000-foot cliffs of the enlarged crater or 'caldera,' which is believed to have resulted from the destruction of the upper part of the original cone, to which the name, Mt. Mazama, has been given. Three lakes lie in the craters of as many volcanoes next north of Rome. A number of similar but larger lakes are found in the volcanic cones of Java.

River-made Lakes

A river flowing in a serpentine or meandering course on a smooth flood plain frequently changes its course, leaving a narrow, curved lake in its previous channel, as in the left middle-distance of Fig. 6. Many such ox-bow lakes, as they are often called, are found in the flood plain of the lower Mississippi. A trunk river, which is well supplied with detritus from its headwaters, will build up or aggrade a flood plain near its banks more than at a distance to one side of them; those lower parts may then be occupied by marshy sloughs, as in the right foreground and left background of Fig. 6. Such a river may, indeed, build up its flood plain so actively that its side streams which build up their plains less rapidly are converted into lake-like water-bodies near their junction with the trunk river, as in the right background of Fig. 6. The branches of the Red River of Louisiana and of the lower Danube in Russia afford examples of this kind. Basins are sometimes enclosed or divided by the fan deltas of entering streams.

Artificial Reservoirs

Reservoirs, formed by building dams across valleys, closely resemble natural lakes. California possesses many such water-bodies.

Lake-like Bays and Lagoons

Arms of the sea, more or less completely land-locked, are also somewhat lake-like. It should be understood that Figs. 2 to 8, 13 to 15, 21, 25, 26, and 29, are not pictures of actual lakes and landscapes, but only ideal diagrams, drawn in a highly conventionalized manner with the object of supplementing the explanations of the text.

Lakes Are Ephemeral

It follows from the above principles that lakes should be regarded as representing only a passing phase in the action of the antagonistic

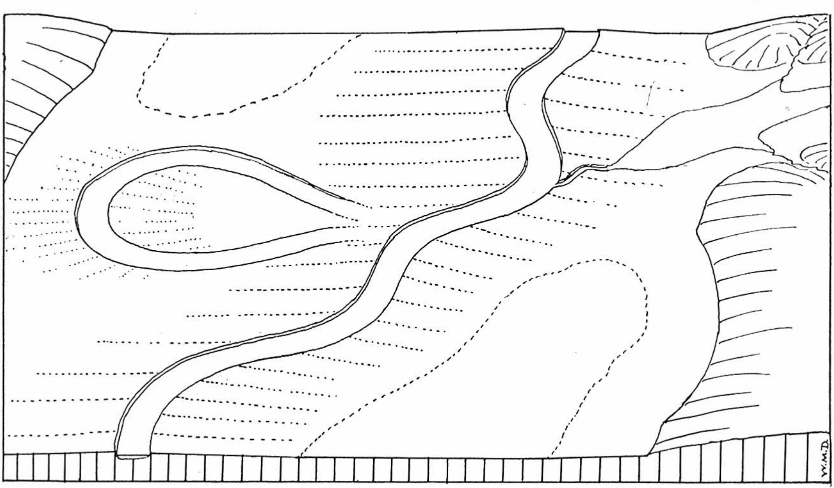

FIG. 6. Diagram of river-made lakes and sloughs.

processes that are concerned in the shaping of the land surface. The land-shaping processes are as a rule so slow in their action that we speak, properly enough from the viewpoint of human history, of the 'everlasting hills,' and we take little or no account of the changes suffered by most land forms—such as Mt. Sinai or the Seven Hills of

Rome—during the latter part of the human period of geological time. But the student of geology must free himself of the idea that land forms are permanent, however fitting such an idea may be in the study of human history; he must strive to look on land forms as old Mother Earth herself would look upon them; that is, as forms which are, in terms of earth history, undergoing relatively rapid change.

Every element of the landscape should therefore be studied as representing a mere transitory stage of the systematic changes by which land forms pass from their earlier to their later, from their initial to their ultimate form. In such study those water forms which we call lakes are, because of the delicacy with which water assumes a level surface, very helpful in showing where hollows or basins in the land surface occur, and the changes in the outline and area of lakes are therefore reflections of the associated changes in the form of their basins. Thus conceived, the study of lakes gains much interest to an observant traveler; and thus equipped with a general understanding of the lakes of the world, the observer is better prepared for an appreciative understanding of the lakes of his own State.

Part II. THE LAKES OF CALIFORNIA

Sources of Information

California possesses a large number of lakes and lake-like water bodies of the various kinds above explained. The account of them presented below is believed to be more complete than any other that has yet been prepared. It has been made up in part from personal observation,[2] but much more largely from the study of articles by other observers and also from the examination of large-scale topographic maps. Although much information has been thus secured, the knowledge of California lakes is as yet by no means complete. It is therefore hoped that what is here told about those which have already been examined may lead to new investigations. Many of the less known lakes are unquestionably fertile subjects for further study, such as has already been given to the Alkali Lakes of Surprise Valley by R. J. Russell, to Medicine Lake of the Modoc lava beds by M. A. Peacock, to Sierran lakes of glacial origin by Eliot Blackwelder, to the glacial and volcanic lakes of Lassen Volcanic National Park by Howel Williams, and to other lakes by various investigators whose instructive essays are cited below. In case new studies of our lakes should include good photographs, preferably from an elevated point of view so as to show the whole breadth of the water surface in its setting with its near as well as its far shore, the State Division of Mines would be glad to add prints of such views to its growing collection of landscape portraiture.[3]

Although by no means all the lacustrine water bodies of the State are named on the following pages, it is believed that examples of all the different kinds of lakes that California possesses are included. Practically all the lakes named are shown on the large, two-sheet out-

[2] The study of lakes has long engaged the author's attention; see his essay "On the Classification of Lake Basins," Proc. Boston Soc. Nat. Hist., vol. 21, pp. 315-381, 1882, and his shorter article on the same subject in Science, vol. 10, pp. 142-143, 1883.

[3] The address of the State Division of Mines is: Ferry Building, San Francisco, California.

line map of the State, published in 1929 by the U. S. Geological Survey on a scale of 1: 500,000. For the sake of brevity the location of various lakes is concisely stated in relation to neighboring mountains, rivers or other large natural features, and occasionally in relation to near-by towns or cities. Surface dimensions are given roughly in miles as taken from the topographic maps of the U. S. Geological Survey, from the charts of the U. S. Coast and Geodetic Survey and from other sources; altitudes and depths are given, not always accurately, in feet.

Lakes in Young Fault-Block Basins

The Modoc lava field, which occupies a large area in the northeastern part of California with a thickness of 4000 or 5000 feet has, according to a recent study by Peacock,[4] been broken into several long fault blocks 10 or 20 miles in breadth, trending about north-south and crossing the northern border of the State into Oregon; the blocks have been gently and somewhat unevenly tilted so that their upraised edges form bold, little eroded scarps, from 200 to 400 feet or more in height. Three lakes occupy the down-tilted areas beneath the scarps, somewhat as in Fig. 7, and it would be difficult to find better examples of their

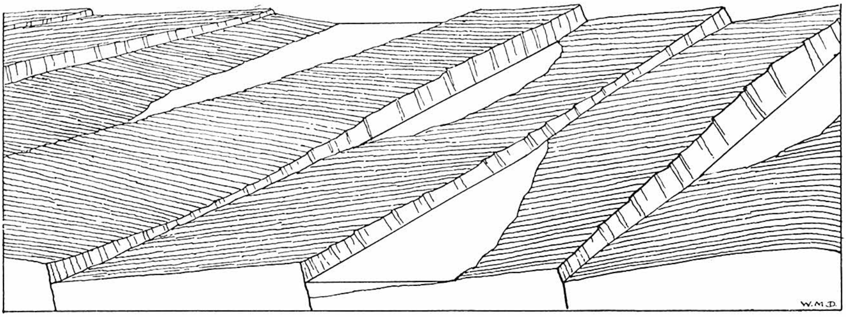

FIG. 7. Diagram of diversely tilted fault blocks, with lakes occupying the depressions.

kind. Clear Lake, one of three of that name in the State, lies 10 miles south of the Oregon line; it has been somewhat enlarged as a reservoir for irrigation and now measures 8 by 3 miles. Farther west is Tule Lake, formerly known as Rhett Lake, at an altitude of about 4140 feet. In 1884, it had an area of 184 square miles; in 1924, its area was halved; in 1930, it was "a small and shallow pond" which appeared to be vanishing. Still farther west is Lower Klamath Lake, 4175 feet in altitude and 27 by from 3 to 8 miles in size, of which only half lies in California. It also is diminishing in area, and much of it now is a reed marsh. The most probable cause for the diminution of Tule and perhaps of Lower Klamath Lake also is that their underground discharge is increasing. This, taken in connection with the steepness of their limiting fault scarps, suggests a very recent date for the faulting.

A small example of a water-filled fault-basin is seen in Marlette Lake, as described by Reid.[5] It is 2 miles long, at an altitude of 8000

[4] Peacock, M. A., The Modoc Lava Field, Northern California. Geog. Rev., vol. 21, pp. 259-275, 1931.

[5] Reid, J. A., The Geomorphogeny of the Sierra Nevada Northeast of Lake Tahoe. Univ. Calif. Publ., Bull. Dept. Geol. Sci., vol. 6, pp. 89-161, 1911.

feet, in the broad-topped Carson range, the uplifted mountain block next east of Lake Tahoe in Nevada. The basin is so little filled with detritus that its origin would seem to be geologically recent.

Lakes in Aggraded Fault-Block Basins

Many intermont troughs and basins produced by strong faulting or flexing are found among the uplifted fault-block mountains of the Great Basin between the Wasatch mountain range of Utah and the Sierra Nevada, and a number of them are included within the arid

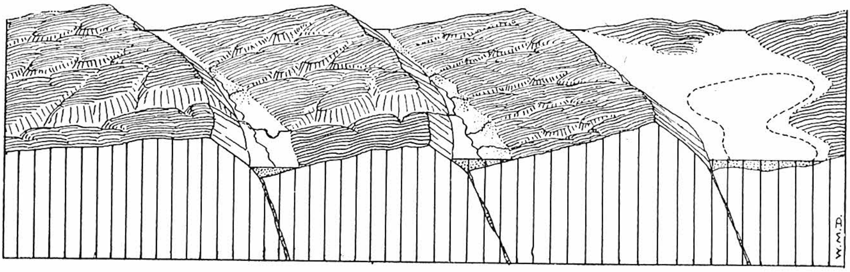

FIG. 8. Diagram of the great fault blocks of the northern Sierra Nevada, with the plain of Honey Lake on the east.

northeastern and southeastern corners of the Golden State. The adjoining mountains are as a rule well dissected by deep valleys and the troughs or basins are therefore heavily filled or aggraded with down-washed detrital deposits which form nearly level plains, commonly known as 'valleys,' as in the foreground of Fig. 8. Relatively shallow playa lakes, many of them without outlets because of the dryness of the climate, lie on the lowest part of the plains.

Playas are divided, according to Foshag, into two classes, water-tight or saline and leaky or dry. Water-tight playas are "salt encrusted areas, covered by a sticky tenacious mud when wet or a light fluffy soil when dry. During the rainy season they are often covered by shallow bodies of water and for the greater part of the year they are more or less moist. The water table seldom lies more than a few feet below the surface. The dry playas are entirely dry, only during periods of excessive or prolonged rainfall in the encircling ranges is water present on the surface for more than a few days at a time. Their surface consists of hard, smooth, sun-baked clay without visible concentration of salt."[6]

A typical example of the latter class is found in the shallow and variable Honey Lake, which lies on a broad and arid detrital plain of aggradation next below the great east-facing scarp of the northern Sierra Nevada, not far west of the Nevada line, somewhat as shown at the right end of Fig. 8. The scarp is believed to be the modified face of a great fault which constitutes one of the most distinctive features of the mountain range. It may therefore be believed that the Honey Lake area has been depressed and aggraded, while the strongly uplifted mountain mass was eroded. Recent slight movements on the fault are

[6] Foshag, W. F., Saline Lakes of the Mohave Desert Region. Econ. Geol., vol. 21, pp. 56-64, 1926.

to be associated with several weak earthquakes felt there between 1880 and 1885, and in 1921.[7]

This interesting lake is 3950 feet in altitude, 15 by 9 miles in area during wet winters, and yet then only from 1 to 4 feet in depth. Its water is alkaline and the lake is adjoined by barren alkaline flats. The surrounding plain is available for agriculture only where it can be irrigated. During dry summers the lake diminishes and occasionally vanishes, leaving an utterly barren playa with a surface nearly as smooth as that of the winter lake. The region then presents an extreme contrast to its condition when it was submerged to a depth of 350 feet, some thousands of years ago, by the northwest arm of a great inland sea of very irregular outline, to which the name of Lake Lahontan has been given. The shorelines made by its waves are still to be traced on the enclosing mountain slopes, but since then it has been evaporated away. One must therefore infer that the climate of the present epoch is warmer and drier than that of the epoch when Lake Lahontan was flooded. The climatic changes thus recorded probably occupied scores, perhaps hundreds of thousands of years; yet they are but a fraction of the time represented by the heavy aggradation of the Honey Lake intermont plain with detritus supplied by the down-wearing of the adjoining mountains.

In the extreme northeastern corner of the State is the flat floor of a down-faulted and heavily aggraded trough, of the kind shown in the foreground of Fig. 8, known as Surprise Valley, Fig 9, over

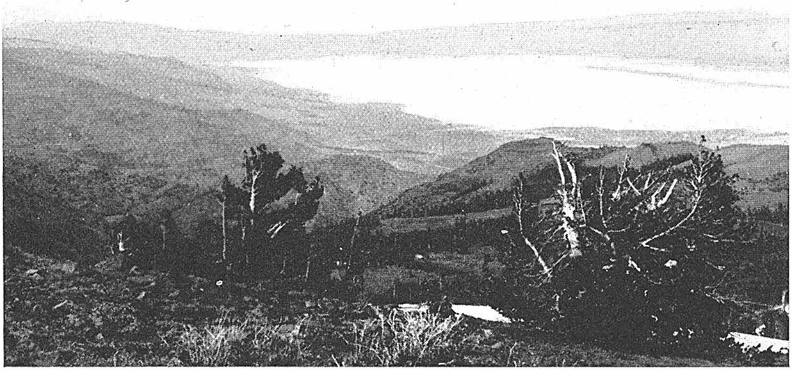

Photo by R. J. Russell.

FIG. 9. Looking northeast from crest of the Warner Range over Surprise Valley.

40 miles long and 8 miles wide, with an altitude of about 4700 feet. It lies between the great uptilted, and immaturely dissected lava-bed fault blocks known as the Warner Range on the west and as the Hayes Canyon Range of northwestern Nevada on the east. On this flat floor

[7] Kemnitzer, W., The Eagle Lake Earthquake of July 21, 1921. Seism. Soc. Amer. Bull., vol. 11, pp. 192–193, 1921.

lie three shallow and variable sheets of water which are named on the U. S. Topographic Map of their district as Upper, Middle, and Lower Alkali Lakes; but according to R. J. Russell, who has given an excellent description of them,[8] they are hardly known as lakes to the people who live on the surrounding plain. Two lakes may be seen from the crest of the Warner Range, looking northeast, Fig. 9, and southeast over the plain of Surprise Valley. Like Honey Lake, these shallow water sheets attain their greatest depth of a foot or two after winter rains; they almost or quite disappear in the summer, thus laying bare their silt beds or playas of the dry class. In winter when their water sheets are frozen over and in summer when their beds are dry and hard-baked, they may be driven over.

These lakes are bordered along their eastern or leeward shoreline by rather broad belts of salt flats, from the brine of which salt is won for local use, and sand dunes. Along their western side is a broad belt of grasslands, subject to temporary flooding from the mountains in the wet season. Here, marked by groups of willows, numerous springs bring forth the ground water that is fed by rainfall on the Warner Range. Some of the springs are hot; others bring fine silt to the surface and build small mounds around their vents, locally known as 'mud volcanoes.' The grassland belt is the best farming area of the intermont plain; as seen from the mountains its fields have a checkerboard appearance, in pleasing contrast to the uncultivated and almost valueless adjoining surface.

Like other lakes of their kind in the Great Basin these Alkali Lakes, the vague shorelines of which migrate with the winds, are the successors of an ancient and much larger lake, which flooded a large part of the intermont basin plain and to which the name, Surprise Lake, has been given. Its shorelines on the mountain slopes show it to have had a length of 70 miles and a depth of 550 feet. The climate then must have been cooler and rainier than now.

Goose Lake, as described by R. J. Russell[9], is another shallow water sheet, which occupies, at an altitude of 4800 feet, a large part of a moderately down-faulted trough below the western slope of the above-named Warner Range. It measures 30 by 10 miles, but one-third of its length extends into Oregon. A shallow gorge eroded through the lava beds on the south indicates that the lake formerly had a somewhat persistent discharge to Pit River, which flows westward through the highlands between Mt. Shasta and Lassen Peak to the Sacramento; but at present the lake overflows only when the water is brushed southward by a strong north wind, as happened in 1910.

Farther south, close to the eastern base of the Sierra Nevada lies Mono Lake, 6420 feet in altitude and 12 miles in diameter. This lake have been described by I. C. Russell[10]. It is believed to occupy a basin of depression, produced by down-faulting with relation to the up-faulting of the adjoining mountain range, but the enclosure of

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[8] Russell, R. J., The Land Forms of Surprise Valley, Northwestern Great Basin. Univ. Calif. Publ., Geogr, vol. 2, pp. 323–358, 1927.

[9] Russell, R. J., Basin Range Structure and Stratigraphy of the Warner Range, northeastern California. Univ. Calif. Publ., Bull. Dept. Geol. Sci., vol. 17, pp. 388–496, 1928.

[10] Russell, I. C., Quaternary History of Mono Valley, California. U. S. Geol. Survey Eighth Ann. Rept., pp. 281–394, pls. 17, 19, 21, 1889.

its waters may be due, at least in part, to volcanic barriers. As in the case of the Nevada lakes above described, a much larger lake, known by its high-standing shore lines, formerly occupied the basin in which Mono Lake now stands. The beauty of the present lake is much enhanced by the grandeur of the mountain scenery on its western side. The famous Tioga Road makes its descent there from the Sierra crest in a deep ravine. A considerable area south and southeast of the lake is covered with volcanic cones and lava flows, which have presumably diminished the extent that the lake might otherwise have. A volcanic island in the lake and several glacial moraines near it on the west will be referred to below in the sections on lakes of volcanic and of glacial origin.

Still farther south where the climate is even warmer and drier, a number of dry lake-beds on the lowest part of many intermont plains may be here instanced as showing that lakes were formerly more abundant than now, and as thus indicating the cooler and moister climate of that earlier time. South of Mono Lake 110 miles in Owens Valley and again at the eastern base of the Sierra Nevada, is the shallow Owens Lake, 3569 feet in altitude, 15 by 9 miles, formerly larger, now mostly reduced to a saline incrustation: this is therefore a playa of the saline class. To the southeast is the dry plain or playa of China Lake, 2124 feet in altitude, 7 by 2 miles; still farther east between the Argus and Slate ranges, is Searles Lake, 11 by 6 miles, 1623 feet in altitude, now heavily crusted over with a sheet of salt but containing a body of brine below, in consequence of which it has become the seat of an important chemical industry: this is another example of a saline playa. Again farther east, on the desert floor of the intermont depression known as Panamint Valley between the Slate and Panamint ranges, is Dry Lake playa, a white plain of saline clay, measuring 17 by 2 or 3 miles at an altitude of 1050 feet; another playa lies farther north in the same valley. Beyond Panamint Valley is the more famous Death Valley, of similar nature and again containing a playa of saline clays, but lying for the most part below sea level.

All of these now extinct lakes were, in the Glacial Period, on the course of the then enlarged Owens River, and each one of them except the last named then expanded to much greater area and depth than its saline successor of today and rose to the level of the lowest sag in the barrier to the east: thus each lake, as Gale, cited below, was the first to point out, overflowed to the next lower member of the series. At the level of each sag of overflow a shore line was more or less clearly marked around the lake by wave-built beaches, still discontinuously traceable. The lake of Death Valley, believed to have been fed by the overflow from Panamint Lake across Wingate Pass, does not appear to have risen to a sag of overflow as it was the farthest member of the series; hence its level, being dependent on inflow and evaporation, fluctuated up and down. Its faint shore lines have been detected at a number of points and indicate that it had a length of two or three score miles when at its highest level.

In the southern part of the Inyo Range, next east of the southern Sierra Nevada, are two down-faulted and aggraded 'holes,' known as Saline and Deep Spring Valleys. In each of them a saline lake or incrustation lies near the scarp of down-faulting. The first has been described by Gale [11] and by Knopf [12]; the second by Miller [13].

Many playas of the dry kind, representing vanished lakes mostly of moderate size, as in Fig. 10, might be mentioned as occurring in the arid southeastern part of the State. Like all their fellows these playas are covered with a very shallow sheet of water after heavy rains, and their clay floors are then impassable; but when the water is evaporated in the dry season the clay surface is firm and smooth, except where ridged and hard-baked ruts remain to mark the path of adventurous cars. One of the playas, known by the generic name of Dry Lake, 17 by 2 miles, is crossed by the Santa Fe railroad in its traverse of the northern part of the Mohave Desert. Another known as Bristol Lake, on the same railroad line farther east, is varied by the invasion of a black and ragged lava flow from a small volcanic cone on the west. Two smaller playas north of that railroad are crossed by the Cave Springs road to Death Valley. Others are too numerous to specify. It is on the level surface of a dry playa that the deceptive imitation

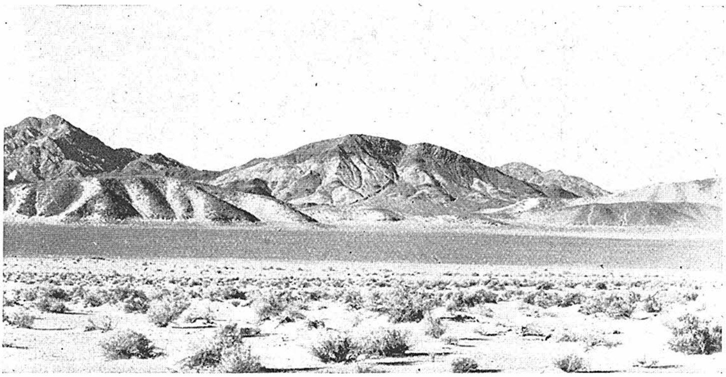


Photo by Eliot Blackwelder

FIG. 10. Silver Lake playa, in the southern part of a long depression which, farther north, is known as Death Valley.

of a lake, known as a 'mirage,' is developed on calm summer days. It is due to the super-heating of a thin layer of air next to the ground, so that when it is looked at from one side the light of the farther sky is reflected from it to the observer. As such reflection is a normal characteristic of true lakes, an inexperienced observer is likely so to misinterpret it in the desert.

Lake Elsinore, 5 by 1 or 2 miles, 1220 feet in altitude, is a shallow, brackish and variable water sheet lying in a faint depression at the highest part of the long, aggraded fault trough next northeast of the Santa Ana Mountains, 60 miles southeast of Los Angeles. Whether the shallow basin of the lake is determined by small and recent movements on faults, or by detrital fans washed in from the enclosing mountains has not yet been fully decided. The lake occasionally rises enough, in

[11] Gale, H. S., Salt, Borax and Potash in Saline Valley, Inyo Co., Cal. U. S. Geol. Survey Bull. 540, 1914.

[12] Knopf, Adolph, A Geologic Reconnaissance of the Inyo Range. * * * U. S. Geol. Survey Prof. Paper 110, 1918.

[13] Miller, W. J., Geology of Deep Spring Valley, Calif. Jour. Geology, vol. 36, pp. 510–525, 1928.

years of exceptionally heavy rainfall, to overflow northward by Temescal Creek along the fault trough to Santa Ana River. The scanty water supply of its district is made the most of in developing its scenic attractions.

Ancient Lakes of Intermont Basins

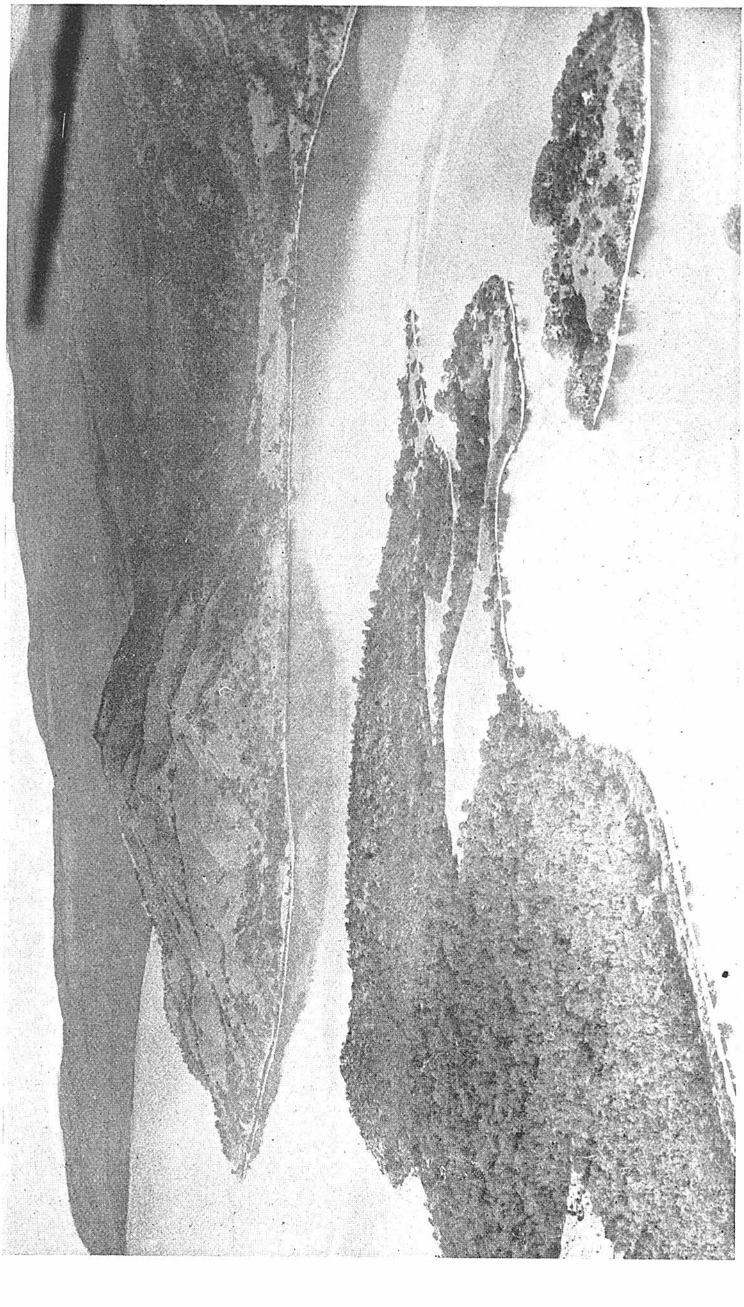
As the foregoing pages have presented accounts of playa lakes which vary with the seasons and of ancient lakes which indicate past variations of terrestrial climate through thousands of years, a brief mention of certain basin plains may be added which appear to indicate the occasional occurrence of still more ancient lakes. The part of the Sierra Nevada west of the above-described Honey Lake has been explained by Diller [14] as consisting of several west-sloping fault blocks with east-facing and more or less modified fault scarps, somewhat as represented in Fig. 8. Northeasternmost is Diamond Mountain block, some 40 miles in length, with a strong scarp, 2000 feet high overlooking the Honey Lake plain. The surface of the block slopes gently southwestward for some 20 miles into a long depression at the base of the next or Grizzly Mountain block; and that block, also sloping southwestward, is followed in its turn by the larger Claremont block which slopes down to the vast plain of the Great Valley. The inter-block depressions are aggraded with detrital plains, known as Indian and American valleys.[15] Lakes may have existed there intermittently during the time of slow faulting but none are present today. A larger example of an intermont basin which may have held a shallow lake at times during its aggradation is found in the so-called Sierra Valley, a broad plain which lies southeast of Indian and American valleys and which will be described below in connection with Lake Tahoe after the section on volcanic lakes.

Similar inferences as to the former occurrence of temporary lakes may be made with respect to several smaller intermont basin plains in the northern Coast Ranges, such as Potter and Long valleys, as well as to the somewhat larger basin-plain now mostly submerged beneath the waters of Clear Lake, 100 miles north of the Golden Gate, of which further account is given in the second-following section. All of these plains may have been intermittently flooded by shallow lakes during the slow down-flexing or down-faulting of their basin floors, but there is no sufficient reason for thinking that the basins were so suddenly produced that they at first held deep lakes which were then, after their rapid production ceased, slowly filled in with detritus and converted into plains as their outlets were cut down. Whatever lakes occupied the basins are best interpreted as shallow and temporary features compared to the associated fault-block mountains and basin plains.

The same statement holds good for the many longer and larger intermont basin plains of the southern Coast Ranges, of which typical examples are found in the Panoche and the Quien Sabe valleys, the first measuring 10 by 4 miles at an altitude of 1300 feet, the second 8 by 1 or 2 miles at an altitude of 1600 feet; both are drained by small

[14] Diller, J. S., Geology of the Taylorsville Region, California. U. S. Geol. Survey, Bull. 353, 1908.

[15] A view of the Indian Valley plain and of the dissected fault scarp to the west of it is given by Diller in Plate LI of his report on the Geology of the Lassen Peak District. U. S. Geol. Survey Eighth Ann. Rept., pt. 1, pp. 395–432, 1889.



Air-view by G. E. Russell, San Francisco

FIG. 11. The Narrows of Clear Lake, looking north.

streams through mountain gorges. Apparently on account of the southeastward decrease of rainfall, one of the larger southern examples, known as the Carrizo Plains, is peculiar in lacking a stream outlet. It is enclosed by a broad mountain mass on the west and on the east by the Temblor Range, the latter being one of the latest linear upheavals by which the breadth of the Coast Ranges has been increased at the expense of the Great-Valley plain. The smooth, treeless Carrizo surface, mostly given over to wheat fields, has been built up in faintly concave form by the inwash of detritus from the valleys eroded in the inclosing ranges; so that it now has a length of 40 miles, a width of 5 miles and an altutude of from 1950 feet at its middle to about 2600 at the ends. Over its lowest, medial part is spread Soda Lake, 5 miles long; a shallow water sheet after winter rains, a white and barren desert during the hot and dry summers. It lies near the western border of the plain because of the more abundant inwash of waste from the Temblor Range on the east.

Sag Ponds

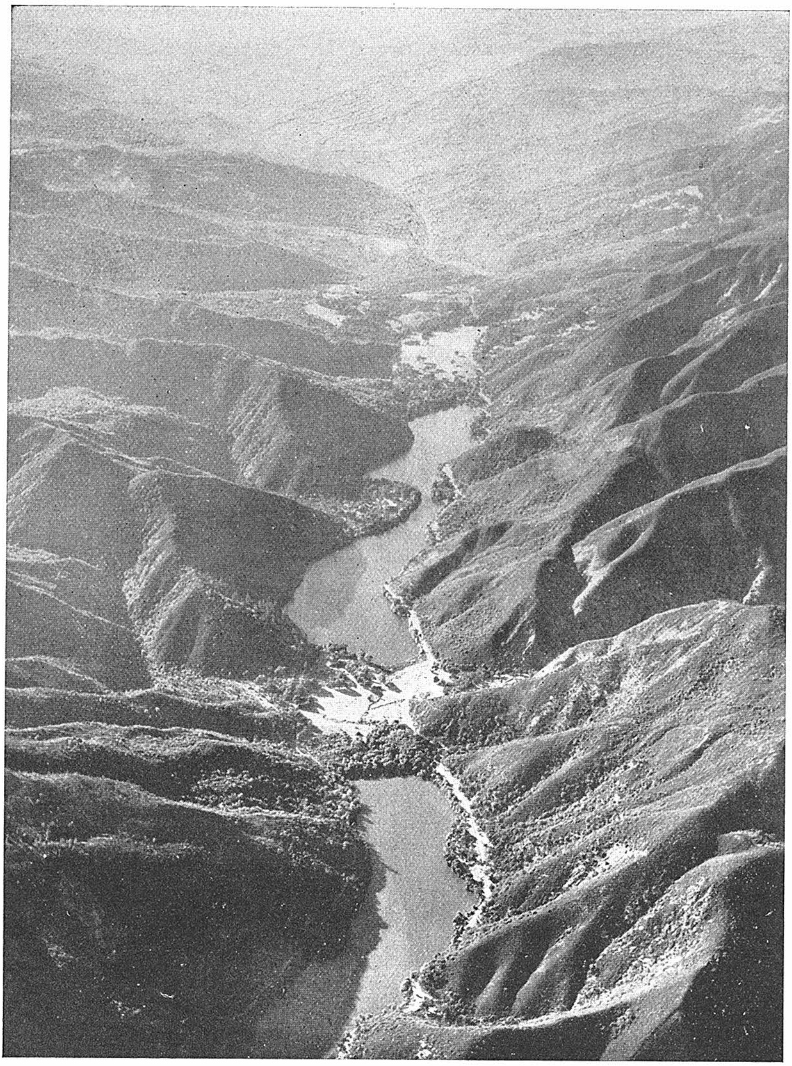
Here and there along the Elsinore fault or rift and still more frequently along the more famous San Andreas rift, a slight movement on which caused the San Francisco earthquake of 1906, numerous little water-holding depressions, known as "sag ponds," mark the sites of local subsidences. One of the largest of its kind is Lake Elizabeth, about 2 miles long, on the San Andreas rift in the western part of the Mohave Desert, 50 miles northwest of Los Angeles. An unnamed sag pond, a mile in length, occurs on a rift at the base of the recently up-faulted El Paso Range, 6 miles northwest of Randsburg.

Landslide Lakes

The chief Californian lake of this class is Clear Lake,[16] which floods the greater part of an intermont basin plain in the northern Coast Ranges. It has given name to the county, in the center of which it lies. Long previous to the production of the lake the plain, measuring about 25 miles northwest-south, by 15 miles in greatest width, was drained by two outflowing streams, the divide between which may have been marked by low mountain spurs near the lake middle. One of the streams (Cold Creek) had cut a deep gorge westward through an enclosing range to Russian River, which led it to the Pacific 55 miles north of the Golden Gate; the other (Cache Creek) had cut a longer and deeper gorge eastward through the opposite range, which led it to the Sacramento and thus to the head of San Francisco Bay. After a time the eastern stream was crossed near its gorge entrance by a small lava flow, and its headwaters were thus diverted to the western stream.

At a still later date a landslide, descending only a few centuries ago from the southern side of the western gorge near its mid-length, filled it up for a mile or more to a higher level than that of the lava flow near the far end of the basin plain. The obstruction was so effec-

[16] This account is condensed from a study of Clear Lake by the author, as yet unpublished, in the preparation of which much assistance has been received from Olaf P. Jenkins, Chief Geologist, Division of Mines. It was he who first found the trench through the lava flow, which has proved to be of so great significance in the history of the lake.



Air-view by Erickson.

FIG. 12. The Blue Lakes, in the former outlet gorge of the Clear Lake basin plain. The obstructing landslide is just beyond a white field in middle distance. The two lakes are separated by the inwashed deltas of side streams nearer the foreground.

tive that a lake, fed by the streams that flowed into the basin, slowly rose higher and higher behind the slide, spreading over more and more of the plain, until it overflowed across a sag in the lava flow. The overflowing stream thereupon cut a trench (Redbank Gorge) across the flow, thus lowering the lake about 60 feet below its highest level, giving it a discharge through the eastern gorge, and re-enforcing the previously beheaded eastern stream (Cache Creek). The reduced lake now stands at an altitude of 1310 feet, with a size of 19 by 8 miles and a maximum depth of about 50 feet. Two narrow eastern arms are separated from the main western body at a picturesque Narrows, Fig. 11, near the lake mid-length. Had there been no outlet for the lake through the eastern gorge, the lake would probably have risen till it overflowed across the landslide in the western gorge and its outlet stream would very likely have washed away most of the slide in a destructive flood centuries ago, thus draining the lake and laying bare again the intermont basin plain. But such western overflow was effectively prevented by the presence of the eastern gorge. The landslide is of so enormous a volume that its removal by surface rills or leakage of ground-water is out of the question.

Since the formation of the lake its slender arm that at first occupied the part of the western gorge back of the landslide has been cut off from the main body of the lake by the broad delta of Middle Creek, which comes from the north; and the arm has been further shortened by the delta of Scott Creek, which entered it from the south. Its short remainder is now divided by the combined deltas of two wet-weather side streams, thus forming the picturesque little Blue Lakes, Fig. 12, beautifully enclosed by the steep sides of the gorge. These lakelets, therefore, belong in the class of lakes, the basins of which are barred by deltas, as will be told in a later section.

Clear Lake was artificially modified 20 years ago by the building of a 30-foot dam at the entrance to the eastern gorge and by the blasting out of a rocky barrier to a few feet greater depth near the entrance of the eastern outlet stream into the trench through the lava barrier, with the object of storing greater volume of water supplied by the winter rains and of withdrawing it to lower than ordinary lake level for irrigation of rice fields in the Yolo basin of the Sacramento in the summer. In consequence of these changes, the lake surface now usually stands a few feet below the level of the shore beaches that were formed before the changes were made. Unfortunately, the moderate rainfall of the region, 25 or 30 inches a year, does not supply the inflowing streams with much more water than is lost by evaporation, 53 inches in a year, from the lake surface, and therefore the outflow available for irrigation is usually small.[17]

The various changes that have taken place in the drainage of the basin have had a curious effect on the distribution of river fish. In consequence of the lava flow by which the head of the eastern stream was cut off and diverted to the western stream, one must infer that various species of fish belonging to the Sacramento system were transferred to the Russian River. This inference finds support in a study by Snyder who, nearly a quarter-century before the existence and the

[17] Chandler, A. E., Water Storage on Cache Creek, California. U. S. Geol. Survey Water-Supply Paper 45, 1901.

effects of the lava flow were discovered, pointed out that the fish of Russian River are like those "of the upper courses of the streams tributary to the Sacramento which flow from the western side of the Great Valley, the channel forms common to the main river [Sacramento] being absent" from the Russian River; and he therefore concluded that "the fish fauna of the Russian River was probably derived from the Sacramento," for "the Sacramento, a vastly larger and probably older system, not only contains all the [12 indigenous] fluviatile species known from the Russian River, but also others not there represented."[18] If the history of Clear Lake involved only its blockade by the landslide in the western gorge and the resulting shift of west-flowing stream through the eastern gorge to the Sacramento system, the above prophetic statement would have lacked confirmation; but the discovery of the lava flow and its effects confirms the prophecy by giving it a sound geological foundation.

A fine highway, ascending the lower part of the western gorge from Russian River valley, surmounts the landslide, skirts the Blue Lakes, crosses the delta plain of Middle Creek, follows the north shore of the main body of the lake, passes the Narrows and continues along the northern and shorter one of the two eastern arms. A side road, zigzagging up the mountain slope north of the main body affords a fine view of the lake and of the Konocti group of volcanoes, which reach altitudes over 3500 feet, adjoining the longer or southeastern lake arm. A considerable area of the basin plain, known as Big Valley, adjoining the main body of the lake on the south, is largely devoted to fruit raising.

This fine lake, the only lake in the northern Coast Ranges, is perhaps even more largely resorted to by summer visitors than Lake Tahoe in the Sierra Nevada. Its attractive scenery is therefore of a considerable esthetic value to the State, while its fisheries are of growing economic value. Moreover, in consequence of its production Lake County has become the home of many waterfowl which would otherwise not remain there.

Several other smaller lakes of landslide origin occur in the deeply eroded valleys of the Warner Range, already referred to as forming the western boundary of Surprise Valley in the extreme northeastern corner of the State. They have been well described by Russell,[19] who explains that their formation is favored by the occurrence of weaker volcanic beds under a capping of resistant basalt, so that the basalt, forming a 'rim rock' at the top of the valley sides, is sapped by the more yielding beds below it. One of these small lakes which, like the above described much larger fault-basin lake some 40 miles farther west, repeats the name of the still larger landslide lake in the northern Coast Ranges, measures only $\frac{1}{2}$ by $\frac{1}{8}$ miles, with a depth of 90 feet; it stands at an altitude of 5750 feet in a canyon 1000 feet deep in the western slope of the range. Two landslides, one from each side of the canyon, form its barrier; their scars are fresh-looking and the delta of the inflowing stream is small; hence the age of the lake is perhaps not over a century. Blue Lake, 10 miles farther south, is of similar

[18] Snyder, J. O., The Fauna of Russian River, California, and Its Relation to that of the Sacramento. Science, vol. 27, pp. 269–271, 1908.

[19] Russell, R. J., Landslide Lakes of the Northwestern Great Basin. Univ. Calif. Publ., Geog., vol 2, pp. 231–254, 1927.

and recent origin, but it is barred by a single slide. These two lakes drain to Pit River. Lost Lake lies in a sharply eroded canyon on the eastern slope of the same range at an altitude of 7400 feet; it is about 1700 feet in diameter; its delta is 50 per cent larger than its own area, and the scar of its landslide, a mile in length, is less fresh than those of Clear and Blue lakes. The outlets of these lakes all cascade down over the great boulders of their barriers.

Jess Valley is again, according to Russell, the filled-in and drained bed of a much older and larger landslide lake in the valley of Pit River, between Clear and Blue lakes, where that river, passing from the western base of the Warner Range, cuts a gorge through another up-faulted block of lava beds of less altitude. The nearly level surface of the valley measures 6 by $2\frac{1}{2}$ miles at an altitude of 5300 feet. Its obstructing slide filled the gorge for half a mile and is estimated to contain 45,000,000 cubic yards of detritus. Several other meadows of similar origin are found farther down the gorge; but they are now trenched by the river, so that their remnants form terraces on the gorge walls. The same experienced observer reports that Eagle Lake, 30 miles northwest of Honey Lake, 5115 feet in altitude and 12 by from 2 to 4 miles in size, appears to be barred on its southeastern side by a landslide; if so, it would rank next after Clear Lake. He adds that this lake rises and falls without regard to rainfall, and that when it sinks numerous springs flow actively from the outer slope of its apparent barrier and supply streams that reach Honey Lake. This suggests that the barrier is of porous nature, as a landslide might well be, and that the water passages through it are intermittently closed and opened.

The small Kern Lakes, in the southern part of the remarkably rectilinear, north-south canyon of Kern River, west of Mt. Whitney in the southern Sierra Nevada, have been described by Lawson.[20] The southern one was originally barred by a rock slide which came down from the eastern wall of the canyon about 100 years ago and obstructed the canyon floor for a mile of its length; but the lake, now less than a mile across, has been much diminished by in-washed detritus. Kern River, continuing through the lake, has barred off its course by the high edge of its flood plain. The northern lake, a mile farther upstream, diminished by Kern River delta to a half-mile diameter, is separated from the lower lake by the detrital fans of two small streams from the east: it is believed that these fans were much increased in size in 1868, and that the separation of the upper from the lower lake dates from that year. Mirror Lake in the Yosemite Valley is also of rock-fall origin and will be described in the latter part of the next section.

A small lake, now extinct, was formed by a landslide in Grapevine Canyon, where the Ridge Road leading from Los Angeles northward to the central part of the State enters the southern part of the Great-Valley plain. This canyon is cut in the mountains which there curve around from the Sierra Nevada on the east to the Coast Ranges on the west; and the slide came from the mountain flanks on the west side of the canyon mouth. The uneven surface of the down-creeping mass is distinctly unlike the smooth and undisturbed slopes on either side of it. The lake which rose back of the slide has long since been filled with

[20] Lawson, A. C., The Geomorphogeny of the Upper Kern Basin. Univ. Calif. Publ., Bull. Dept. Geol. Sci., vol. 3, pp. 291–376, 1904. See pp. 343–345.

detritus, through which as well as through the slide itself a gorge has now been eroded. The thousands of travelers who daily follow the Ridge Road cross over the lower part of the slide, where the impetus of its flow banked it up against the east side of the canyon mouth; the road there makes a winding descent to the gently sloping "fan" of flood-washed stony and bouldery detritus that slants far forward on the vast plain. Another ancient slide seems to have blocked the stream farther up the same canyon near Old Fort Tejon.

Two small landslide lakes are known in the northern corner of Lassen Volcanic National Park. One, Manzanita, originated according to Williams, cited below, about 200 years ago when a slide known as the Chaos Jumbles descended from Chaos Crags and blocked the valley of Manzanita Creek;[21] another, Reflection, lies in a hollow of the extremely rough landslide surface.

Small lakes or ponds of another kind lie at the head of valley-side landslides where a hollow is formed because the downward movement of sliding mass is commonly faster and farther at its under than at its upper surface, so that its head is tilted backward, as near the left

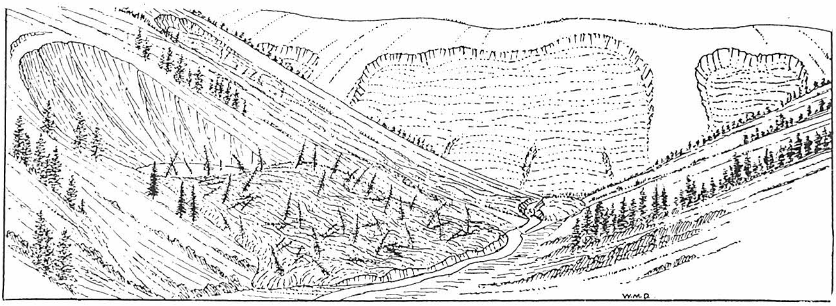


FIG. 13. Landslide diagram. In foreground, a recent slide with tilted trees; a small lake is held in the hollow back of it. A longer narrow slide is a short way beyond the nearer one. Three mountain-side slides are incompletely shown in the distance.

foreground of Fig. 13. The irregularity of the down-sliding is often shown by diversely tilted overthrown trees. Large slides sometimes involve a great, slab-like mass that stretches half a mile or more along a mountain side and nearly or quite as far down the mountain slope, as in the background of Fig. 13. In consequence of its somewhat irregular descent, the smooth forms of ordinary degradation are changed to curiously disorderly forms. At the head of these greater slides, many small, pond-holding hollows may be formed. Such ponds are short lived, but they may linger longer than the larger ponds that are held back on valley floors by the bulging front of slides, because such ponds are soon drained away by the valley stream.

Landslides of this kind are numerous in those parts of the Coast Ranges where serpentine rock prevails, for that rock is prone to slip down from a mountain side after a valley is deeply eroded beneath it. Valley sides subject to sliding should evidently be avoided as far as possible by roads, pipe-lines, towers for electric power wires, and other structures for which stable foundations are desirable. The disorderly

[21] A fine view of the lake is given in the frontispiece of Day and Allen's report on Lassen Peak, cited below.

surface of slides may still be recognized years after any little ponds at their head have disappeared. However, a number of ponds still remain above the slides that abound on the slopes of Mustang Ridge, northeast of Peachtree Valley, which is in its turn northeast of the much larger Salinas Valley in the southern Coast Ranges.

According to a personal communication from Dr. J. H. Maxson of the California Institute of Technology, several landslide ponds occur in the serpentine areas of the Klamath Mountains in the northern part of the State.

Lakes of Glacial Origin

Glaciation of Californian Mountains

Most of the larger lakes named in the preceding sections lie on relatively low ground, presumably because they are associated with down-faulted areas or with down-sliding valley sides. The numerous lakes of the kind now to be described are found on mountainous highlands where their basins have been produced by the erosive action of great glaciers which covered considerable spaces in the higher parts of the Sierra Nevada and smaller spaces of other Californian mountains. That remarkable episode occurred in the Glacial period of recent geological time, a period of cooler and snowier climate on mountains that is believed to have been contemporaneous with the cooler and moister period when lakes were formed on interior desert lowlands.

In order to appreciate the importance of glaciation in respect to lake production, it should be understood that, in Preglacial time, there were in all probability no lakes on the Sierran highlands. The reason for this is that the highlands had then been long subjected to the ordinary erosional processes of weathering and streaming, which would have destroyed any lakes that might have been produced there in earlier times by faulting as described on foregoing pages, or by ancient volcanic action as will be described on following pages. Lake Tahoe is hardly an exception to this rule, for although produced by a combination of faulting and volcanic action, as will be told below, it is not on the highlands but occupies a deep trough below them.

The great Sierran glaciers of that time, the area of which has been mapped by Blackwelder,[22] had their sources in lofty valley heads where heavy snows were collected below the mountain summits and transformed into ice. The many separate glaciers that had their source in the high valley heads of each of the Sierran river systems united in broad sheets as they slowly advanced down the highlands of the western Sierran slope, but the sheets were irregularly interrupted by spurs and mounts that rose from the highlands to a greater height than the ice thickness. Then the sheets narrowed into faster moving ice tongues as they were drained down the previously eroded trunk valleys. While the descent was in progress the glaciers were melting to smaller and smaller volume as they reached lower and lower levels of warmer climate. By reason of the more extended area of their gathering grounds and of the larger number of their converging branches, the glaciers of the long western slope had greater size and pushed their ends down to lower levels than those on the shorter and

[22] Blackwelder, Eliot, Glacial and Associated Stream Deposits of the Sierra Nevada. Cal. State Div. Mines, Mining in California, July–October, 1932, pp. 303–310.

steeper eastern slope of the mountains, which are diagrammed in Fig. 4. Thus the Tuolumne glacier, west of Mono Lake, extended for 34 miles along the crest of the range and ended 35 miles southwest of the crest; while for the San Joaquin glacier, south of that lake, the corresponding dimensions are 52 and 25 miles. On the steeper eastern slope, the measures along the crest and down the slope from it were much smaller.

Two Epochs of Glaciation

Two terminal moraines are shown in each glaciated valley of Fig. 4. The lake that may have once occupied the earlier formed, outer basin has been filled by inwashed detritus and converted into a plain or meadow. The inner basin still holds a lake. Such is very commonly the case in the glacial troughs of the Sierra Nevada. It is inferred from this and from other evidence of a similar nature that there have been at least two epochs of glaciation. Critical studies of this kind in various parts of the world have indeed shown that the Glacial period was composite in the sense of including several alternations of colder Glacial epochs and milder Interglacial epochs. An excellent discussion of this problem for the Sierra Nevada is given by Blackwelder in his essay cited below; he there shows that, besides two later Glacial epochs, which he calls the Tahoe and the Tioga epochs, the work of which is illustrated in Fig. 4, there were two earlier Glacial epochs, the records of which are much modified and obscured by later erosion. The lakes produced in the latest or Tioga epoch are the chief subject of the following pages; but first the relation of the recent Tioga glaciers to the less recent Tahoe glaciers may be briefly stated.

There are four chief points to be considered. First, the Tahoe glaciers of the Sierra Nevada were longer than the Tioga glaciers and extended farther down their valleys, somewhat as shown by the moraines in the right half of Fig. 4. Thus while the largest Tioga glaciers ended at levels of about 6000 feet on the western and about 7000 feet on the steeper eastern slope of the mountains, the Tahoe glaciers ended perhaps 1000 feet lower. For example, in the Tahoe epoch the branch glaciers of Tenaya and Merced canyons joined to form the great trunk Yosemite glacier, which continued about 7 miles and ended at about the level of 4000 feet near the end of the great cliff-walled trough, the shape of which was largely produced by the intense glacial erosion of a pre-existing narrower and shallower valley, as Matthes has so well shown.[23] But in the Tioga epoch, the branch glaciers each ended in its own trough where lakes of the same names are now found, about 8 miles above the trough junction.

Second, the Tahoe moraines are many times larger than the Tioga moraines; some of the largest measure nearly 1300 feet in height. Third, by reason of their greater age, the cliffs of the Tahoe cirques are weathered to somewhat subdued forms, the cirque-floor basins are occupied by meadows, and their trough-end lakes are in nearly all cases now converted into detrital plains. Fourth, whatever lake basins the Tahoe glaciers produced at higher levels than the Tioga

[23] Matthes, F. E., Geologic History of the Yosemite Valley. U. S. Geol. Survey Prof. Paper 160, 1930.

moraines are not now to be distinguished from the basins now occupied by the lakes of the Tioga epoch.

The following pages, therefore, refer chiefly to lakes produced in the Sierra Nevada by the later Tioga glaciers, even if their work consisted largely in cleaning out detritus-filled rock basins of earlier Tahoe production. Some brief statements concerning extinct lakes of the Tahoe stage will be given at the close of this section.

All the Californian lakes of glacial origin are of relatively small size, but many of them are of great beauty; and as they are often closely associated with the superb scenery of the High Sierra they are greatly enjoyed by lovers of outdoor life when the hot summers of the lowlands prompt ascent to the cooler mountains. As the glacial lakes of the State far outnumber all others, much has been written about them. By far the best illustrations of these lakes, many of which are accessible only to mountaineers, are to be found in the annual volumes of the Bulletin issued by the Sierra Club of San Francisco, in which they are pictured in an incomparable series of photographs.[24] The loftiest glacial lakes occupy basins in cirque floors; these will be first described. Next will come those somewhat irregular lakes which lie at intermediate altitudes on trough floors or on the open Sierran highlands. Lowest are those which fill the terminal overdeepening of the enlarged valley-troughs, where they are partly enclosed by terminal moraines; these are most frequently visited.

Lakes in Glacial Cirques

Cirque lakes occupy shallow rock-basins in the floors of the great cliff-walled cavities excavated at the heads of glacial troughs, somewhat in the form of enormous quarries, 500 or 1000 feet deep and half a mile or a mile across. They abound in the High Sierra, where they are found below the loftier summits at altitudes of from 8000 to 10,000 feet. There and more strikingly in the northern and southern part of the range, where the mountains are not so high, cirque lakes were developed best on northeastern slopes, where snow drifting was favored of the westerly winds and where snow melting by sunshine was least effective. The peaks above such lakes are therefore unsymmetrical, being more rounded on the southwest slope and deeply cliffed on the northeast.[25] The cirques of the earlier Tahoe epoch, not reoccupied by the Tioga glaciers, are now, as above noted, weathered to somewhat dulled forms; their floors are cluttered over with talus from their walls and their lakes are converted meadows. Those occupied by the later and smaller Tioga glaciers are as bare as if recently abandoned by the ice.

Where several cirques are excavated opposite each other in the radiating valleys of a massive, dome-like mountain of Preglacial sculpture, the cirque lakes are separated from one another by high spurs, the upper parts of which are narrowed into saw-tooth pattern, while the central summit is reduced to a sharpened peak, as in Fig. 14; but where several Preglacial valleys, heading in a group of mountains, converge and join in a trunk valley, the cirque-headed troughs have a sim-

[24] Among many others the following views are especially fine: Sierra Club Bulletin, vol. VII, Pls. 31, 40; vol. VIII, Pl. 6; vol. IX, Pls. 16, 20; vol. X, Pl. 226.

[25] Gilbert, G. K., Systematic Asymmetry of Crest Lines in the High Sierra of California. Jour. Geology, vol. 12, pp. 579–588, 1904.

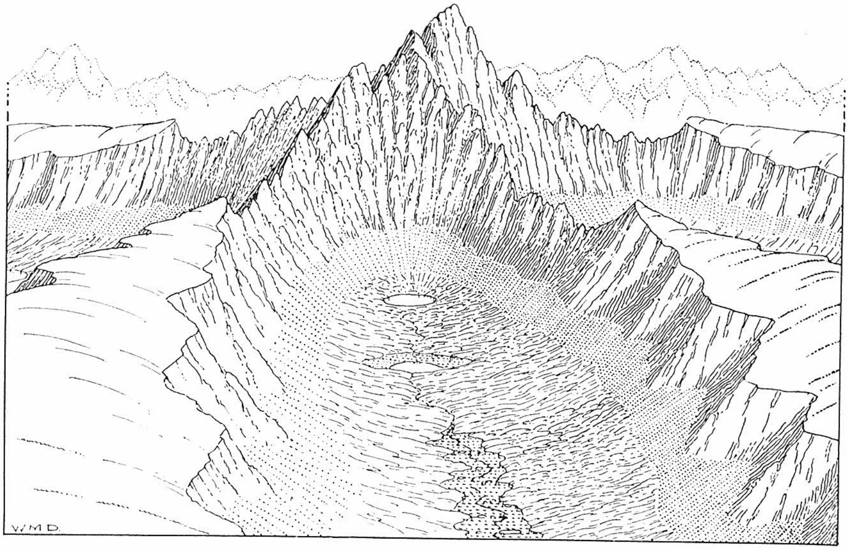


FIG. 14. A group of cirque-headed glacial troughs radiating from a lofty peak which has been sharpened by cirque recession on all sides. Small lakes or meadows are seen on the foreground trough floor.

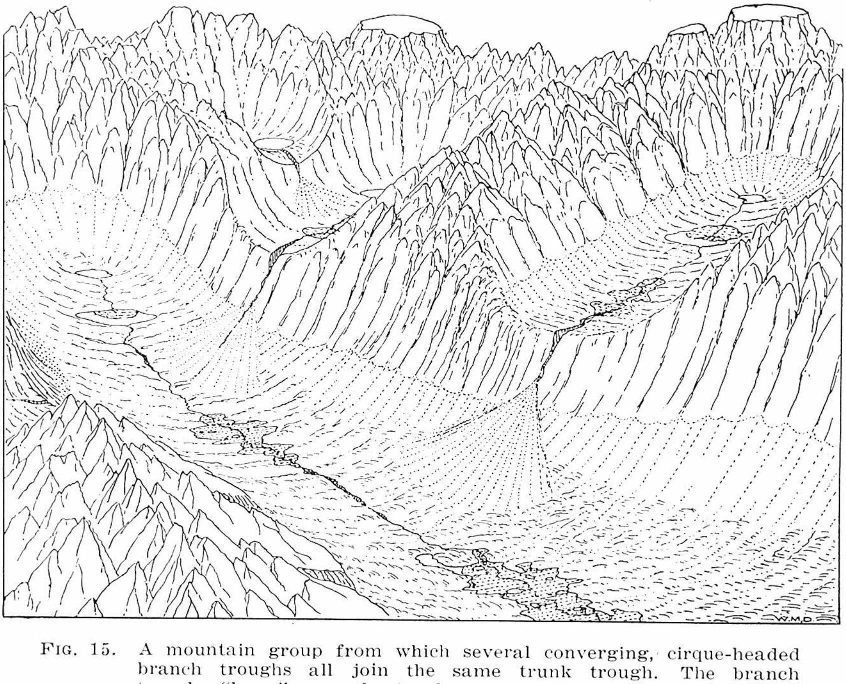


FIG. 15. A mountain group from which several converging, cirque-headed branch troughs all join the same trunk trough. The branch troughs "hang" over the trunk trough. Small lakes or meadows are seen on the trough floors.

ilar converging arrangement and the smaller ones 'hang' over the larger one, as in Fig. 15; here all the cirque lakes of such a group are rather closely associated. But it should be understood that vast as is the work of glacial sculpture in the High Sierra, the erosional work of ordinary weathering and streaming by which the mountains had been given their Preglacial form was vaster still.

It is in intimate association with these profoundly sculptured mountain forms that cirque lakes (Fig. 16) should be studied. If taken alone they cannot be appreciated, for their little basins are but a subordinate part of the great cirque-headed, cliff-walled troughs in which they are contained. The basins differ in no significant respect from the rest of the gigantic excavation, except that they are scoured to slightly greater depth so that they hold water. The same principle holds true, though perhaps less manifestly, in the study of all the other lakes of the State; it should be applied to the fault-basin and the landslide lakes already described and to the volcanic, river-made and other lakes to be detailed below. All are but items in the evolution of the landscape which they for a time adorn.

The Tehipite, Mt. Whitney and several other sheets of the U. S. Topographic Map show many striking examples of lakes in trough-head cirques excavated in the dome-like masses of the High Sierra. Regarding the concave cirque heads, W. D. Johnson, a skillful topographer, wrote in homely fashion: "These sharp outlines were suggestive of nothing so much as the scattered remnants of a sheet of dough on the biscuit board, after the biscuit tin has done its work."[26] A fuller discussion of these remarkable mountain forms is given by Lawson.[27]

Sometimes a series of small lakes, like beads spaced on a string, is seen occupying a succession of rock basins beginning in a cirque floor and continuing down stream from it. It is to be presumed that the convex rock sills between the basins were more resistant to glacial erosion than the basin rocks; the greater resistance may be due to the number and attitude of the joints in the rock quite as well as to variations in its composition.[28] Such series of lakes are to be seen at the headwaters of Iillilouette Creek, 16 miles southeast of the Yosemite Valley; also between Mammoth Mountain and Mammoth Crest, high up on the eastern slope of the Sierra, 22 miles south of Mono Lake; again, but more confusedly, farther south in the remarkable Sixty-lake Basin at the headwaters of Kings River under Mt. King, and still farther south under Mt. Genevra. Garnet Lake and Thousand-island lakes, about 9800 feet in altitude, are exceptional among cirque lakes in being beset with rocky islets; they are drained by a roundabout stream to the Middle Fork of San Joaquin River.

Cirque lakes become less abundant and disappear in the northern and far-southern Sierra Nevada where the altitude of the range decreases. Gold Lake, 2 miles long, on a head branch of the Middle Fork of Feather River, is one of the largest in the northern mountains.

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[26] Johnson, W. D., Grade Profiles in Alpine Crests. Jour. Geology, vol. 12, pp. 571–578, 1904; reprinted in Sierra Club Bulletin, vol. 5, pp. 271–278, 1905.

[27] Lawson, A. C., The Geomorphogeny of the Upper Kern Basin. Univ. Calif. Publ., Bull. Dept. Geol. Sci., vol. 3, pp. 291–376, 1904; see pp. 357–362. This article gives in Pl. 42 an excellent view of a fine cirque lake next southwest of Mt. Whitney, the highest summit of the Sierra Nevada.

[28] A striking view of a rock sill is given in Pl. 4 of Johnson's article above referred to.

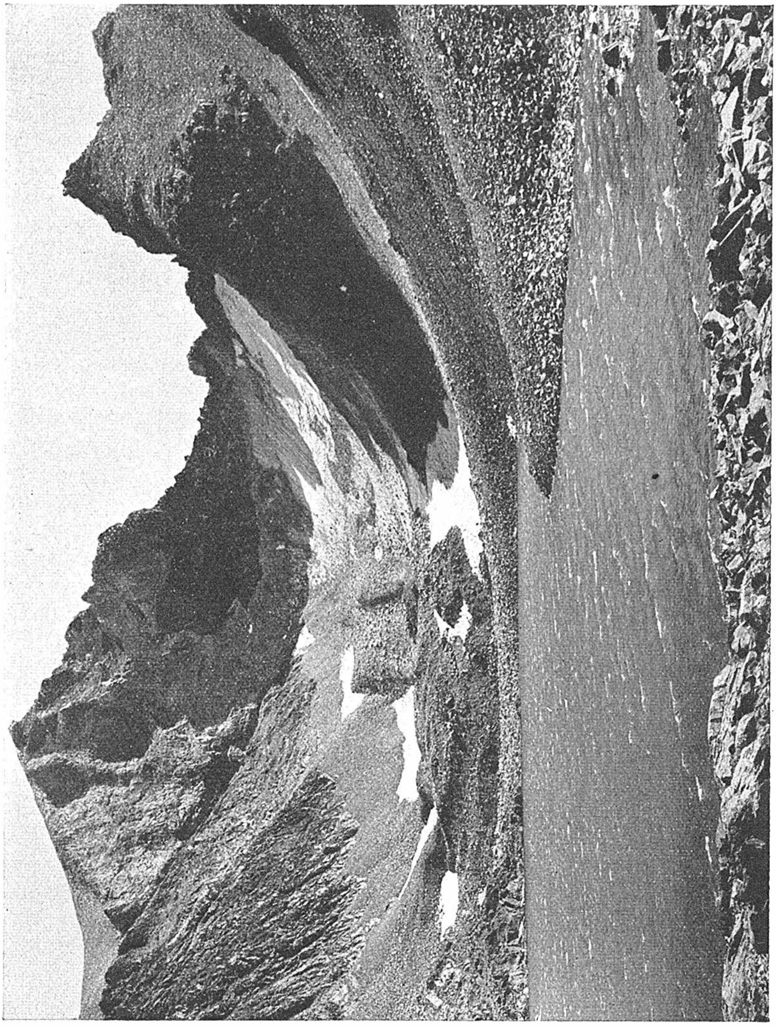

Photo by Ansel Easton Adams. Courtesy of Sierra Club.

FIG. 16. Typical glacial cirque and lake. Rodgers Peak from the north, Sierra Nevada.

Not so far north a group of cirque lakes is found under Sierra Buttes near the North Fork of Yuba River; one of them is figured by Turner.[29] Another northern group is found around Fall Creek Mountain, near the South Fork of the same river. Farther south, where the mountains gain altitude, cirque lakes are to be counted by the hundred, as may be seen on the Mt. Goddard sheet of the U. S. Topographic Map at the head of San Joaquin River, the Mt. Lyell sheet east of the Yosemite Valley, and the more southern Mt. Whitney sheet. In the far-southern part of the range, a number of small cirque lakes occur on the headwaters of Kaweah River in the Sequoia National Forest; fourteen such lakes, more or less converted into marshes, are clustered around the headwaters of the North Fork of Stanislaus River, as shown on the Big Trees topographic map.

Irregular Lakes on Trough Floors

Lakes of this kind lie on unevenly scoured trough floors, where some parts are a little deeper than others. They are of long-oval outline when they occur in narrow, steep-walled, well-smoothed troughs, but they are of very irregular outline and are often beset with low rocky islets and knobs of round-scoured rock when they occur in broadly open, flat-floored troughs. Their depth by no means indicates the depth of trough-floor excavation beneath the floor of a Preglacial valley, but only the excess of scouring of one part of the floor below another part. These irregular lake basins therefore correspond to the deeper parts of the bed of a stream channel eroded by running water. As their depth is usually small they are frequently replaced by inwashed stream detritus and thus converted into nearly level meadows, as in the foreground of Figs. 14 and 15.

Apparent examples are seen in the irregular Silver, Loon and Pleasant lakes, in branch troughs of the South Fork of American River. It may be here noted that, although glacially enlarged valley-troughs are commonly described as U-shaped in cross profile, they are, as a rule, much more like well opened, round-bottom Vs. It is only by way of exception, and in the Sierra Nevada only in the terminal troughs of Tahoe glaciation, that the U-shape is closely approached, as is shown by the rarity of cliff-walled valleys of the Yosemite type, among which Matthes has shown that Kings River, Hetch Hetchy and Tehipite troughs are to be included with the Yosemite masterpiece.[30]

Lakes on Ice-Scoured Sierran Highlands

The irregularly scattered lakes of the broad Sierran highlands lie in small and shallow rock basins. Where the country rock is granite, they are formed amid smoothly scoured and severely barren undulations of the surface; but on weaker rocks, where forests alternate with grassy glades, they are associated with a more pleasingly picturesque scenery. One should here, in order to appreciate the transformation of the landscape that ice-scouring has accomplished in the glaciated areas, recall what was said above as to the absence of highland lakes in Preglacial time, and to that may be added Lawson's description of

[29] Turner, H. W., U. S. Geol. Survey Geol. Atlas, Downieville folio (No. 37), Fig. 3, 1897.

[30] Matthes, F. E., *op. cit.*

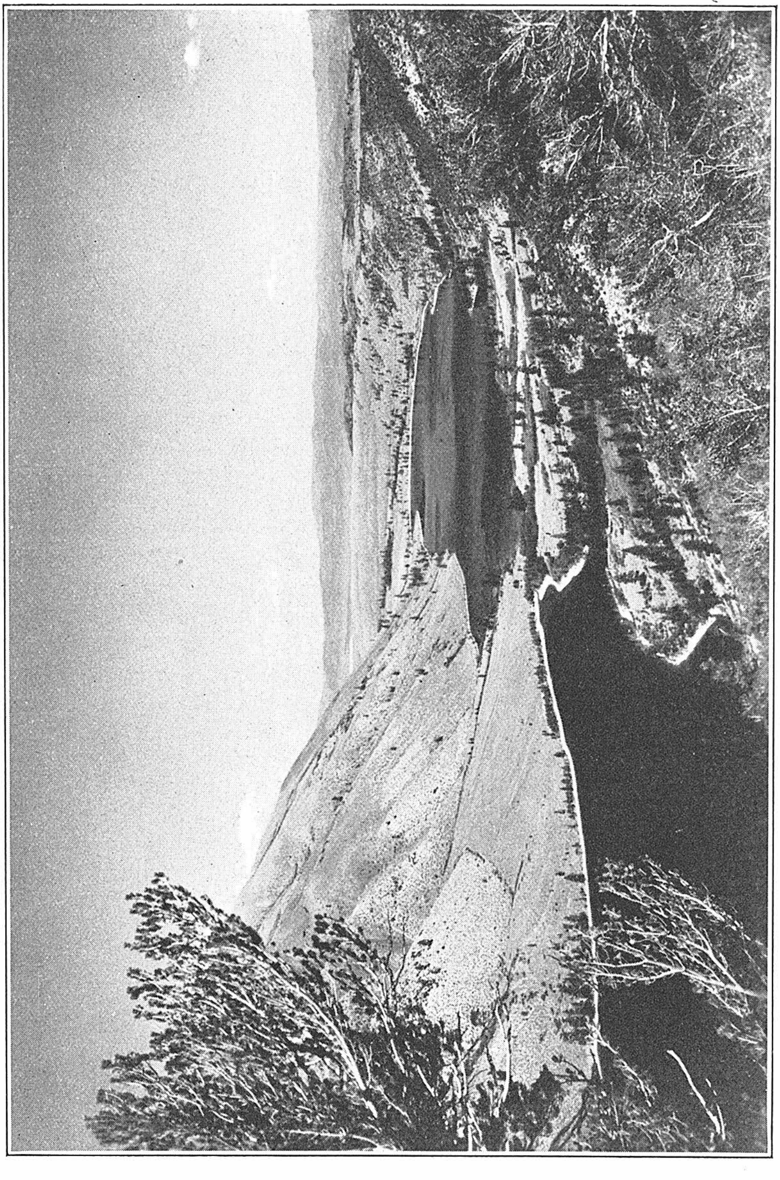

Photo by Eliot Blackwelder, Courtesy of Geological Society of America, Fig. 10, vol. 42, no. 4.

FIG. 17. Twin Lakes, Sierra Nevada.

a non-glaciated southern area of the mountains. That experienced observer wrote: "A remarkable feature of the upland surfaces is the prevailing absence of water courses or incisions of any kind due to stream cutting. * * * The surface is everywhere encumbered by blocks of granite, formed by the intersection of joints and dislodged by the heaving action of frost. The veneer of loose blocks is so thick that the waters from summer rains and from melting snows do not gather in runways and so establish lines of stream cutting, but flow in a diffused fashion between and beneath the blocks. * * * It is only when we get to the bottom of the canyons and cirques that the granite is tight enough to hold water on its surface. It would thus appear that these upland surfaces are as free from the attack of running water as are the driest deserts."[31]

It may be said further that the highland veneer of granite blocks has probably been continued from an early time before the upheaval of the mountain mass, when it was part of an extensive and soil-covered lowland of long-continued degradation, which in its southern area at least probably had a desert climate; for on such a lowland the well disintegrated soil at the surface must have been underlaid by less disintegrated joint blocks to a certain depth below the surface. Not that all the joint blocks on the non-glaciated highlands of today were then prepared, but that the present blocks there are the direct successors of their ancient predecessors. A veneer of similar blocks probably overspread all the highlands in Preglacial times, but in the areas that became glaciated they were swept away down to firm rock, as the following quotations show.

Lindgren has described the more barren highlands as "vast stretches of dazzling white granitic rock surface, worn and rounded"; and he adds concerning a climax area: "There are few more imposing sights than the ice-swept rock deserts of the * * * Devil's Basin,"[32] a wide area at an altitude of 8200 feet, dotted with little lakes or with grassy flats at the head of the South Fork of American River, 7 miles southwest of Lake Tahoe. Humphrey Basin is a similar area, over 11,000 feet in altitude, at the head of the South Fork of San Joaquin River; it is included on the Mt. Goddard map sheet, which shows the well-named Desolation Lake, a mile in length. The depth of these highland lakes is not a true measure of glacial erosion that the highlands have suffered; it measures only the excess of erosion in the lake basin below that on the neighboring surface.

Blackwelder remarks that the ancient glaciers left on the scoured highlands "vast areas of comparatively bare granite, upon which so little forest grows that the rocks stand out gray and white."[33] The monotony of these rock deserts is here and there relieved by tree-covered patches of glacial detritus; also by perched boulders, left there when the ice cover melted away. The undulating and polished granite

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[31] Lawson, A. C., *op. cit.*, pp. 313, 314.

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

[33] Blackwelder, Eliot, Pleistocene Glaciation in the Sierra Nevada. Geol. Soc. America Bull., vol. 42, pp. 865–922, 1931. This paper contains several excellent views: Fig. 1, a lateral glacial trough hanging high over a main trough; Fig. 2, talus in a glacial trough; Fig. 3, glacially polished granite with perched boulders; Fig. 10, a divided trough lake, here reproduced in Fig. 17; Fig. 15, a meadow replacing a glacial lake.

surface, more or less scaled off, and the perched boulders are well illustrated in Matthes' report (Pls. 35B, 36, 37B), referred to above.

The lakes on the scoured highlands are not infrequently rimmed with low walls or 'ramparts' of boulders and stones, which have been, according to Gilbert,[34] gradually pushed out from the shallow bottom in the milder spells of winter weather, when the ice expands a little after having contracted during preceding spells of severe cold. When its temperature falls 7° Fahrenheit, the ice of a frozen lake a mile across will contract a foot. Cracks are then opened through the ice; but they are soon closed by new-formed ice. A warm spell then expands the ice and it spreads a little on the shores. A repetition of this through many winters has resulted in shoving outward all boulders that the shore ice rests upon, and thus in time a rampart is formed.

Trough-End Lakes

Lakes lying at the end of an over-deepened valley-trough of the Tioga epoch, where their retention is aided by a loop of morainic ridges, are nearly always of simple, long-oval outline and of a considerable depth, some being as deep as 200 or 300 feet; but their original length is somewhat decreased by the inwashed delta of the trough stream. Thus Merced Lake, in a trough-end basin of the Tioga epoch drained by Merced River to the Yosemite Valley, is now partly filled by a forested delta, well shown in Plate 12B of Matthes' report. Blackwelder notes that near these lakes, ''acres of polished and grooved rock are a familiar sight''; also that the rock polish is here better preserved than on similar surfaces scoured by the earlier Tahoe glaciers.

The oftenest seen lake of this important class is Donner Lake, which lies next north of and well below the line of the Southern Pacific Railroad where it descends the eastern slope of the Sierra Nevada from Donner Pass to Truckee Valley. It is 3 miles long and is enclosed by heavy morainic ridges, in great part of Tahoe age, at an altitude of 6095 feet. Another terminal lake in the same drainage basin, but less often seen, as it lies higher in the mountains to the northwest, is Independence, about 2 miles long at an altitude of nearly 7000 feet. The southern or main upper course of Truckee River, which drains Lake Tahoe, leads to several well known terminal lakes: Fallen Leaf Lake is a popular summer resort on the southwest side of Lake Tahoe; it is of about the same length as Donner, but has an altitude of nearly 6400 feet. The Tioga terminal moraine, close around the foot of the lake, is of small size; the Tahoe moraines, enclosing the Tioga moraine, are vastly larger; one on the southeast of the lake is over 3 miles long and rises 900 feet like a great railroad embankment. The glacial origin of this beautiful lake was recognized by Le Conte 60 years ago; but in stating that the basin of Lake Tahoe also had been filled by ice he showed an exaggerated idea of the dimensions of the ancient glaciers.[35]

A recent and well illustrated essay by Jones on this picturesque district limits the glaciers to more moderate lengths.[36] Cascade Lake, 3 miles northwest of Fallen Leaf and of similar size and altitude, is

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[34] Gilbert, G. K., Lake Ramparts. Sierra Club Bulletin, vol. 6, pp. 225–234, 1908.

[35] Le Conte, Joseph, On Some Ancient Glaciers of the Sierra. Am. Jour. Sci., 3d ser., vol. 10, pp. 126–139, 1875.

[36] Jones, Wellington, Glacial Land Forms in the Sierra Nevada South of Lake Tahoe. Univ. Calif. Publ., Geogr., vol. 3, pp. 135–157, 1929.

pictured as seen from above in a compound loop of morainic ridges. A mile farther north is Emerald Bay, like the other two lakes except that it lies at the level of Tahoe, with which it is connected through a frontal opening in its 600-foot moraines. Echo Lake, a mile long, 3 miles south of Fallen Leaf, belongs in a somewhat different class, as it lies at an altitude of 7500 feet just back of the lip of its lateral trough, which hangs 500 feet above the floor of the main and much larger trough of the Upper Truckee glacier. This lake is peculiar in having its waters artificially diverted from Truckee River and led southward through a tunnel to a head branch of the South Fork of the west-flowing American River, to increase the volume of that Fork for electric power. Other examples of trough-end lakes are Emigrant, Huckleberry and Tilden, each about 2 miles long and all in steep-sided branch troughs of the North Branch of Tuolumne River.

A peculiar group of glacial lakes, well illustrated on the topographic map of the Yosemite National Park, 1932, is found in the semicircular glacial trough which is drained by the well-named Reversed Creek back of Reversed Peak, about 12 miles south of Mono Lake. The creek heads

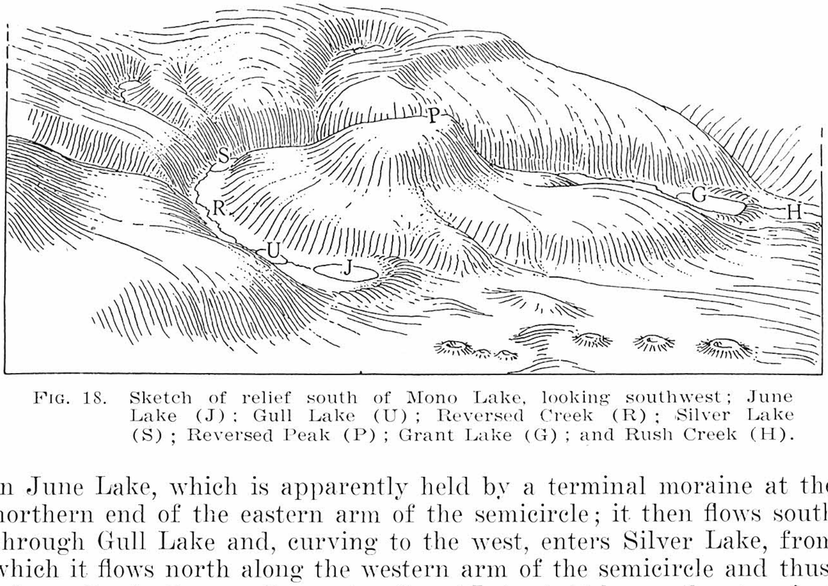

FIG. 18. Sketch of relief south of Mono Lake, looking southwest; June Lake (J); Gull Lake (U); Reversed Creek (R); Silver Lake (S); Reversed Peak (P); Grant Lake (G); and Rush Creek (H).

in June Lake, which is apparently held by a terminal moraine at the northern end of the eastern arm of the semicircle; it then flows south through Gull Lake and, curving to the west, enters Silver Lake, from which it flows north along the western arm of the semicircle and thus, a few miles farther north, reaches Grant Lake, held by another terminal moraine, through a gap in which the outlet, there known as Rush Creek, continues to Mono Lake, about 7 miles distant.

Twin Lakes, 3 miles in combined length, stand at altitudes of 7076 and 7096 feet on a fork of Walker River, 15 miles southwest of Mono Lake. They result from the subdivision of a single, trough-end lake by inwashed detrital fans near its mid-length, as explained and illustrated by Blackwelder, whose fine photograph of them is here reproduced in Fig. 17. These lakes are shown with many others on the Bridgeport topographic map. The most famous double lake of this kind is in Switzerland, where an originally single lake, occupying the long and greatly overdeepened valley trough of the River Aar, has been divided into Lakes Brienz and Thun by the combined deltas of two opposite side-streams; the beautiful town of Interlaken stands on the fans; and the outlet of Lake Brienz winds between the fans to Lake Thun.

A group of tarns, known as the Volcanic Lakes, occupy the floor of the large, cirque-like trough head of Dougherty Creek, a south branch of the Middle Fork of Kings River; they are believed to be not of volcanic but of glacial origin and are said to have taken their name from some volcanic rock near by.

Extinct Glacial Lakes in the Sierra Nevada

It has been noted above that the trough-floor and terminal lakes of the long Tahoe glacial troughs are now as a whole converted into treeless meadows or forested valley floors of inwashed detritus, the meadows being attractive features of the Sierran highlands. Such meadows and plains are longer than the lakes which they replace, because their gently slanting surface extends farther up the valley-trough floor than the level surface of the lake could reach.

The best known example of this kind occupies the great cliff-walled glacial trough of the Yosemite Valley, of which Matthes has given an admirable description, above cited. The lake which originally filled the gouged-out terminal rock basin of the trough and which was partly held back by the terminal moraine of its 20-mile Tahoe glacier, is estimated to have had a length of 5½ miles, and it was therefore one of the largest of its class. There is little question that the marvelous scenery of the Valley would be more marvelous still if the lake had not been destroyed. Another detrital plain occupies the lower part of Tenaya Canyon, the eastward extension of the Yosemite. Mirror Lake (see Matthes' Plate 47a), a small pool on that plain, is not a remnant of the rock-basin lake that the plain replaces, for that lake has been completely filled; the little lake is due, again according to Matthes, to the active, avalanche-like downfall of rock blocks from the oversteepened cliffs, by which the stream that formed the plain has recently been slightly obstructed. One of the longest aggraded troughs in the Sierras is found in the Tuolumne Meadows; it probably conceals several trough-floor rock-basins.

Non-Sierran Glacial Lakes

The only glacial lakes in the mountains of southern California are two small ones, Dollar and Dry, in cirques below Mt. San Gorgonio, the dominating dome-like summit, 11,485 feet in altitude, of the San Bernardino Mountains.[37] The mountains in the northern part of the State contain a considerable number of glacial lakes, all of small size. Curiously enough, Lassen Volcanic National Park, between the Sierra Nevada and Mount Shasta, contains according to Williams[38] many more glacial than volcanic lakes. The park district pretty surely possessed a good number of lava-barred lakes during a former time of greater volcanic activity; but the lakes then produced have been converted into plains and some of the lakes found there today appear to result from the excavation of these filled basins by ice action. To

[37] Fairbanks, H. W., and Carey, E. P., Glaciation in the San Bernardino Mountains, California. Science, vol. 31, pp. 32–33, 1910.

[38] Williams, Howel, Geology of the Lassen Volcanic National Park, California. Univ. Calif. Publ., Bull. Dept. Geol. Sci. vol. 21, pp. 191–385, 1932.

the south and east of Lassen Peak, Helen, Emerald, Shadow and Cliff lakes, each only a quarter-mile or less in diameter, occupy basins wholly the product of glacial erosion. Farther east Rainbow, Twin, Swan and the six Cluster lakes have been similarly produced. The same may be said of a score of little wet-weather ponds on the lava flow of Crater Butte, east of the park center. Horseshoe Lake, nearly a mile across, and Juniper Lake, about 1 by 2 miles, in the southeastern part of the park, occupy intervolcanic depressions modified by glacial action.

Farther northwest, a good number of small cirque lakes occur in the Klamath Mountains at altitudes of from 6500 to 7500 feet.[40] A small lake of this kind in the neighboring Siskiyou Mountains is shown in Fig. 19 and a small meadow-marsh resulting from the filling of such a lake is shown in Fig. 20.

Photo by J. H. Maxson.

FIG. 19. Island Lake, Siskiyou Mountains.

Lakes in Basins of Limestone Solution

Limestone is a relatively soluble rock: some of its underground fractures or "joints" are commonly more or less enlarged into passages or caverns by the solution of their walls in ground-water. Such enlargement commonly begins along the intersection of two joints; and as it progresses surface streams frequently disappear by descending at "sinks" into the underground passages. If such an under-

[40] Hershey, O. H., Ancient Alpine Glaciers of the Sierra Costa Mountains in California. Jour. Geol. vol. 8, pp. 42–57, 1900. See the Sawyers Bar and Seiad sheets of the U. S. Topographic Map.

ground passage is obstructed, a pond or lake may be formed over the sink. It has been suggested by Baker[41] that Bear Lake, which had a length of about a mile in a flat-floored valley at an altitude of about 6700 feet in the San Bernardino Range, is of this origin. A dam at the lake outlet now holds back a reservoir 5 miles long when filled to capacity.

Photo by J. H. Maxson.

FIG. 20. A marshy meadow replacing a small glacial lake, Siskiyou Mountains.

In certain limestone districts lakes are formed by the obstruction of rivers where calcareous tufa is deposited in river channels, apparently where springs charged with limestones in solution emerge from the channel bed. No lakes of this kind have been reported in California.

Lakes of Volcanic Origin

Several lakes of volcanic origin occur in Lassen Volcanic National Park in the northern part of the State, but the lakes there are mostly of glacial origin, as already told. They are all well shown on the topographic map of the park (1929). Two of the best known are Butte (formerly Bidwell) and Snag lakes, each about a mile long and at an altitude of about 6500 feet: they were first described by Diller[42], but the following details are taken from a later and fuller account by Williams.[43] He explains that the valley of a north-flowing stream was obstructed by a lava flow in preglacial time, as in the upper right corner of Fig. 21, and a lake several miles in length was formed upstream from the obstruction. The basin was, however, much modified by a glacier which for a time crept along the valley floor, although it did not succeed in wholly removing the lava barrier. After the glacier disappeared a lake occupying the modified basin was more or less filled with marshy deposits. Then a small volcano, known as

[41] Baker, C. L., Mohave Desert Region in southern California. Univ. Calif. Publ., Bull. Dept. Geol. Sci., vol. 6, pp. 333–383, 1911. See p. 364, Pls. 41, A and B.

[42] Diller, J. S., A Late Volcanic Eruption in Northern California. U. S. Geol. Survey Bull. 79, 1891.

[43] Williams, Howel, *Op. cit.*

Cinder Cone, was built up on the western side of the valley and a ragged lava stream that was extruded from its base spread over a medial part of the original lake basin, as in the middle of Fig 21, thus producing Snag Lake.

The small Hat Lake, at the northeast base of Lassen Peak, is the youngest lake in the park, as it was formed in consequence of the obstruction of the headwaters of Hat Creek by a mudflow from the peak during the eruption of 1915.

Lakes not infrequently occur in the craters of recently extinct volcanoes. Thus a small lake occupies the summit cavity of Crater Butte, east of Lassen Peak. A little wet-weather lake of the same kind occupies the crater of an unnamed cone about 20 miles farther east; a tiny lake is mapped at an altitude of 12,000 feet in the crater of Shastina, a secondary volcano on the west slope of Shasta; and two minute lakes are found in the craters of small cones on Paoha Island in Mono Lake.[44]

Medicine Lake in northeastern California stands near the center of the Modoc lava field which has been mentioned above in the account of several fault-basin lakes at the northern boundary of the State; and this lake like those has been described by Peacock,[45] in brief as follows: A broad and low dome of lava was built up by local eruptions of fluid lavas on the larger field; and the dome was crowned by an imperfect ring of later cones, of which Mt. Hoffman is one, most of them made of cinders; their brown or reddish color is more or less concealed by a forest cover. The highest member of the ring, Big Glass Mountain, about 8000 feet in altitude, composed of dark obsidian or volcanic glass, which appears to have been viscous when erupted and which therefore accumulated in a huge pile instead of spreading out in nearly level

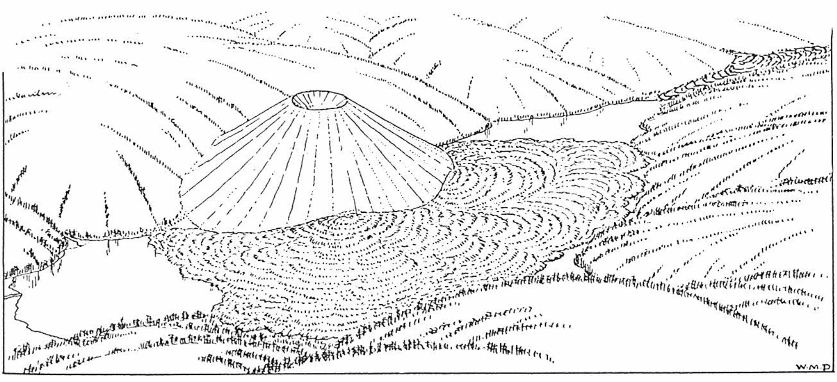

FIG. 21. Diagram of volcanic lakes.

flows. The ring includes also several smaller cones of pumice or frothy lava, white and barren. Some of these eruptions are of extremely recent date; one of the lava flows, when just at the limit of its advance, pushed and charred a tree trunk that is still standing at the lava edge.

[44] Russell, I. C., Quaternary History of Mono Valley, California. U. S. Geol. Survey Eighth Ann. Rept., pt. 1, pp. 261–394, 1889. See pp. 373.

[45] Peacock, M. A., The Modoc Lava Field, Northern California. Geog. Rev., vol. 21, pp. 259–275, 1931

Within the ring of cones a hollow space remains less filled up, and in its lowest part lies Medicine Lake, about 2 miles long at an altitude of 6500 feet. It is clear and fresh although it has no overflowing outlet.

Similar to but much smaller than Medicine Lake is Thurston Lake, which occupies a deep hollow that is accidentally enclosed by the up-building of several volcanic mounts around it in the volcanic district which adjoins Clear Lake, above described, on the south. The water surface in these two lakes is said to stand at the same level and to vary equally with change of seasons, as if a connection between the lakes were maintained by underground percolation. Several similar hollows among these volcanic mounts are now occupied by detrital plains.

Ancient Volcanic Lakes

A number of lava-barred lakes of earlier origin in the Lassen Peak region have been converted into meadows. For example, about 20 miles southeast of the peak, an ancient lava flow ran into and formed a dam across the valley of the North Fork of Feather River, and the river thereupon rose in a lake; but what with inwash of detritus and erosion of an outlet gorge through the dam, the lake has disappeared. Its bed is known as Big Meadows, 15 miles in length,[46] now in part flooded in a reservoir as told below. Similar features are found around Mt. Shasta; the largest plain, known as Shasta Meadows and measuring 20 by 10 miles, lies 20 miles northwest of the great volcano at an altitude of 2750 feet. It is probable that several similar meadow plains would be found near Lassen Peak, were it not that their unconsolidated detritus has been removed by glacial scouring. Juniper and Horseshoe lakes, already described in the section on lakes of glacial origin as occupying inter-volcanic depressions modified by glacial erosion, deserve mention here also, because in preglacial time they were probably represented by detrital plains.

In his account of Mono Lake, I. C. Russell made brief mention of a former lava-barred lake, now represented by a small playa basin; it lies about 30 miles northeast of Mono. A well defined but extinct lake of the same origin in Truckee Valley is now, according to Lindgren,[47] represented by Martis Valley, a plain of fine sediments 4 miles across at an altitude of 5900 feet, next east of the town of Truckee. The lake rose to an altitude of 6000 feet in consequence of a lava barrier that blocked Truckee River not far to the east. The river has now not only washed a quantity of sediment into the basin but has drained away the lake by cutting down a gorge through the barrier; since then it has trenched a shallow valley along the northern border of the lake-basin plain.

A larger example of a plain that replaces a volcanic lake occupies Mohawk Valley in the northern Sierra Nevada. The original depression is believed to have been a down-faulted trough, drained westward by the Middle Fork of Feather River, and therefore resembling the two similar fault-troughs farther northeast, drained by the North fork,

[46] This ancient lake is mapped in Plate 47 of J. S. Driller's report on the Geology of the Lassen Peak District. U. S. Geol. Survey Eighth Ann. Rept., pt. 1, pp. 395–432, 1889.

[47] Lindgren, Waldemar, U. S. Geol. Survey Geol. Atlas, Truckee folio (No. 39), 1897.

as above described under fault-basin lakes. According to Turner[48] the Mohawk trough was blocked on the northwest by a heavy body of lava; the lake thereupon rose to a level of 5100 feet, thus gaining a length of 11 miles and a width of 2 or 3, with a northeast arm 7 miles long. Although now drained by a gorge cut through the lava barrier, the lake-shore terraces, more or less dissected by local brooks and the bottom deposits at levels of from 4400 to 4600 feet memorialize the vanished lake. Not far south is the larger intermont basin plain of Sierra Valley of similar origin; it will be described in the next section with Lake Tahoe.

Two small examples of extinct, lava-barred lakes are known near the above-described Clear Lake of the northern Coast Ranges. One lies between the two eastern arms of the lake in a mountain cove, the eastward opening of which has been blocked by a small lava sheet. The resulting basin, measuring a mile or more in length, is mostly occupied by a plain, but its western part is overspread after winter rains by the shallow Borax Lake, which vanishes in summer leaving a barren, white flat. A larger basin plain, measuring 1 by 4 miles, lies in an upland valley north of the lake arms; the valley outlet is reported to be blocked by a lava flow: this secluded plain presents an attractive, park-like appearance by reason of the scattered oaks that flourish on its level fields.

An extinct lake in the southern Sierra Nevada, now represented by several miles of meadows at an altitude of 8200 feet, is drained by Golden Trout Creek, which cascades down a gorge that it has cut in an obstructing lava flow in its westward descent to the canyon of the Upper Kern River. The lava flow came from a near-by cone of small size.[49]

Hot-Spring Lakes

In striking contrast to an above-described lake, the basin of which results from the solution of limestone rock in descending surface waters, are certain small lakes of Lassen Volcanic National Park. They result from the solvent action of ascending hot-spring waters which, coming from an underground source where high volcanic temperatures still prevail, rise through the lavas of extinct volcanoes, disintegrate them, carry away their more soluble minerals, and leave an insoluble residue of sticky kaolin mud on the shallow floor of the resulting cavity.

The largest and best known of these is the famous Boiling Springs Lake—Lake Tartarus of the earlier maps—which is situated at an elevation of 5750 feet in a cavity on the northeast slope of Red Mountain, near the middle of the southern border of the park. According to Day and Allen,[50] it is 220 yards across when filled to overflowing. Its shore is then marked by a chain of steaming springs and bubbling mud-pots. At times of lower water, it is more quiet. The group of hot-spring pools known as Bumpus Hell of similar origin, at an altitude of 8000 feet in a crater-shaped cavity 500 by 1400 feet across, 2 miles south of Lassen Peak, is remarkable for its boiling fountains and sulphurous

[48] Turner, H. W., U. S. Geol. Survey Geol. Atlas, Downieville folio (No. 37), 1897.

[49] Lawson, A. C., The Geomorphogeny of the Upper Kern Basin. Univ. Calif. Publ., Bull. Dept. Geol. Sci., vol. 3, pp. 291–376, 1904. See p. 320, pls. 31, 35, 36.

[50] Day, A. T., and Allen, E. T., The Volcanic Activity and Hot Springs of Lassen Peak. Carnegie Inst. Washington Publ. 360, 1925. See pls. 8, 9; Fig. 44.

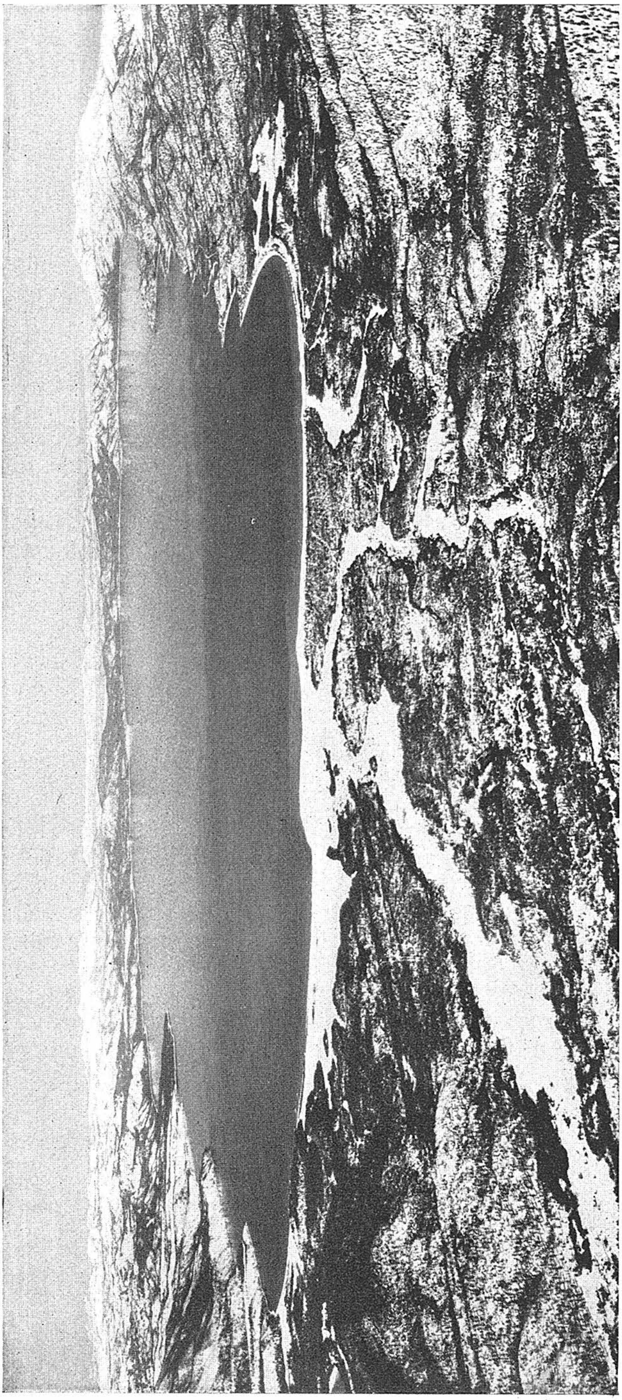

FIG. 22. Air-view of Lake Tahoe.

odors. The steam issuing from one of its roaring fumaroles had a temperature of 250° C. in 1916. The temperature of its pools was 86° C., which is the boiling point of water at that altitude.

The water of hot volcanic springs is explained by some geologists as wholly derived from the steam liberated from molten rock or 'magma', during its ascent from deep subterranean sources; it is therefore called 'juvenile' water, because it is believed never to have reached the earth's surface before. Detailed analyses of the Lassen Peak hot springs have led the above-named authors to reject this view; they regard the water of those springs as chiefly supplied, like ordinary springs, by local rainfall, and explain its high temperature by the addition of a relatively small amount of steam released from underground magmas.

Lake Tahoe and Sierra Valley

Lake Tahoe, the most famous of Californian lakes but partly included in the western angle of Nevada, deserves a section for itself (Fig. 22). It measures 21 by 12 miles, stands at an altitude of 6225 feet, and has the altogether exceptional depth of 1645 feet. Its origin is composite, as explained by Lindgren[51] and Reid.[52] It is held by a volcanic barrier in the southern part of a great, down-faulted trough, 70 or 80 miles in length, northwest-southeast, which in association with the faults of the more northern part of the Sierra Nevada described by Diller, as told above, separates some outstanding mountain blocks from the main mass of the Sierra Nevada along the northern third of its eastern border. A main scarp of the range, which here forms the western side of the Tahoe basin, may be traced more or less continuously for 120 miles northwestward. Tahoe is thus related to lakes in little filled intermont troughs, as well as to volcanic lakes.

The barrier which shuts off the basin of Tahoe from the rest of its long trough is a somewhat ancient and much dissected volcano, known as Mount Pluto, 8700 feet in summit altitude. Lindgren explains that when this great barrier was first formed, the lake rose several hundred feet higher than now. Its outlet, Truckee River, then ran northward between the western slope of the volcano and the main eastern scarp of the Sierra Nevada. The lake level was slowly lowered as the outlet cut a gorge through the lava barrier. A second rise of lake level was caused by a later lava flow which blocked the first-cut gorge, thus making the lake doubly of volcanic origin; then a second gorge was eroded and the lake was again lowered. According to Blackwelder,[53] glaciers from the west entered Truckee Canyon and built large moraines in it as much as 200 feet above the present lake level; thus obstructing the outlet for a third time and making it partly of glacial origin. Fallen Leaf and other lakes, held back by moraines on the southwestern side of Tahoe, have been mentioned above.

Lake Tahoe is probably best known outside of California from having been mentioned in "Roughing It" by the American humorist, Mark Twain, who wrote amusingly of the transparency of its waters, in which he "could see trout by the thousands winging about in the emptiness"

[51] Lindgren, Waldemar, The Tertiary Gravels of the Sierra Nevada of California. U. S. Geol. Survey Prof. Paper 73, 1911. See pl. 1.

[52] Reid, J. A., The Geomorphogeny of the Sierra Nevada northeast of Lake Tahoe. Univ. Calif. Publ., Bull. Dept. Geol. Sci., vol. 6, pp. 89–161, 1911.

[53] Personal letter, dated July 6, 1932.

at a depth of 80 feet. Because of its mild summer climate and of its picturesque surroundings, its shores have become a popular summer resort. A general account of the scenery of the lake in connection with its complex origin has been prepared by Louderback.[54]

The northern part of the long, down-faulted trough was also cut off from the middle part by volcanic eruptions and there an extensive basin plain, known as Sierra Valley, measuring 19 by 15 miles at an altitude of from 4800 to 4900 feet, has been filled in with heavy detrital deposits. Like the above mentioned Indian and American valleys, not far to the northwest, this basin plain, which is today marshy in its western part, may have been at various times in its growth overspread by a shallow lake; but today it is drained nearly dry by the successful erosion of the deep gorges of Feather River through the mountains on the west.

The basins of Lake Tahoe and of Sierra Valley thus appear to be of similar origin, but they present certain contrasts. Lake Tahoe at an altitude of 6225 feet is drained to the east through a short gorge cut in its lava barrier; Sierra Valley at an altitude of about 4800 feet is drained to the west through a long canyon cut nearly all across the Sierran range. Lake Tahoe consists of a high-standing body of in-drained water, while Sierra Valley consists of a lower-standing body of in-washed detritus. The reason for the second contrast is probably to be found in part in the second lava flow on the flanks of Mount Pluto, by which Lake Tahoe was raised above the level of most of the in-filling detritus that had accumulated in the earlier formed lake; but it is probably because of the first lava flow that the much greater altitude of the Tahoe water-surface than of the Sierra Valley plain is due.

River-Made Lakes

Oxbow Lakes

Various kinds of lakes or sloughs are associated with California's larger rivers. Oxbow lakes, representing cut-off river meanders in various stages of extinction, as illustrated in Fig. 6, occur along the Sacramento with radius of quarter or half a mile, and less frequently and of smaller size along the San Joaquin. Pear Slough, near this river, is an excellent example; its name is perhaps taken from its pear-like outline. Here may be mentioned Murphy Lake, occupying a curved and narrow channel 3 miles long, northeast of the junction of Feather River with the Sacramento; also McGriff, Mary, and Horseshoe lakes, apparently of similar origin, which lie east of the Sacramento farther north.

Flood-plain Marshes

Extensive reed marshes or tulares, known as 'basins,' occur on the less aggraded lateral parts of the flood plain of the lower Sacramento River, as illustrated in Fig. 6. They may be given the appearance of large lakes when the river overflows after winter rains. Thus Sutter Basin, 10 by 2 or 3 miles, lies to the east of the river, and Yolo Basin or Slough, 20 by 4 miles, lies to the west; its less aggraded part includes

[54] Louderback, G. D., Lake Tahoe, California-Nevada. Jour. Geography, pp 277–279, 1911.

a more permanent sheet of water known as Big Lake, $1\frac{1}{2}$ miles in diameter. The extensive reed growth in these basins is disadvantageous in a region of moderate rainfall where the conservation of water supply becomes important, for the loss of water by evaporation from the growing reeds is many times greater than from a free water surface.[55] A similarly disadvantageous loss is suffered by the Nile where it flows through an extensive papyrus marsh many miles south of its flood plain in Egypt.

Side-stream Lakes

The shallow valleys of small tributary streams are not infrequently laked back of the alluvial up-building of the flood plains of their trunk rivers, as in the upper right part of Fig. 6; and the backed-up lake water then invades the branches of the tributary valley just as the sea invades branching valleys on a subsiding coast and transforms them into branching bays. Such appears to be the origin of Stone Lake, with 4-mile branches, to the east of the lower Sacramento; and of Cache Slough in the extensive marshes of the Yolo Basin; and of the branched Lindsey Lake, west of the river. Also of Plumas Lake, 3 miles long backed up by Feather River flood plain; of Tracy Lake, 2 miles long with several branches, and Sycamore Slough, 3 miles long, backed up by the Mokelumne; and of Kings River Slough, held up for a slender length of 10 miles by the San Joaquin. Although these little lakes have no renown outside of the State, hardly indeed, outside of their county, they provide for their neighboring residents a pleasing departure from the monotonous flatness which characterizes scores and scores of miles of the vast intermont plain, known as the Great Valley.

An example of a laked side stream in a mountain valley is found in the curved range which encloses the Great-Valley plain on the south. The upper part of Grapevine Canyon, the mouth of which holds an extinct landslide lake as told above, has a flat floor heavily aggraded with detritus, perhaps supplied by a landslide in its headwaters. In consequence of this a side valley up stream from Old Fort Tejon is ponded in the shallow Lake Castaic; but the lake is often dried off and then one sees only its white, playa-like bed. This lake "is of gruesome memory; for old-timers will tell you that once upon a time some exasperated white men, of the type that modern lynchers are made of, drove a whole village of Indians, men, women, and children, into it, because it was assumed that some of the number were responsible for the murder of the cook and a boy at Fort Tejon."[56]

Many little wet-weather ponds, from a quarter of a mile to a mile across, are found on the plain of the Great Valley between San Joaquin and Kings rivers, as shown on Conejo, Fresno, San Luis Ranch and Ingomar sheets of the U. S. Topographic Map. Their origin is not clearly understood.

Lakes barred by Fan Deltas

A few small examples of lake of this class have already been given; first, the little Blue Lakes that are associated with the above-described

[55] State of California, Dept. of Public Works, Water Resources Bull. 28, 1931. See p. 253.

[56] Saunders, C. J. The Southern Sierras of California. Boston, 1923. See p. 74.

Clear Lake of landslide origin; later, the glacial Twin Lakes that are divided by the fan-deltas of opposite side streams. The examples now to be described are of much greater size. The extensive and low-grade detrital fans that are spread out by Kings and Kern rivers as their contribution to the vast intermont basin-plain of the Great Valley, have obstructed the weak drainage of its drier southern part, and evanescent lakes have thus been formed. Tulare (Spanish for reed-marsh) Lake, south of Kings River fan, was formerly a shallow water-sheet, many miles across; it is now hardly more than a marsh, since the greater part of its water supply has been withdrawn for irrigation.

The following account of the extinct Tulare Lake is condensed from the "Official Historical Atlas of Tulare County," published in 1892 by the County Supervisors. In the early years of American occupation the lake measured at high water 44 by 22 miles and its area was 760 square miles; in 1891, it had shrunk to 22 by 17 miles and its area was 195 miles. It fluctuated greatly in level, having stood at 220 feet above Suisun Bay in 1862 and 192 feet in 1883. In the flood season of 1862 the attempt was made to run a stern-wheel steamboat from the San Joaquin River to the lake, but the steamer grounded and for many years after the hull and the stern-wheel were incongruous objects on the dry plain. However, in 1875 a small steamboat was built on the lake and used as a pleasure and freight boat for some years; several smaller boats have also been launched there for business and pleasure. In 1891 fish abounded, and terrapin were shipped in large quantities to the San Francisco market. The shallow waters as well as the surrounding marshland were then a favorite resort for water fowl, such as swans, cranes, curlews, duck, geese, and snipe.

Buena Vista and Kern lakes, 7 by 5 and 6 by 4 miles when flooded, are shallow and vacillating water sheets near the southern end of the Great Valley plain, where they are held by the low delta of Kern River just as Tulare Lake was formerly held by the delta of Kings River. They are said to be reduced to hayfields in summer, and even in winter their flooding is lessened by a canal leading northward where the front of the delta meets the western hills. The plain of Buena Vista Lake, shown on Mouth of Kern topographic map, does not vary 5 feet in altitude across a breadth of 6 miles.

By far the largest delta-barred basin in California, and probably the largest in the world, is found where the northwest end of a great intermont trough of depression is separated by the delta-plain of the Colorado River from its much longer and deeper southeastern part, which is occupied by the Gulf of California. As first described many years ago by Blake,[57] the basin was thought to have been occupied in large part by the head of the Gulf before the delta barrier was built; but it was understood that "occupation of the valley by sea water * * * has extreme antiquity * * * dating back to Middle Tertiary," and that it gradually became fresh because of the flow of the Colorado River into it and its outflow by a channel along the delta front. The modern disappearance of the resulting lake was ascribed to evaporation in the arid climate there prevailing.[58] Later

[57] Blake, W. P., Ancient Lake in the Colorado Desert. Am. Jour. Sci., 2d ser., vol. 17, pp. 435–438, 1854.

[58] Blake, W. P., The Cahuila Basin and the Desert of the Colorado. Carnegie Inst. Washington, Publ., 193, pp. 1–12, 1914. See p. 3.

studies, especially those of Free[59] and Buwalda,[60] recognize the effectiveness of the delta barrier, but explain the basin that it encloses by the progressive depression of the land during the time of delta growth, so that although 2200 square miles of the basin floor are now below sea level, the deepest part being 275 feet below, it has never been overflowed by sea water.

The recent depression of the floor is attested by the occurrence of low fault scarps which cross the piedmont detrital fans built on the basin margin by inflowing wet-weather streams. The salt beds of the basin floor have been shown by Ross[61] to be of such composition that they are best explained, not by evaporation of an enclosed arm of the sea, but of a river-fed fresh-water lake. That such a lake has existed there is shown by its shore lines, about 30 feet above sea level; it must have been formed when the Colorado happened to flow westward into the basin, and the southward outlet of the lake must have followed the margin of the delta where it abuts against the western mountains. The lake necessarily disappeared by evaporation when the river chanced to give up its westward course and flow southward directly to the Gulf.

The present Salton Sea is a temporary water body that was formed on the floor of this great delta-barred basin by the accidental overflow of the Colorado River between 1905 and 1907. The water body then gained a size of 17 by 43 miles and an area of 410 square miles with a maximum depth of 83 feet, and thus became the largest lake in the State. Its area is now slowly decreasing by evaporation and it is destined to disappear. Accounts of it have been prepared by several observers.[62]

Plunge-Pool Lakes

A pool is excavated by the plunging water of a cataract. The plunge-pool of this kind beneath Niagara is about as deep as the falls are high. If the Niagara River were diverted to another course the pool would hold a small lake at the head of the river gorge. Some small lakes of this kind are known in south-central Washington, where the Columbia River, turned in the Glacial Period from its great northwest bend by the large Okanogan glacier from British Columbia, ran by a more direct course across the lava plains toward its canyon through the Cascade Mountains. It cut back a gorge on that temporary course, at the retreating head of which it plunged down in a great cataract, subdivided by several projecting ledges in the gorge-head cliff. When the invading Canadian glacier disappeared on the return of a milder climate in the Postglacial or present epoch, the river resumed its roundabout course and left the temporary course dry, except that several little lakes occupy the pools excavated by the plunging cataract. The site of the vanished cataract is now deservedly protected as a National Monument.

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[59] Free, E. E., Sketch of the Geology and Soils of the Cahuila Basin. Carnegie Inst. Washington, Publ., 193, pp. 21–33, 1914.

[60] Buwalda, J. P., The Salton Basin, Southern California. Science, vol. 71, pp. 104–106, 1930.

[61] Ross, W. H., Carnegie Inst. Washington, Publ., 193, pp. 35–46, 1914. See p. 46.

[62] Mendenhall, W. C., Ground Water of the Indio Region. . . . . U. S. Geol. Survey Water-Supply Paper 225, pp. 21–24, 1909.

MacDougal, D. T., and others, The Salton Sea. . . . . Carnegie Inst. Washington, Publ., 193, 1914; also Am. Jour. Sci., 4th ser., vol. 39, pp. 231–250, 1915.

Kennan, George, The Salton Sea, 1917.

Mention is made of this kind of lake in order to note that miniature water pools of the same kind occasionally occur in the valleys of desert mountain ranges in the southeastern part of the State, where short-lived torrents fed by summer cloudbursts excavate minute plunge-

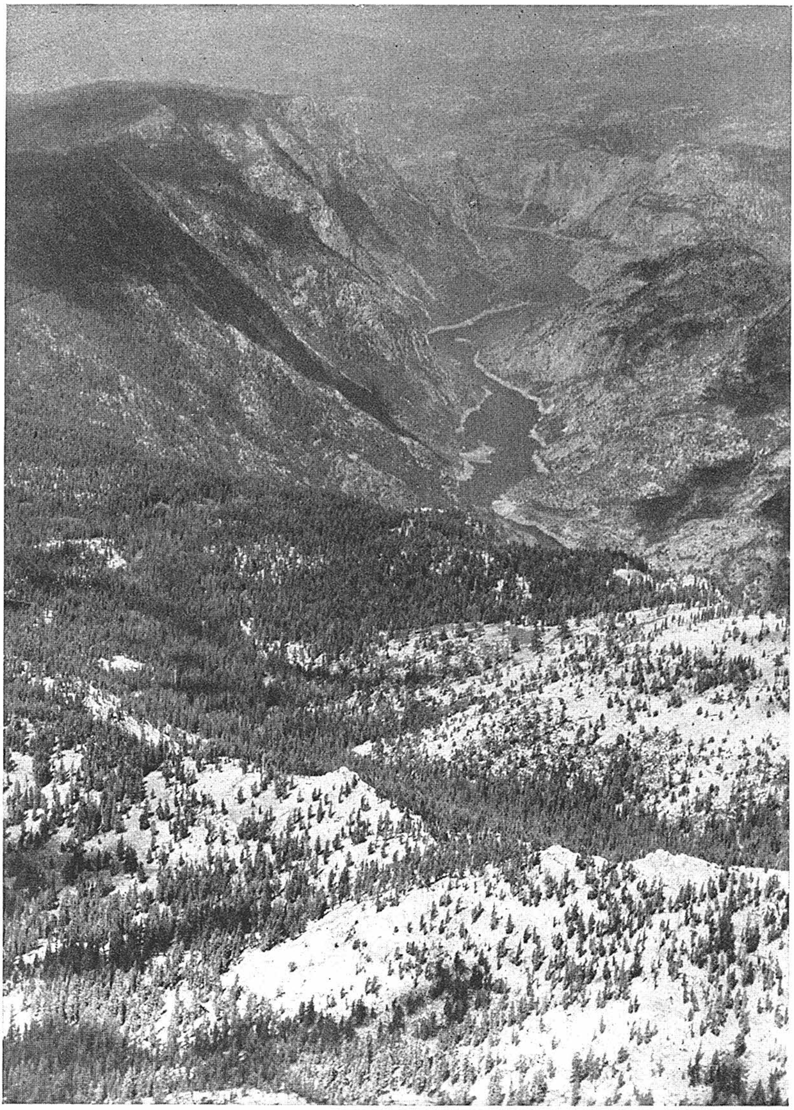

FIG. 23. Air-view of Hetch Hetchy Reservoir.

pools along their steep courses. The pools are known as 'tanks,' and also by the Spanish name, 'tinajas,' or water jars. They are usually more or less filled with boulders and gravel, but they also hold water for a time after a flood and are then the only available water supply for miles around. Where water is priceless, little tinajas may rank as lakes.

The McCoy tanks are in a range of the same name 20 miles west of the lower Colorado. One of them is "a little bowl in porphyry. It is water-tight and holds water for several months." Farther north in the Little Maria Mountains, Mohave tank in granite has been "formed by flood waters pouring over a cliff about 15 feet high in the canyon bed"; in October, 1917, "a pool of water 12 to 15 feet in diameter and 2 to 3 feet deep stood in the little basin." It has never been known to be entirely dry and is "a favorite watering place for mountain sheep and other wild animals." [63] A detailed account of some remarkable tinajas in Arizona is given by Bryan.[64]

Lake-Like Reservoirs

Artificial reservoirs, constructed for the irrigation of agricultural lands or for the supply of municipal districts or of electric power stations, are truly lake-like in their appearance. Such reservoirs should be deep enough to prevent the growth of reeds, because when reeds are present they cause a great increase of evaporation, as noted above in the account of flood-plain marshes. A number of reservoirs are, indeed, natural lakes artificially enlarged. Some of these water bodies, like the backed-up lakes mentioned in the second preceding section, illustrate very clearly the manner in which the valleys of a subsiding coast are converted into bays. Many small reservoirs are not here listed.

Clear Lake, second largest of its name and already described as occupying a fault basin in the northeastern part of the State, is now enlarged in a reservoir measuring 8 by 3 miles. Big Sage, Thomas and Tule Lake reservoirs, of smaller size, the latter not to be confused with the vanishing Tule Lake farther north, are held in branch valleys of Pit River south of Goose Lake, and Britton reservoir is held in the valley of Pit River itself where it is cut through the northern mountains between Mt. Shasta and Lassen Peak. Mountain Meadow and Almanor reservoirs, 6 by 2 and 13 by 5 miles, lie in valleys of the North Fork of Feather River at the northern end of the Sierra Nevada proper, 25 and 35 miles west of Honey Lake: the former submerges part of Big Meadows, above described as the bed of a lava-barred lake; the latter is the largest reservoir in the State.

Farther south and mostly in or near the foothills of the Sierra Nevada, Pardee reservoir, 8 miles long, is on the Mokelumne; Woodward, 3 miles long, is on a small stream east of Stockton, and Melones, 5 miles long, is on the Stanislaus River. The glacial Lake Eleanor, 1 by 1½ miles, in the mountains on an upper branch of Tuolumne River, has been enlarged in a reservoir 2½ miles in length.

On the upper Tuolumne is the famous Hetch Hetchy reservoir (Fig. 23), 8 miles long, in a wonderful trough of the Yosemite type. The proposed construction of this reservoir aroused nation-wide opposition. Many lovers of nature, among whom John Muir was most widely known, protested that the great scenic attractions of the valley would

[63] Brown, J. S., The Salton Sea Region, California. U. S. Geol. Survey Water-Supply Paper 497, 1932. See pp. 111, 264, 275, 276.
[64] Byran, Kirk, The Papago Country, Arizona. U. S. Geol. Survey Water-Supply Paper 499, 1925. See pp. 123–131.

FIG. 24. Air-view of Arrowhead Reservoir.

be diminished if it were laked;[65] but the pressing need of a better water supply for the cities of the San Francisco peninsula, supported by the profitable use of the water in its descent from the high-level reservoir in furnishing electric power, overcame the esthetic protests. Although a reservoir in a mountain valley is evidently a modification of nature, it is not necessarily a disfigurement; and the artificial production of a beautiful reservoir in Hetch Hetchy Valley may be taken as a compensation for the destruction by natural processes of the lake which in prehistoric times beautified the Yosemite.

Farther down Tuolumne River are Don Pedro reservoir, measuring 7 miles in its bent length, and Owens reservoir, 4 miles long. Exchequer reservoir on the lower Merced River is of irregular outline and measures 12 miles in its winding length. In Owens Valley at the eastern base of the southern part of the same range, Upper and Lower Haiwee reservoirs, each about 3 miles long, are on the line of the Los Angeles aqueduct, south of Owens Lake.

Bear Lake, 6 miles long, and Arrowhead Lake, 2 miles long, are reservoirs in the highlands of the San Bernardino mountains; the latter is shown in Fig. 24.

All these reservoirs resemble Clear Lake of the northern Coast Ranges, in that their dams obstruct valleys very much as its landslide does; but few reservoirs resemble Clear Lake in having their outflow diverted from the valley by which their waters were formerly discharged. Two exceptional cases somewhat of that kind deserve special mention: One is Echo Lake, south of Lake Tahoe, already mentioned as having its waters diverted from the north and east-flowing Truckee River to the headwaters of the west-flowing South Fork of American River. The other, Pilsbury reservoir, 6 by 2 miles, occupies the branching headwater valleys of Eel River in the Coast Ranges, about 20 miles north of Clear Lake: its outflow runs down the valley to the much smaller Van Arsdale reservoir, but there the outflow is led by a tunnel through a ridge at the head of Potter Valley, where it joins the East Fork of Russian River. In the same region of the Coast Ranges are East Park and Stony Gorge reservoirs, 25 and 35 miles northeast of Clear Lake.

In the San Francisco peninsula south of the Golden Gate the long trough that has been eroded on the San Andreas rift holds two reservoirs, known as San Andreas and Crystal Spring lakes, 3 and 6 miles long when filled to capacity. In the Mt. Hamilton Range southeast of San Francisco Bay, two reservoirs, Chabot, 2 miles long, and Calaveras, 3 miles long, contribute to the pressing need of larger water supply for the growing bay cities.

Santa Barbara reservoir, 4 miles long, is in the valley of the Santa Inez River, north of the east-west mountain range of the same name. Arrowhead reservoir, 2 miles long, and also the artificial enlargement of the above-mentioned Bear Lake, 5 miles long when filled to capacity, are on the highlands of the San Bernardino and San Gorgonio mountains. Inland from San Diego and not far north of the Mexican boundary are Sweetwater, Lower Otay, Barrett and Moreno reservoirs, 4, 3, 6, and 3 miles in length. Farther north are the slender Hodge

[65] See Muir's article, The Hetch Hetchy Valley, Sierra Club Bulletin, vol. 6, pp. 211–222, 1908, which includes a fine view of the valley in its natural state.

reservoir, 6 miles long, and the broader Henshaw reservoir, 5 by 4 miles.

Here may be briefly mentioned the shallow water sheets of artificial origin, covering square-mile sections or quarter-sections on the level, Great Valley plain, maintained by various gun-clubs in order to attract migrating water-fowl. Several of them are shown on the Hamlin School and Miramonte sheets of the U. S. Topographic Map. They remain dry through most of the year, but are flooded by pumping up ground water late in the autumn and so remain into the winter. It is estimated that 1,000,000 wild ducks are shot yearly on these ponds. In their temporary existence they are but little longer lived than the mirages of the desert playas.

The Nile has a lake-like appearance where it spreads over its flood plain above the great dam at Assouan in Egypt. A great and deep-branching lake is now in process of production on the Colorado River by the building of the Hoover Dam in Black Canyon, to which the name of Boulder Canyon, next upstream, is popularly given.

Lake-Like Bays and Lagoons

A number of coastal bays, more or less completely enclosed from the ocean, gain a lake-like appearance. One of them, the Bay of San Francisco, by far the greatest in area as well as in importance in California, is also one of the most famous arms of the sea in the world. Like other famous sea arms, such as the magnificent bay on which the city of Rio de Janeiro is situated in Brazil, or the beautiful bay on which Sydney is situated in Australia, this lake-like bay in California is due to the submergence of former valley-like lowland areas in consequence of a slight subsidence of its district, and the same subsidence converted a former river-cut gorge in the coastal mountains into the famous Golden Gate.

Although the original area of the bay has been considerably diminished by the growth of salt marshes in its shallow shore waters, the main body, San Francisco Bay, still measures 47 by 5 to 12 miles; its northern extension, San Pablo Bay, set apart from the main body by a peninsular arm of the east shore, is 14 miles across; here the muddy water from the rivers of the Great Valley and the clearer water of flood-tide from the ocean are often distinguishable on opposite sides of the bay by their contrasted colors. The innermost reach above Carquinez Narrows is Suisun Bay, 14 by 2 to 6 miles, much shoaled and encroached upon by the marshy delta-lands of the Great Valley rivers.

This great bay may be compared with Clear Lake, in the Coast Ranges 100 miles to the north, because, as has been told on an earlier page, the lake, like the bay, has recently flooded part of an aggraded intermont plain. To be sure, the bay is of salt water at sea level, while the lake is of fresh water at an altitude of 1300 feet; the bay has flooded a large part of an extensive pre-existent plain because that part of the plain was depressed below sea level, while the lake has flooded part of a smaller plain because the drainage outlet of the plain was recently obstructed by a landslide; the bay has become an active center of population, industry and commerce, thereby gaining world-wide fame, while the lake preserves a quiet, rural quality which adds to its charm; but the resemblances of the two as well as their differences deserve recognition.

All the other lake-like bays of the California coast are of much smaller size. Beginning at the north they are as follows: Earl Lake, 1 mile by 6, and Talawa Lake, about 3 miles long, are both, the first behind the second, enclosed by a long, wave-built, smoothly beached sand reef, which swings out to a low rocky headland next north

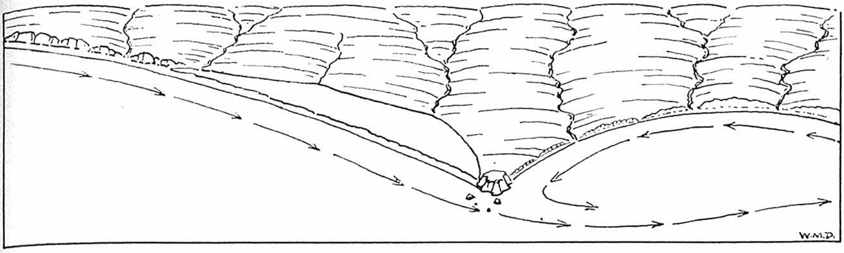

FIG. 25. Diagram of lagoon enclosed by a wave-built beach.

of Crescent City, 10 miles south of the Oregon line. The two lakes are separated by a narrow strip of sand which may be an earlier-formed reef of somewhat sharper curvature than the outer reef; for such curvature would have suited the beach drift very well before the cliffs to the north were cut back as straight as they are now. On smoothly curved beaches of this sort (Fig. 25), in adjustment with the approach of the surf because formed under its control, a long line of breakers plunges almost simultaneously in calm weather for miles together.

In consequence of a slight submergence of the coast, Klamath River is embayed for about 2 miles back from its mouth, which is

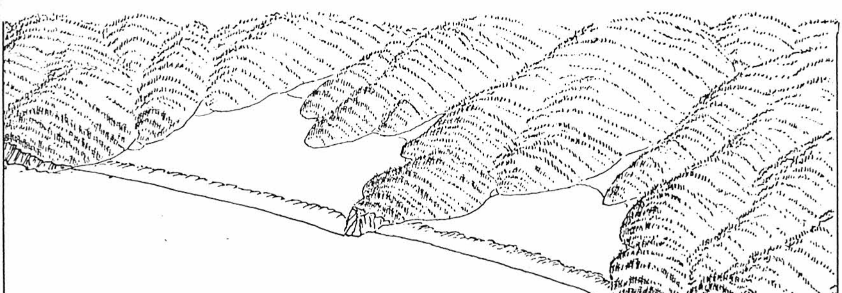

FIG. 26. Diagram of lagoons enclosed by wave-and-current-built beach on a coast embayed by slight subsidence.

partly closed by a sand spit. Farther south, where the strongly cliffed coast is adventurously followed by the Redwood Highway high above sea level, three valleys, slightly embayed by the same submergence of the coast, are closed somewhat as in Fig. 26 by heavy sand reefs, on which drift logs abound: the first is Freshwater Lagoon, Fig. 27, about a mile across its front; closely following is Stone Lagoon of larger size; third and farther south is Big Lagoon, 3 miles across. The fresh water in these enclosed bays, supplied by streams and springs from the backland, stands a little higher than mean sea level and is discharged by percolating through the enclosing sand reef. Roughly 20 miles farther south the saline waters of Humboldt Bay appear to invade three separate valleys, all enclosed by a single sand reef with a tidal inlet near the middle of its 13 miles of length; the northern

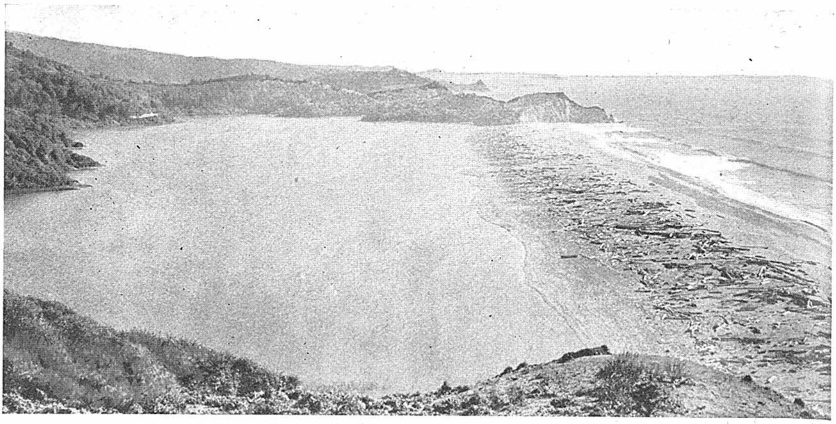

Photo by Patterson Bros., Santa Rosa.

FIG. 27. Freshwater Lagoon, below the Redwood Highway, north of Eureka; looking south.

and southern embayments are each 4 miles long; the middle one has a much smaller inland reach; all are diminished in area by invading deltas. The city of Eureka lies next south of the northern embayment. Eel River, 5 miles to the south, might also mouth in a bay, had it not

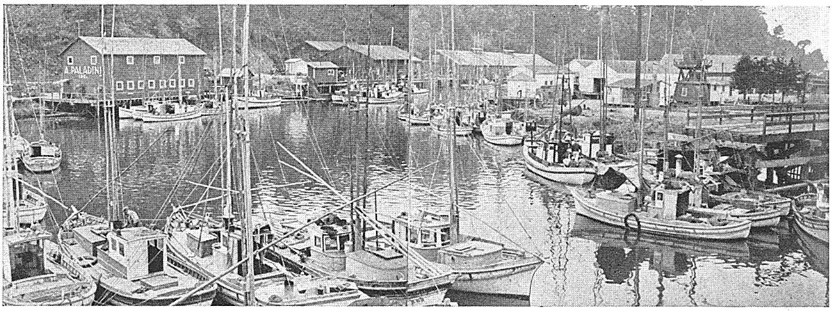

Photo by Olaf P. Jenkins.

FIG. 28. The embayed mouth of Noyo Creek, Mendocino County.

been silted up by that good-sized stream, which is many times larger than the little creeks of the Humboldt embayments.

No bays of importance are found in the following 170 miles of the mountainous and boldly cliffed coast; but practically all the streams, none of them of great size, which there issue from the mountains, mouth in small fresh-water lagoons held back by heavy beaches. The streams may break through the beaches at times of flood; at other times their small discharge is accomplished by percolation through the beach sands. One such enlarged stream, the Noyo, Fig 28, offers a striking contrast to its solitary neighbors as it swarms most picturesquely with little fishing boats, for which an artificial cut through the enclosing beach is maintained; not that the slightly enlarged stream is a commodious harbor, but that the cliffed outer coast is absolutely harborless. Several other similarly enlarged streams served as local harbors for the lumber industry some 15 or 20 years ago; but their use has now either decreased or ceased with the decline of lumbering thereabouts.

At the end of the 170-mile stretch of harborless coast Russian River, having made its way in a fine, 13-mile gorge through the coastwise ranges, is enlarged by slight submergence into an estuary a mile or more in length, nearly closed at its mouth by a beach, of which Holway gives a good illustration.[66] Five miles farther on, Bodega Head, originally a two-mile, rocky island separated by a mile-wide strait from the coast, is now land-tied by a broad beach which is swept out to it from the shore on the north by the long-shore beach drift, thus transforming the strait into a bay open to the south; and a

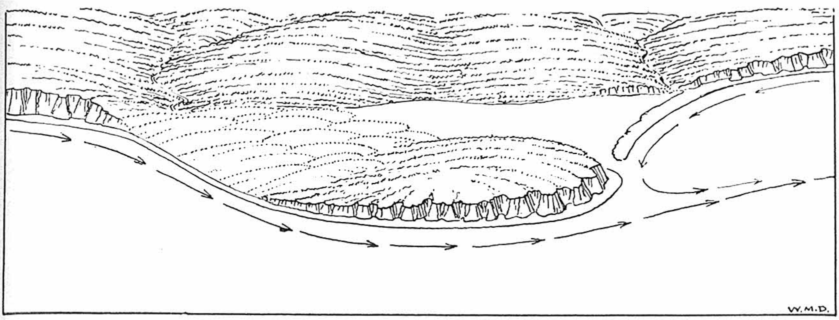

FIG. 29. Diagram of a land-tied island with a bay behind it, closed by a sand-reef beach controlled by a back-set eddy current.

smaller beach, built by a backset or beach drift from the shore on the south, nearly encloses the bay; only a narrow tidal inlet is left open next to the end of the rocky island. A striking feature of the bay is the great drove of large dunes, the sands of which, impelled by north-west winds, are slowly climbing over the broader beach and the northern part of the rocky island and invading the bay, somewhat as drawn in Fig. 29. The dunes make a delightful summer picnic ground when the inland plain of the Great Valley is blazing hot!

Two miles to the south is the little Estero Americano, or American Estuary, like the Russian River estuary except in being of much smaller size and more completely closed. Then come Tomales and Bolinas bays, which head against each other in the party submerged depression that has been worn down on the shattered rock of the San Andreas rift, and which thus nearly insulate the Point Reyes peninsula. The strait that has been transformed into the above-named Bodega Bay lies in the northern continuation of this rift depression. Tomales Bay, open-

[66] Holway, R. S., The Russian River, a Characteristic Stream of the Californian Coast Ranges. Univ. Calif. Publ. Geogr., vol. 1, pp. 1–60, 1913.

ing to the north, is 16 miles long by a mile or so wide; it is imperfectly enclosed by a beach and bar, wave-driven from the north. Bolinas Bay, originally opening to the south and measuring 1 by 4 miles, is now almost closed by Stinson Beach, which is driven obliquely across its mouth by a backset beach drift from the south. The sands for this beach appear to be derived chiefly from the cliffs south of the Golden Gate, whence they travel 20 miles northward, making their way across the entrance to the Golden Gate along its offshore, submarine bar, curved on a 5-mile radius, before reaching the beach.

It is because of this northward shift of the sands that the surviving inlet of Bolinas Bay is at the northwest end of the enclosing beach; and it is because Bolinas is much smaller than Tomales and therefore has weak tidal currents that it is so much better enclosed. Its inlet exhibits a typical example of what may be called a double-headed tidal delta, the outer head of which is built out in a slight salient by the ebb tide and smoothed off by the shore waves, while the much larger and more freely branching inner head of the delta is built by the flood tide in the quiet waters of the bay.

On the south side of Point Reyes peninsula, which makes out between Tomales and Bolinas bays, is Drakes Estero, a fine embayment 4 miles long, with 3 arms that branch into as many valleys in the hilly uplands; it is enclosed by a beach formed by back-set drift, farther northwest than the one which encloses Bolinas Bay. Three smaller embayments of similar origin are near by; two lie next to the east on the southern coast, and one on the northern coast of the wave-trimmed peninsula.

Five miles south of the Golden Gate is Merced Lake, a true lake in being of fresh water, with two 2-mile arms that enter the hills of the San Francisco peninsula and are enclosed by the broad beach of its ocean shore and by the sand dunes that are swept by the westerly winds from the beach.

Several lagoons lie back of the 25-mile beach and dunes of the wide-open Monterey Bay, the middle of which lies 80 miles south of the Golden Gate. Two of the largest are expansions of Salinas and Pajaro rivers; but three others, one of which is known as Elkhorn Slough, do not appear to be related to stream courses. Some of these lagoons communicate with the ocean by narrow tidal inlets, but the Salinas lagoon is enclosed by a sand beach, except when floods from winter rains break through it. Near the southern end of the long beach several minute brackish or salt pools, which are said by Galliher in his account of Monterey Bay to have biological affinities with desert saline lakes,[67] lie back of the invading dunes.

Farther south, the bold and strongly cliffed coast of the Santa Lucia Range extends practically without a bay for 100 miles. All of the streams that here discharge directly to the ocean are of small size; they seem to be slightly embayed by submergence and the little coves are lagooned by beaches. Beyond this long and high range, which runs parallel to the coast, are several shorter ones which trend more to the southeast and head abruptly at the shore. Between them lie aggraded plains, well beached and duned; and back of the first beach of this

[67] Galliher, E. W., Sediments of Monterey Bay, California. California State Min. Bur., Mining in California, January, 1932, pp. 42–79, 1932. See Fig. 5 and pl. III.

series is Morro Bay, 3 by 2 miles, the beach of which has been guided by back-set beach drift. The town of San Luis Obispo stands at the head of the plain, 13 miles back from the bay. The next intermont plain, on which Santa Maria is the chief town, is heavily invaded by dunes from its beached front: here, a few miles inland is the small Guadalupe Lake; it was probably of greater size before the invasion of its area by dunes.

Then for over 30 miles southward to Point Conception, for 60 miles eastward along the Santa Barbara coast of the east-west Santa Inez Range, and for 30 miles southeastward along the lower Ventura coast to the east-west Santa Monica Range, no bays or lagoons are mapped, apart from a few small pools, such as those back of the long Hueneme beach of the Oxnard plain in the last 10 of the total 120 miles. Only at the end of that distance is there a narrow, beach-enclosed, tidal lagoon a few miles in length at the western end of the Santa Monica Range.

The 30-mile southern coast of that range is again without embayments; and not till a long beach swings southward from it is a little tide-marsh bay enclosed in the low coast lands; the shore resort of Venice lies on the enclosing beach, 15 miles west of Los Angeles. A few miles farther south rises the promontory of the San Pedro Hills, formerly an island; after it is rounded and the coast trends east again, Wilmington Lagoon, 3 miles long with 3 miles more of tidal marsh, lies back of a long beach that has been built westward by back-set beach drift, so that its tidal inlet is driven against the eastern base of the San Pedro Hills.

The back-set beach drift which has built this beach is, like several other drifts of the same kind mentioned above and one more to be mentioned below, the result of a coastal promontory or salient which holds the dominant southeastward sea current offshore. The lagoon, now provided with an artificial entrance cut through its beach and improved with wharves and docks, serves as the harbor for the growing maritime commerce of Los Angeles, which lies 20 miles inland to the north. The shore resort of Long Beach is at the east end of the lagoon. Beyond it are four more beach-barred lagoons of smaller size.

Farther on still is a marsh that might be a good-sized beach-barred bay, had it not been silted up by the Santa Ana River, the largest stream of southern California. Then comes the bay known as Newport Harbor, 5 miles long at high time, shut in by a broad, wave-driven and southward-growing beach, on which a summer population gathers; the tidal currents at the harbor entrance are dangerously strong; the Santa Ana River, deflected southward by the wave-driven beach, used to mouth through this bay; it now has an artificial mouth farther north, cut through the long beach that encloses its marshes.

The following coast is, apart from two small salients, rather smoothly cliffed and beached in a long southeastward curve for over 60 miles; but near the middle of that distance half a dozen small streams, apparently a little drowned at their mouths and more or less marshed, are beach-barred. Next comes Soledad Mountain back of La Jolla, beyond which False Bay is another beach-enclosed embayment, 2 by 3 miles, again with dangerous tidal currents at its inlet. Finally, beyond the southward-stretching peninsula of Point Loma, San Diego

Bay is reached, 12 by 2 or 3 miles, enclosed by a long beach, built northward from near the Mexican boundary by a wave drift to the low Coronado Island. This beach, 12 miles in length, is the finest example of its bay-enclosing kind in the State. One of the longest beach-enclosed lagoons in the world stretches northward for scores of miles in a graceful curve from the Rio Grande delta along the low coast of Texas.

Conclusion

In closing this review the author desires to remind his readers once more that the study of Californian lakes is by no means complete. It is therefore eminently possible that further investigations will lead to many new descriptions as well as to corrections in some of the foregoing descriptions. But if lovers of nature, young as well as older, gain an increased enjoyment of Californian lacustrine scenery by reason of what is here told of its origins, and if some of the more observant among them are thereby incited to make new investigations of the ways in which Californian lakes are brought into being, the enjoyable labor of gathering the material presented above will be doubly repaid.