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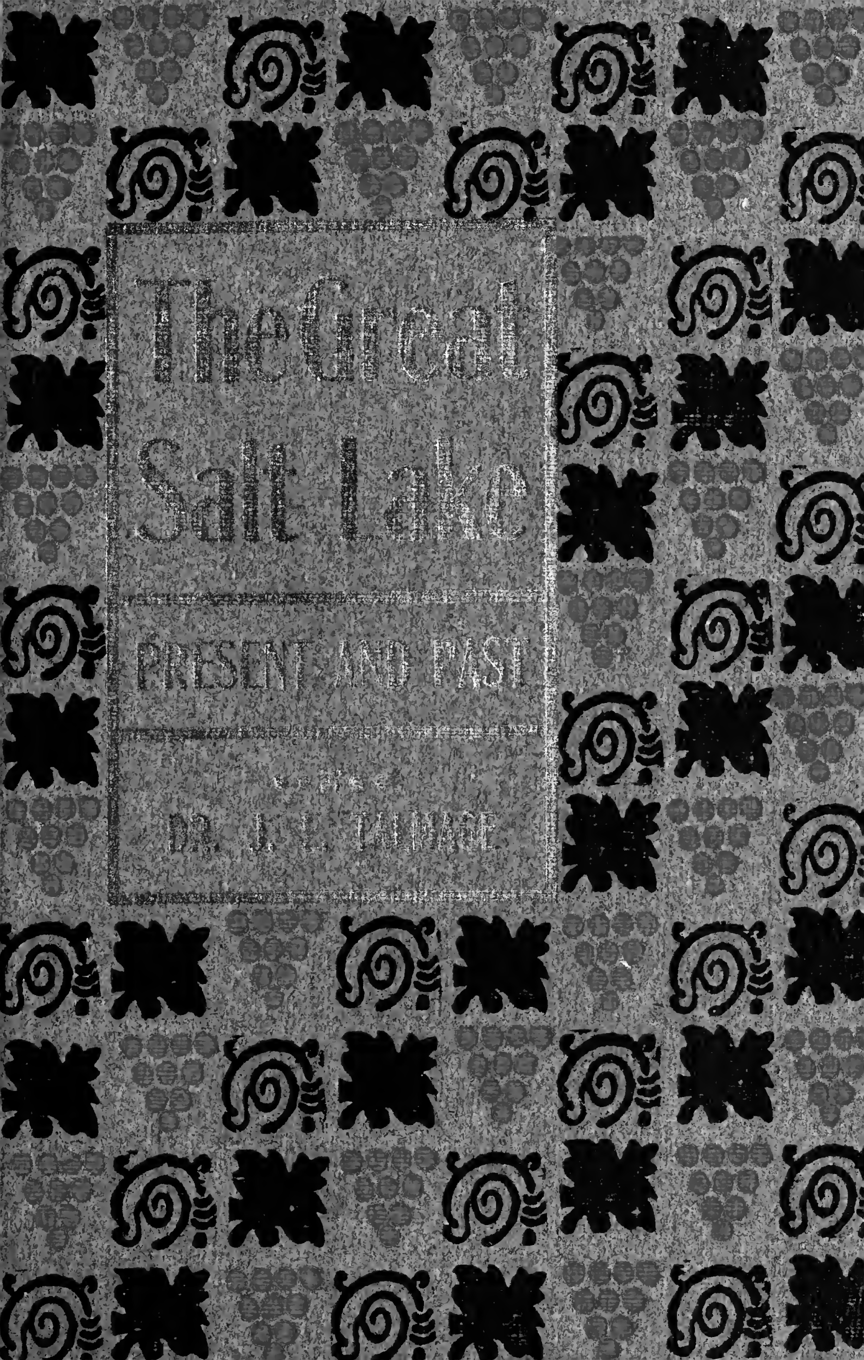

The Great Salt Lake

PRESENT AND PAST

DR. J. E. TALMAGE

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THE

GREAT SALT LAKE

PRESENT AND PAST.

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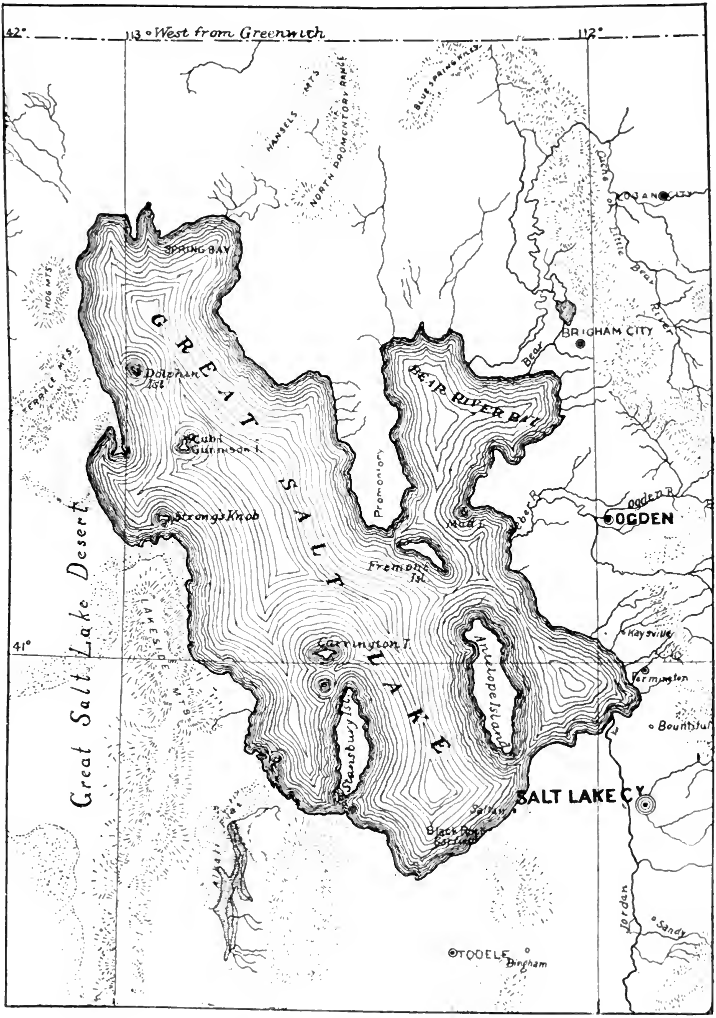
Photograph by Savage. I. Black Rock; south end of Great Salt Lake. (Oregon Short Line Ry.)



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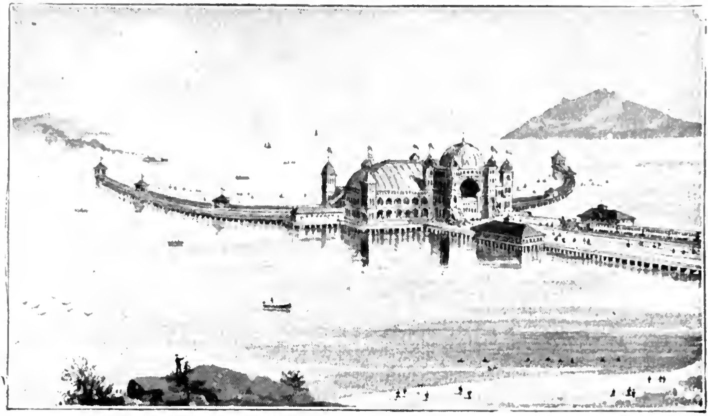
Photograph by Johnson.



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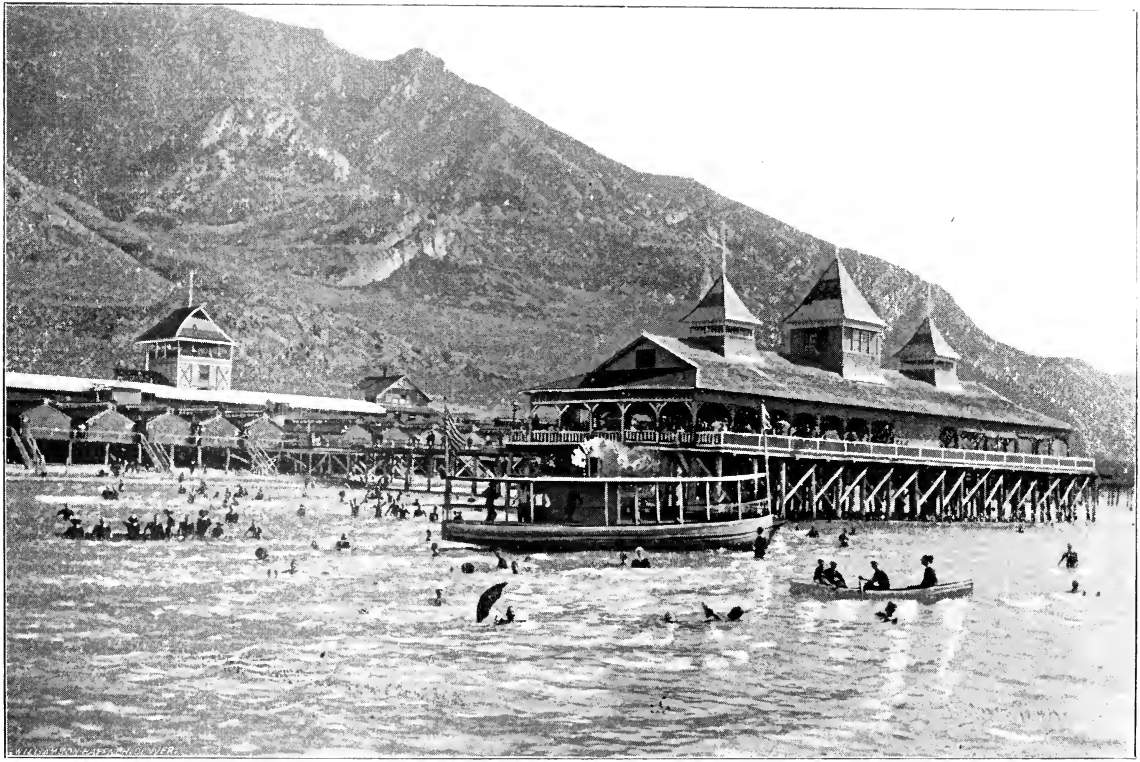

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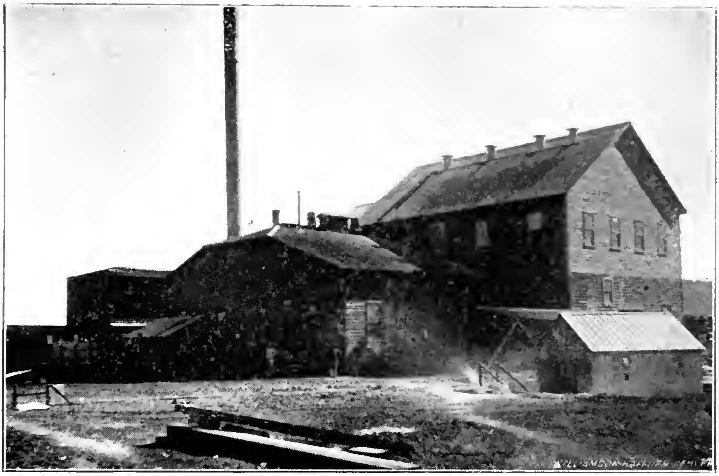

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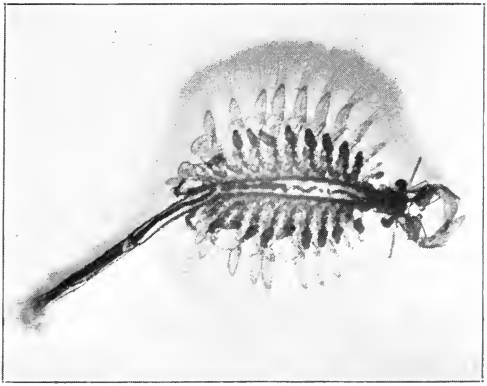

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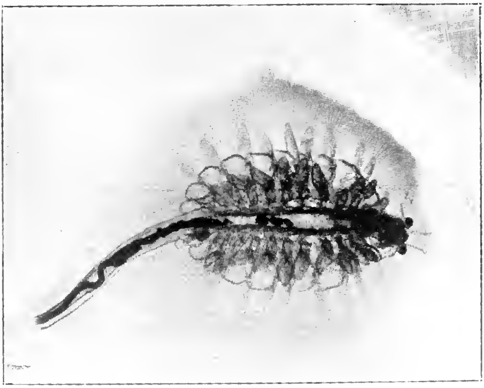

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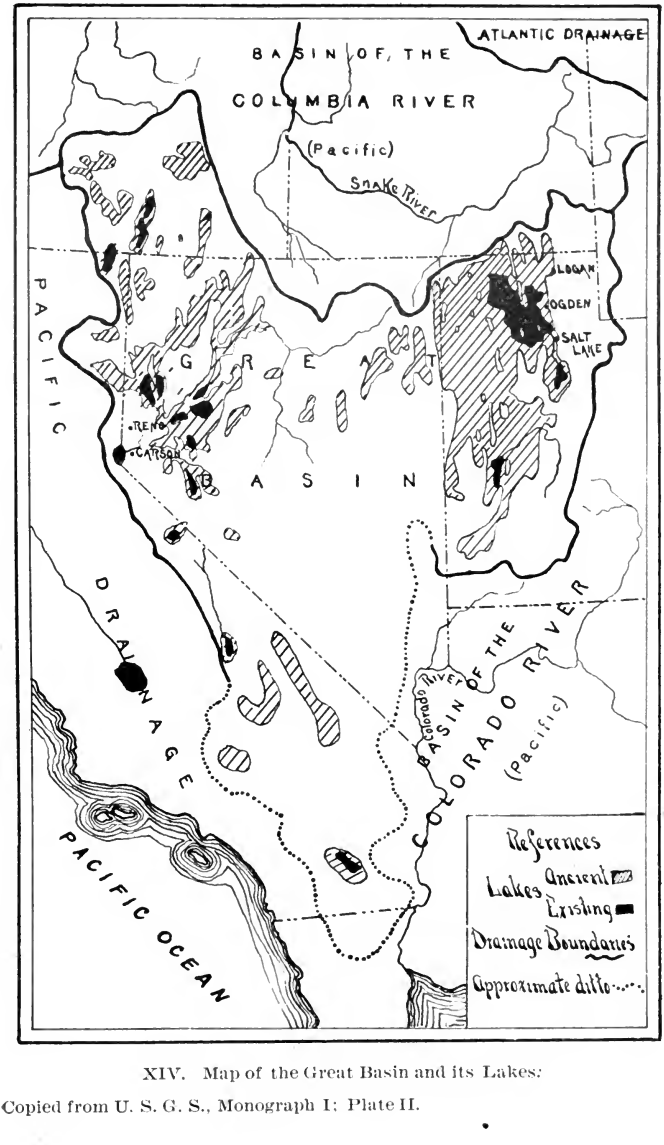
From photomicrographs by J. E. Talmage.



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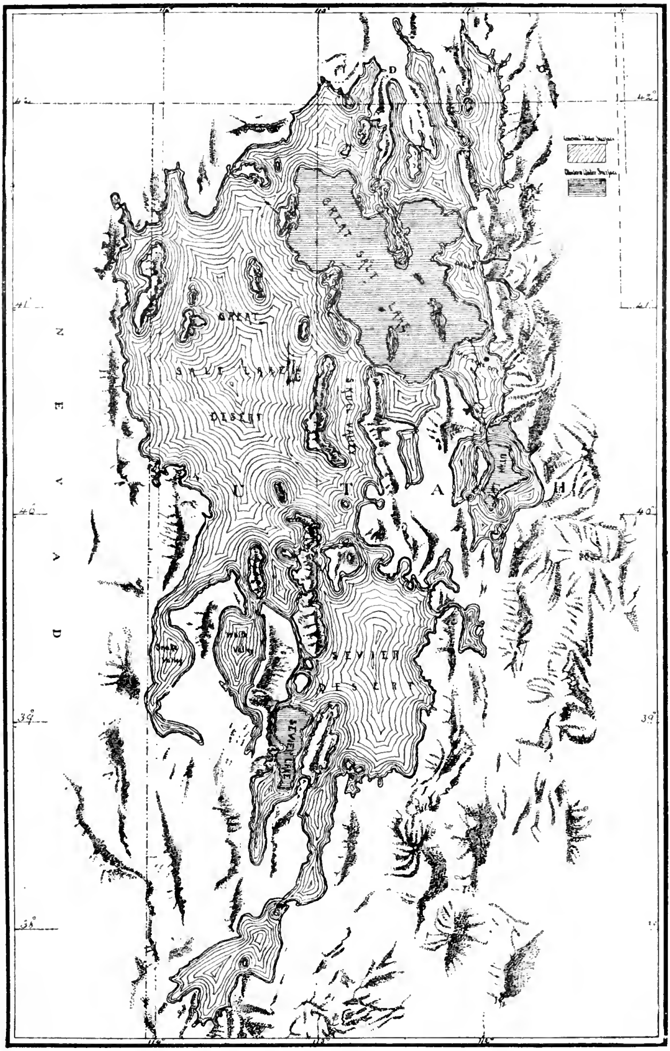

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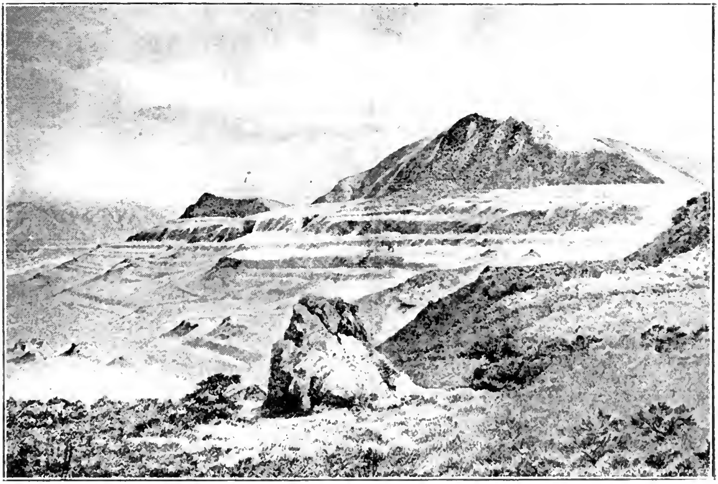

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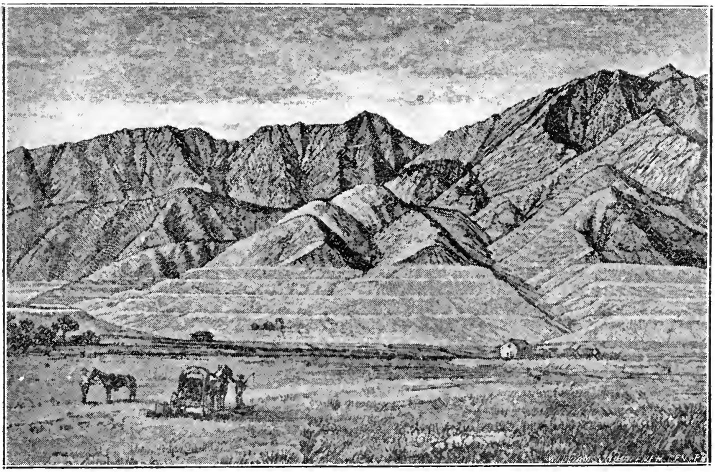

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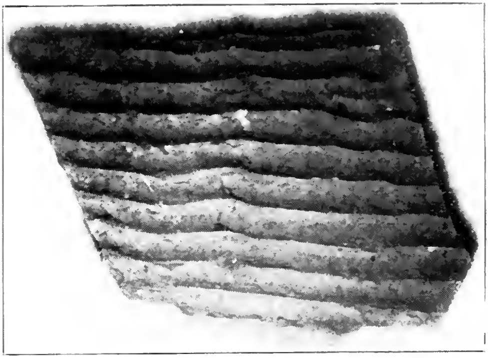

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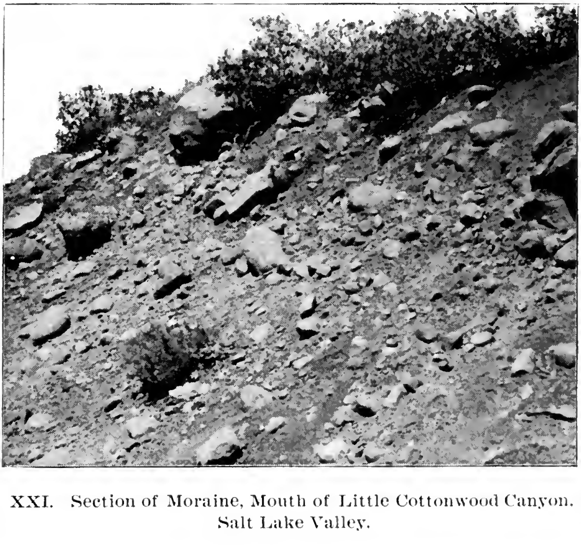

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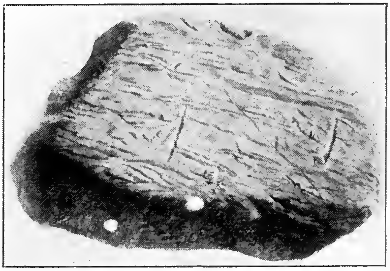

XXII. Glaciated Stone, from Little Cottonwood Moraine.

THE

GREAT SALT LAKE

PRESENT AND PAST.

BY

Edward

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THE DESERET NEWS,
SALT LAKE CITY, UTAH.
1900.

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PREFATORY.

In some parts the following pages are reprints of articles that have appeared over the writer's signature in local and scientific periodicals; in other portions they are little more than a compilation of facts already of record. Perhaps sufficient excuse for the present publication may be found in the fact that reliable information regarding the Great Salt Lake is of difficult access to the general reader, inasmuch as it is mostly contained in the valuable though ponderous tomes of the national surveys. The popular writings on the subject, with some exceptions, have been criticized as extravagant and untrustworthy. The truth regarding Utah's Dead Sea is sufficiently impressive without recourse to fabulous embellishment, even if such were in any sense justifiable.

The writer has drawn freely on the valuable records of investigators, and acknowledgment of authorities has been made in place. J. E. T.

Salt Lake City, Utah,
July, 1900.

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THE GREAT SALT LAKE.

PRESENT AND PAST.

I.

INTRODUCTORY.

The record of fact and tradition concerning the Great Salt Lake, as written by the hand of man, dates back a little more than two centuries; but a history of times far more remote may be read from Nature's manuscript, inscribed on the stony pages of ancient shores and in the sediment which formed the floor of the lake of by-gone days.

Though generally designated by the adjective "Great," the Salt Lake, as we shall presently see, is but a shrunken remnant of a vastly larger water body, which once existed as a veritable inland sea, completely filling the valley in the lowest portion of which the modern lake rests, and extending beyond the northern and western boundaries of the present State of Utah. To this ancient sea the name "Lake Bonneville" has been applied.

But the geological past of the "Dead Sea of America" may well be left for later consideration; we can the better interpret such after an examination of existing conditions. It is, therefore, the lake of present and historic times to which attention is first invited.

Long prior to the time at which white men first trod the shores of this briny sea, strange stories of its existence and of the marvelous properties of its waters had found their way into civilized lands. In 1689 Baron La Hontan, a French traveler and explorer of note, gathered from the Indian tribes of the Mississippi valley their traditions of a great salt sea lying amid the solitude of the western mountains; and these stories, doubtless embellished by additions from his own imagination, the traveler sought to perpetuate. His narrative was first published in English in 1735. No facts of value were given by La Hontan concerning the lake; indeed there is room for doubt as to whether the water-body about which the Indians had talked to him was the Great Salt Lake.

In 1776 Padre Escalante, a Spanish official exploring for routes of travel, crossed the south-eastern rim of the Great Basin region, and followed the Timpanogos or Provo River (by him named Purisima) down to its termination in Utah Lake. From the Indian tribes of what is now Utah Valley he learned of a lake many leagues in extent, with waters extremely noxious and salty, lying in the valley northward. Escalante appears to have contented himself with this hear-say information, for there is no record of his having reached the shores of Great Salt Lake.

Perhaps the truth regarding the first white man's visit to the lake may never be known. There have been many rival claimants for the honor of having discovered the briny waters, and historians have failed in their efforts to decide the question of priority.

There are many accounts of occasional visits to the lake or its vicinity by traders and trappers between 1820 and 1833; among such venturesome travelers may be named Miller of the Astor company; Provost (after who Provo City has been named), and Bridger, for whom some strongly claim the honors of discovery. Hubert Howe Bancroft, the voluminous writer on Pacific Coast history, is one who accords this credit to Colonel James Bridger. Bridger is said to have descended Bear River to its mouth in the lake, the journey having been undertaken to settle a wager as to the course of the river named.

Between 1831 and 1833 Captain Bonneville, a Frenchman in the service of the United States as an army officer, while traveling on leave, explored portions of the lake shores and wrote short descriptions, mostly geographical, which have proved of value. Several years later an account of Bonneville's explorations was given publicity by Washington Irving, whose book, "Adventures of Captain Bonneville," is well known. An attempt was made to attach Bonneville's name to the salty lake, but without success. As already stated, the designation "Lake Bonneville" has now been applied to the ancient sea which preceded the Salt Lake of today.

In 1843 John C. Fremont, then Brevet-Captain U.S. A., sighted the lake from an elevation in Weber County now known as Little or Low Mountain, and considered himself the first discoverer of this mountain-sea. He likened himself to Bilboa discovering the Pacific. Fremont reached the lake and rowed upon its waters; but history denies him the distinction of having been first to discover or to navigate the lake. Fremont's visit was made in the course of a government expedition to the Rocky Mountains; and his report* is regarded as the earliest authentic record of the physical conditions of the region. His party included the renowned hunter and scout, Kit Carson, and tradition has it that a rude boat consisting of a tree-trunk hollowed-out Indian fashion, which was found on the shores of the lake after the settlement of the region by the Mormon people, was the identical craft used by Kit Carson. The boat in question is now to be seen at the Deseret Museum, Salt Lake City. There is much doubt as to the truth of the story, however, for more authentic accounts say that the explorations of Fremont and Carson

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* "Report of the Exploring Expedition to the Rocky Mountains in the year 1842, and to Oregon and North California in the years 1843-44," by Brevet-Capt. J. C. Fremont. Washington, 1845.

on the waters of the lake were accomplished in rubber boats.

In 1849 and 1850 Captain Howard Stansbury, U. S. A., under government commission made a fairly thorough survey of the lake and the region contiguous. His report contained valuable data concerning the lake area, the depth, density, and composition of the water, and the extent of the shore line.*

Since the advent of the Mormon pioneers in 1847, and during the phenomenally rapid settlement of the region and the development of its varied resources, reliable observations have been recorded, both by residents and by competent investigators operating under private or government auspices. To Grove Karl Gilbert much praise is due for his elaborate and masterly study of the Great Salt Lake, particularly in relation to its past history. His work, "Lake Bonneville,"† is and will ever be a classic in the geological literature of America.

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* "Exploration and Survey of the Valley of the Great Salt Lake of Utah," etc., by Howard Stansbury, Capt. Corps Topographical Engineers, U. S. A. Philadelphia, 1852.

† Monographs of the United States Geological Survey, Vol. I:—"Lake Bonneville" by Grover Karl Gilbert; Washington, Government Printing Office, 1890.

II.

DESCRIPTIVE.

The Great Salt Lake today is an object of very general interest, attracting as it does the attention of scientist, lay-scholar, and curiosity-seeker alike. In the popular mind it holds a place as one of the strongest natural brines known, and as the site of attractive bathing resorts. To the chemist this remarkable body of water represents a practically inexhaustible reservoir of valuable material awaiting the potent influences of manufacturing industry. To the geologist it appeals as the dwarfed remains of an ancient sea, with the fossil evidence of its past history preserved in the deposits and sculpturing of its abandoned shores, and in the sediments of its desiccated floor.

The events characterizing its principal epochs may be determined with a fair measure of accuracy, and the story of its fluctuations recounts the succession of marvelous climatic changes through which the region of the Great Basin has passed.

As is generally known, the Great Salt Lake is the largest inland water body existing within the United States west of the Mississippi valley. It lies in the north central part of the State of Utah, between the parallels 111.8 degrees and 113.2 degrees longitude west from Greenwich, or 34.7 degrees and 36.1 degrees west from Washington, and between 40.7 degrees and 41.8 degrees north latitude.

Owing to the frequent and great fluctuations in volume incident to climatic variations and other conditions of change, its area is inconstant, and the recorded surveys of the water surface show great discrepancies. In general terms its present dimensions have been recorded as follows: Average length, 75 miles; greatest width, 50 miles; extent of surface, 2,125 square miles.

The altitude of the lake surface is 4,210 feet above sea-level; and this fact alone is promise sufficient of many interesting results to the investigator, for at such a height the general conditions are unusual. The remarkable clearness of the atmosphere throughout the lake region appeals with force to the visitor, whose persistent underestimating of distance may be either amusing or annoying. From any convenient point of vantage the observer may survey the lake as a glassy continuation of the valley floor, with mountain-walled back grounds, which are broken on the central part of the western shore where the Great Salt Lake Desert and the lake itself have a margin in common.

ISLANDS OF THE LAKE.

Rising from the water surface are precipitous islands, appearing in their true character of mountain peaks and ranges, the lower part of their masses being submerged. Of these water-girt mountain bodies, Antelope and Stansbury islands are the largest; and the others are Carrington, Fremont, Gunnison, Dolphin, Mud, and Hat or Egg islands, and Strong's Knob. The islands appear as continuations of the mountain ranges which diversify the contiguous land area, and an examination of their structure confirms this inference.

At present, communication between main-land and islands is effected by boat; though at low water periods, Antelope and Stansbury islands have been accessible by fording. Limited areas of the larger islands are under cultivation, and the regions have long been utilized as pasture lands. Some discoveries of mineralized deposits have been reported from the lake-washed mountains but thus far no profitable mining for metals has been accomplished.

The tiny hill whose summit rises from the briny waters as a rocky knoll, known as Hat or Egg island, is the principal rookery of the feathered frequenters of the lake. There congregate during the breeding season thousands of pelicans and gulls, and when they depart they are accompanied by the new generation of their kind, in uncounted numbers. A visit to this isle of nests at the proper time reveals the spectacle of great flocks of half-fledged pelicans, awaiting the arrival of their fisher-parents, or ravenously devouring the scaly contents of the parental pouches. The fish thus supplied are caught by the old birds at the mouths of the fresh water streams which feed the lake reservoir.

On the islands, which for ages have been monopolized by the birds as a nesting-ground, great deposits of guano have accumulated; and this material is now utilized as a valuable fertilizer.

The rivers which feed the lake all enter it on the eastern side; they depend upon the supplies furnished by the Wasatch and Uintah mountains. Of these streams the most important are the Jordan, which brings down from the south the surplus waters of Utah Lake, the Weber, and the Bear. Beside these there are several small streams locally designated as creeks, which deliver a moderate contribution during high-water seasons.Generally, however, the lower portions of the creek-beds are dry, the water having been diverted at higher levels for irrigation purposes. From the west no streams reach the lake, the few that rise on this side losing themselves in the desert plain, or disappearing entirely through evaporation.

The scenic glories for which the lake region is mostly famed depend not alone on mountain heights, or valley floor, neither on water expanse nor island cameos; not on one nor two nor all of these combined, pleasing though the combination be; these are but the canvas on which Nature paints with a richness beyond the colors of purely earthly origin. 'Tis when the sunbeams fall aslant in the freshening dawn, or when the orb of day is sinking in the west, that the landscape and the water blaze forth with tints and shades which the artist strives in vain to catch and imitate.

A description of such a scene is a fit theme for the poet; the picture ought to be attempted by the master-hand alone. But the poet—frail as the rest of us—may substitute his witchery of rhythm and rhyme for the actual harmonies of the desert scene; and the painter may intrude his ideal into the picture. The truth here declared in Nature's language and colors calls for no embellishments. I trust rather the scientific observer, whose love for the beautiful,while no whit less than that professed and held by his brothers, poet and painter, is kept within the bounds of truthful decorum.

Let us call to our service the words of Prof. Russell, whose geological researches in these and contiguous parts have afforded him abundant opportunity for observation.*

"The scenery about this great lake of the Mormon land and in the encircling mountains is unusually fine,in spite of the aridity and the generally scant vegetation of the region. The sensation of great breadth that the lake inspires, together with the picturesque islands diversifying its surface, and the utter desolation of its

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* "Lakes of North America" by Israel C. Russell, Professor of Geology, University of Michigan; Boston, Ginn & Co., 1895. pp. 78-79.

shores, give it a hold on the fancy and waken one's sense of the artistically beautiful in a way that is unrivaled by any other lake of the arid region. The unusually clear air of Utah, especially after the winter rains, renders distant mountains remarkably sharp and distinct, particularly when the sun is low in the sky and a strong side-light brings the sharp serrate crests into bold relief and reveals a richness of sculpturing that was before unseen. At such times the colors on the broad deserts and amid the purple hills and mountains are more wonderful than artists have ever painted, and exceed anything of the kind witnessed by the dweller of regions where the atmosphere is moist and the native tints of the rock concealed by vegetation. The hills of New England when arrayed in all the gorgeous panoply of autumnal foliage are not more striking than the desert ranges of Utah when ablaze with the reflected glories of the sunset sky. The rich native colors of the naked rocks are then kindled into glowing fires, and each canyon and rocky gorge is filled with liquid purple, beside which even the imperial dyes would be dull and lusterless.

"At such times the glories of the hills are mirrored in the dense waters of the lake, their duplicate forms appearing in sharp relief on the paler tints of the reflected sky. As the sun sinks behind the far-off mountains, range after range fades through innumerable shades of purple and violet until only their highest battlements catch the fading glory. The lingering twilight brings softer and more mysterious beauties. Ranges and peaks that were concealed by the glare of the noon-day sun start into life. Forms that were before unnoticed people the distant plain like a shadowy encampment. At last each remote mountain crest appears as a delicate silhouette, in which all details are lost, drawn in the softest of violet tints on the fading yellow of the sky.

"To one who only beholds the desert land bordering Great Salt Lake in the full glare of the unclouded summer sun, when the peculiar desert haze shrouds the landscape and the strange mirage distorts the outline of the hills, the scenery will no doubt be uninteresting and perhaps even repellent. But let him wait until the cool breath from the mountains steals out on the plain and the light becomes less intense, and a transformation will be witnessed that will fill his heart with wonder."

III.

THE LAKE AS A PLEASURE AND HEALTH RESORT.

The peculiar advantages and attractions of the Great Salt Lake for bathing purposes were known to the earliest white explorers; and even prior to their visits, the Indians, who are not famous for their love of ablutions, had discovered the difference between a dip in fresh water and a bath in this natural brine. The aborigines who dwelt near the shores of Utah lake forty miles to the south, specifically known as the Timpanogotzis, informed Padre Escalante of the strange properties of the water. The Padre writes, "The other lake with which this one communicates is, as they informed us, many leagues in extent; and its waters are noxious and extremely salt, so that the Timpanogotzis asserted to us that when any one rubbed a part of his body with it he would feel an itching sensation in the moistened part."*

The peculiarity of the lake water as a medium for the bath lies in its rich content of dissolved mineral matter, and in the consequent high degree of density. Dr. L. D. Gale reported a specific gravity of 1.17 on a sample collected in 1850; with the rise of the lake and the corresponding dilution of the brine, the specific gravity

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* Translation from the original manuscript-journal of Padre Escalante, describing his journeyings from Santa Fe to Utah Lake, etc., in 1776; by Philip Harry; published in Capt. Simpson's Report, 1876; p. 494.

fell to 1.111 in 1869 (Prof. O. D. Allen), and to 1.102 in 1873 (Bassett); then the density increased as the lake waters became more concentrated, reaching 1.1225 in 1885, 1.261 in 1888, and 1.679 in 1892. In December 1894, the density was 1.1538, and in May 1895, 1.1583; in June 1900, it was 1.1576. These data will be presented in greater detail on a subsequent page.

It is seen that the Salt Lake brine is among the most concentrated and therefore the densest of natural waters; indeed it is surpassed in point of density by but one large water body—the Dead Sea.

As would be surmised of a liquid possessing so high a specific gravity, the Salt Lake water is extremely buoyant, and this fact the bather soon demonstrates to his fullest satisfaction. It is a physical impossibility for the human body to remain submerged, and the skilful swimmer may float without effort, rather upon than in the brine. One of the earliest accounts of bathing in the lake is that given by Captain Howard Stansbury in his official report; an abstract therefrom is presented herewith, with the simple comment that the multiplied experiences of many confirm his statements as to general properties and effects of the water, and show the circumstances of the individual experience described to be consistent and probable:

"We frequently enjoyed the luxury of bathing in the water of the lake. No one without witnessing it can form any idea of the buoyant properties of this singular water. A man may float, stretched at full length, upon his back, having his head and neck, both his legs to the knee, and both arms to the elbow, entirely out of the water. If a sitting position be assumed, with the arms extended to preserve the equilibrium, the shoulders will remain above the surface. The water is nevertheless extremely difficult to swim in, on account of the constant tendency of the lower extremities to rise above it. The brine, too, is so strong, that the least particle of it getting into the eyes produces the most acute pain; and if acidentally swallowed, strangulation must ensue. I doubt whether the most expert swimmer could long preserve himself from drowning if exposed to a rough sea.

"Upon one occasion a man of our party fell overboard, and although a good swimmer, the sudden immersion caused him to take in some mouthfuls of water before rising to the surface. The effect was a most violent paroxysm of strangling and vomiting, and the man was unfit for duty for a day or two afterward. He would inevitably have been drowned had he not received immediate assistance. After bathing it is necessary to wash the skin with fresh water, to prevent the deposit of salt arising from evaporation of the brine. Yet a bath in this water is delightfully refreshing and invigorating."*

"* Exploration and Survey of the Valley of the Great Salt Lake of Utah," by Howard Stansbury, 1852, p. 212.

The force of waves on the lake is astounding to one who has had experience in troubled waters of ordinary density alone. Even a moderate disturbance gives to the shore breakers prodigious power, and affords the bather the exciting experience of heavy surf-fighting. Storms on the open lake are serious happenings to the small boats that navigate its surface, even though the atmospheric disturbance may be that of but an insignificant squall at sea.

As will be readily understood, boats for service on the lake must be of special construction, affording proper displacement in the dense water. A craft that would sink to the water line in sea-water would ride so high on the lake brine as to be top-heavy and unsafe.

* * *

The natural attractions of the lake as a pleasure resort have been recognized from the time of the first settlement of the valley. Long prior to the erection of bath houses and pavilion piers, the shores were frequented by pleasure-seekers with whom boating and bathing were favorite sports. At the present time there are a number of resorts at different places along the shore, but of these two only are of considerable proportions. These in the order of their establishment are Garfield Beach and Saltair Beach resorts. They are both situated at the southern extremity of the lake, within easy access by rail from Salt Lake City.

In this part, the lake shore and bottom, free from rocky irregularities and mud, is covered with a peculiar and uniform deposit of "oolitic sand," which forms an ideal bathing floor. Firm to a moderate degree, it is yet conveniently soft and elastic, affording to the wader and to all who desire to keep within the limits of shallow water the advantages of a prepared bottom.

SALTAIR.

The Saltair Beach resort is a monumental testimonial to the enterprising energy of Utah capitalists. The pavilion is situated thirteen miles due west from Salt Lake City, and may be reached by a twenty minute ride on the Salt Lake and Los Angeles railroad. The railway here runs over a recently desiccated portion of the old lake bottom, which preserves many features of actual desolation, and affords an illustration of what the entire valley was in the geological yesterday. Saline pools and playas appear as the shore is approached, and vegetation dies away, save occasional patches of wild sage, (*Artemisia tridentata*), greasewood (*Sarcobatus vermicularis*), and rabbit brush (*Lynosyris*).

The train runs on a pile-supported track 4,000 feet into the lake before the pavilion is reached. The buildings form a symmetrical group, with a large central structure connected with a semicircular extension at each end curving toward the lake. The architecture is after the Moorish style, and the general effect is as beautiful as the structure is substantial and serviceable. The pavilion was erected in 1893 at a cost of a quarter of a million dollars.

In length the buildings extend over 1,115 feet, with a maximum width of 335 feet. The top of the main tower is 130 feet above the water surface. Part of the lower floor serves as a lunch and refreshment pavilion; the area thus utilized is 151 by 252 feet. The upper floor in the main building is used as a ball room; its dimensions are 140x250 feet. The dancing floor is domed by a roof constructed after the plan of that covering the famed Salt Lake City Tabernacle, and the proportions of the two vast assembly rooms are nearly the same.

On the semi-circular sweeps which flank the central pavilion 620 bath-rooms are provided. The bathing appointments are of the best, and the many flights of stairs leading to the water reach the bottom at points giving a range of depth from fifteen inches to four feet. Deeper water may be reached at some distance outward. During the bathing season the observed temperature of the water ranges from 50 degrees to 86 degrees F.

At night the pavilion is brilliantly illuminated by means of electric lamps. There are 1,250 incandescent lights and 40 ordinary arc lights, with one arc light of 2,000 candle power surmounting the main tower.

As would be naturally expected, a resort of such attractiveness is secure in the matter of patronage. The records show an annual total of over 160,000 visitors.

The buildings are supported on 2,500 piles each 10 inches in square cross-section, and driven 14 feet into the lake bottom. Owing to the peculiar nature of the formation, the piles are of unusual stability. To a depth of a few inches the bottom consists of loose or slightly compacted oolitic sand; for two feet or more beneath this is a layer of sand cemented by calcareous matter; then with a thickness of seven or eight feet comes a layer of sodium sulphate—the mirabilite of the mineralogist and the glauber salts of commerce—doubtless precipitated from the lake water during an earlier stage of its history.

In the work of pile-driving it was found to be practically impossible to penetrate this layer of "soda," even with the best steel-pointed instruments. A method at once simple and efficient was adopted. Through pipes, steam under moderate pressure was conveyed to the sodium sulphate bed; the substance dissolved at once, and the driving of piles became easy. Concerning the stability of the piles when driven, Mr. C. W. Miller, manager for the Saltair Beach Company, writes, "After the piling has been allowed to set for twenty-four hours, it is impossible to drive it even a quarter of an inch, though you might hammer the piling until you wore it down." This bed of mirabilite extends for an undetermined though certainly a very considerable area inland, for wherever canals have been cut to a sufficient depth in connection with the salt ponds inshore, the substance has been encountered as a continuous layer, though of varying thickness.

GARFIELD.

The present Garfield Beach resort may be regarded as a development of years, the stages of which were marked by the successful operation of many minor establishments. As early as 1876 a small pavilion and about a hundred bath-rooms were erected at Lake Point—a little less than two miles beyond the site of the existing pavilion, on the line of the Utah and Nevada railway. This enterprise was carried on under railway auspices, at the instance of Hon. W. W. Riter. In 1885 Captain Thomas Douris built a pier, and provided bathing and boating facilities near the present location of Garfield pavilion. A year or so later the railway company constructed bath-rooms at Black Rock. But all of these temporary acommodations were superceded in 1887 by the construction of the commodious pavilion now in service. This comprises two hundred bath-rooms, and ample provisions for promenades and halls. Its original cost was over $70,000, to which may be added nearly half as much more for subsequent improvements. The attendance of pleasure-seekers at the Beach has reached a total of 84,000 in a single year. The resort is on the line of the Utah and Nevada road, which now is operated as a branch of the Oregon Short Line railway.

In driving the piles for Garfield pavilion a layer of sodium sulphate, locally known as "soda," was struck, as already described in connection with the work at Saltair. As the simple method of using steam in penetrating the soda layer was not suggested, steel-shod piles had to be used; and even with such the work was not accomplished without difficulty and high cost.

Attempts have been made to procure a supply of artesian water at Garfield and at Saltair. Pipes have been driven on shore, and into the lake bottom. Good flows are generally struck at a depth of from 100 to 150 feet, but the water is always salty or brackish. All the potable water used at the resorts named is conveyed from a distance.

Beside boating and bathing, the lake offers attractions to the lover of the gun. Wild duck and other water fowl congregate in the brackish water near the mouths of inflowing streams, and on many of the lake islands.

The lake is steadily growing in popularity and favor as a pleasure and health resort. Situated in close proximity to the high roads of trans-continental travel, it is visited every year by multitudes. From the east it is reached by the Union Pacific and the Rio Grande Western railways, and from the west by the Southern Pacific line.

The general purity of the atmosphere, the exhilarating effect of the lake-breezes, the benefits of altitude, and the pleasing climate unite in making the lake region a natural sanitarium. Lovers of pleasure and health-seekers flock to this mountain-girt lake in rapidly increasing numbers every year.

IV.

STATISTICAL AND GENERAL.

It is well known that an enclosed water body, such as a lake devoid of an outlet, is particularly sensitive to climatic changes. Such a lake rises and falls as evaporation increases or diminishes in relation to supply by precipitation. The variations in volume as shown by the shore-records of the Great Salt Lake are unusually large.

The fluctuations in surface area are even greater than would be expected from a study of the variable relations between supply and loss; and this fact is explained by the very gradual inclination of the shores. The entire valley is remarkable for its flatness, as any observer may see for himself if he will climb one of the hills in the vicinity of Salt Lake City; but even more striking is the small increase of water depth as one passes from the lake-shore outward.

A slight rise in the lake level results therefore in a great increase of water surface. As was pointed out by Stansbury, a rise of but a few feet would enable the lake to reclaim a large part of its former domain over what is now the Great Salt Lake Desert.

The writer has conversed with residents of towns near the shore who remember when the water's edge was in places two miles beyond its present line; and the same people are able to point out the ruins of farm fences a mile inland from the present margin, marking the location of fields which were destroyed by the rising waters, and which are now left dry and barren.

We have of ready access two reliable maps of the lake, by comparison of which recent variations in the water area may be demonstrated. The earlier of these is Stansbury's map, based on work done in 1849 and 1850, at which time the lake stood at the lowest level observed by man; and the later map is that prepared under the direction of Clarence King in connection with the field work of the Fortieth Parallel Survey, dated 1869, when the water was approaching the highest stage of recent times. According to the first of these the lake covered 1,750 square miles; the second survey showed an area of 2,170 square miles.

As would be inferred from the foregoing facts, the average depth of the lake is subject to small and slow variations only. On the whole the lake is extremely shallow. In 1850 the greatest depth found was but 36 feet, and the average but 13 feet. Later, the lake rose 10 feet, with a consequent increase of water area through the submergence of the flat shore-borders, but with an increase of average depth not exceeding 5 feet. The maximum depth observed at the highest stage was 49 feet. The average depth of Salt Lake today is probably not more than 15 feet.

The fact that the lake is a closed water body with no out-flowing stream, would indicate the certainty of variations in its volume, unless indeed the improbable chance of a constant balance between the supply furnished by precipitation, and the loss through evaporation were realized. A body of water provided with a channel of ready discharge may maintain a tolerably constant level, the outlet acting as a regulator and permitting the escape of the surplus water; but the level of a lake entirely enclosed will depend, as stated, upon the relation between the supply and the loss through evaporation.

For an undetermined period prior to 1850 or thereabouts, the Salt Lake had been steadily diminishing in volume. For ten or fifteen years after the time named the water oscillated with a tendency to rise; then it rose rapidly and reached its maximum height in the course of this increase of volume about 1872 or 1874. Although it is now sinking year by year, it has not yet reached its low level of 1850.

Antelope Island, one of the land bodies of the lake, is connected by a bar with the delta of the Jordan River; this bar is now under water at a depth of 3 to 8 feet. Fremont records that on August 13, 1845, he rode across the bar to Antelope Island, the water being in no part more than 3 feet in depth.*

There is a well-defined and regularly recurring annual oscillation of the lake, marked by a higher water

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* Fremont's "Memoirs" I, p. 431.

level in May and June, and a low stage in the late summer months; but beside this, oscillations of wider duration are known to occur. A combination of evidence from many sources points to the following facts; they are presented in Gilbert's words:

"From 1847 to 1850 the bar was very dry during the low stage of each winter, and in summer covered by not more than 20 inches of water. Then began a rise which continued until 1855 or 1856. At that time a horseman could with difficulty ford in winter, but all communication was by boat in summer. Then the water fell for a series of years, until in 1860 and 1861 the bar was again dry in winter. The spring of 1862 was marked by an unusual fall of rain and snow, whereby the streams were greatly flooded and the lake surface was raised several feet. In subsequent years the rise continued, until in 1865 the ford became impassable. According to Mr. Miller, the rise was somewhat rapid until 1868, from which date until the establishment of the guages, there occurred only minor fluctuations."*

A bar connecting Stansbury Island with the mainland was dry in 1850. Since the rise of the lake in or about 1865, the bar has never been entirely above water, though at present it is fordable during the entire year. The islands have been used as herd grounds by the inhabitants of Salt Lake Valley, the cattle being trans-

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* "Lake Bonneville," p. 240; "Lands of the Arid Regions," ch. iv.

ferred from the shore or back during the low water periods. The Stansbury bar is 7 feet higher than the bar running to Antelope Island.

These fluctuations, while surprisingly great when placed in comparison with ordinary lake oscillations, are trifling as compared with the great variations in volume which marked the stages of Bonneville history. We observe current changes actually in progress, while the variations of earlier times we can but picture in imagination.

The aridity of the Great Basin is due to the very small precipitation of moisture and to the great evaporation resulting from the high temperature. Humid air currents traveling eastward from the Pacific suffer a condensation of their vapor before reaching the Basin; when they arrive their condition is changed to that of drying winds.

An estimate of the energy of the evaporation process may be made as follows: The preparation of salt from the lake water constitutes at present an important industry. In the process of manufacture, the lake brine is pumped into elevated conduits through which it is conveyed to large ponds; in the ponds it evaporates without artifical heat. The pond area, the pump discharge per hour, and the length of time during which the pumps have to be operated in order to keep the water at the same level in the ponds, may all be determined. From the official reports of one of the salt companies, it is learned that their ponds cover 971 acres; that the pumps discharge 14,000 gallons of water per minute, and that when the ponds have been filled, it is necessary to operate the pumps to their full capacity from ten to twelve hours daily during the summer months in order to maintain the level. Making allowance at the start, as a guard against over-estimate, let us assume that the evaporating surface of the ponds is 1,000 acres in area. At the rate of 14,000 gallons per minute, 8,400,000 gallons would be delivered in ten hours. This represents the loss by evaporation per day of 24 hours. Considering the lake surface to be 2,125 square miles—the usually accepted area—the rate of evaporation shown above would indicate a daily removal from the lake of 11,424,000,000 gallons of water, or 342,720,000,000 gallons per month of 30 days. The weight of the water so lifted is 95,447,916 tons per day or 2,863, 437,500 tons per month. The same high rate of evaporation continues through at least three months of the year. The estimate here indulged in is founded on the unproved supposition that the rate of loss is the same over the deep parts of the lake body as from the shallow pond waters; it is evident indeed that such cannot be the case; but even if the numbers would more nearly represent the truth when halved, quartered, or divided by ten, the result is sufficiently astounding.

As is now generally known, there has been a notable increase in the water supply of the Salt Lake valley, and indeed of the entire Basin Region, within the period of human occupancy. The supply keeps ahead of the demands of the growing population. By way of example, I cite the following items of traditional history, for which information I am indebted to the Historian's Office, Salt Lake City: Between 1850 and 1860 the site of the present town of Kaysville was first occupied for habitation. For years after the time of first settlement, a dozen families composed the entire population, and the settlers were loath to welcome additions to their numbers, owing to scarcity of water. The tiny creek on the banks of which the diminutive and scattered village had been established, scarcely furnished water enough for the irrigation of the few small farms owned by the settlers. Kaysville now is a thriving little town with a population of over 1,800. Similar conditions have prevailed in the history of other towns on the lake margin. Forty-five years ago ten families composed the population of Farmington and fourteen that of Bountiful. These places are at present prosperous towns, the first with over a thousand inhabitants, the second supporting over 2,500 souls. The prevailing pursuit of the people is agriculture, and water is needed for every farm. Yet there is enough and to spare, and additions to the farming population are regarded as desirable.

To account for this remarkable increase in the water supply, numerous theories have been proposed, most of them meeting with temporary favor, soon to be lost. Of such theories three are generally current; these are called respectively, the volcanic theory, the climatic theory, and the theory of human agencies.*

The volcanic theory supposes the increase to be merely an apparent rise in the lake volume, and this is ascribed to orogenic disturbances whereby the lake bottom has been deformed, and the water caused to recede from some parts and to overflow others. The hypothesis is untenable in the light of the fact that the elevation of lake level is real, indicating an actual increase in the water volume. The water has risen along the entire shore line. On the islands and along the mainland margin old storm lines are now submerged, and everywhere the shore has been transferred inland. Independent observation confirms the belief that the rising of the lake is due to an increase in the water supply of the entire hydrographic basin, for the streams have all grown in volume to a degree commensurate with the lake growth. The water body not only rose with comparative rapidity above a height which for an indefinite period had marked its maximum limit, but it maintained its higher level for more than a decade; and such a condition is not explicable on the supposition of a simple deformation of the bed. With reference to the general and actual rising of the water in opposition to

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* "Lands of the Arid Regions," p. 67.

any supposed increase which is apparent only, I quote from the "Lands of the Arid Regions," page 67:

"The farmers of the eastern and southern margins have lost pastures and meadows by submergence. At the north, Bear River Bay has advanced several miles upon the land. At the west, a boat has recently sailed a number of miles across tracts that were traversed by Captain Stansbury's land parties. That officer has described and mapped Strong's Knob and Stansbury Island as peninsulas, but they have since become islands. Antelope Island is no longer accessible by ford, and Egg Island, the nesting ground of the gulls and pelicans, has become a reef. Springs that supplied Captain Stansbury with fresh water near Promontory Point are now submerged and inaccessible; and other springs have been covered on the shores of Antelope, Stansbury, and Fremont Islands."

The climatic theory refers the phenomenon of increase to a permanent change in the conditions controlling precipitation and evaporation within the drainage basin. While the recorded observations of rainfall are few, an actual increase in precipitation is indicated. An increase of less than ten per cent would probably account for the observed phenomena, and the influence of climatic change appears to be a probable explanation, in part at least, of the greater supply.

Major Powell has advocated the claim of the theory of human agency. By the cultivation of the land, and the deforesting of the hill slopes, man favors the rapid removal of the precipitated moisture through the increase of stream volume. Well covered soil retains the moisture whether it falls as rain or as snow, and in time returns it to the atmosphere through the medium of evaporation. The more completely the precipitated water is so held, the less reaches the lake through stream discharge; and conversely, as the streams are augmented the lake rises. Considering the theory of climatic change and that of human agency as the two hypotheses most worthy of credence, the writer of chapter iv of "Lands of the Arid Regions," says:

"On the whole, it may be most wise to hold the question an open one whether the water supply of the lake has been increased by a climatic change or by human agency. So far as we now know, neither theory is inconsistent with the facts, and it is possible that the truth includes both. The former appeals to a cause that may perhaps be adequate, but is not independently known to exist. The latter appeals to causes known to exist, but quantitatively undetermined. It is gratifying to turn to the economic bearings of the question, for the theories best sustained by facts are those most flattering to the agricultural future of the Arid Region. If the filling of the streams and the rising of the lake were due to a transient extreme of climate, that extreme would be followed by the return to a mean condition, or perhaps by an oscillation in the opposite direction, and a large share of the fields now productive would be stricken by drought and returned to the desert. If the increase of water supply is due to a progressive change of climate forming part of a long cycle, it is practically permanent, and future changes are more likely to be in the same advantageous direction than in the opposite. The lands now reclaimed are assured for years to come, and there is every encouragement for the work of utilizing the existing streams to the utmost. And finally, if the increase of water supply is due to the changes wrought by the industries of the white man, the prospect is even better."

As has been stated, the lake is now steadily decreasing in volume. This cannot be regarded as evidence of a turn in the series of climatic changes toward a state of increasing aridity, nor as proof of less potent human influences. As population grows, the area of land brought under cultivation enlarges very rapidly, and many of the streams, which but a few years ago made important contributions to the lake volume, now send but an insignificant tribute; and in other instances the stream channels below the uplands are entirely dry during the greater part of the year. There is little ground for doubt that in the near future even the flood season contributions of water will be practically cut off, for the increasing demands of the growing irrigation system will compel the construction of artificial reservoirs in the upper stream regions, and thus the water will be stored for subsequent distribution upon the land.

The geological evidence of a former desiccation of the lake is conclusive, and the industrial energy of man is assuredly contributing in a very effective manner to the process of present shrinkage; but that the desiccation shall again reach completion in the near future is by no means certain. As the lake surface diminishes, the area exposed to solar evaporation is lessened, and a level may be reached at which the loss by evaporation will be more nearly met by the stream supply.

V.

THE LAKE WATER.

The variation in volume and the consequent oscillations in level characterizing a lake without outlet, and the particularly striking example of such afforded by the Great Salt Lake have been already referred to. As shown by geological investigation, the lake has shrunk, from a level approximately 600 feet above the present surface to its existing volume, by desiccation alone. Thus through long ages the solid matter leached from rock and soil and carried into the lake by streams has been undergoing concentration, until the water has reached its present condition of unusual density. Analyses of samples of lake water collected at times of high and low level show great variations in dissolved solids, and these variations are of course approximately commensurate with the fluctuations in volume.

The first recorded determination of the solids dissolved in the lake water is that of Dr. L. D. Gale, published in Stansbury's report. Gale's results together with those of later examinations are presented here.*

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* For compilation of analyses of Salt Lake water with a discussion of the same, see Monograph I., U. S. Geological Survey,—"Lake Bonneville," by G. K. Gilbert, pp. 252-254.

Solid contents and specific gravity of water taken from the Great Salt Lake:

		Total Solids.		
Date of Collection.	*Specific Gravity.*	*Per cent by weight.*	*Grams per litre of sample.*	*Authority.*
1850	1.170	22.282	260.69	L. D. Gale.
1869 (summer)	1.111	14.9934	166.57	O. D. Allen.
August, 1873	1.102	13.42	147.88	H. Bassett.
December, 1885	1.1225	16.7162	187.65	J. E. Talmage.
February, 1888	1.1261	———	———	" " "
June, 1889	1.148	———	———	" " "
August, 1889	1.1569	19.5576	226.263	" " "
August, 1892	1.156	20.51	238.12	E. Waller.
September, 1892	1.1679	21.47	250.75	J. E. Talmage.
1893	———	20.05	———	J. T. Kingsbury.
December, 1894	1.1538	21.16	244.144	J. E. Talmage.
May, 1895	1.1583	21.39	247.760	" " "
June, 1900	1.1576	20.90	241.98	H. N, McCoy and[*] Thomas Hadley.

The difference existing between the writer's results from the sample collected September 1892, and those obtained by Waller on a sample taken during the preceding month, is greater than would be expected from the progressive concentration during so short an interval. It is more likely due to an actual difference between the samples, they probably having been taken from different parts of the lake.

The statements most commonly current regarding the solid contents of the lake water are based on the earliest examination by Gale. In 1889[†] the present writer protested against this excessive estimate of average composition, as at that time the lake was and for

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[*] Specific gravity determined by Dr. McCoy; total solids by Mr. Hadley.

[†] "The Waters of the Great Salt Lake," by J. E. Talmage, Science (New York), December, 1889; vol xiv,, pp. 444—446.

many years preceding had been at a relatively high level and of corresponding dilution. The opinion was then expressed that "it would be more correct to quote the average contents of the Salt Lake water at sixteen per cent solid matters, than at twenty-two per cent" as was at that time most commonly done. It was pointed out however that the lake was then undergoing a process of rapid shrinkage, and the inference is plain that the proportion of total solids was correspondingly increasing. At the present time (June, 1900) the water has not yet reached the degree of richness chronicled by Dr. Gale. It would appear safe to say that the average of solid matter dissolved is about twenty-one per cent by weight at present.

Inasmuch as solids dissolved in natural water are frequently expressed in terms of grains per gallon, it may be interesting to transform some of the foregoing readings into the more common expressions. Let it be remembered that 10 grains of solid matter to the imperial gallon is the equivalent of .014 per cent by weight. The mean of the writer's analyses quoted above of samples taken in December 1885, (16.7162 per cent solids) and in August 1889, (19.5576 per cent) is 18.1369 per cent; this corresponds to 11,777.64 grains per gallon. For convenience of comparison these results are given below in connection with the results of analyses of other waters, potable and mineral, from Utah and other places. The gallon here referred to is the imperial gallon, containing 277.27 cubic inches; such a measure of pure water at the temperature of 62 degrees F. weighs 10 pounds avoirdupois, or 70,000 grains.*

Source.	*Total Solids expressed in grains per gallon.*	*Authority.*
River Loka, Sweden	0.05	Wells.
Boston, U. S., Waterworks	1.22	Johnston.
Loch Katrine, Scotland	2.3	Wanklyn.
Schuylkill River at Philadelphia	4.26	Johnston.
Detroit River, Michigan	5.72	“
Ohio River at Cincinnati	6.74	“
Loire at Orleans	9.38	“
Danube, near Vienna	9.87	“
Lake Geneva	10.64	“
River Rhine at Basel	11.8	Wanklyn.
Thames at London	18.5	“
Average of 12 artesian wells, Provo, Utah	18.6	J. E. Talmage.
Salt Lake City supply	16.92	“
Spring water, Provo, Utah	23.3	“
Formation Springs, Idaho	27.8	“
Octagon Spring, at Soda Springs, Idaho	126.66	“
Well water, Gunnison, Utah	148.01	“
“Ninety per cent Spring,” at Soda Springs. Idaho	198.41	“
Warm Springs, Spanish Fork Canyon, Utah	413.72	“
Atlantic Ocean	2,688,00	Wanklyn.
Salt Lake	11,777.64	J. E. Talmage.
Dead Sea	17,064.42	“

As comparisons between the Great Salt Lake and the Dead Sea are common, the two lakes representing the highest known condition of natural concentration in large water bodies, the content of solid matter in the

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* See "Domestic Science," by J. E. Talmage, second edition, p. 200—201; George Q. Cannon & Sons' Co., Salt Lake City, 1892.

Dead Sea water is of interest in the present connection. It must be remembered, however, that great discrepancy exists among published accounts of the composition of this water. Bernan gives 14,025.48 grains per gallon; Captain Lynch collected a sample at a depth of 1,110 feet, and found it to contain 18,902 grains per gallon. The amount given in the foregoing statement, (17,064.42 grains per gallon) was determined by the author in a sample taken from the Dead Sea in April 1886, by Dr. J. M. Tanner.

The composition of the solid matter existing in the lake water is a subject of importance. Some results of analyses are here given:

Analyses of Salt Lake water, acids and bases theoretically combined; expressed in percentage of weight of samples:—

	Gale.	*Allen.*	*Bassett.*	*Talmage.*	
	1850.	*1869.*	*1873.*	*1885.*	*1889.*
Sodium chloride.	20.20	11.86	8.85	13.586	15.743
Sodium sulphate	1.83	0.93	1.09	1.421	1.050
Magnesium chloride..	0.25	1.49	1.19	1.129	2.011
Calcium sulphate........................	......	0.09	0.20	0.148	0.279
Potassium sulphate.................	......	0.53	....	0.432	0.474
Potassium chloride.....................	......	......	1.89	......	......
Excess of chlorine......................	......	......	0.20	.....	......
Total.............................	22.28	14.99	13.42	16.716	19.557

Allen reports traces of boric and phosphoric acids. Lithia is also present in quantities sufficient to give the spectroscopic effect with little difficulty.

In the analyses given on the authority of the writer, the data represent in most instances averages of several determinations.

One of the most comprehensive of the analyses published is that by E. Waller, giving the results of examination on a sample collected August 9, 1892.* The report is as follows:

Analysis of a sample of the water of Great Salt Lake collected August 9, 1892.

[Expressed in grams per litre; Specific Gravity, 1.156]

Elements and Radicals.		Probable Combination.	
Sodium	75.825	Sodium chloride NaCl	192.860
Potassium	3.925	Potassium sulphate K_2SO_4	8.756
Lithium	0.021	Lithium sulphate, Li_2SO_4	0.166
Magnesium	4.844	Magnesium chloride, $MgCl_2$	15.044
Calcium	2.424	Magnesium sulphate, $MgSO_4$	5.216
Chlorine	128.278	Calcium sulphate, $CaSO_4$	8.240
Sulphur trioxide	12.522	Ferric and aluminium oxides $Fe_2O_3 + Al_2O_3$	0.004
Oxygen in sulphates	2.494		
Ferric oxide and aluminium oxide	0.004	Silica, SiO_2	0,018
Silica	0.018	Surplus sulphur trioxide, SO_3	0.051
Boron oxide	Trace	Total	230.355
Bromine	Faint trace	Total solids by evaporation	238.12
		Total solids [duplicate]	237.925

The most striking discrepancy between the results of Waller's analysis and those recorded in the table on page 59, is the absence of sodium sulphate in the list of probable combinations presented by Waller, and the presence of this substance in every other analysis herein recorded. As is generally understood, an ultimate

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* See "School of Mines Quarterly" (Columbia College, New York,) vol. 14, 1892, p. 58. Quoted with approving comment by I. C. Russell in "Lakes of North America," Boston, 1895, p. 81.

chemical analysis gives the proportions of elements and radicals present; the combinations of these into definite salts, etc., is attended with some uncertainty as to accuracy. Waller has evidently combined all the sodium with chlorine, as sodium chloride or common salt, which certainly is the most abundant substance in the solid residue yielded by the lake water. Nevertheless sodium sulphate is known to exist in the lake brine, for, as shall be hereafter shown, a copious precipitation of the sulphate occurs whenever the water falls to a certain critical degree of low temperature. It is safe to say that many thousands of tons of the substance are deposited, some of it thrown by wave action upon the shores, in the course of every cold winter. And that an abundant deposition of sodium sulphate has taken place during a prior period of lake history has been already affirmed on the conclusive evidence afforded by the thick bed of the substance encountered in the driving of piles at Saltair and Garfield and in the cutting of canals on the neighboring shore lands. (See pp. 39,41) Gilbert estimates the quantity of sodium sulphate contained in the lake water at thirty millions of tons.*

The source of the solid matter contained in natural waters is found to be the rock and soil through which the water passes, either by downward percolation and flow, or by upward passage under pressure. If such rocks

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* "Lake Bonneville," Monograph I, U. S. G. S., 1890; p. 253.

supply alkaline chlorides in excess, the evaporation of the water so charged will yield salt; if alkaline carbonates be the principal substances dissolved out from the rocks, alkaline residues will result from evaporation. It is evident that the streams supplying Great Salt Lake have traversed salt-bearing formations.

* * *

The composition of the waters flowing into the lake presents itself as a subject of interest in this connection. The streams from the Wasatch and Uintah mountains, which constitute the greater part of the lake supply, while carrying in solution nearly double the quantity of dissolved solids usually present in river water, (due rather to the unusual evaporation from their surface incident to the arid conditions than to more active solution from the rocks) give nevertheless no indication of mineral contents to the taste or other senses. Analyses of the principal waters supplying the lake give an average of about 0.2446 part of dissolved mineral solids per thousand.

Beside the rivers and creeks from the adjacent mountains, the lake has other sources of supply from fissure springs, which open at points on the shore or on the bottom. Few of these springs are markedly saline, and but one is known to be excessively so. Their content of salt is probably derived from the former sediments of the region.

It is estimated that the combined waters from surface streams and springs would probably contain less than double the percentage of solids held by the surface streams alone. Prof. Russell's assumption* is, that on the evidence now within reach, the combined spring and stream waters supplying the lake contain about 0.3 part solid matter in a thousand, or three one-hundredths of one per cent. Such a proportion of mineral matter, even if wholly common salt, would not reveal itself to the taste; and it is safe therefore to conclude that but for the concentrating effect of evaporation the lake would belong to the category of fresh-water bodies.

The enormous quantity of saline matter held in this lake of brine affords a striking example of the effect of concentration long continued. As stated, few of the inflowing streams are rich in salt. The Malad river is an exception; in its lower part this stream becomes brackish from the contributions of saline springs.

The evaporation, which has been in uninterrupted progress for ages past, has produced a nearly saturated brine. Along the lake margins, in partly-isolated areas, the shallow water has already begun to deposit salt; but in the open lake the water yet holds its salt in permanent solution. Russell records that in 1880 the water

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* "Lakes of North America, p." 82,

between Stansbury Island and the mainland was floored by a glistening pavement of salt, strong enough to support a horse and rider over the greater part of the area. It is evident that the Salt Lake, while approaching a degree of concentration equal to that of 1850, has not yet become a thoroughly saturated brine. Nevertheless, at low temperatures an abundant precipitation of sodium sulphate occurs, as already stated. During the winter season, as the temperature sinks below a critical point, somewhere near the freezing point of fresh water, the sulphate separates from the water in the crystallized form as Mirabilite. As the separation takes place, the lake water becomes opalescent. Much of the precipitate is heaped upon the shore by wave action; and under particularly favorable conditions the shore deposit is over a foot in depth. When the water is warmed to the critical point of temperature, the crystalline substance is rapidly re-dissolved. Clusters of large and perfectly formed crystals may be found during cold weather on the posts supporting the bath houses, and on other stationary solid objects submerged in the lake.

The analytical data given show that the lake water is a concentrated brine, with sodium chloride greatly predominating, and with magnesium chloride and sodium sulphate existing also in large proportions. Most of the saline lakes of the Great Basin hold alkaline and earthy carbonates in solution, and the absence of such from the Salt Lake water has been a subject of much comment. In this respect the Salt Lake compares closely with the Dead Sea, though widely differing in other respects, notably in the predominance of sodium over magnesium salts. The sulphates delivered to the lake by the contributing streams remain in solution, except, as specified, at low temperatures. Calcium carbonate, however, is precipitated as soon as the stream-water which carries it reaches its briny receptacle. A similar phenomenon is observed in the calareous sediments at the mouths of many rivers.

The calcium carbonate which analysis proves to exist in no inconsiderable quantity in most of the inflowing streams, and which diligent search has thus far failed to reveal in the lake water, is accounted for by the accumulation of calcareous particles along portions of the shore, particularly at the southern extremity. This material, commonly known as oolitic sand, is found in spherules, ranging between the size of No. 10 and No. 8 shot. By wave action it is drifted upon the shore and in some places it constitutes dunes several yards in depth. The fact that it is confined to the shore suggests the possibility of the rounded form being the result of rolling. The globular bodies possess a concentric structure, and in many cases a nucleus of silica is detectable. Dr. A. Rothpletz has advanced the theory that the ooliths of the Salt Lake are a product of the algae which exist along the shores. He claims that the stones are generally covered with colonies of Glaeocapsa and Gloeothecae, which organisms are known to excrete calcium carbonate; and he holds that most of the marine ooliths, at least those characterized by concentric and radial structure, are the products of lime-excreting schizophytes.* Rothpletz's views have not been generally approved. While the oolitic sand is the only abundant shore accumulation of calcium carbonate, it is probable that a marly deposit is forming with other lake sediments in the deeper parts.

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* Botanisches Centralblatt, 1892, p. 35.

VI.

LIFE IN THE LAKE.*

The popular literature of the day persists in asserting that no living thing exists or can exist in the dense brine of the Great Salt Lake. There is little excuse for the perpetuation of such an error; yet cyclopedias and school geographies and magazines continue to reiterate the false statements. It is readily seen that the conditions prevailing in the lake are not favorable to the existence of the ordinary aquatic forms of life; and that cases of adaptation to life in the brine would naturally be rare.

Of animals but few species have been found in the lake, but of these few two are represented by swarming numbers. Among the animal forms already reported as common to the lake, the writer has confirmed the presence of four:—(1) *Artemia fertilis*, Verril; (2) the larvae of one of the Tipulidae, probably *Chironomus oceanicus*, Packard; (3) a species of Corixa, probably *Corixa decolor*, Uhler; (4) larvae and pupae of a fly, *Ephydra gracilis*, Packard.

The larvae of the *Ephydra* are found in abundance amongst the algae that strew the shores or appear as surface patches in the shallow parts; while the mature

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* A portion of the matter presented under this sub-title has already appeared as an article by the writer in "The American Monthly Microscopical Journal," vol. 13, pp. 284-286.

insects, as small black flies, swarm along the shores where conditions have proved favorable for their development. The larvae of the tipula may be taken anywhere near shore during the warm months; and the pupa cases of both species are often washed ashore in great numbers, where they undergo decomposition with disagreeable emanations.

Of the lake animals, the *Artemia fertilis* (or *Artemia gracilis*) commonly known as the brine shrimp, exists in greatest numbers. They are tiny crustaceans, seldom exceeding one-third inch extreme length. They may be found in the lake at all seasons, though they are most numerous between May and October. I have taken them in the midst of winter, when the temperature of the water was far below freezing point; it will be remembered that the concentrated brine of the lake never freezes. The females greatly preponderate; in fact, during the colder months it is almost impossible to find a male. In the latter part of the summer the females are laden with eggs, from four to sixteen having been repeatedly counted in the egg pouch. The males are readily recognized by the very large claspers upon the head. (See plate XII). The shrimps are found near shore during calm weather, but rain or wind drives them into the lake. At times they congregate in such numbers as to tint the water over wide areas.

They are capable of adapting themselves to great variation in the composition of the water, as must necessarily be the case with any tenant of the Salt Lake. I have specimens of the artemiae gathered from the lake in September 1892, and the water then taken showed on ananlyses, 14,623.23 grains of dissolved solids to the imperial gallon, the greater part of this being salt. Indeed, I have captured the creatures in the evaporating ponds of the salt works, where the brine was near its point of saturation.

It is not difficult to accustom them to a diluted medium; I have kept them alive for days in lake water diluted with 25, 50, 80 and 90 per cent fresh water, and from eight to eighteen hours in fresh water only. Of course the changes from brine to fresh water were made gradually, though a sudden transfer from the lake brine to fresh water or even to distilled water is not followed by speedy death. On the contrary, the creatures live for hours after such sudden change, with few signs of discomfort or inconvenience except their inability to rise in the water of low density.

The ability of the shrimps to withstand the effects of rapid dilution of the medium is surprising if we assume that their tissues are ordinarily impregnated with the salt of the lake brine. The violent osmosis between the dense fluids of the tissues and the fresh water without would appear to insure disruption. It is possible, however, that the tissues do not absorb the brine in its entirety; indeed, if the shrimps just taken from the lake be subjected to a single quick rinsing with fresh water, they are but slightly salty to the taste.

During a cruise upon the lake in September 1892, our party found the crustaceans swarming in the open water. When near the middle of the lake, with a small tow-net we gathered a quart of the shrimps in the course of a few minutes. Thereupon we resolved upon an experiment the subsequent recital of which has shocked the gastronomic sensibilities of many friends. Reasoning that the bodies of the artemiae are composed largely of chitin, we concluded that the question of their palatability was at least worthy of investigation. By a simple rinsing with fresh water the excess of lake brine was removed, after which the shrimps were cooked with no accompaniments save a little butter and a suggestion of pepper. They were actually delicious. If the shrimps could be caught and preserved in quantity, I doubt not they would soon be classed as an epicurean delicacy. Repeated washings for five minutes removed the brine so completely that salt had to be added to make the dish palatable.

As to their food—in captivity they live upon meat, bread, or vegetables, in fact upon almost anything in the nature of food; and they are not slow in attacking the bodies of their own dead. In the lake they probably subsist upon the organic particles brought down by rivers, upon the algae which flourish about the shores, and upon the larvae and pupae of the insects tenanting the water.

The mounting of specimens of the brine shrimp for permanent microscopical use requires considerable care and some modification of the ordinary procedure. Most of the common mounting media cause the delicate structure to become distorted, or produce such a degree of transparency as to render the object invisible. A method which has given the writer good results consists in mounting the specimen in a preparation of lake brine with corrosive sublimate and an alcoholic solution of carbolic acid. To this fluid, placed upon the slide, the living artemia is transferred directly from the lake brine; the creature dies quickly, and in so doing spreads itself most perfectly. While objects so prepared are of admirable arrangement and definition as temporary mounts, the structure is liable to break down after a lapse of months.

A better permanent result may be secured as follows: Place the artemiae in Peryeni's fluid; they will be quickly killed, and will be hardened by the action of the fluid in from 12 to 20 hours. They should then be transfered to alcohol, the strength of which should be increased by degrees, beginning with 40 per cent and running to 95 per cent. The structure will take some of the analine stains quite readily; it may then be carried through absolute alcohol with phenol, then through phenol and turpentine, and be permanently mounted in balsam.

In point of zoological classification it may be said that the brine shrimp is a crustacean, and is generally referred to the order *Phyllopoda* one of the divisions of the sub-class *Entomostraca*. In all phyllopods except those of the highest family of the order, a carapax covers the greater part of the body. To this highest family—the *Branchipodidae* the artemia belongs.

The *Artemia* is distinguished from a nearly allied form, the *Branchinecta* in the following particulars: *Artemia* possesses eight abdominal segments; the second pair of antennae or claspers, which are highly developed in the male, are flat and of triangular shape in the second joint; the ovisac of the female is short. *Branchinecta* has nine segments composing the abdomen; the claspers are simple and cylindrical; the ovisac is long and slender.

Commenting on the structural and other relations between these two forms,* Prof. J. S. Kingsley says: "Under ordinary circumstances these [differences] would be considered as of generic value; but what shall we say when we know the results of the observations and experiments of the Russian naturalist, Vladimir Sch-

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* Riverside Natural History, vol ii,, pp. 40-41.

wankewitsch? Condensed from his account these were as follows: In 1871 the spring flood broke down the barriers separating the two different lakes of the salt-works near Odessa, diluting the water in the lower portion to 8 degrees Baume, and also introducing into it a large number of the brine shrimp, *Artemia salina*. After the restoration of the embankment the water rapidly increased in density, until in September 1874, it reached 25 degrees of Beame's scale and began to deposit salt. With this increase in density a gradual change was noticed in the characters of the artemiae, until late in the summer of 1874, forms were produced which had all the characters of a supposed distinct species, *Artemia muehlausenii*. The reverse experiment was then tried. A small quantity of the water was gradually diluted, and though conducted for only a few weeks, a change in the direction of *Artemia salina* was very apparent.

"Led by these experiments he tried still others: Taking *Artemia salina*, which lives in brine of moderate strength, he gradually diluted the water, and obtained as a result a form which is known as *Branchinecta shaefferi*, the last segment of the abdomen having become divided into two. Nor is this change produced by artificial means alone. The salt pools near Odessa, after a number of years of continued washing, became converted into fresh water pools, and with the gradual change in character, *Artemia salina* produces first a species known as *Branchinecta spinosus*, and at a still lower density *Branchinecta ferox*, and another species described as *Branchinecta medius*."

Observations on the artemiae of the Salt Lake under conditions of slow increase or decrease of the brine density indicate the occurrence of changes in structure, but no long continued experiments of conclusive results have been reported.

The artemia is interesting to the zoologist as furnishing an example of parthenogenesis, i. e., reproduction by means of unfertilized eggs. Siebold of Munich has investigated this subject, and he announces that with the entomostracans, *Apus* and *Artemia*, this parthenogenic reproduction is common. He reared several broods composed entirely of females; yet from these, eggs were produced which hatched vigorous young. Packard treats parthenogenesis as a modified process of reproduction by budding.

The eggs of the artemia are capable of sustaining long continued drought without losing their vitality. Eggs have been sent in mud from the Salt Lake to Munich, Germany, where they have been successfully hatched by Siebold. It would be interesting to determine whether the fertilized eggs and those of parthenogenetic origin are of equal vitality under unfavorable conditions. In the light of known facts concerning reproduction among other forms, it would be reasonable to expect that unfertilized eggs would prove less able to withstand vicissitude.

The following remarks by Gilbert* regarding the brine shrimp are of interest: "Packard ascribes the phenomenal abundance of the *Artemia* to the absence of enemies, for the brine sustains no carnivorous species of any sort. The genus is not known to live in fresh water or water of feeble salinity, but commonly makes its appearance when feebly saline waters are concentrated by evaporation. It has been ascertained that a European species takes on the characters of another genus, *Branchinecta* when it is bred through a series of generations in brine gradually diluted to freshness; and conversely, that it may be derived from *Branchinecta* by gradual increase in the salinity of the medium. It is found, moreover, that its eggs remain fertile for indefinite periods in the dry condition, so that whatever may have been the history of the climate of the Bonneville Basin, the present occurrence of the *Artemia* involves no mystery. During the Bonneville epoch its ancestors may have lived in the fresh waters of the basin, and during the epoch of extreme desiccation, when the bed of Great Salt Lake assumed the playa condition, and was dry a portion of the year, the persistent fertility of its eggs may have preserved the race. Or, if the playa

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* "Lake Bonneville," p. 259. See also Twelfth Annual Report U. S. Geol. and Geogr. Survey of the Territories, 1883, Part 1, pp. 295-592, particularly pp. 330-334.

condition with its concomitant sedimentation was fatal to the species, it may be that the alternative fresh water form survived in upper lakes and streams of the basin so as to re-stock the lower lake whenever it afforded favorable conditions."

The lake flora has received even less attention than has been bestowed upon its limited fauna. The existence of plant-life in the water is indicated by the abundance of animal life therein, and examination confirms the inference. The shore waters show an extensive vegetable growth, principally, perhaps entirely, of algae. A number of species seem to be indicated from the widely varying colors of the vegetable masses, and three have been recognized. Diatoms have been found in the brackish waters of the playa-pools ashore, and diatomaceous deposits make up part of the old lake beds.

Much has been said at different times as to the possibility of adapting fish to a life in the lake. In the absence of experimental data it would be rash to conjecture; though it would appear unlikely that fish could thrive in such a brine. Yet the fear expressed, that even if fish could be accustomed to the lake water they would starve unless artificially fed, is unfounded, for the waters contain an abundant food supply—crustaceans, insect larvae and pupae, and algae.

The fauna and flora of the Great Salt Lake are subjects inviting thorough investigation.

VII.

ECONOMIC IMPORTANCE OF THE LAKE.

The composition of Salt Lake water is such as to warrant the assurance of the lake becoming a valuable source of useful products. Indeed these briny waters have already begun to yield of their chemic riches, which, as guaged by the standard of human needs, are inexhaustible. The most abundant solids dissolved in the water are sodium chloride (common salt,) magnesium chloride, and sodium sulphate. Of these the first and the last named are easily separable.

The preparation of common salt from the lake water has been carried on since the early settlement of the region. The salt first produced acquired a bad reputation owing to its impurity; but this defect was due to carelessness or ignorance in the process of manufacture. The most primitive method consisted in constructing low dikes along the shore; over these barriers the waves carried large quantities of brine during times of storms, and the water thus imprisoned was allowed to evaporate by solar heat resulting in an abundant yield of impure salt. The evaporating pools were in some instances below the lake level, and little opportunity was given for the removal of the mother liquors after the crystallization of the salt. The brine was allowed to evaporate to dryness, or at best the salt deposit was gathered from the mother liquor with little chance of purification, by draining. The crude product thus obtained contained, of course, all the impurities which ought to have been separated by the removal of the mother liquor. In consequence, Salt Lake salt was in ill favor; it was pronounced unfit for dairy use because it refused to remain properly incorporated with the butter, some of its ingredients appearing as an efflorescence on the surface.

Prior to very recent times, Utah presented an unenviable spectacle by importing salt into this, the richest salt region of earth. Now, however, the refined salt is in demand as one of the best and purest products in the market. A number of large salt-works have been established on the shores of the lake, and the industry is of assured and increasing success.

The most important producers of salt from the lake have been, in the order of their successful operation, the Jeremy Salt Co., the Inland Crystal Salt Co., and the Intermountain Salt Co. The first named has suspended, and the other two are consolidated under the name, Inland Crystal Salt Company. This company is now operating its plant on a large scale, producing all grades of salt from the coarse product used for metallurgical and packing purposes, to the finest table salt. Another establishment, the Saginaw Salt Co., is in business on the east shore, in Davis county, but there crude coarse salt only is produced.

The process of manufacture employed by the Inland Crystal Salt Company is thoroughly efficacious and satisfactory; and as it represents the highest attainment in salt manufacture from natural brine here or elsewhere, and at the same time demonstrates the profits of this important industry in this region, it merits attention.

The lake brine is lifted by means of centrifugal pumps to a height of fourteen feet above lake level; it is then conveyed through flumes to the settling and evaporating ponds which are situated from one to two miles inland. The ponds cover about fourteen hundred acres of land, not all of which, however is in use every season. The pumps pour into the flumes about fourteen thousand gallons of brine per minute, and are kept in operation about ten hours daily during the pumping season of about 150 days beginning usually in March. By the time the ponds have been filled the evaporating season is well advanced, and about the same supply of water is required during the warmer months to maintain a constant level. No accurate record of pumping hours is kept at the plant, the work being regulated so as to maintain the level of the brine in the ponds. Long continued rains, which, however, are of rare occurrence except in the early part of the season, cause a rise in the ponds, and at times necessitate the return of part of the brine to the lake to prevent overflow.

A portion of the pond area is used as a settling basin wherein the water deposits its suspended matters; thence is is conveyed to the evaporating ponds proper. The evaporation is accomplished by solar heat alone. The season lasts about four months during which a layer of salt with an average depth of six inches deposits. This affords a practical yield of about 900 tons to the acre, or at the rate of 150 tons per inch depth per acre. The saline mud forming the pond floor is practically water-tight.

About one-tenth of the amount of brine carried to the ponds is returned to the lake as a mother-liquor after the deposition of the crystals. This frees the salt from most of the magnesium compounds, and from sodium sulphate; it will be remembered that these were the substances which rendered the product of the more primitive methods unfit for use.

The salt harvest begins in late August or early September. Movable rails are laid into the ponds, and the crop is gathered into hand cars. The material is then piled in symmetrically shaped heaps, and, as required is conveyed to the refinery or to the railway for shipment as crude salt.

With the entire pond area in service a yearly crop of over a million tons is possible. For such a supply there has been as yet no adequate demand, and the richest harvest reported for any year is 150,000 tons.

The manager of the plant reports on cost of production as follows: "Common labor is paid for at a rate ranging from $1.50 to $2.00 per day. The expense of manufacture is the cost of pumping the brine from the lake to the harvesting ponds, which, estimating interest on cost of apparatus for pumping, flumes, ponds, etc., is as near as can be estimated 50 cents per ton. In addition to the foregoing the salt after depositing must be harvested and piled, which, under contract costs 25 cents per ton. The coarse salt is sold on the cars at the works at a dollar per ton."

The refining process may be summarized under the follow operations: —

(1.) The crude salt is run through a Hersey drying cylinder, heated by steam.

(2.) The dried salt is subjected to fan action, whereby the fine powder, which includes practically all the objectionable sodium sulphate, is removed.

(3.) The granular salt is then ground to the varying degrees of fineness required for dairy salt, table salt, etc.

The lake salt so prepared is of a particularly high grade of purity; indeed, it challenges comparison with commercial salt from any other source. The company reports analyses showing for the lower grades 98 per cent and for the better kinds 99 per cent sodium chloride. Analyses made by the writer a few years ago showed the following composition of samples procured by purchase in the retail market:

	Refined salt made by the Inland Salt Co. 1889.	*Table salt Inland Salt Company.*	*Coarse salt Jeremy Salt Company.*	*Table salt Jeremy Salt Company.*
Sodium chloride.........	98.407 %	98.121 %	98.101 %	98.300 %
Calcium chloride.........	.371	.311	.322	.345
Calcium sulphate........	.650	.422	.364	.680
Magnesium sulphate..	.030	.022	.021	.042
Moisture	.442	.911	.952	.158
Insoluble matters......	.102	.201	.214	.472
Loss and error......		.012	.026	.003
	100.002	100.000	100.000	100.000

The powder separated by fanning after the drying process affords material for a valuable by-product. This powder consisting mostly of fine salt mixed with sodium sulphate, is worked up with sulphur and is molded into large blocks for use on cattle and stock ranges. The demand for this "cattle-salt" is said to be greater than the supply from the fan-powder alone.

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Common salt is practically the only chemical compound derived from the lake on a commercial scale, though the possibility of obtaining cheaply from the brine an extensive array of chemical products is readily apparent. In the statement of the composition of lake water before given (see page 59) the presence of sodium sulphate is shown. This substance in a prepared state is known as Glauber-salt; as a naturally-occurring mineral it is called Mirabilite.

The deposition of glauber-salt from the brine has been mentioned as a regular winter occurrence. The substance separates in the crystalline condition, and even as found upon the shores where it has been heaped by the waves, it is of a remarkable degree of purity. Very pure samples may be broken off as crystalline aggregates from any submerged support. The following figures represent the averages of the writer's analyses on a number of samples collected from opposite sides of the lake:

	1. *East shore deposit.*	*2.* *West shore deposit.*
Sodium sulphate	43.060	42.325
Sodium chloride	.699	.631
Calcium sulphate	.437	.267
Magnesium sulphate	.025	.018
Water	55.070	55.760
Insoluble matters	.700	.756
Loss and error	.009	.243
	100.000	100.000

For purposes of comparison it should be known that chemically pure Mirabilite consists of anhydrous sodium sulphate, 44.1 per cent, water, 55.9 per cent.

When the temperature falls to the critical point the lake-water rapidly assumes an opalescent appearance from the separation of the sulphate. The substance sinks as a crystalline precipitate, and large quantities are thrown by the waves upon the beach. Under favorable conditions the shore may be covered to a depth of several feet with crystallized mirabilite. On several occasions the writer has waded through the crystalline deposit sinking at every step to the knees.

The substance must be gathered, if at all, soon after the deposit first appears; for if the water reach the critical temperature on the ascending scale, the whole deposit is again taken into solution. The re-solution is a rapid process, a single day sometimes sufficing for the complete disappearance of all the deposit within reach of the waves. Warned by experience, the collectors heap the stuff upon the shores above the lap of the waves; in this situation it is comparatively secure. The work is easily accomplished by the use of horse-drags and scrapers. Large quantities of the mirabilite are yet to be seen in heaps—remaining from the harvesting of years ago. To a depth of a few inches the material effloresces, but within the heaps the hydrous crystalline condition is maintained.

The temperature at which the mirabilite separates has not been accurately determined. That we are concerned with but a small range of temperature is evident from the sudden appearance and disappearance of the solid precipitate as the temperature varies. Gilbert says* that the precipitation begins when the water falls below 20 degrees F. I have reason to believe that the critical temperature is higher than this.

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* "Lake Bonneville," p. 253.

I camped with a party by the lake shore in the early days of January 1895, with the main purpose of ascertaining the temperature of the mirabilite separation; but the weather, which for days prior to our visit had been cold, moderated and soon grew unusually warm. The following observations are incorporated for illustration: January 3, 11 a. m., temperature of water off pier as determined by five thermometers, 35.8 degrees F.; temperature of air in neighborhood, 41 degrees F.; during a period of two hours the temperature of the water as indicated by self-registering instruments, reached a minimum of 35.5 degrees F.; yet the sulphate was then separating and crystals were readily obtained by dredging. On the same day crystals of mirabilite formed on the cord attached to the submerged self-registering thermometer when the instrument recorded 35 degrees F. At the same time large clusters of well-formed crystals were taken from the pavilion posts. During the night of January 3-4, the mirabilite crystals attached to the pier were partly dissolved; the temperature readings recorded were, maximum 37.5 degrees F., minimum 35 degrees F. I believe the critical temperature of the separation to be within a few degrees of the freezing point of fresh water.

At present there is no demand for the mirabilite, and no effort is made to gather it. Should use be found for it however, no fears as to possible insufficiency of supply need be entertained. Even though the enormous amounts cast up by the waves during the winter months prove insufficient, the shallow water near shore could be dredged with profit; and should this fail, recourse may be had to the bed of the material already stored at a moderate depth beneath the lake bottom, and below the recently abandoned bottom now inshore.

The manufacture of sodium carbonate from the mirabilite would seemingly promise rich returns. In the time-honored and efficient Le Blanc process of carbonate preparation, sodium sulphate is first produced from common salt by an expensive treatment with sulpuric acid. That stage of the operation is accomplished by Nature in the lake and the sulphate is thrown up in lavish quantities in a manner favorable for easy collection. The limestone and the coal required for the conversion of the sulphate into carbonate are cheap and of ready access in the region; and in the sodium carbonate market Utah ought to be able to undersell most other producers.

Years ago a sodium carbonate plant was established in Salt Lake City, and an excellent product was obtained. Caustic soda and sodium hyposulphite have also been prepared from the lake water. But the high cost of railway transportation has killed this in common with many other industrial undertakings in this naturally favored region. Sooner or later, however, a market is sure to be found, and the briny waters of Utah's Dead Sea shall then yield their riches to the hand of chemic industry.

VIII.

THE GREAT BASIN.

Great Salt Lake has been mentioned as the largest water body existing in the Great Basin region, and incidentally the Great Basin has been otherwise referred to in the preceding pages. A brief consideration of geographical basins in general, and of the Great Basin in particular may prove of interest.

The term "basin" is employed by the student of earth-science to designate the area comprised in a drainage system, or that which forms a local unit of drainage as a distinct part of a drainage system. Thus the terms "basin" and "drainage area" or "drainage district" are seen to be practically synonymous. A lake basin is a depression in the crust occupied by the waters of a lake, and the expression "hydrographic basin" is applied to the region drained by a river and its tributaries, including the lake, if there be such, in which the waters collect.

In the case of rivers emptying into a lake, if the latter have an outlet the out-flowing stream and the region drained by it below the lake will be included in the hydrographic basin, and if the river reach the sea the drainage basin will extend to the shore. If however, the lake be without an outlet, as long as the loss of water by evaporation be equal to or less than the amount received, so that the lake cannot rise and find an outlet, the hydrographic basin is spoken of as a closed, an interior, or a drainless basin.

The largest closed drainage area in North America is the Great Basin now under consideration. The region to which this name is applied is of outline roughly triangular as indicated on the map. (See plate XIV). It extends about 880 miles in greatest length running east of south and west of north, and 572 miles in extreme width from east to west. The area thus included is about 210,000 square miles, comprising the western half of Utah, the greater part of Nevada, and portions of eastern California, south-eastern Oregon, south-eastern Idaho, and south-western Wyoming. The southern part of the Great Basin has not been definitely serveyed; its approximate outline is indicated by a dotted line on the map.

The name "basin" suggests the typical form of a depression with a well-defined rim, and drainage basins are actually walled in by water-partings, which however may not be of conspicuous height. But the Great Basin is no such single depression, nor is the topography of the region suggestive of the basin structure. The area is characteristically mountainous, presenting a great number of depressions, many of them occupied by lakes; yet the region is a unit from the standpoint of drainage, for it sends no stream beyond its borders, and the removal of water from the surface is wholly due to evaporation. The central part is elevated above the marginal portions, as was shown by the geologists of the Fortieth Parallel Exploration. Summarizing part of the excellent work done by these geologists, Gilbert says:

"The work of this corps covered a belt one hundred miles broad, spanning the Great Basin in its broadest part, and within this belt the Pleistocene lakes were studied, and for the first time approximately mapped. It was shown that the corrugated surface of the Great Basin in this latitude is higher in the middle than at the east and west margins, warranting general subdivision into the Utah Basin, the Nevada Plateau, and the Nevada Basin; that the Utah Basin formerly contained a large lake, Bonneville, extending both north and south beyond the belt of survey; that the Nevada Basin contained a similar lake, Lahontan, likewise exceeding the limits of the belt; and that the valleys of the central plateau held within the belt no less than eight small Pleistocene lakes."*

Captain Bonneville explored part of the Great Basin area in 1833, and his map, while necessarily crude and unreliable as to detail, suggests the existing conditions of interior drainage. To Fremont,† however, belongs the credit of having first clearly shown the true char-

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* "Lake Bonneville," by G. K. Gilbert, p, 17. For citations made above see Geological Exploration of the 40th Parallel; Vols. I and II. Washington, 1877, 1878.

† "Report of the Exploring Expedition to the Rocky Mountains in the year 1842," etc., by Brevet-Captain J. C. Fremont. Washington, 1845.

acter of the region with respect to drainage, and by him the name "Great Basin" was first applied.

Our present knowledge of the Basin region rests on the work of Fremont just cited, and that of Stansbury in 1850, Simpson in 1859, the parties in charge of the 40th Parallel Survey and the Survey West of the 100th Meridian, and the labors of the Great Basin division of the U. S. Geological Survey as at present constituted.

A glance at the map shows that the closed area of the Basin is bounded by the drainage district of the Columbia river on the north, by Colorado river drainage on the east, and by Pacific drainage on the west. While this is by far the largest closed drainage basin in North America, eight times greater indeed than the estimated area of all other closed basins of the United States combined, it must be remembered that "North America as compared with other continents is not characterized by interior drainage. According to data compiled by Murray, the closed basins in Australia aggregate 52 per cent of its area, those of Africa 31 per cent, of Eurasia 28 per cent, of South America 7.2 per cent, of North America 3.2 per cent. The Great Basin is great only in comparison with similar districts of our own continent. The interior district of the Argentine Republic is half as large again, and that of central Australia exceeds the Great Basin seven times. Sahara exceeds it sixteen times, and the interior district of Asia twenty-three times."*

Most of the existing lakes within the Basin area are alkaline or salt; though a few having outlets to lower levels are fresh. Among the fresh water-bodies are Utah Lake, which sends the Jordan River to Great Salt Lake; Bear Lake discharging through Bear River into Salt Lake, and Lake Tahoe, the "gem of the Sierras," which overflows through Truckee canyon into Pyramid and Winnemucca lakes, 2,400 feet below. Among the salt and alkaline lakes of the Basin are Great Salt Lake and Sevier Lake in Utah; Soda, Walker, Winnemucca, and Pyramid Lakes in Nevada; Albert Lake, Oregon. Mono Lake and Owen's Lake, California.

The term "saline lakes" is used in a generic sense and includes both salt and alkaline lakes. There are two principal ways by which saline lakes may be formed:— (1.) By the isolation of a part of the sea, as for example by the cutting off of bays, or by the elevation of a portion of the ocean floor, carrying up sea-water in the depressions. (2.) By the accumulation of river or spring water in depressions without outlet, with concentration of the water by evaporation. Lakes resulting from the first process may be said to be of

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* "Lake Bonneville;" p. 12. For citations from Murray see Scottish Geog. Mag. vol. III, pp. 65-77.

oceanic origin; then those of the other class are of terrestrial origin.

Saline lakes of oceanic origin are of necessity salt; those of the terrestrial type are salt or alkaline according to the predominating minerals washed from the rocks and accumulated by evaporation. Alkaline chlorides produce salt lakes, and alkaline carbonates result in alkaline lakes. Alkaline lakes are relatively rare, though notable occurrences of the sort characterize the Great Basin. The California lakes, Mono and Owen, are perhaps the best examples; they both contain considerable quantities of sodium carbonate together with other carbonates and some salt. Borax lakes also occur in California and Nevada.

But whatever may be the nature of the dissolved solids, the lake will not become saline unless it is entirely enclosed, so that its loss of water by evaporation exceeds its supply. Should the water supply of a saline lake increase, as by climatic changes, the lake will rise, and if the process continue will find an outlet and in time be rinsed out, thus becoming a fresh-water body.

The aridity of the Great Basin is a matter of general knowledge. The subject is thus stated by comparison and estimate by Gilbert:—* "On the broad plain bounded east and west by the Appalachian Mountains and the Mississippi River, 43 inches of rain falls in a year. On the lowlands of the Great Basin there

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* "Lake Bonneville," p. 6-7.

falls but 7 inches. In the former region the average moisture content of the air is 69 per cent of that necessary for saturation; in the lowlands of the Great Basin it is 45 per cent. From the surface of Lake Michigan evaporation removes each year a layer of water 22 inches deep. The writer has estimated that 80 inches are yearly thus removed from Great Salt Lake, and Mr. Thomas Russell has computed from annual means of temperature, vapor tension, and wind velocity, that in the lowlands of the Great Basin the annual rate of evaporation from water surfaces ranges from 60 inches at the north to 150 inches at the south."

No sketch of the Great Basin would be complete without some reference to the peculiar mountain structure of the region. Geographical maps show that the mountainous character predominates from the Wasatch to the Sierra. The ranges within the Basin are short, and strikingly uniform in their general trend north and south. The structure of these mountain ranges is so different from the usual order, and so characteristic of this particular region, that mountains of the kind wherever found are to be classed as belonging to the Basin Range type.

Ordinary mountain ranges consist essentially of stratified rocks, the strata of which have been crushed and crumpled by lateral pressure, so as to appear in section as complicated folds. Anticlinal arches and synclinal troughs follow each other in close or more open folds according to the degree of compression. Such mountain ranges were originally sea sediments, and their situation marks old marginal sea-bottoms. This, the common mountain structure, is spoken of as the anticlinal type.

But the Basin ranges are of monoclinal structure, —as if great crust blocks had been tilted on edge. One face of a mononclinal ridge is relatively steep,it is in fact the rough face of the crust block which has been broken by faulting; the other slope is gentler, following in general the dip of the upturned beds. Mononclinal mountain masses result from tension by which the crust is broken up into great blocks.

Of the origin of the Basin ranges, and of the Wasatch and Sierra mountains which virtually form the walls of the Basin, Le Conte* writes: "The Sierra received its present form and altitude by the upheaving on its eastern side of a great mountain block—300 miles long and 50 to 70 miles wide—forming there a normal fault, with a displacement of probably not less than 15,000 feet. * * * On the other boundary of the Basin region the Wasatch was at the same time also heaved up on its western side, forming there one of the

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*Elements of Geology, 4th ed., p. 277. See also American Journal of Science, Vol. 33, p. 262 for an article by the same author.

greatest faults known. [40,000 feet displacement according to King.] * * * The whole Basin region, including the Sierra on one side and the Wasatch on the other, was lifted, probably by intumescent lavas, into an arch, and by tension split into great oblong crust blocks. The arch broke down, the crust blocks re-adjusted themselves to form the Basin ranges, and left the abutments, viz, the Sierra and the Wasatch, with their raw faces looking toward one another across the intervening Basin. It must not be imagined, however, that this took place at once as a great cataclysm, but rather that it took place very slowly—the lifting, the breaking down, and the re-adjustment, all going on at the same time."

In some of the depressions between these displaced crust blocks water has accumulated and thus have the lakes of the Great Basin been formed. Other depressions, the receptacles of but limited drainage may hold water for a short period only immediately after a rainy season or following the heavy storms known as cloudbursts; such ephemeral water bodies are called playa-lakes.

IX.

THE ANCIENT LAKE—LAKE BONNEVILLE.

That the Great Salt Lake is a remnant of a larger body of water which once filled the entire valley and extended beyond the valley walls to the north, south, and west, is apparent to even the unscientific observer. Yet our knowledge of this ancient water body has been accumulated but gradually, and many investigators and observers have contributed thereto.

Capt. Fremont in 1842 recorded the occurrence of a line of drift-wood observed by him a few feet above the level of the existing lake; and in this he read the indications of variation in level at that time recent, but he made no record of the grander phenomena of ancient shore lines on the adjacent mountains.

Capt. Howard Stansbury, whose valuable labors in connection with the survey of Great Salt Lake in 1849-1850, have been mentioned, observed the lines of early shore action, and inferred therefrom the former existence of a great lake or sea. Referring to a particular plain near Lakeside on the line of the Southern Pacific railway, he wrote:

"This extensive flat appears to have formed at one time the northern portion of the lake, for it is now but slightly above its present level. Upon the slope of a ridge connected with this plain, thirteen distinct successive benches, or water marks, were counted, which had evidently at one time been washed by the lake, and must have been the result of its action continued for some time at each level. The highest of these is now about two hundred feet above the valley which has itself been left by the lake, owing probably to gradual elevation occasioned by subterraneous causes. If this supposition be correct, and all appearances conspire to support it, there must have been here at some former period a vast inland sea, extending for hundreds of miles; and the isolated mountains which now tower from the flats,forming its western and southwestern shores, were doubtless huge islands similar to those which now rise from the diminished waters of the lake."*

In 1852 Lieut. E. G. Beckwith visited portions of the Great Basin in charge of a government expedition. He was impressed by the distinctness of the old beach lines, and correctly concluded that the Salt Lake had stood at a higher level. He says:

"The old shore lines existing in the vicinity of the Great Salt Lake present an interesting study. Some of them are elevated but a few feet (from five to twenty) above the present level of the lake, and are as distinct and as well defined and preserved as its present beaches; and Stansbury speaks, in the Report of his exploration, pages 158, 160, of drift wood still existing upon those

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* "Exploration and Survey of the Valley of the Great Salt Lake of Utah," etc., by Howard Stansbury. Philadelphia, 1852, p. 105.

having an elevation of five feet above the lake, which unmistakably indicates the remarkably recent recession of the waters which formed them, whilst their magnitude and smoothly-worn forms as unmistakably indicate the levels which the waters maintained, at their respective formations for very considerable periods.

"In the Tuilla [Tooele] Valley at the south end of the lake, they are so remarkably distinct and peculiar in form and position that one of them, on which we traveled in crossing that valley on the 7th of May, attracted the observation of the least informed teamsters of our party—to whom it appeared artificial. Its elevation we judged to be twenty feet above the present level of the lake. It is also twelve or fifteen feet above the plain to the south of it, and is several miles long; but it is narrow, only affording a fine road-way, and is crescent-formed, and terminates to the west as though it had once formed a cape, projecting into the lake from the mountains on the east—in miniature, perhaps, not unlike the strip of land dividing the sea of Azoff from the Putrid Sea. From this beach the Tuilla [Tooele] Valley ascends gradually towards the south, and in a few miles becomes partly blocked up by a cross-range of mountains with passages at either end however, leading over quite as remarkable beaches, into what is known to the Mormons as Rush Valley, in which there are still small lakes or ponds, once, doubtless, forming part of the Great Salt Lake.

"The recessions of the waters of the lake from the beaches at these comparatively slight elevations, took place beyond all doubt, within a very modern geological period; and the volume of the water of the lake at each subsidence—by whatever cause produced, and whether by gradual or spasmodic action— seems as plainly to have been diminished; for its present volume is not sufficient to form a lake of even two or three feet in depth over the area indicated by these shores, and, if existing, would be annually dried up during the summer.

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"But high above these diminutive banks of recent date, on the mountains to the east, south, and west, and on the islands of the Great Salt Lake, formations are seen, preserving, apparently, a uniform elevation as far as the eye can extend,—formations on a magnificent scale, which, hastily examined, seem no less unmistakably than the former to indicate their shore origin. They are elevated from two or three hundred to six or eight hundred feet above the present lake; and if upon a thorough examination they prove to be ancient shores, they will perhaps afford (being easily traced on the numerous mountains of the Basin) the means of determining the character of the sea by which they were formed," etc.*

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* Lieut. E. G. Beckwith, in Pacific Railroad reports, vol. 2, p. 67: Washington, 1855,

Observations were accumulated by Blake, Simpson and his assistant, Englemann, by King, Hague, Emmons, Hayden, Bradley, Poole, Peale, and others, all increasing our stock of information regarding the ancient lakes of the Great Basin, and bearing more or less directly on the early history of what is now the Great Salt Lake.* But it is to Grove Karl Gilbert and his associates to whom we owe the greater part of our present knowledge of the Great Salt Lake and its geological history. His report, forming the first volume of the U. S. Geological Survey monographs, is the standard work on the subject.

Careful examination furnishes evidence at once abundant and conclusive that this ancient lake extended southward over the Sevier Desert, and probably over the Escalante Desert also, nearly to the Arizona line; westward over the Great Desert, into Nevada; and northward to the upper limit of Cache valley and therefore 25 miles beyond the Idaho boundary. It formed the largest of the many flooded Pleistocene lakes of the Basin region. In 1876, Gilbert named this inland sea Lake Bonneville, in honor of Captain Bonneville, who gave the first authentic description of the existing lake as a result of his explorations in 1833, and after whom Washington Irving endeavored to establish the name "Lake Bonne-

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* For an excellent summary of investigations on the past of the Great Salt Lake, see "Lake Bonneville," pp. 12-19.

ville" as the designation of the existing Great Salt Lake.

When at its highest level, Lake Bonneville had an extreme north and south length of 300 miles, a greatest east and west extent of 180 miles; it presented an area of 19,750 square miles. The lake reached from 42 degrees 30 minutes to 37 degrees 30 minutes north latitude, and was divided almost equally by the line of 113 degrees west longitude.

The Great Salt Lake, while it is the largest and most important, is not the only existing fragment of Lake Bonneville. Utah and Sevier lakes remain, occupying the lowest parts of their separate valleys to the south. Lake Utah is a body of fresh water with 127 square miles surface; it sends its overflow through the Jordan River northward to the Great Salt Lake. Sevier Lake is a saline body of variable dimensions, attaining during humid seasons a considerable area. In 1872, it covered 188 square miles; while in dry times it practically evaporates away, leaving a crystalline residuum of impure sodium chloride and sulphate five inches in depth, to mark the lowest part of its site.

The principal divisions of Lake Bonneville were: (1) The main body, comprising the area of the existing lake and that of the Salt Lake Desert; (2) Cache bay to the north; (3) Sevier bay, and (4) Escalante bay, to the south. The names used are identical with the existing geographical designations. These parts of the great lake were defined by peninsulas and archipelagos, which appear today as hills and mountain spurs, while the connecting straits are represented by valley passes. These facts are shown on the accompanying map. Some of the hills rising from the plain, which constitutes the Salt Lake Desert, have their bases deeply buried beneath lake sediments; they rise from the land level as abruptly as the islands of the present lake above the water, and the popular names by which they are known, designate them as islands still. (See plate XIX.)

The shore lines appearing upon the mountain sides against which the ancient waters beat, are, throughout the greater part of their extent, so distinct that even the school boy is led to think of them as old water margins. Along these terraces abundant proofs of littoral structure may be found. In places pebbly beaches tell of lapping waves, while the covering and cementing tufa attached to the worn stones testifies to chemical precipitation or deposit by evaporation. Ripple marks are as clearly shown in the sandstones and hardened clays as on the shores which are at present washed by the briny waters. Embankments, wave-cut caves, and all the other usual phenomena of littoral action exist in a state of impressive perfection. In many places, especially along the eastern margin, where the waters beat against the face of the Wasatch mountains, the lines have suffered extensive deformation through fault disturbances; indeed, in the immediate neighborhood of Salt Lake City, the fault scarp is so fresh as to still present the rough face of recent fracture.

The work of stream erosion is apparent in the transverse gashing of the shore terraces; this and the erosive action of atmospheric agencies are operating toward a general degradation of the terrace structure. These destructive processes, however, have not as yet been able to hide, or even to seriously disfigure the evidence of former conditions. The map of Lake Bonneville can be drawn with as great an assurance of accuracy as attends the charting of any existing water body. (See plate XV.)

Each shore line indicates, of course, a practically constant level of the lake during a considerable length of time, or a periodical return to the same level at short intervals during a long cycle of years. There is, however, little evidence of interruption in the process of shore sculpture, and a constancy of level rather than a return of the water to the same height at each of the stages marked by a shore line is indicated. On the Oquirrh mountains bounding the Salt Lake valley on the west, ten distinct lines have been counted, sketched, and photographed by the writer; but here, as indeed all along the old shore margin, three principal levels appear and a fourth is seen with great distinctness on one of the large islands of the lake. These have been designated as follows:

1. The Bonneville shore line, the highest and most conspicuous; this is at a height of 1,000 feet above the present mean level of the water.

2. Provo shore line, 375 feet below the Bonneville. This was named by Howell from the great size and perfection of the delta constructed at this level by the Provo River as it enters Utah valley from the canyon.

3. Intermediate shore lines, between the Bonneville and the Provo. These lines show a series of fluctuations in lake level each of comparatively short duration. While the embankments are large they are devoid of great sea cliffs and caves such as characterize the Bonneville and the Provo. On Stansbury Island, one of the largest bodies of land rising from the waters of the Salt Lake, a lower level has left a clearly defined terrace, 300 feet above the present water surface; this has been called:

4. Stansbury shore line.

The chronological order of the principal shore line formation is as follows: 1. Intermediate; 2. Bonneville; 3. Provo; 4. Stansbury. While the Bonneville level is the highest and most conspicuous of the shore terraces, it marks a shorter duration of constant level than does the Provo. It is in fact the most conspicuous because it is the highest, deriving its prominence from its clearly defined contrast with the features of sub-aerial topography immediately above it. (See plate XVIII.)

Years prior to the discovery of any outlet through which the great lake could have discharged its surplus waters, the existence of such an escape channel was predicted. Gilbert declared (1) that the Bonneville shore lines would be found to have been determined by an overflow of lake water, and (2) that the Provo line would be traceable to a similar determining cause.* Writing in 1890 he says: "The first of these predictions has been verified in its letter, but not in its spirit; the second has proved to have full warrant. My anticipation was based on the following consideration: A lake without overflow has its extent determined by the ratio of precipitation to evaporation within its basin; and since this ratio is inconstant, fluctuating from year to year and from decade to decade, it is highly improbable that the water level will remain constant long enough to permit its waves to carve a deep record. I failed to take account of the fact that the highest shore-mark of the series is conspicuous by reason of the contrast there exhibited between land sculpture and littoral sculpture. We know that the height of the Bonneville shore-line was determined in a certain sense by overflow, since a discharge limited the rise of the water; but the

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* Exploration West of the 100th Meridian, III., p, 90.

carving of the shore was essentially completed before the discharge, and as soon as that began the water fell. At the Provo horizon, on the contrary, a constant or nearly constant water-level was maintained by discharge for a long time." *

The search for the Bonneville outlet was prosecuted with the assurance that such a channel existed. A number of passes were found but slightly above the required level, and indeed "a difference of only a few feet determined the actual point of discharge." On the northern rim of Cache valley at Red Rock Pass, near Oxford, Idaho, the outlet channel was discovered. The topographical features and the erosion record were so distinct as to place the question of the source of Bonneville River practically beyond doubt. The honor of this discovery is accorded to Gilbert, though Peale has disputed Gilbert's rights of priority on the basis of Bradley's suggestion, made in 1872.† Bonneville River flowed through Marsh Valley, being joined in this part of its course by the Portneuf. The combined streams then followed Portneuf Pass to Snake River, thence to the Columbia. Above its junction with the Portneuf the Bonneville River must have equalled and possibly exceeded in size the Niagara. Regarding the duration of the river's existence Gilbert says:

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* Lake Bonneville, p. 171.

† American Journal of Science, June, 1878.

"How long the discharging river maintained its colossal dimensions can not be learned, but the period certainly was not great. The entire prism of water between Bonneville and Provo planes would be discharged by the Niagara channel in less than twenty-five years; and if the Bonneville River reached a greater size, it would have maintained it only for a shorter time."*

Alluvial fans and deltas exist at the mouths of canyons opening into the valley. Of the fans or cones, some were constructed prior to the Bonneville epoch, while others show by the absence of shore lines and lake sediments that they are more recent than the high water marks. A typical alluvial cone of large dimensions occurs at the base of a prominent spur of the Wasatch range a mile north of Salt Lake City. This cone derives additional interest from the fact that its surface shows the course of a well developed fault scarp. In Salt Lake valley and elsewhere the alluvial cones formed by the streams issuing from canyon openings at short intervals coalesce and present the appearance of almost continuous terraces. In such cases the existing stream reveals a section of the deposit, a study of which, together with an examination of the slope and general configuration will enable the observer to distinguish be-

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* "Lake Bonneville," p. 177,

tween the cone formation on the one hand and the lake terrace and delta on the other.

The existence of deltas along the old lake shores was pointed out by Bradley in 1872;* but it remained for Howell and Gilbert to give the subject full and careful study. While in places delta formations are preserved at the Bonneville level, the best and largest belong to the Provo stage. The streams following the receding lake would indeed destroy much of their own delta construction at higher levels and earlier periods. However, at some places the delta structure presents a record of Intermediate, Bonneville, and Provo stages complete. Following the American Fork river from the canyon toward the mouth of the stream in Utah Lake,the observer may read the history of delta formation and destruction with comparative ease. As revealed by the stream-made section the Bonneville delta shows a height of 120 feet at its outer margin, and a radius of over 4,800 feet. The Intermediate delta being the first formed, was partly covered by the later Bonneville; both were cut through by the stream as the lake fell to the Provo level, and the material so removed was built into a still younger delta.

The deltas of the Logan river form a series of sloping terraces extending downward from the mountain face. Each delta indicates the partial destruction of earlier depositions above. In Salt Lake valley, the delta formed

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* "Geological Survey of the Territories," 1872, p. 192.

by City Creek (the main source of the water supply for Salt Lake City today), reveals itself as high benches through which the stream has kept for itself a passage. Wave-action appears to have been unusually strong at this place, and consequently the typical delta form is considerably modified. The delta constructed by the Provo river in Utah valley, covers over 20,000 acres, and another occurs a few miles to the south—the work of the Spanish Fork stream—with an area of 8,000 acres.

The occurrence of calcium carbonate, usually as calcareous tufa, is common to the shores of most of the Great Basin lakes. The extensive accumulation of this material in Lake Lahontan has received due attention from King and Russell.* In Lake Bonneville, however, the deposition has taken place on a small scale only. Where this material occurs at all it is found as an incrustation on the faces of cliffs, or as a cement coating the pebbles and forming them into a coherent conglomerate. None of the calcareous deposit is found in spots which once were quiet coves or bays; while the largest quantities occur where the waves must have produced the strongest surf action. It has been suggested that the aeration of the water probably promoted the precipitation of the calcium carbonate, and that the particles coalesced at

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* "Exploration of the 40th Parallel, I., p. 514."

the instant of separation.* In the open lake the deposition of calcium carbonate went on in the usual manner, the particles remaining separate and forming an ordinary sediment. None of the Thinolite, named and described by King in connection with Lahontan and Mono lakes, has thus far been found within the Bonneville district.

That the diminution of lake volume from the height of the Provo line to the present level, is due to desiccation and not to a process of emptying by overflow, is shown by the absence of any break or notch in the rim below the level of the shore named, through which the water could have found an outlet, and from the deposits of mineral matter in the lake floor. In the parts recently vacated by the receding waters, the saline matters effloresce upon the soil during dry seasons, and disappear in times of abundant precipitation. Careful analyses of these substances show marked correspondence with the mineral contents of today. As the retreating waters divided the lake into separate areas, each lakelet proceeded in the process of desiccation according to its own relative conditions of supply and evaporation.

In some parts, particularly in the region of the old Sevier body of Lake Bonneville, deposits of gypsum are found. These may not be the effect of any chemical de-

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* "Lake Bonneville," p. 169.

position; as Gilbert suggests, they may be the result of evaporation of water that had derived the material by simple solution from the rocks. The gypsum is occassionally found in the form of small free crystals, and as in the Sevier desert, these may be drifted by wind action into glistening dunes. The author of the monograph on Lake Bonneville says:

"Perhaps no gypsum deposit in the world is so easily exploited as this; it needs merely to be shoveled into wagons and hauled away. Mr. Russell estimates that the dunes contain about 450,000 tons, and a much larger amount can be obtained from the playa."*

While the exposure of an extensive series of formations and systems of rocks is made visible by the orogenic disturbances which have resulted in the elevation of the Wasatch and contiguous ranges, these aid us but little in determining the time of the Bonneville epoch or the age of the lake beds. In the lake floor, however, fairly conclusive evidence as to the true geological age may be found. Tertiary strata of well determined age exist within the Bonneville basin and in places these are found unconformably overlaid by the lake sediments. The Tertiary deposits, while presenting a wide variety of texture, are quite readily distinguishable from the

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*"Lake Bonneville, p.223."

later lacustrine beds by lithological character and by their disturbed positions. It is evident therefore that the lake deposits are post-Tertiary. Moreover the "Bonneville beds are thus seen to be the latest lacustrine deposit of the basin, and this fact indicates their synchronism with the latest littoral evidence of a lacustrine condition."

Over the valley surface the beds are practically undisturbed; in some parts they rise by gentle slopes almost to the level of the shore lines. Gilbert has carefully studied the section exposed along the old river bed, running northwest from the Sevier desert, between McDowell and Simpson mountains to the Salt Lake desert, and this he announces as almost a typical section.* Through this channel a stream connected Sevier Lake with the larger Salt Lake, after the division of Lake Bonneville into separate bodies in its shrinkage course. This river existed in post-Provo times, for the shore lines extend along the bordering hillsides, the Bonneville line being fully 700 feet above the highest banks of the channel. Gilbert states that his exploration "demonstrated that the entire site of the channel was submerged during both Bonneville and Provo epochs." The channel walls of the old river bed reveal the following members in ascending order:

1. Yellow clay with local dashes of sand sedi-

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* "Lake Bonneville," p. 190.

ment and nodular aggregates of selenite crystals. Of this a depth of ninety feet is exposed, but the bottom has not been reached.

2. White marl, a layer ten feet in thickness, overlying the yellow clay, on an eroded surface. The lower layers of the marl contain shells of nearly the same species as occur in the clay below.

3. Free sand; a top layer grading without break of continuity into the marl below; an average thickness of ten feet is recorded. This succession of beds is less distinct on the slopes and particularly so near the shore lines where the true sedimentary deposits are mixed with littoral material. The eroded surface of the yellow clay indicates a break in the process of lake deposition, and this interruption is further shown by the alluvial deposits and all the proofs of sub-aerial erosion between the yellow clay and the white marl. It is evident therefore that there are two distinct flood times in the Bonneville history, two periods of greatest operation of lacustrine agencies separated by a perior of dryness. The second of these periods was probably not more than one-fifth of the duration of the first. Gilbert sums up the evidence on the subject as follows:*

"Then followed two epochs of high water, with an interval during which the basin was nearly or quite empty. The first of these epochs was at least five times

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* "Lake Bonneville," p. 317.

as long as the second. The second scored its water mark ninety feet higher than the first, and would have encroached still farther on the basin sides had it not been checked by outflow. During the epoch of outflow, the discharging current eroded the rim,and thus lowered the lake 375 feet;and after the outflow had ceased, the water fell by desiccation, with one notable interruption, to its present level in Great Salt Lake. The inter-Bonneville epoch of low water was of greater duration than the time that had elapsed since the final desiccation."

A similar dual flooding has been demonstrated by the labors of King and Russell in the region of Lake Lahontan, a body of water which may be regarded as a twin sister to Lake Bonneville.*

The correlation of these periods of maximum flooding with the prime divisions of the Glacial Epoch has been established with considerable certainty. The evidence points to periods of low temperature corresponding with the times of greatest water surface. Low temperature with consequent decrease of loss by evaporation is an important factor, if not indeed, the most effective among the causes which determined the successive maxima of Lake Bonneville and its related water bodies in the Basin.

The fossils, particularly the fresh water shells, testify to unfavorable conditions of growth. They are few

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* "Exploration of the 40th Parallel," I., p. 524.

and in the individuals are dwarfed, as would be expected of species struggling for life under the rigors of a glacial climate. Quoting again:*

"In the case of Lake Lahontan, and in the case of the first Lake Bonneville, the unfavorable condition may possibly have been impurity of water, but the second Lake Bonneville was freshened by outflow, and the dwarfing of its mollusks is best explained by low temperature. * * * These phenomena sustain the theory that the Pleistocene lakes of the western United States were coincident with the Pleistocene glaciers of the same district, and were produced by the same climatic changes. It follows as a corollary that the glacial history of this region was bipartite, two maxima of glaciation being separated, not by a mere variation in intensity, but by a cessation of glaciation."

Well-defined ice deposits occur in a few places along the old shore, below the high water marks. One of the best examples is found at the mouth of Little Cottonwood Canyon but a few miles south of Salt Lake City (See plates XXI) Emmons first directed attention to the fact that the glacier here referred to deposited its moraines within the Bonneville area. † The south lateral moraine is well preserved; the other has lost its typical form, prob-

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* **"Lake Bonneville, p. 318."**

† **"Exploration of the 40th Parallel," II., p. 354.**

ably through an expansion or a change of direction of the glacier whereby the north moraine was disfigured. The moraine material is traceable downward from the canyon gateway for a full mile upon the plain, and in its lower parts it is covered by alluvium to a depth of sixty-five feet at least, and by a lacustrine deposit of sand. The glacier existed during a period of high water—probably that of the Provo shore line.

Major Powell presents a summary of the labors of his associates on Bonneville history in this concise way:*

"First, the waters were low, occupying, as Great Salt Lake now does, only a limited portion of the bottom of the basin. Then they gradually rose and spread, forming an inland sea, nearly equal to Lake Huron in extent, with a maximum depth of 1,000 feet. Then the waters fell, and the lake not merely dwindled in size, but absolutely disappeared, leaving a plain even more desolate than the Great Salt Lake Desert of today. Then they again rose, surpassing even their former height, and eventually overflowing the basin at its northern edge, sending a tributary stream to the Columbia River; and, last, there was a second recession, and the waters shrunk away, until now only Great Salt Lake and two smaller lakes remain."

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* U. S. Geological Survey, report for 1880-81, p. xvii.