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J. W. POWELL DIRECTOR

GEOLOGICAL HISTORY

OF

LAKE LAHONTAN

A QUATERNARY LAKE OF NORTHWESTERN NEVADA

BY

ISRAEL COOK RUSSELL

WASHINGTON
GOVERNMENT PRINTING OFFICE
1885

WASHINGTON, D. C., *March* 28, 1885.

SIR: I have the honor to submit for publication a memoir on Lake Lahontan by Mr. I. C. Russell.

The principal work of my Division has been the investigation of the Quaternary lakes of the Great Basin. In this investigation Mr. Russell has been my principal assistant since the year 1880. During the first season he accompanied me in the field for the purpose of familiarizing himself with the methods of research which had been developed in the course of the earlier work, but in subsequent years he was assigned independent districts. His report on the most important of these is communicated in the present volume.

After the completion of his field work, I visited some of the more instructive localities of the Lahontan basin and repeated his observations. I am thus familiar not only with his methods but with some of the principal facts which he discusses, and am enabled from personal knowledge to characterize his work as accurate and thorough.

Very respectfully, your obedient servant,

G. K. GILBERT,

Geologist in Charge, Division of the Great Basin.

Hon. J. W. POWELL,

Director U. S. Geological Survey.

PREFACE.

The explorations reported in the present volume are a continuation of the studies of the Quaternary geology of the Great Basin begun by Mr. G. K. Gilbert when the present survey was organized. The work has been carried out under Mr. Gilbert's direction, and to him I am indebted not only for every facility he could offer for advancing my work, but also for important advice and numerous suggestions. Whatever value may be attached to the results of my labors will be due in great measure to the wisdom and unvarying kindness of the Chief of the Division of the Great Basin.

With the exception of the reconnaissance of 1881, I have had the assistance of Mr. Willard D. Johnson in all matters relating to topography throughout both the field and office work connected with the preparation of this volume. The energy and completeness with which he has carried forward his special work under peculiar difficulties, not met with outside the desert regions of the Far West, deserve the highest praise The accuracy of the accompanying maps that Mr. Johnson has drawn from his own survey will make them a reliable basis for determining future changes in the lakes and rivers of the region explored.

During the summer of 1882, I was accompanied by Messrs. W J McGee and George M. Wright, as geological aids, and to each I have the pleasure of crediting much valuable assistance. The accompanying drawings of geological sections will attest the accuracy of Mr. McGee's work.

The survey of nearly 8,500 square miles in northern Nevada, which was necessary in order to compile the accompanying pocket map and many of the smaller illustrations, was carried out by Mr. A. L. Webster, assisted by Mr. Eugene Ricksecker. It is to be hoped that Mr. Webster's work will be issued as an independent atlas sheet, in order that its full value may be appreciated.

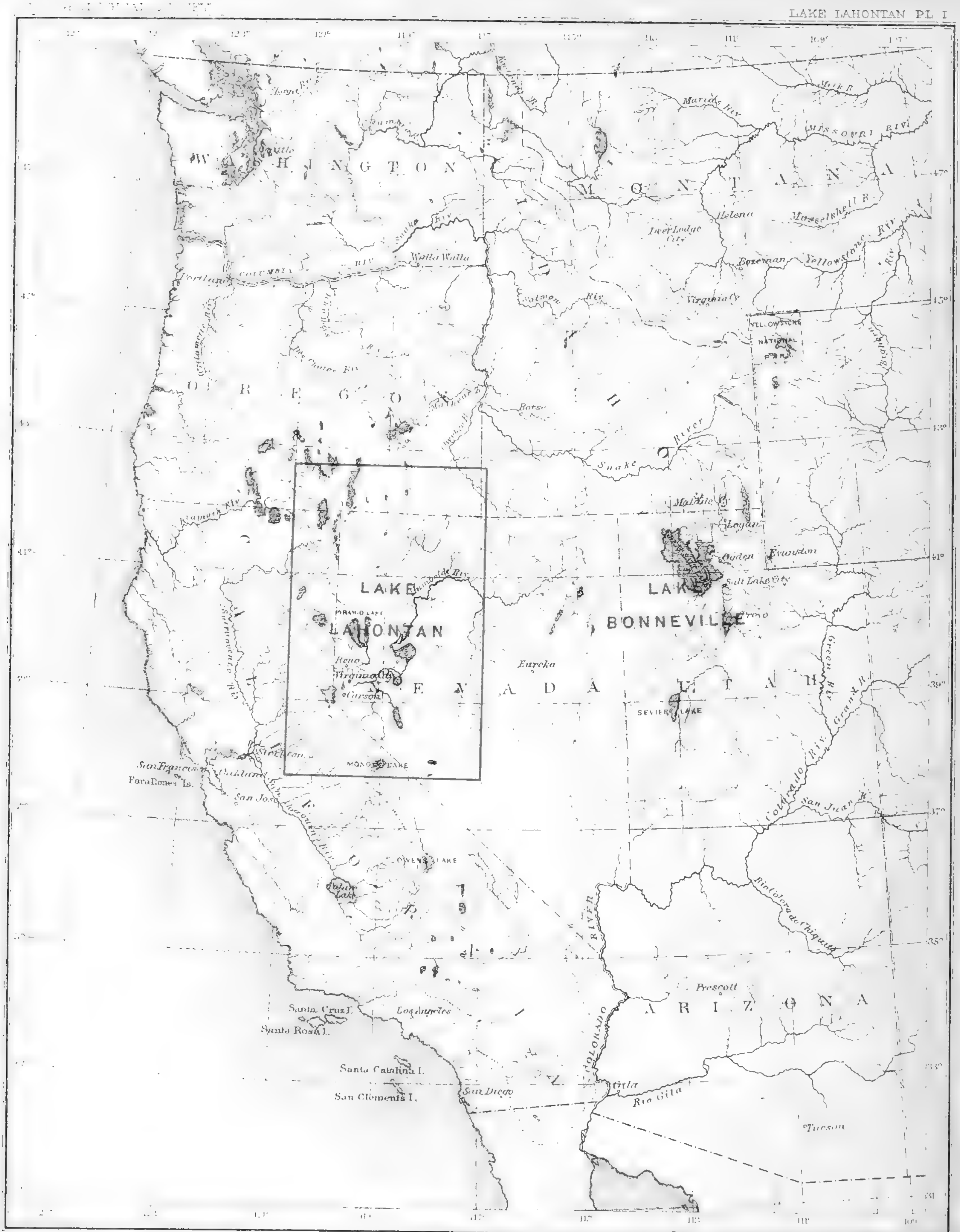
Since this report was written the analyses by Prof. F. W. Clarke and Dr. T. M. Chatard, contained in the following pages, have been published in Bulletin No. 9 of this Survey, to which the reader is referred for additional information in reference to methods of analysis.

I. C. R.

CONTENTS.

TABLES OF CHEMICAL ANALYSES.

ILLUSTRATIONS.



QUATERNARY LAKES OF THE GREAT BASIN.

Quaternary Lakes ▭ Boundary of the Great Basin ~~~ Area represented on Plate XLVI. ▯

Scale of Miles

100 75 50 25 0 100 200 300

GEOLOGICAL HISTORY OF LAKE LAHONTAN.

BY ISRAEL C. RUSSELL.

ABSTRACT OF MONOGRAPH.

The present volume records the history of a large lake which flooded a number of the valleys of northwestern Nevada at a very recent geological date, but has now passed away. This ancient water-body is known as Lake Lahontan—named in honor of Baron La Hontan, one of the early explorers of the headwaters of the Mississippi—and was the complement of Lake Bonneville. The former, situated mostly within the area now forming the State of Nevada, filled a depression along the western border of the Great Basin at the base of the Sierra Nevada; the latter, embraced almost entirely in the present Territory of Utah, occupied a corresponding position on the east side of the Great Basin, at the foot of the Wasatch Mountains. The hydrographic basins of these two water-bodies embraced the entire width of the Great Basin in latitude 41°. Lake Bonneville was 19,750 square miles in area, and had a maximum depth of about 1,000 feet. Lake Lahontan covered 8,422 square miles of surface, and in the deepest part, the present site of Pyramid Lake, was 886 feet in depth. The ancient lake of Utah overflowed northward and cut down its channel of discharge 370 feet. The ancient lake of Nevada did not overflow. Each of these lakes had two high-water stages, separated by a time of desiccation. In the Lahontan Basin, as in the Bonneville, the first great rise was preceded

by a long period of desiccation, and was followed by a second dry epoch, during which the valleys of Nevada were even more completely desert than at present. During the second flood stage the lake rose higher than at the time of the first high water, and then evaporated to complete desiccation. The present lakes of the basin are of comparatively recent date, and are nearly fresh, for the reason that the salts deposited when the Quaternary lake evaporated were buried or absorbed by the clays and marls that occupy the bottom of the basin.

As Lake Lahontan did not overflow, it became the receptacle for all the mineral matter supplied by tributary streams and springs both in suspension and in solution. The former was deposited as lacustral sediments and the latter as calcareous tufa, or formed desiccation products when the lake evaporated.

The introductory chapter indicates the position of the field of study, and contains a sketch of the Great Basin, as the explorer finds it to-day, of which the desiccated bed of Lake Lahontan forms a part; also a brief notice of previous explorations, and an account of what was known of Lake Lahontan before the present study was begun. Routes of travel and areas surveyed are indicated on Plate II.

Chapter II (on the genesis of Lake Lahontan) contains a summary of the facts which show that the lake filled a compound orographic basin, resulting from the tilting of faulted beds. A description is given of the character of the irregular area whose drainage the lake received, together with an account of the outline and area of the basin which held the ancient lake.

The question of outlet is discussed in detail, the conclusion being that the lake did not overflow (page 32).

Chapter III (on the physiography of the Lahontan Basin) contains a description of the region as it exists at the present time. The most distinctive characteristics of the valleys and mountains are briefly noticed; an account of the existing rivers is given, including measurements of volume, chemical composition, etc. The present springs of the basin are also described and analyses of the waters of a few of them presented. These analyses are believed to represent approximately the character of the tributaries of Lake Lahontan. The existing lakes are next considered. These are Honey Lake, California; Pyramid, Winnemucca, Humboldt, North Carson, South Carson, and Walker lakes, Nevada. Each of these is described with some detail with special reference to its geological bearings. All the lakes mentioned above, excepting Humboldt, are inclosed, *i. e.*, are without outlet, and their waters are somewhat saline and alkaline, but not concentrated brines. They cannot, therefore, be considered as remnants left by the incomplete desiccation of Lake Lahontan. The Soda lakes, near Ragtown, Nevada, are specially considered, and detailed observations are presented which show that they occupy extinct volcanic craters (page 73). Attention is given, on page 81, to the peculiar playas or broad mud-plains of the arid region of the Far West, as well as to the temporary lakes, called playa-lakes, which frequently flood them.

Chapter IV (on the physical history of Lake Lahontan) is divided into sections.

Section 1 contains a compendious discussion of shore phenomena in general.

Section 2 is devoted to the presentation of the shore phenomena of Lake Lahontan, and contains detailed descriptions and maps of the terraces, bars, embankments, etc., that were formed about its shores. The highest of the ancient water lines is named the "Lahontan Beach." It indicates the maximum extent of the lake as shown on the accompanying pocket map. The most conspicuous terraces below the Lahontan Beach are the "Lithoid", "Dendritic", and "Thinolitic." Each of these marks the upper limit of a variety of tufa from which it derives its name (page 102).

Section 3 treats of the sediments of the lake and presents detailed sections of the exposures observed. The sediments consist of two deposits of lacustral marls, separated by a heavy layer of current-bedded gravels; thus recording two lake periods and an intermediate low-water stage (page 43).

Accumulations of pumiceous dust, white marl, and aeolian sands are described under the head of Exceptional Sedimentary Deposits (page 146).

Section 5 is devoted to the illustration of geological structure, as displayed in the lake basin, and is followed by a résumé of the physical history of the lake (page 169).

Chapter V (on the chemical history of Lake Lahontan) is also divided into sections.

Section 1 treats of the general chemistry of natural waters as they occur in streams, springs, lakes, oceans, and inclosed lakes or seas, and is an introduction to the chemical history of Lake Lahontan.

Section 2 is an account of the tufas precipitated from the water of the lake. These present three main divisions, named, respectively, "Lithoid," "Thinolitic," and "Dendritic." The first is a compact, stony variety, and is the oldest of the principal calcareous deposits that sheath the interior of the basin. It occurs from a horizon thirty feet below the Lahontan beach all the way down the sides of the basin to the lowest point now exposed to view (page 190). Thinolite is composed of crystals, and was formed in the ancient lake when it was greatly reduced by evaporation; its upper limit is about 400 feet below the Lahontan beach (page 192). Dendritic tufa has a branching or dendritic structure, whence its name; it is superimposed upon the previously-formed varieties. Its upper limit is 180 feet below the Lahontan beach (page 201). The aggregate thickness of the tufa deposits is from thirty to perhaps fifty or seventy-five feet. Chemical analyses show that all the varieties are composed of somewhat impure calcium carbonate. Following the description of these deposits is a discussion of the conditions favoring the deposition of calcareous tufa from lake waters (page 210).

Section 3 considers the salts precipitated from the waters of the lake when evaporation took place, and discusses the manner in which lakes may be freshened by desiccation (page 223).

Section 4 contains an account of the efflorescences now forming on the surface of the deserts in the Lahontan Basin, and presents a brief description of the more valuable salt-works of the region, which are all supplied by the salts contained in Lahontan sediments (page 230).

Chapter VI presents the life history of the ancient lake as determined from the abundant molluscan remains and other fossils that have been found. The shells show that the lake was fresh throughout its higher stages. During the period when thinolite was formed it seems to have been too concentrated to admit of the existence of molluscan life, as no fossils have been found in that deposit. A chipped implement discovered in the upper lacustral beds indicates that man inhabited the Far West during the last rise of Lake Lahontan (page 247).

Chapter VII is a summary of the history of the former lake (page 250).

Chapter VIII contains a discussion of the Quaternary climate as determined from the records of Lake Lahontan. The periods of greatest lake expansion are correlated with the two glacial epochs of the Sierra Nevada, and are believed to indicate cold and moderately humid periods (page 259). That the lake did not overflow is taken as evidence that the climate, even during the high stages of the lake, was only moderately humid. The climatic changes that brought about such marked alterations in the character of the Great Basin are thought to have been of moderate intensity.

Chapter IX is devoted to a summary of the evidence bearing on the determination of the geological age of the lake. The conclusion reached is that it existed during the Quaternary, but was more recent than the date usually assigned for the close of the glacial epoch.

Chapter X brings the present study to a close, and contains an account of the orographic movements that have affected the Lahontan basin since the last high-water period. The post-Lahontan faults actually observed are represented on Plate XLV.

CHAPTER I.

INTRODUCTORY.

THE FIELD OF STUDY.

The region treated of in the present volume embraces about 90,000 square miles in northwestern Nevada, together with small portions of southern Oregon and eastern California.

The object of the explorations herewith reported was the study of the Quaternary geology of the country visited, and particularly the geological history of Lake Lahontan—a lake, now extinct, which occupied many of the valleys of northwestern Nevada at a very recent geological date. The basin of Lake Lahontan is one of the many independent drainage areas of which the Great Basin is composed, and its geology is a page in the history of the vast region lying between the Rocky Mountains and the Sierra Nevada.

The Great Basin is to-day an arid region, but during the Quaternary its climate was probably colder and more humid than at present. The Sierra Nevada and Wasatch ranges, now for the most part bare of snow during the summer, were formerly crowned with vast névés from beneath which flowed many magnificent ice-rivers; the desert ranges of Utah and Nevada were also snow-covered, and some of them gave birth to local glaciers. The valleys which are now dry and treeless, and in many instances absolute deserts, destitute of any kind of vegetation over hundreds of square miles, were then occupied by lakes, the largest of which were comparable in extent and depth with those now drained by the Saint Lawrence. Some of these old lakes had outlets to the sea and were the sources of considerable rivers, others discharged into sister lakes; a considerable number, however, did not rise high enough to find outlet, but were entirely inclosed, as is the case with the Dead Sea, the Caspian, and many of the lakes of the Far West at the present time. The largest of the Quaternary lakes of the Great Basin, thus far explored, has been very fully described by Mr. Gilbert and others under the name of Lake Bonneville. The second in size, Lake Lahontan, is the subject of the present report.

The topography of the region to which we wish to direct attention, together with its Quaternary hydrography, is represented on the accompanying pocket map. The relation of the region to the entire area of interior drainage, and the more general geography of the Far West, is indicated on the frontispiece. Before presenting the results of our geological observations it seems desirable to glance briefly at some of the more prominent characteristics of the region of interior drainage of which the district to be described is a component part.

THE GREAT BASIN.

In crossing from the Atlantic to the Pacific, between the Mexican boundary and the central portion of Oregon, one finds a region, bounded by the Sierra Nevada on the west and the Rocky Mountain system on the east, that stands in marked contrast in nearly all its scenic features with the remaining portions of the United States. The traveler in this region is no longer surrounded by the open, grassy parks and heavily-timbered mountains of the Pacific slope, or by the rounded and flowing outlines of the forest-crowned Appalachians, and the scenery suggests naught of the boundless plains east of the Rocky Mountains or of the rich savannas of the Gulf States. He must compare it rather to the parched and desert areas of Arabia and the shores of the Dead Sea and the Caspian.

To the geographer the most striking characteristic of the country stretching eastward from the base of the Sierra Nevada is that it is a region of interior drainage. For this reason it is known as the "Great Basin." No streams that rise within it carry their contributions to the ocean, but all the snow and rain that falls inside the rim of the basin is returned to the atmosphere, either by direct evaporation from the soil or after finding its way into some of the lakes that occupy the depressions of the irregular surface. The climate is dry in the extreme, the average yearly rainfall probably not exceeding 12 or 15 inches.

The area thus isolated from oceanic water systems is 800 miles in length from north to south, and nearly 500 miles broad in the widest part, and contains not far from 208,500 square miles—an area nearly equal to that of France. The southern part of the region includes the Colorado Desert, Death Valley, and much of the arid country in southern California and Nevada. In northern Nevada the Carson and Black Rock deserts exhibit the extreme of desolation. The most northerly part of the Great Basin, occupying the central portion of Oregon, is less barren, its rugged surface abounding in long and narrow mountain ranges, volcanic table lands, and isolated mesas, weathering as they grow old into rounded buttes, that are covered with luxuriant bunch-grass and bear a scattered growth of cedars and pines. At the south the valleys of the Great Basin are low-lying, Death Valley and the Colorado Desert being depressed below the level of the sea; but at the north the valleys have a general elevation of from 4,000 to 5,000 feet, while the intervening mountain ranges rise from 5,000 to 7,000 feet above them.

Diversifying this region are many mountain ranges and broad desert valleys, together with rivers, lakes, and cañons, topographic elements to be found in all quarters of the world, but here characterized by features peculiar to the Great Basin The mountains exhibit a type of structure not described before this region was explored, but now recognized by geologists as the "Basin Range structure." They are long narrow ridges, usually bearing nearly north and south, steep upon one side, where the broken edges of the composing beds are exposed, but sloping on the other, with a gentle angle conformable to the dip of the strata. They have been formed by the orographic tilting of blocks that are separated by profound faults, and they do not exhibit the anticlinal and synclinal structures commonly observed in mountains, but are monoclinal instead.

The valleys or plains separating the mountain ranges, far from being fruitful, shady vales, with life-giving streams, are often absolute deserts, totally destitute of water, and treeless for many days' journey, the gray-green sagebrush alone giving character to the landscape. Many of them have playas in their lowest depressions—simple mud plains left by the evaporation of former lakes—that are sometimes of vast extent. In the desert bordering Great Salt Lake on the west and in the Black Rock Desert of northern Nevada are tracts hundreds of square miles in area showing scarcely a trace of vegetation. In winter, portions of these areas are occupied by shallow lakes, but during the summer months they become so baked and hardened as scarcely to receive an impression from a horse's hoof, and so sun-cracked as to resemble tessellated pavements of cream-colored marble. Other portions of the valleys become incrusted to the depth of several inches with alkaline salts which rise to the surface as an efflorescence and give the appearance of drifting snow. The dry surface material of the deserts is sometimes blown about by the wind, saturating the air with alkaline particles, or is caught up by whirlwinds and carried to a great height, forming hollow columns of dust. These swaying and bending columns, often two or three thousand feet high, rising from the plains like pillars of smoke, form a characteristic feature of the deserts.

Most of the rivers of the Great Basin have their sources in the melting snows of the mountains which form its eastern and western borders, and flow into the desert valleys within the rim of the undrained area. Of such the Bear, Weber, and Sevier rivers are examples along the eastern border; on the west the Truckee, Carson, and Walker rivers have a similar origin and destiny. A single river, the Humboldt, is anomalous in that both its source and its terminus are well within the area of interior drainage.

The rivers of the Great Basin vary greatly in volume with the varying seasons, and some of them disappear entirely during the hot summer months In the streams that are perennial a high percentage of the annual discharge is crowded into a brief space toward the end of the rainy season. Thus the arteries of this parched and heated country make but one feverish pulsation in a year. The streams usually diminish in volume as they descend into the valleys, and in many instances their waters are lost on the thirsty deserts and their channels run dry. In general they are larger near their sources than at their mouths. Commonly, too, instead of being pure, sparkling waters, refreshing to the lips as well as to the eye, they are heavy with sediment and bitter and alkaline to the taste.

The lakes into which much of the surface drainage finds its way are commonly saline and alkaline—their shores desert wastes, shunned by animals and by all but salt-loving plants. Of the saline lakes, the typical example is furnished by Great Salt Lake in Utah, an inland sea whose features call to mind the familiar descriptions of the Dead Sea in Palestine. Mono Lake in California, and Abert and Summer lakes in Oregon, are also highly charged with saline matter, and are remarkable for the amount of sodium and potassium salts which they contain. Pyramid, Walker, Winnemucca, and Carson lakes in Nevada, as well as many smaller lakes throughout the Great Basin, are also without outlets, but yet, contrary to what we would expect, they hold but comparatively small percentages of saline matter in solution.

Other lakes, which indicate still more pointedly the contrast between an arid and a humid climate, we may call *playa-lakes*. These are sheets of shallow water, covering many square miles in the winter season, but evaporating to dryness during the summer, their beds becoming hard, smooth mud-plains or *playas*. In many instances a lake is formed on a playa during a single stormy night, only to disappear beneath the next noonday sun. When the weather is unsettled these lakes are scarcely more permanent than the delusions of the mirage, but come and go with every shower that passes over the land. Other playa-lakes retain their integrity for a longer period, and only become dry during excessively arid seasons. Examples of these are furnished by Honey Lake in California, North Carson Lake ("Carson and Humboldt Sink") in Nevada, and Sevier Lake in Utah, all of which have been known to become dry during the past few years. The water of playa-lakes has a greenish yellow color, due to the extremely fine silt which is held in suspension and not allowed to settle, because every breeze stirs the shallow alkaline water to the bottom. A remarkable lake of this class is sometimes formed in the northern part of the Black Rock Desert, in Nevada, during extremely wet seasons. Its water is furnished mainly by Quinn River, and it has been known to have a length of 50 or 60 miles, with a breadth of 20. During the summer it disappears entirely, leaving an absolutely barren plain of mud, Quinn River at the same time shrinking back a hundred miles towards its source. The peculiar history of playas and playa-lakes will be more fully described in connection with the physiography of the Lahontan basin, which is the subject of Chapter III.

A few lakes situated on the borders of the Great Basin have outlets, and discharge their surplus waters into reservoirs at lower levels within the area of interior drainage. These are of the same type as the ordinary lakes of humid climates, with waters as pure and fresh as springs and melting snow can furnish. Their finest example, Lake Tahoe, lies just within the western rim of the Great Basin, at an elevation of 6,247 feet, amid the peaks of the Sierra Nevada. Its outlet, the Truckee River, flows downward with a descent of 2,400 feet to Pyramid and Winnemucca lakes, where the water is evaporated, leaving the lower lakes charged with soda salts. Just within the eastern border of the Great Basin lie Bear Lake and Utah Lake, the former discharging its waters through the Bear River and the latter through the Jordan River to Great Salt Lake. These streams carry down from the mountains their small percentages of saline matter, as a contribution to the already saturated solution of the inland sea where their waters are evaporated.

It may be taken as a rule that all lakes which overflow are fresh, and all lakes which do not find outlet become in time charged with mineral salts. River water is never absolutely pure, but contains a small percentage of mineral matter, which is left behind when the water is evaporated. Should this process continue long enough it is evident that a lake without an outlet would in time become a saturated solution, from which the less soluble mineral salts would begin to crystallize.

The examination of those inclosed lakes of the Great Basin that are comparatively fresh, and especially of the lakes occupying the Lahontan basin, shows that salt lakes may in some instances become essentially fresh without overflowing. It has been suggested by Mr. G. K. Gilbert, in explanation of this apparent anomaly, that a lake may evaporate to dryness and its salts become buried beneath the deposits of playa-lakes, so that on the return of humid conditions the water that reoccupies the old basin may be comparatively, if not absolutely, fresh.

To the artist the scenery of the arid lands of the Far West contrasts with that of more humid regions by the russet-brown desolation of the valleys, the brilliant colors of the naked rocks, and the sharp, angular outlines of the mountains. A country without water is necessarily a desert, while with abundant moisture, at least in tropical and temperate latitudes, it becomes a garden of luxuriant vegetation. In the most desert portions of the Great Basin the annual precipitation does not exceed four inches, while in the valleys on the borders of the basin it probably reaches 20 or 30 inches. Throughout this region the only fruitful areas are along the margins of streams, or where springs come to the surface. In such places, where water can be had for irrigation, one finds oases of delicious shade, with green fields and orchards yielding an unusually abundant harvest. Thus in nearly all its physical features the Great Basin stands in marked contrast with those favored lands where rain is more abundant and more evenly distributed.

The rainfall that a region receives is a potent though silent factor, which controls an almost infinite series of results in its physical history and topography. In a humid region vegetation is usually luxuriant; the rock forms are masked by forests, erosion is rapid, and the rocks are commonly buried beneath the accumulations of their own *débris* or concealed by layers of vegetable and animal mould that in turn are clothed with vegetation. The hills have flowing outlines and are dark with foliage. The valleys have gently sloping sides that conduct the drainage into streams meandering through broad plains, and the whole scene has the softness and beauty of a garden. In an arid land like the Great Basin all this is changed. The mountains are rugged and angular, usually unclothed by vegetation, and receive their color from the rocks of which they are composed. From the gorges and cañons sculptured in the mountain sides alluvial cones descend to the plain. These sometimes have an extent of several miles, and they are steep or gentle in slope according to the grade of the streams that formed them. The valleys, even more dreary than the mountains, are without arboreal vegetation and without streams, and form a picture of desolation and solitude. In traveling through the Great Basin one sometimes rides a hundred miles without sight of a tree, and many times that distance without finding shade enough to protect him from the intense summer sun.

The bare mountains reveal their structure almost at a glance, and show distinctly the many varying tints of their naked rocks. Their richness of color is sometimes marvelous, especially when they are composed of the purple trachytes, the deep-colored rhyolites, and the many-hued volcanic tuffs[1] so common in western Nevada. Not unfrequently a range of volcanic mountains will exhibit as many brilliant tints as are assumed by the New England hills in autumn. On the desert valleys the scenery is monotonous in the extreme, yet has a desolate grandeur of its own, and at times, especially at sunrise and at sunset, great richness of color. At mid-day in summer the heat becomes intense, and the mirage gives strange delusive shapes to the landscape, and offers false promises of water and shade where the experienced traveler knows there is nothing but the glaring plain. When the sun is high in the cloudless heavens and one is far out on the desert at a distance from rocks and trees, there is a lack of shadow and an absence of relief in the landscape that make the distance deceptive—the mountains appearing near at hand instead of leagues away—and cause one to fancy that there is no single source of light, but that the distant ranges and the desert surfaces are self-luminous. The glare of the noonday sun conceals rather than reveals the grandeur of this rugged land, but in the early morning and the near sunset the slanting light brings out mountain range after mountain range in bold relief, and reveals a world of sublimity. As the sun sinks behind the western peaks and the shades of evening grow deeper and deeper on the mountains, every ravine and cañon becomes a fathomless abyss of purple haze, shrouding the bases of gorgeous towers and battlements that seem incrusted with a mosaic more brilliant and intricate than the work of the Venetian artists. As the light fades and the twilight deepens, the mountains lose their detail and become sharply outlined silhouettes, drawn in the deepest and richest purple against a brilliant sky.

[1] The word *tufa* is used throughout this volume to designate deposits of calcium carbonate. When the volcanic product is meant, for which the same name is sometimes used, we shall designate it by the word *tuff*.

The succession of seasons is less plainly marked on the deserts of the Great Basin than on the forest-covered hills of the Atlantic slope. As autumn advances, but little change appears in the color of the landscape, excepting, perhaps, a spot here and there of gold or carmine high up on the mountains, where a clump of aspens or of dwarfed oaks marks the site of a spring that trickles down and loses itself among the rocks. The valleys with their scanty growth of sage remain unchanged, as do the dusky bands of pines and cedars on the higher mountains. As the autumn passes away, the skies lose their intense blue, and become more soft and watery, more like the skies of Italy. The hues of sunset appear richer and more varied, and during the day cloud masses trace moving lines of shadow on the surface of the desert. By and by storm-clouds gather in black, gloomy masses that envelop the ranges from base to summit. These early storm-clouds cling close to the mountains and yield to the parched deserts but a few scattered drops of rain. The observer from below hears the raging tempest amid the veiled peaks, while all about him is sunshine. The mountains wrapped in impenetrable clouds, the glare of lightning and the deep roll of thunder as it echoes from cliff to cliff and from range to range, bring to mind the scriptural account of the storms of Sinai. And when the black clouds at last roll back from the mountains, and the sun with a wand of light dispels the storm, behold what a transfiguration! The peaks are no longer dark and somber, but glitter with the silvery sheen of freshly fallen snow.

As winter approaches, the storms amid the uplands become more frequent, until every range is white as snow can make it, and the tent-like mountains gleam like the encampment of some mighty host. Long after they are covered, the valleys between are bare as in midsummer, and the snow seldom lies upon them for more than a few days at a time. The highlands retain their snow far into summer, but on none of the ranges can it be said to be perpetual. In the valleys there are flowers beneath the sage-brush by the middle of April, but from that time until November scarcely a drop of rain falls. For many days and sometimes for weeks the skies are without a cloud.

The agriculture of this arid region is restricted to those scanty areas of land that can be irrigated. Of more importance is the grazing of sheep and cattle on the bunch-grass that frequently abounds amid the mountains and sometimes grows beneath the sage-brush. The mines of the precious metals, however, are the principal source of wealth, and to them must now be added a growing industry in salt, borax, sulphur, and carbonate of soda.

The Great Basin is not attractive to the pleasure-seeker, but to the geologist it is peculiarly fascinating, both because the absence of vegetation gives such unusual facilities for investigation, and because of the character of the problems to be solved. It is in this inhospitable region, now so arid that many a lost traveler has perished from thirst, that the great lake existed in recent geological time, which has been made a subject of study by the writer and his associates, the results of which are now presented.

EXPLORATIONS.

The existence of a great area of interior drainage on this continent, similar in many ways to the desert region of southern Asia, was not known, except to the early Spanish missionaries, among whom the name of Father Escalante is most prominent, and to trappers and hunters, who left no records of their observation, until Capt. B. L. E. Bonneville reached its eastern border in 1832.[2] A year later, a party led by Joseph Walker traveled across to the Pacific coast, by way of the Humboldt River and the Carson Desert. This expedition returned by a more southern route, and determined that much of the country explored did not drain to the ocean.

Ten years later, J. C Fremont, then a lieutenant in the Army, carried his bold explorations into the same region, and gave the name of "The Great Basin" to the rugged and arid country which he traversed westward of the Rocky Mountains. A comprehensive, and, for the most part, an accurate, description of the general features of the Great Basin, was published by Fremont in his report of 1848;[3] a detailed narrative of his journeys in 1842, '43, and '44 having been published three years previously.[4]

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[2] Adventures of Captain Bonneville, by Washington Irving.

[3] Geographical Memoir upon Upper California, Washington, D. C., 1848, p. 7.

[4] Exploring Expedition to the Rocky Mountains. Washington, 1845.

A summary of the results of exploration in this region previous to 1857 was prepared by Lieut. G. K. Warren, and published in Volume XI of the Reports of the Pacific Railroad Explorations, to which we must refer the reader for detailed information in this connection.

A portion of the region of interior drainage is within the boundaries of California, and came within the limits of the explorations of the geological survey of that State, carried on under the direction of Prof. J. D. Whitney. Volume I of the reports of that survey contains a brief account of the Great Basin,[5] relating principally to its southern border, which was compiled from the notes of several travelers.

Since the completion of railroad communication with the Pacific coast in 1869, important advances have been made in our knowledge of the Great Basin. The Central and Southern Pacific railroads have crossed it and sent numerous branches through its desert valleys, both northward and southward from the trunk lines; many towns and mining camps have sprung up along these highways, and almost every foot of easily irrigable land has been appropriated by settlers. Herds of cattle and sheep find subsistence on the mountains and in the sage-brush-covered valleys which were once thought to be too barren to become of service to man. Some of the most productive silver mines in the world have been developed in this inhospitable region. Throughout the eastern border of the Great Basin, in Idaho, Utah, and Arizona, the followers of the Mormon faith have found a "promised land," which by untiring toil and industry they have reclaimed from its primitive desolation and made the home of thousands. With all this advancement, however, the Great Basin is but thinly settled, when we consider its vast area; but, owing to its desert nature, probably contains a larger population than its agriculture alone can sustain. Together with the settlement of the country, exploration has gone forward until but little of the great *terra incognita* of thirty years ago remains unmapped; scarcely more than a beginning has been made, however, in unraveling its complicated geological history. The United States Geological Exploration of the Fortieth Parallel, in charge of Clarence King, mapped the geology of a belt 100 miles wide across its northern portion. A large part of the Great

[5] Page 461.

Basin was also mapped by the surveys in charge of Capt. George M. Wheeler and Major J. W. Powell; and geological explorations have been carried over large areas by the geologists connected with these surveys. The present Geological Survey has made special studies of a few of the principal mining centers of the Great Basin, and commenced the investigation of its surface geology in a systematic manner. Even with such a favorable beginning, many years of patient investigation, accompanied at times with hardships and privations, will be required before the geology of the Great Basin can be fully written.

The exploration of the Lahontan basin, so far as is definitely recorded, began in 1833, when it was crossed by the party in charge of Joseph Walker, as previously mentioned. No report of this journey has been published excepting in Irving's attractive book describing the adventures of Captain Bonneville. In 1843, '44, '45, and '46, Fremont traversed the Lahontan basin throughout nearly its entire extent from north to south and made many geographical discoveries; but although he noted the presence of tufa deposits about Pyramid Lake, and published a sketch of the tufa-coated island which suggested its name, he does not seem to have recognized that his route led through the desiccated bed of an ancient inland sea.

In 1854, Capt. E. G. Beckwith[6] crossed the northern part of the Lahontan basin, in the region of the Black Rock and Smoke Creek deserts, but gave little attention to the geology of the country traversed; the main object of his exploration being the discovery of a practical railroad route to California. Other reports of a similar nature might be cited, as that of Capt. R. Ingalls,[7] who traversed the Lahontan basin in the latitude of the Carson Desert in 1855; little information of geological importance is contained, however, in the narratives of these earlier expeditions.

The exploring party in command of Capt. J. H. Simpson[8] entered the Lahontan basin at Sand Spring Pass, at the eastern end of Alkali Valley, in June, 1859, and encamped on the slough connecting North and South Carson lakes; the expedition then proceeded southward to Walker Lake, by

[6] Pacific Railroad Reports, Washington, D. C., 1861, Vol. II.

[7] Congressional Documents: 34th, 1st, H. R. Ex. Doc. 1, p. 156.

[8] Explorations Across the Great Basin of Utah, Washington, D. C., 1876, pp. 312, 313.

way of Allen's Springs, and afterwards traversed Mason and Carson valleys, which, as we now know, were also occupied by the waters of Lake Lahontan. The presence of ancient water lines and of calcareous tufa deposits about the borders of the Carson Desert was recorded by Henry Engelmann, the geologist of the expedition, in his report on the geology of the country traversed during the reconnaissance, but time did not permit an extended study of the surface geology of the region. That large portions of the area of interior drainage had at no distant time been occupied by lakes was clearly recognized, and the cause of their disappearance was correctly ascribed to climatic changes.

During the progress of the United States Geographical Surveys west of the 100th Meridian, in charge of Capt. George M. Wheeler, large portions of the Lahontan basin were topographically surveyed, but no report on the geography or geology of the region has been published. The maps prepared by this survey, and also those issued in connection with the exploration of the Fortieth Parallel, were exceedingly useful during the field work of the present investigation, and were freely used in compiling the pocket map accompanying this report, as well as in preparing some of the smaller illustrations.

The exploration of the Fortieth Parallel included a belt 100 miles wide which crossed the Lahontan basin, but left considerable areas both to the north and south unmapped. In the reports of that survey Lake Lahontan received its name, and it is discussed to considerable length by the geologist in charge (Vol. I). Many detailed observations relating to the history of the former lake were recorded by Messrs. Arnold Hague and S. F. Emmons as a part of their report (Vol. II) of field observations. It is not necessary to introduce an abstract of the results reached by these geologists in reference to the history of the former lake, as we shall have frequent occasion to refer to their work in the pages that follow.

In 1872 Dr. James Blake made a journey from Winnemucca, Nevada, to the Pueblo Mountains, Oregon, during which he traversed the northern portion of the Lahontan basin, and made many observations in reference to tufa deposits, terraces, fossil shells, etc. The results of these observations were published in two brief papers in Vol. IV (1872) of the Proceedings of the California Academy of Sciences.[9] In these papers the possibility of an outlet to the ocean for the waters of the Great Basin during the Quaternary is suggested, and measurements are given of the altitude of some of the passes in the northern part of Nevada which lead towards the drainage of the Columbia. That the passes in this region could not have furnished a point of discharge for Lake Lahontan will be shown in the following chapter (page 34).

The study of the surface geology of the Great Basin, undertaken by the United States Geological Survey, was begun in the summer of 1880; a section of the survey, entitled the "Division of the Great Basin," having previously been organized under the leadership of Mr. G. K. Gilbert, with headquarters at Salt Lake City, Utah. The first field season was occupied with the study of Lake Bonneville, the results of which have been published by Mr. Gilbert in a somewhat popular essay in the second annual report of the survey; the final report, in the form of an independent monograph, is now in preparation.

In April, 1881, the writer commenced a geological reconnaissance through the northern part of the Great Basin, during which the northern half of Nevada was crossed and recrossed, and excursions were made into eastern California and southern Oregon. As the first year's exploration was entirely of a preliminary character, without scientific assistants, all detailed study and instrumental work was deferred until the following season. The reconnaissance of 1881 occupied seven months, during which about 3,500 miles were traversed in the saddle, the route being planned with special reference to the study of Quaternary geology. During the season the basin of Lake Lahontan was crossed in various directions and much of its history was deciphered. A sketch of the geology of Lake Lahontan, so far as determined from the first season's explorations, was published in the Third Annual Report of the United States Geological Survey.

While carrying forward the reconnaissance of 1881, the Mono basin, California, was visited and the study of its geological history begun; this task was left unfinished, however, until the region could be topograph-

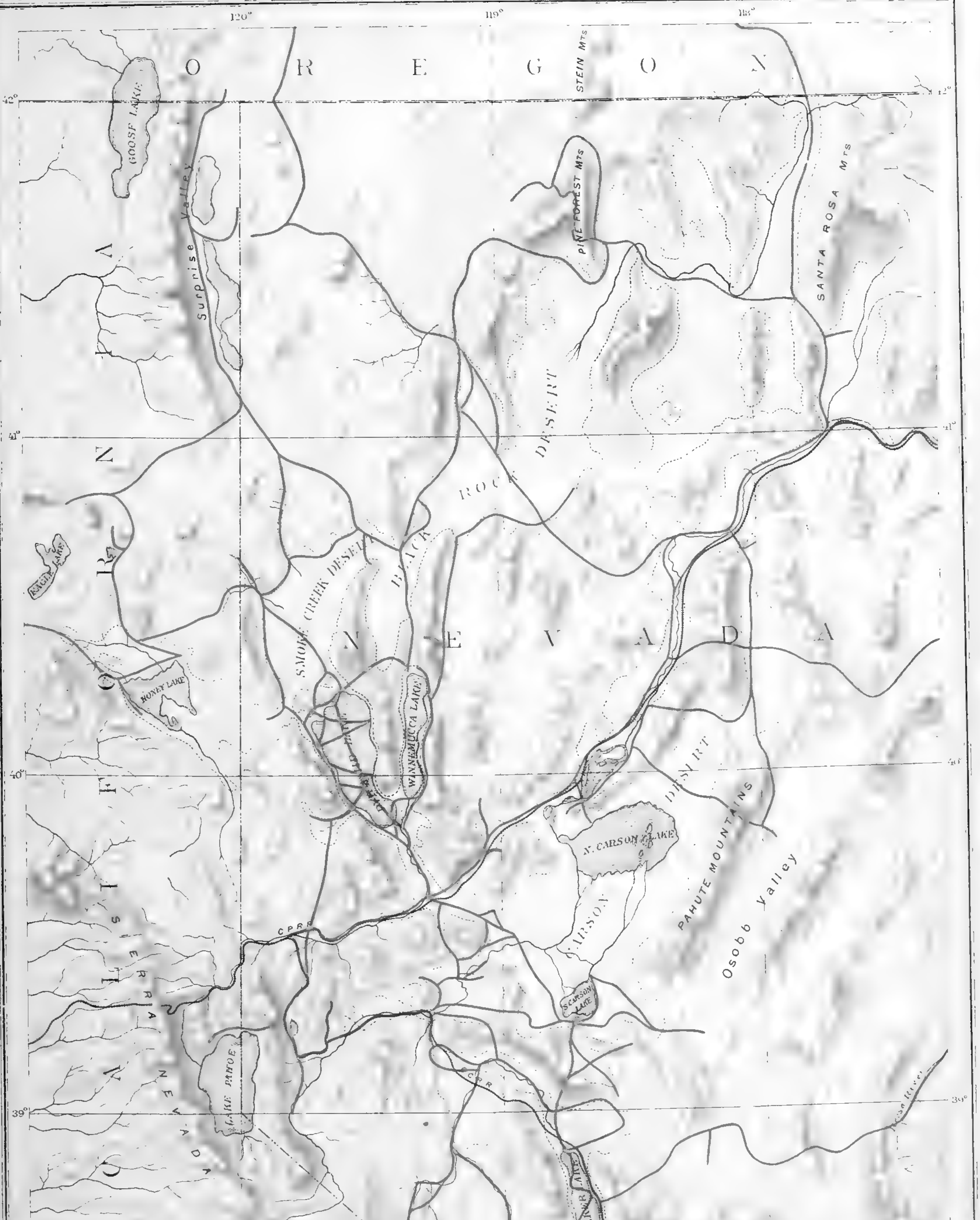
[9] On the absence of a rim to the Great Basin to the west of Pueblo Butte, p. 223. Remarks on the Topography of the Great Basin, pp. 276–278.

ically surveyed. From the experience gained during the first season's work, a plan of investigation was developed which was carried out during the summers of 1882 and 1883.

On taking the field at Winnemucca, Nevada, in the spring of 1882, I was joined by Mr. Willard D. Johnson, of Washington, D. C., who accompanied me on a journey through that portion of the Great Basin that lies north of the hydrographic rim of Lake Lahontan and is situated mostly in Oregon. The results of this exploration, so far as the surface geology of the region is concerned, were published in the Fourth Annual Report of the United States Geological survey. During this reconnaissance the previous conclusion that Lake Lahontan did not overflow northward was fully confirmed. The Great Basin north of the Nevada-Oregon boundary, in common with the main area of interior drainage, is divided into a number of independent hydrographic basins, many of which held Quaternary lakes that must have been contemporaneous with the great lakes of Utah and Nevada

On returning to Winnemucca in July, I was joined by Mr. W J McGee as geological aid, and a few weeks later by Mr. George M. Wright, also in the same capacity. Proceeding southward from Winnemucca we examined the Lahontan sediments, terraces, tufa deposits, etc., occurring in the Humboldt Valley, and then continued our journey southward in order to study the region about Humbolt, Pyramid, Winnemucca, and Walker lakes. Later in the season we entered the Mono Lake basin and began a detailed investigation of its Quaternary geology. Owing to the advance of winter we were obliged to leave the completion of this work until another season.

During the time that the expeditions mentioned above were being carried forward, Mr. A. L. Webster, assisted by Mr. Eugene Ricksecker, was engaged in making a topographical survey of the northeast portion of the Lahontan basin, in order to complete the compilation of the accompanying pocket map. The region surveyed by Mr. Webster embraced about 8,464 square miles, and is indicated on Plate II; the extreme eastern limit of the area surveyed is a few miles to the eastward of the right-hand border of the plate.



Julius Bien & Co. Lith.

ROUTES TRAVELED AND AREAS SURVEYED.

Routes by I. C. Russell

Routes by Scientific Assistants

Scale 29 miles = 1 inch

Lahontan Beach

Areas surveyed

The various routes followed by myself and my scientific assistants during the exploration of Lake Lahontan are shown on Plate II, and will serve to indicate the degree of completeness to which we were enabled to carry our observations. A portion of the field season was devoted by Mr. Johnson to the preparation of local maps, the positions of which are also indicated on map forming Plate II.

The winter of 1882–'83 was passed at the survey office in Salt Lake City, in the preparation of notes and maps for publication, chemical studies connected with our work, etc. In July, 1883, I again took the field in company with Mr. Johnson, and recommenced work in the Mono basin. After devoting all the time practicable to the study of the Quaternary geology of that region I journeyed northward and passed through a large portion of the Lahontan basin, en route to Red Bluff, California, where I disbanded my party in October. In traversing the Lahontan basin I visited several points of interest in the Walker River cañon, about Pyramid and Winnemucca lakes, and on the Black Rock and Smoke Creek deserts, thus being able to review many previous observations.

Mr. Johnson completed his topographical survey of the Mono basin late in December, and brought to a close, at least for the present, the field study of the Quaternary geology of the region from which the Division of the Great Basin derived its name

The explorations conducted by the writer have embraced three field seasons, a part of each having been devoted to the study of Lake Lahontan. The observations made during these several journeys, so far as they relate to the great Quaternary lake of northwestern Nevada, are included in the present report.

Our work in the Mono basin during the same years that the exploration of Lake Lahontan was being carried forward includes a study of the existing lake and of the ancient lake of much greater extent that formerly occupied the same valley; also, the relations of both the ancient and the modern lake to the glacial and volcanic phenomena displayed on a grand scale in the same basin. The results of these studies will be published in the Sixth Annual Report of the United States Geological Survey.

Incident to our geological studies in the Mono basin was a visit to the glaciers now existing amid the lofty peaks of the Sierra Nevada, on its western border. A sketch of the observations relating to these glaciers, together with a summary of what has been published in reference to these and other glaciers of the United States, was issued in the Fifth Annual Report of the United States Geological Survey.

CHAPTER II.

GENESIS OF LAKE LAHONTAN.

THE FORMATION OF LACUSTRAL BASINS.

The discussion of the origin of lake basins has been carried on with so much zeal during the past fifteen or twenty years that we now possess a large amount of literature bearing on the subject. From the facts gathered by many observers, in widely separated localities, it is evident that the depressions holding lakes are extremely diverse in character and have resulted from many causes. In some instances lakes are held in basins produced by orographic movement, *i. e.*, by the unequal folding of rocks, by dislocation due to faulting, etc. Others are the result of erosion, and have for their typical example a rock-basin produced by glacial action. Again, there is a third great group of basins produced by the damming of pre-existing waterways; as, for example, when the drainage of a valley is obstructed by moraines, land-slides, lava-flows, alluvial deposits, etc.

Following the schedule prepared by Davis,[10] we have three broad classes of lake basins:

a. Constructive or orographic basins.

b. Destructive or erosion basins.

c. Obstructive, barrier, or inclosure basins.

Each of these generic divisions is abundantly illustrated in the Great Basin. Very large portions, if not the entire area of interior drainage, have

[10] Classification of Lake Basins, by W. M. Davis; Proceedings of the Boston Society of Natural History, Vol. XXI, 1882, p. 321.

been broken by a vast network of fractures accompanied by a tilting of the included blocks, which have given origin to orographic basins on a grand scale. On the borders of the region, in the glaciated valleys of the Sierra Nevada and Wasatch mountains, rock basins due directly to the erosion of glaciers may be counted by hundreds if not by thousands. From almost any of the peaks of the High Sierra more than a score of lakes of this character may be observed. Lakes occupying barrier basins are also numerous in the cañons of the Cordilleras where ancient moraines obstruct the drainage. A number of the Sierra Nevada lakes which owe their origin to erosion and decomposition, resulting mainly from glacial action, will be described in connection with the Quaternary history of the Mono basin in the Sixth Annual Report of the United States Geological Survey. At present we are constrained to confine our attention to the more central portion of the Great Basin The area formerly occupied by glaciers in this region is very limited, and as flowing ice has been the principal agent in the formation of basins of erosion, this type of lake-basin is wanting, except about the summits of some of the highest of the basin ranges. Barrier basins, produced by the deposition of the current-borne *débris* of ancient lakes in such a manner as to obstruct the drainage of valleys, are not uncommon in the interior portion of the Great Basin, but the depressions characteristic of the region are due to other causes.

ORIGIN OF THE LAHONTAN BASIN.

The more pronounced topographic features of the Great Basin have been found to be the result of orographic displacement. The typical mountain structure of the region is monoclinal; the elements being orographic blocks bounded by faults, and so tilted that their upturned edges form mountain crests with a steep descent on one side and a more gentle slope in the opposite direction. The upheaved edges of faulted blocks usually appear as long and narrow ranges. Their depressed borders under-lie valleys. An ideal cross-section of the mountains and valleys of the Great Basin is shown in the following diagram:

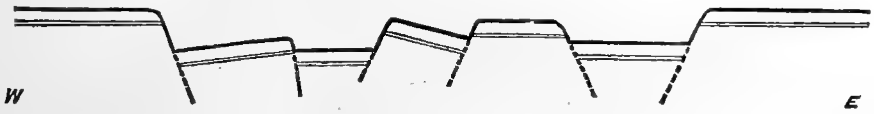


FIG. 1.—Ideal section illustrating Great Basin structure.

The structure here illustrated has been found so typical of the region between the Sierra Nevada and the Rocky Mountains, that it has been named by Gilbert the "Great Basin system" of mountain structure.[11]

The grandest displacements of the Great Basin are those determining its eastern and western borders, *i. e.*, the Wasatch and the Sierra Nevada faults. The first has been described by King, Gilbert, and others, and has been traced by the writer continuously for more than 150 miles; the second has been studied at intervals for over 200 miles without determining its full extent. The Sierra Nevada fault is much less regular in its course, and is more complex than the corresponding displacement along the eastern border of the Great Basin. It is conspicuous in Honey Lake Valley, California, where its scarp forms a line of rugged cliffs, bordering the plain on the west; and again along the west side of Eagle and Carson valleys, from near Carson City southward for fifty miles or more. In the valley of Mono Lake it is strongly pronounced; farther southward, in Owen's Valley, it has again been recognized, but its southern, like its northern terminus, is at present unknown. The details of this profound fracture are far from being understood, as it branches and changes its course in an extremely irregular manner. Disregarding all minor displacements, as well as the results of erosion and sedimentation, we may consider the Sierra Nevada in a general way as the upraised edge of an orographic block, having its eastern border determined by the great fault we have noticed above. The desert region stretching eastward from the base of the mountains is the thrown side of the same displacement. It is on the depressed side of this fault that the Lahontan basin is situated.

[11] U. S. Geographical Surveys West of the 100th Meridian, Vol. III, p. 21.

It is not to be understood, however, that the old lake basin was formed by a single, simple displacement; on the contrary, it is the result of exceedingly complex faulting that affected the entire region included between the Wasatch and the Sierra Nevada mountains. The time when these movements began is unknown, but they antedate the Quaternary, were in process during the existence of lakes Bonneville and Lahontan, and probably have not yet ceased, as will be shown in Chapter X. The old lake basin, instead of being a simple orographic valley, is composed of a large number of separate and independent depressions of the Great Basin type, which are united with one another directly, or by the intervention of narrow passes, and so nearly coincident in level that a single lake 900 feet deep in the lowest depression could flood them all. It is to the union of these various, independent, monoclinal valleys that the extremely irregular outline of Lake Lahontan is due.

Nearly all the ranges of northwestern Nevada are rugged and form serrate crests having an approximately north and south trend, and, as already stated, as a nearly universal rule they are monoclinal. An older structure, however, as first recognized by King,[12] is frequently apparent, in which a folding of the rocks into anticlinal and synclinal may be traced. In the older deformation the rocks were crumpled and contorted as in the Alleghanies and the Alps, but during the later disturbances they were broken without being folded. The monoclinal blocks resulting from the second disturbance are the elements giving character to the present topography; the surface features due to the former structure having been rendered inconspicuous by the later movements. The trend of the fault lines, and consequently of the mountain axes, is in general nearly north and south, but in the central part of the Great Basin, north of latitude 37°, it is more nearly north-northeast and south-southwest.

At present we can only call attention to a few characteristic examples of the displacements that gave origin to the Lahontan basin; these may be taken as types of the prevailing structure of the region.

In the Santa Rosa Mountains, in northern Nevada, the fault determining the trend of the range follows its western base and has a throw of not less

[12] U. S. Geological Exploration of the Fortieth Parallel, Vol. I, p. 735.

than 5,000 or 6,000 feet. The eastern slope is comparatively gentle, and conforms in a general way with the inclination of the beds of volcanic rock composing a large part of the mountains. The bold western mountain face is in reality an eroded fault scarp; the thrown block underlies Quinn River Valley.

In the case of the Jackson Range the principal fault follows its western base; the eastern base of the Pine Forest Mountains is also a precipitous fault scarp; the Black Rock Desert, intervening between these ranges, is a depressed area, which has been deeply buried beneath the sediments of Lake Lahontan. An ideal section from east to west, through these ranges, is shown in the following diagram:

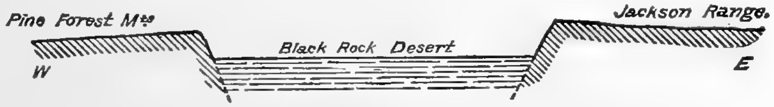


FIG. 2.—Ideal section through the Black Rock Desert, Nevada.

The Pahute Range, on the eastern border of the Carson Desert, has a well defined line of displacement along both the eastern and the western base, as indicated in the following generalized section:

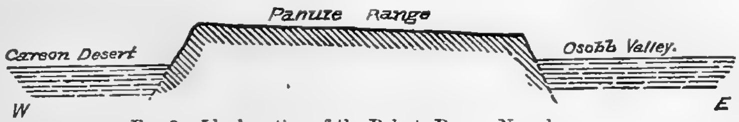


FIG. 3.—Ideal section of the Pahute Range, Nevada.

Great faults may also be traced along the western bases of the West Humboldt and Star Peak ranges. The eastern shores of both Pyramid and Winnemucca lakes are likewise determined by fault scarps, as indicated below.

FIG. 4.—Ideal section through Pyramid and Winnemucca lakes, Nevada.

In Walker Lake Valley the orographic structure so typical of the Great Basin is again repeated; the main displacement in this instance follows the western border of the valley and determines the abrupt eastern face of the Wassuck Mountains. The topography of the valley is well shown on Plate XV.

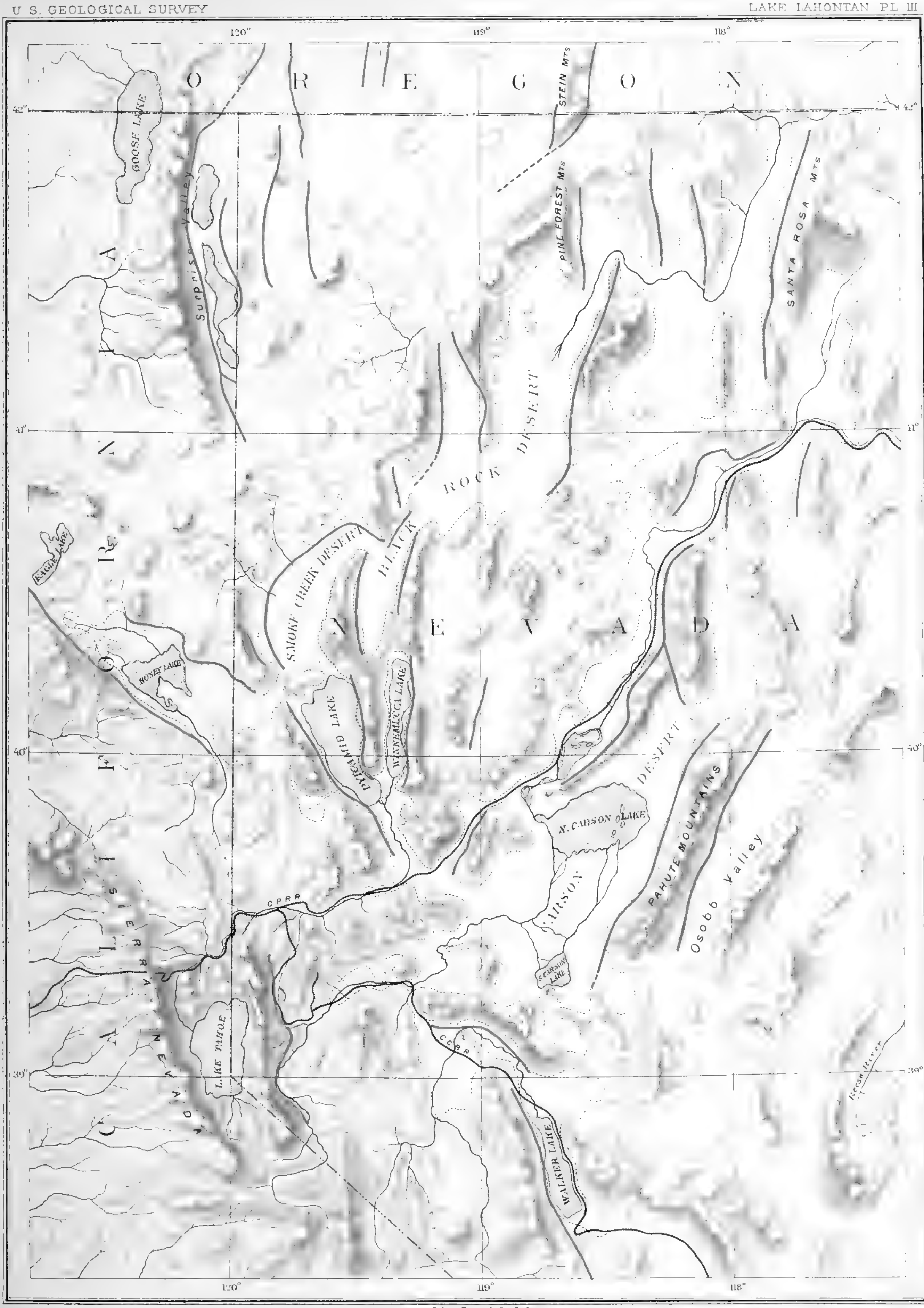
If desirable, illustrations of Basin Range structure might be multiplied almost without number, not only in the Lahontan basin, but throughout Nevada, Utah, and Arizona, and in parts of Oregon and California. On the accompanying map, Plate III, an attempt is made to represent the course of the faults that determined the main features in the present topography of the Lahontan basin. The data for completing a map of this nature, however, so as to present an accurate outline of the orography of the region, have not been obtained, for the reason that special attention has not been directed to the subject The lines of displacement that are shown have been sketched from actual observation, and serve, at least in the absence of more complete data, to indicate the vastness of the system of fractures that have given diversity to the topography of the region. Could every fault be indicated the map would be covered by an irregular network of intersecting lines.

The depression formerly occupied by Lake Lahontan may be taken as the type of a compound rock-basin due to displacement, many of the minor valleys of which it is composed being examples of fault-basins of the simplest kind.

GEOGRAPHICAL EXTENT.

THE HYDROGRAPHIC BASIN.

During the Quaternary period, as at the present time, the region of interior drainage between the Sierra Nevada and the Wasatch mountains was divided into a large number of interior drainage areas or hydrographic basins, two of which were of large size, and have claimed special attention. These are included between the 38th and 42d parallels of latitude, and together occupy the entire breadth of the Great Basin. The one to the eastward embraced northern and western Utah, together with small portions of Idaho and Wyoming, and delivered its drainage to Lake Bonneville. The hydrographic area to the westward included the northwestern part of Nevada, together with small portions of California and Oregon, and discharged into Lake Lahontan. Lake Bonneville received the drainage from



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PRE-QUATERNARY FAULT LINES.

Scale: 29 miles = 1 inch

a surface 52,000 square miles in extent; Lake Lahontan's hydrographic basin embraced 40,775 square miles.

The Bonneville basin has its lowest depression along its eastern border, now occupied by Great Salt Lake; and its form was largely determined by the Wasatch fault. In the Lahontan area the lowest depression is situated near the base of the Sierra Nevada, and the topography of the basin is determined, to a considerable extent, by the fault which follows the eastern base of that range.

The Bonneville and Lahontan drainage areas had a common divide for about 25 miles, between the 41st and 42d parallels, and a little east of the 115th meridian. Southward of the 41st parallel the boundaries of the two great hydrographic areas diverge, the included space being divided by short mountain ranges into a number of independent basins, some of which held Quaternary lakes of considerable size.

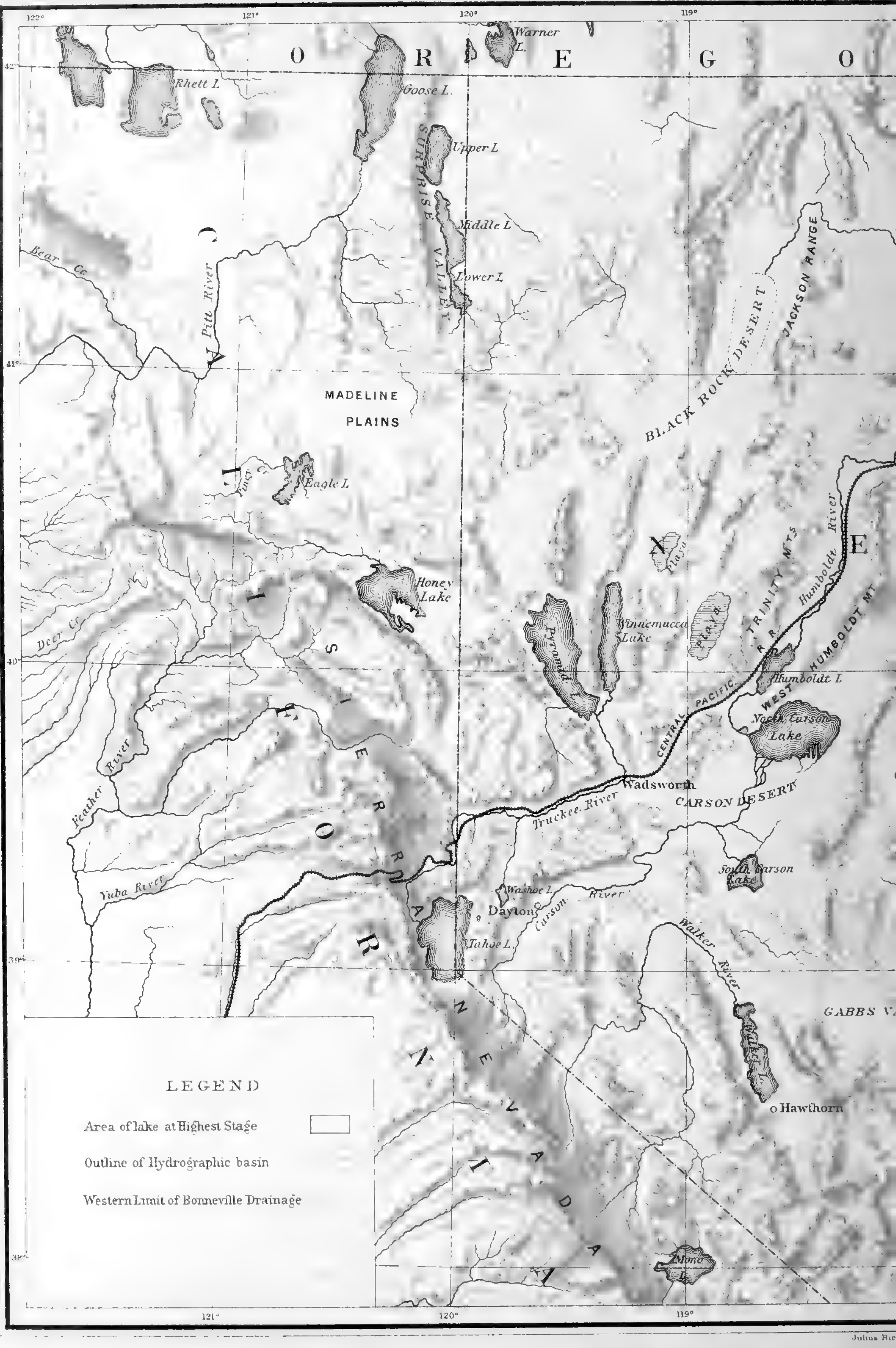
The direction of the streams in the northern part of the Great Basin shows that the area is divided by a central axis, irregular in its trend, from which the surface has a general slope, both eastward and westward, to the bases of the inclosing mountains.

From the Bonneville-Lahontan divide, north of Toano, the Humboldt River flows westward through a narrow and rugged valley which crosses the structural features of the country nearly at right angles. The course of the river seems to have been determined in Tertiary times, or perhaps earlier. During the Quaternary the Upper Humboldt Valley was occupied by a stream larger than the present, which emptied into Lake Lahontan a few miles east of the present site of Golconda. Before reaching the lake, the Quaternary river received considerable additions from the north through the channels of the North Fork, Maggi, Rock, and Rabbit creeks, and the Little Humboldt River. Its most important tributary, however, in ancient as in modern times, came from the southward, and flowed through the narrow Reese River Valley.

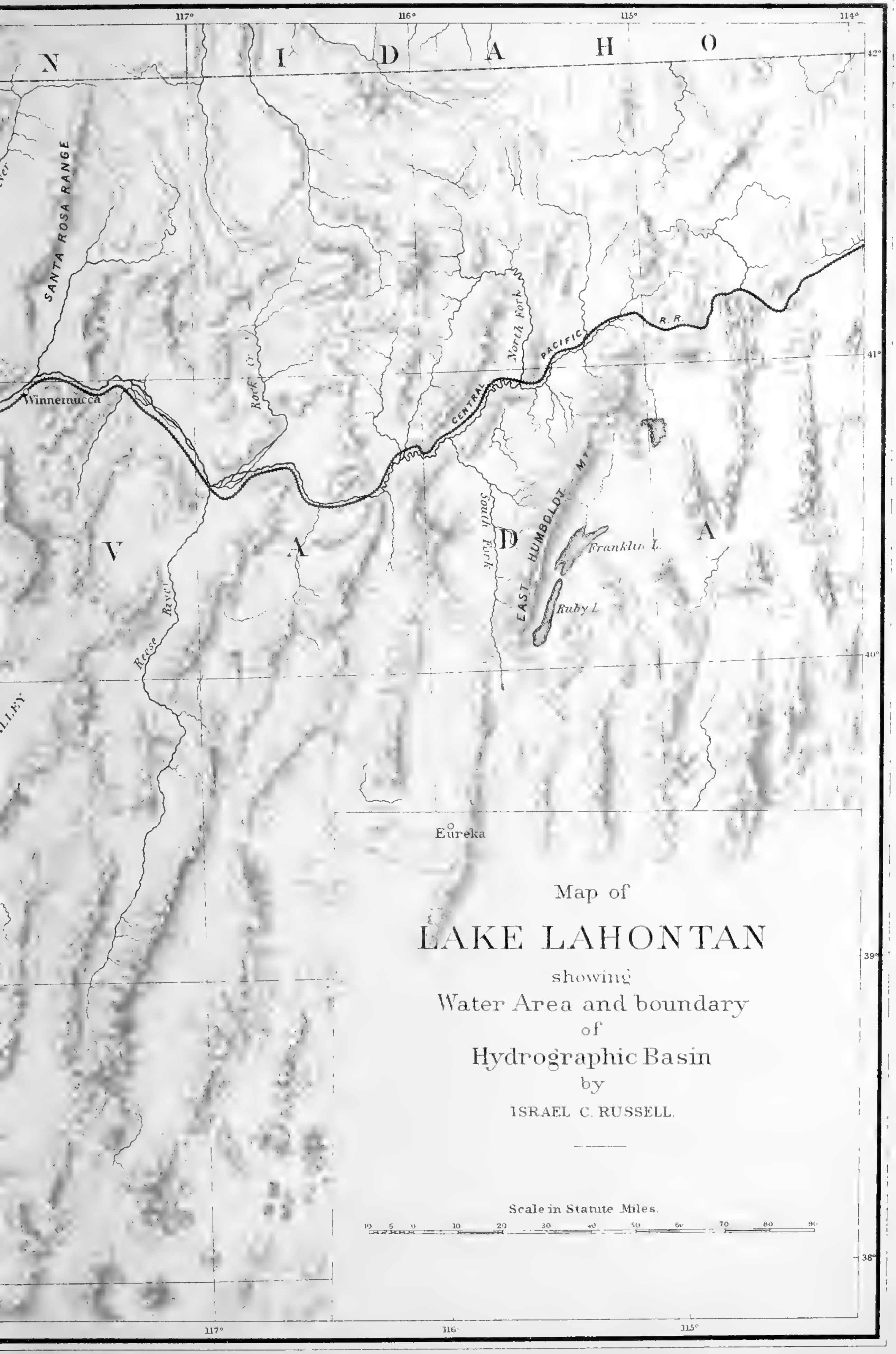
On the north the Lahontan drainage area was bordered by the rim of the Great Basin, and by a number of small and independent areas of interior drainage, situated mostly in Oregon and in the northwestern corner of Nevada. On the west the divide coincided for not less than 260 miles with the western rim of the Great Basin, and was determined by the crest line of the Sierra Nevada, from the eastern slope of which the lake received its greatest tribute. The Walker, Carson, and Truckee rivers gathered the surface drainage of the mountains into previously excavated channels, which bear witness to a long period of erosion antecedent to the existence of the Quaternary lake. The divide between the waters that flowed into Lake Lahontan and the drainage of the interior basins bordering it on the south and east is extremely irregular, but is well defined throughout the greater part of its course by the crests of rugged mountains.

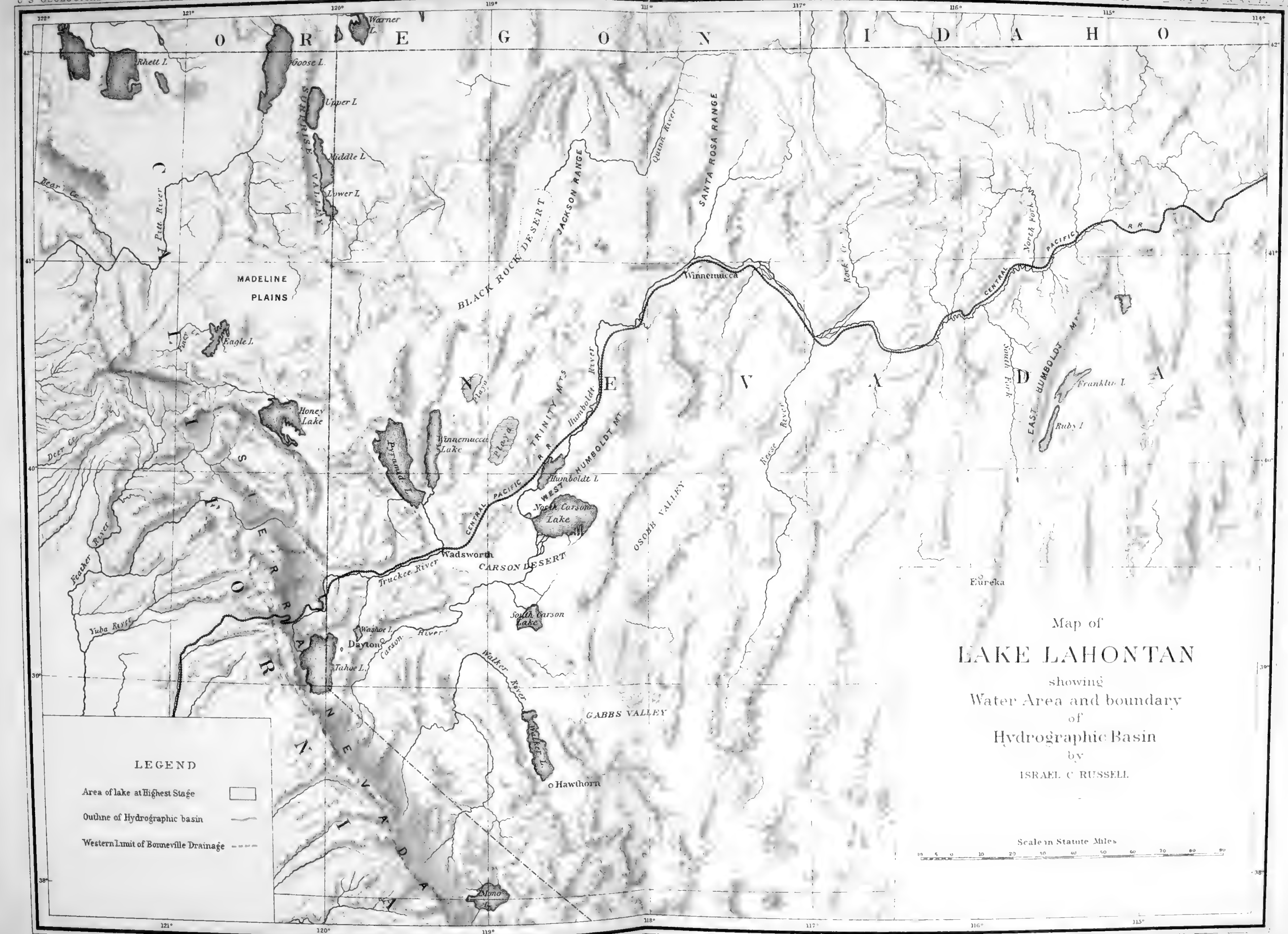
The separate drainage systems into which the basin is divided are the Humboldt and Reese river valleys of the east, Quinn River on the north, the Walker, Carson, and Truckee rivers, together with Smoke and Buffalo creeks, and Snowstorm and High-Rock cañons on the west. The boundary of the region that drained into Lake Lahontan is shown on Plate IV. Besides the areas draining into living streams there are several desert basins within the Lahontan area, as represented on Plate XXIX.

One of the most important conclusions to be derived from a study of the drainage in the region of Lake Lahontan during the Quaternary period is that the country at that time had about its present topographic form. The mountains were then the same as we find to-day, excepting that the lines carved by subaerial erosions are a little deeper, the alluvial cones about their bases are slightly larger, and they have undergone very moderate post-Quaternary orographic movements. The cañons occupied by the tributaries of Lake Lahontan still afford drainage channels when there is sufficient precipitation to form streams. If Quaternary man could revisit his ancient hunting grounds, he would have no difficulty in recognizing the landmarks that were once familiar to him. The mountains and valleys are the same, although their scanty vegetation has probably undergone many changes. The great lakes which were familiar to him, however, have passed away and given place to broad silent plains of desolation. The former rivers have shrunken, and many of their channels are dry.


O R E G O
C A L I F O R N I A
N E
Warner L.
Rhett L.
Goose L.
Upper L.
Middle L.
Lower L.
SURPRISE VALLEY
Bear Cr.
Pitt River
MADELINE PLAINS
BLACK ROCK DESERT
JACKSON RANGE
Eagle L.
Honey Lake
Playa
Pyramid L.
Winnemucca Lake
TRINITY MTS
Humboldt River
WEST HUMBOLDT MT
CENTRAL PACIFIC R.R.
Humboldt L.
North Carson Lake
Deer Cr.
Feather River
Wadsworth
Truckee River
CARSON DESERT
SIERRA NEVADA
Yuba River
Washoe L.
Dayton
Carson River
South Carson Lake
Tahoe L.
Walker River
Walker L.
GABBS V
o Hawthorn
Mono L.
LEGEND
Area of lake at Highest Stage
Outline of Hydrographic basin
Western Limit of Bonneville Drainage
122°
121°
120°
119°
42°
41°
40°
39°
38°

Julius Bie


117°
116°
115°
114°
42°
41°
40°
39°
38°
I D A H O
N
SANTA ROSA RANGE
Winnemucca
Rock Cr.
North Fork
CENTRAL PACIFIC R.R.
South Fork
EAST HUMBOLDT MT
Franklin L.
Ruby L.
V
A
D
A
Reese River
Eureka
Map of
LAKE LAHONTAN
showing
Water Area and boundary
of
Hydrographic Basin
by
ISRAEL C. RUSSELL.
Scale in Statute Miles.
10 5 0 10 20 30 40 50 60 70 80 90



Julius Bien & Co. Lith

THE LAKE BASIN.

As may be learned from the accompanying map, Plate IV, the outline of the hydrographic basin of Lake Lahontan is distinguished by great irregularity, and no less unsymmetrical is the contour line within, that marks the boundaries of the former lake. As nearly as can be estimated, the total area of Lake Lahontan, as previously stated, was about 8,422 square miles. Its northern extremity in Quinn River Valley reached a few miles north of the Nevada–Oregon boundary, and its extension southward was limited by the divide at the southern end of Walker Lake Valley. The distance between these points gives the extreme length of the lake as 250 miles. Its eastern limit was in Humboldt Valley, where the river passes through the Sonoma Range, a few miles to the eastward of Golconda; and the most westerly point near Susanville, in Honey Lake Valley, California. The axis joining these two extremes is 180 miles in length.

The area inclosed by the Lahontan beach is traversed by many mountain ranges, which formed peninsulas and islands during the existence of the lake, and divided its surface into a number of irregular water bodies that were connected by narrow channels. The principal water surfaces were grouped in two rudely parallel series, which were united at their northern and southern extremities by narrow straits. The area thus inclosed formed a large and extremely irregular island that bristled with barren and rugged mountain ranges. For convenience in description, we shall call the two main divisions of Lake Lahontan the Eastern and Western water bodies. The Eastern Body covered the Carson Desert, together with Buffalo, Alkali, and Churchill valleys, which open from it, extended up Humboldt Valley to beyond Golconda, and occupied the southern part of the Little Humboldt Valley. From the Humboldt the lake spread westward of the Eugene Mountains and the Slumbering Hills, and entirely filled Quinn River Valley.

The Western Body comprised the areas now known as the Black Rock and Smoke Creek deserts, together with the valleys of Honey, Pyramid, and Winnemucca lakes. At the north the connection between these two main divisions was by a narrow strait now traversed by the lower part of Quinn

River. The water in this channel during the highest stage of Lake Lahontan was 350 to 380 feet deep. The equally narrow strait connecting the East and West bodies at the south is now occupied by the lower portion of the Truckee River in its course between Wadsworth and Pyramid Lake.

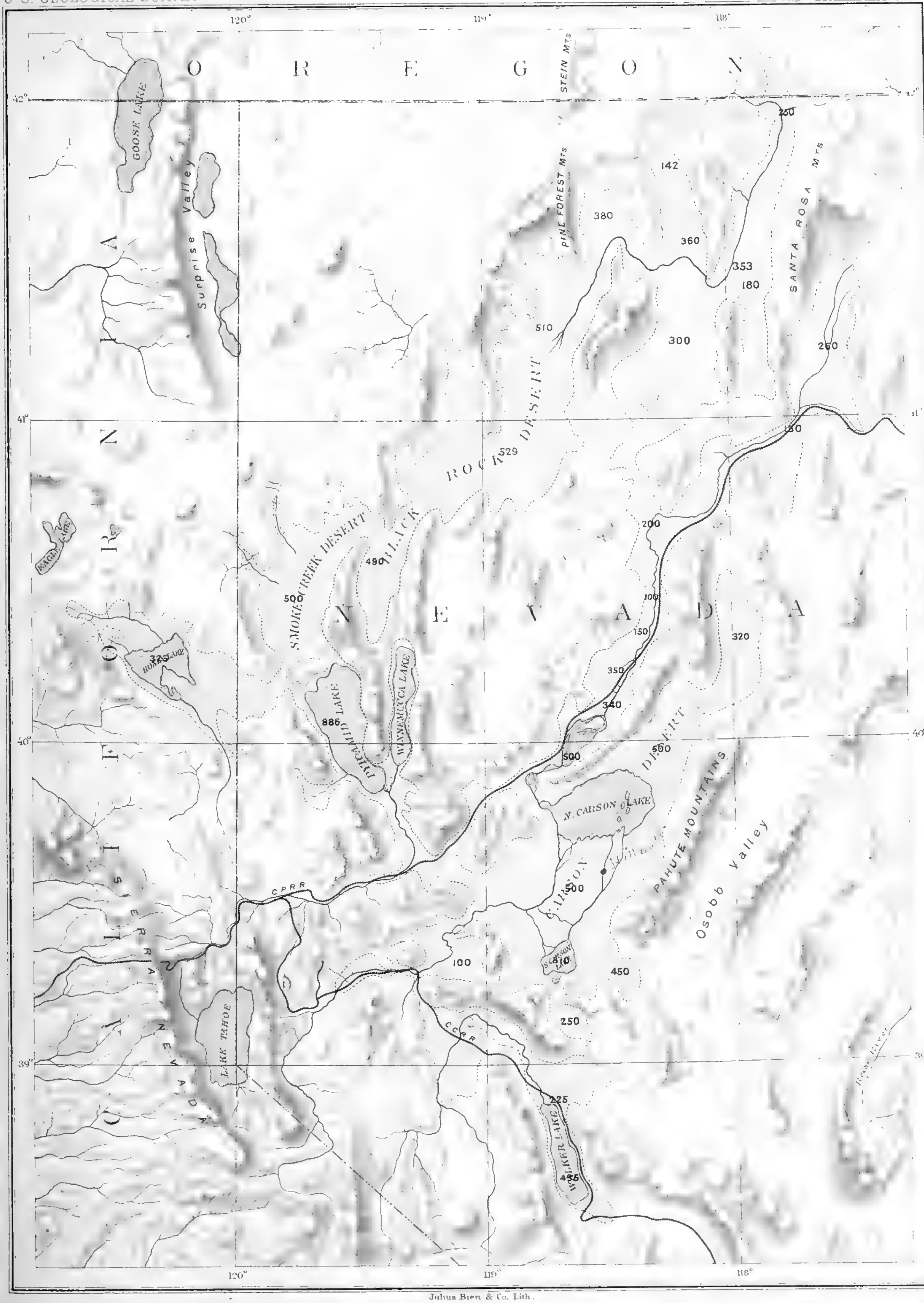
On Plate V, the depth of the water during the highest stage of Lake Lahontan is given in feet. These determinations are mostly from aneroid measurements, and show the lake to have been about 500 feet deep over the Carson Desert, becoming shallow in its extension up the Humboldt Valley. On the Black Rock and Smoke Creek deserts the depth was from 500 to 524 feet. The deepest sounding in the old lake, however, as already stated, was at the present site of Pyramid Lake, where the depth was 886 feet.

While the various valleys composing the basin of Lake Lahontan are orographic in their character, the cañons of inflowing streams are largely due to erosion. All the rivers, as well as the smaller creeks that were tributary to the lake, flowed in deeply cut cañons, many of which were occupied for a long distance by the waters of the lake when it reached its maximum extent. These cañons will be more fully noticed in connection with the description of the Lahontan lake beds.

Lahontan was intermediate in area between Lake Erie and Lake Ontario, but was far less systematic in outline than either; in fact its boundaries were more irregular than any other lake, recent or fossil, that has been explored. As shown on the frontispiece, it was smaller than Lake Bonneville, and ranks as second in size of the Quaternary lakes of the Great Basin.

QUESTION OF OUTLET.

In studying the records of an ancient lake, one of the first questions to which it is desirable to find an answer is whether it overflowed or not; and if it did find an outlet, what are the characteristics of the channel of discharge. The importance of determining the nature of the channel of overflow of a fossil lake is illustrated in the case of Lake Bonneville, which, as is well known from Mr. Gilbert's investigations, rose until it overflowed at Red-Rock



Julius Bien & Co. Lith.

DEPTH OF LAKE LAHONTAN AT HIGHEST WATER STAGE.

Soundings given in feet.

Scale: 29 miles = 1 inch

0 5 10 15 20 25 50 75 100

Pass, in Idaho, and then cut down its outlet to the depth of 370 feet. The level of the first point of discharge determined the horizon of the highest of the Bonneville terraces. The bottom of the gorge cut by the overflowing stream determined the level of the Provo Beach, the most strongly accented of all the Bonneville water lines.

As previous writers on Lake Lahontan have conjectured that there was an outlet at its southern end[13] this was the first portion to be explored when the present study was undertaken. On examining Gabb's Valley, it was fonnd that a mountain barrier intervened between it and the Lahontan basin to the northwest, thus proving that it was not occupied by that lake, and, moreover, was not included in its hydrographic basin. From the southern end of the Carson Desert a long narrow arm of the former lake extended into the desert valley which opens southward from Allen's Springs. The southern end of this valley is low and filled with alluvium which has been formed into gravel bars by the waters of Lake Lahontan; these sweep about the end of the basin in graceful curves, the highest in the series coinciding with the horizon of the highest water level of Lake Lahontan, thus proving conclusively that the lake did not here find an outlet.

The highest of the Lahontan beaches at the eastern end of Alkali Valley is far below the lowest part of Sand Spring Pass, which proves that Lahontan did not enter Fairview Valley through this gap.

The Lahontan beach may be traced with ease along the steep volcanic bluffs bordering the Carson Desert on the south, from Allen's Spring, to where the Carson River breaks through the range. The lake extended through the Carson River cañon and occupied Churchill Valley and the valley of the Carson River as far as Dayton. Opposite Old Camp Churchill there is a narrow gap in the hills bordering the valley on the south, which at first gives promise of having been an outlet of the ancient lake. On following up this valley we find it ascending with a low grade and opening through a narrow gap into Mason Valley, about which there are beach lines, showing that it too was once filled by a lake. The highest beach in Mason Valley is on a level with the top of a narrow divide which has been

[13] King: U. S. Geological Exploration of the Fortieth Parallel, Vol. I, p. 507. Whitney: Climatic Changes in Later Geological Time, p. 110. Memoirs of the Museum of Comparative Zoology of Harvard College, Vol. VII, No. 2.

cut through by a stream that once flowed into Lahontan basin through the channel that opens opposite Old Camp Churchill. The lake which occupied Mason and Walker Lake valleys cut down its point of overflow about 85 feet, and discharged its waters northward. The bottom of the channel, thus formed, where it leaves Mason Valley is between 60 and 70 feet below the level of the Lahontan beach, as determined by measurements of level connected with the profile of the Carson and Colorado Railroad. These measurements indicate that Lake Lahontan did not extend into Mason Valley until after the channel cut by the overflow from that basin was formed. We know, however, that there has been considerable post-Lahontan orographic movement in this region, and it seems not unlikely that the relative height of Mason Valley and the Lahontan beach along the Carson River, may have been changed since the evaporation of the former lake. It is, therefore, possible that Lahontan during its highest stage extended through the pass connecting Churchill and Mason valleys, before the present channel was excavated, and occupied Mason and Walker Lake valleys. The tufa deposits about Walker Lake, as will be explained in a future chapter, are of the same nature as the similar formations in the main areas of Lake Lahontan, and indicate that they were precipitated from waters of the same character.

After determining that Lake Lahontan did occupy Walker Lake Valley, we explored its ancient beaches, and found that the former lake extended only a few miles southward of the one which now fills the bottom of the basin. Well preserved gravel bars sweep around the southern end of the valley but do not reach the level of the pass leading south into Soda Springs Valley; at the end of this basin there is also a low pass that is uncut by stream erosion.

As the localities noticed above are the only ones on the southern border of the Lahontan basin that would suggest a possible outlet, the conclusion that the former lake did not overflow in that direction is positive.

In the northern part of the basin all the passes leading to the valleys draining into the Owyhee, one of the tributaries of the Columbia, were specially examined, as well as the divide between the northern end of the Black Rock Desert and Alvord Valley; at none of these places are there channels of overflow. The divide at the northern end of the Black Rock Desert was the lowest point on the northern rim of the basin, but it was at least 200 feet above the Lahontan beach near at hand; moreover, the rim of the basin at this point was never cut by a transverse channel of erosion. This point was visited by Dr. James Blake in 1872, who determined its elevation to be "590 feet above the valley of Queen's [Quinn] River at the place where it makes a bend to the southwest, to lose itself in the Black Rock Desert."[14] Lake Lahontan at the point in Quinn River Valley designated by Dr. Blake, was 380 feet deep, thus furnishing additional evidence that the ancient lake did not attain the level of the pass in question.

During the topographic survey of the northern portion of the Lahontan basin the highest water line of the old lake was mapped with care and found continuous throughout. The lake extended into King River Valley which formed a complete *cul de sac*, with no opening except into the Black Rock Desert. At the head of Quinn River the bottom of the valley slopes upward until at the divide it is several hundred feet above the horizon of the Lahontan beach. The northern border of Paradise Valley was closely examined by Mr. Webster, and gave positive evidence that it was not a point of discharge for the old lake. During the progress of our work every point on the northern rim of the basin that could be suspected of having been low enough to allow the old lake to overflow was examined either by the writer or his scientific assistants, and found to be unbroken by a channel of discharge such as an overflowing lake must necessarily excavate.

It is important to keep in mind the absence of an outlet while reading Lahontan history, as it has a direct bearing on the character of the shore topography which records the extent of the lake at various stages, and furnishes the key to the chemical history of the waters which formerly flooded the basin.

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[14] Proceedings of California Academy of Sciences, Vol. IV, 1872, p. 276.

CHAPTER III.

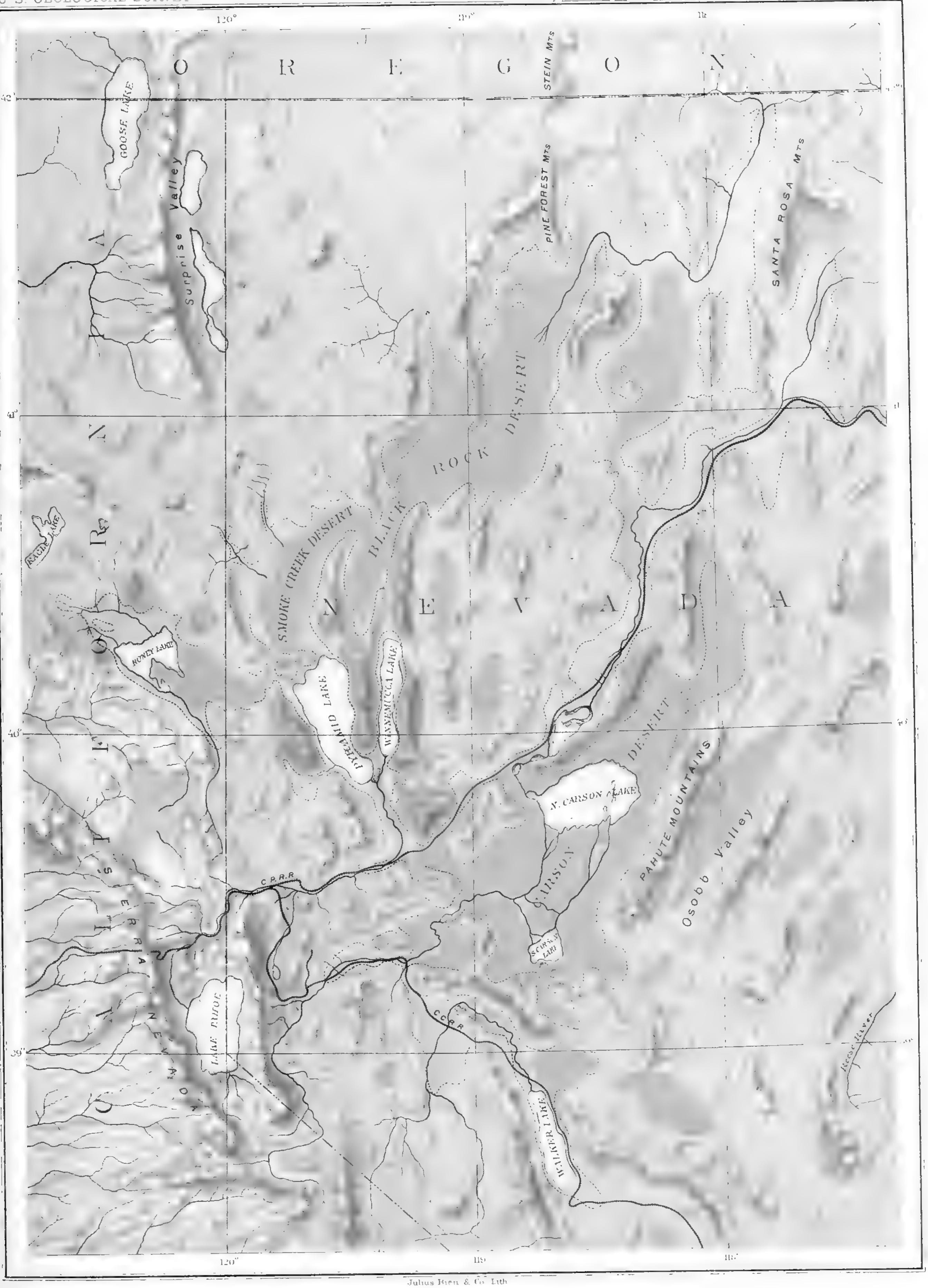
PHYSIOGRAPHY OF THE LAHONTAN BASIN.

VALLEYS.

The region once occupied by Lake Lahontan is a typical portion of the great area of interior drainage of which it forms a part. The valleys throughout the region have an elevation of from 3,900 to 4,500 feet above the sea, and are approximately level plains that have been regions of accumulation for an indefinite period Separating the valleys are rugged and angular mountain ranges rising from a few hundred to four or five thousand feet above the adjacent lowlands The basin of the ancient lake, as well as the greater part of the region that drained into it, may with truth be called a desert country. The absolutely barren portions, however, with the exception of the mountain tops, are mostly confined to the Carson, Smoke Creek, and Black Rock deserts, which are completely destitute of vegetation over hundreds of square miles

The smaller valleys, although mostly desolate and valueless for agriculture, are usually covered with a scattered growth of sage-brush and sometimes with other desert shrubs, and perhaps produce sufficient bunch-grass to form natural pastures. The soil throughout the valleys is usually more or less alkaline, but where water can be had for irrigation it is frequently found to be capable of producing good crops of grass and cereals.

The areas where irrigation has been successful are along the immediate banks of the Humboldt and Reese rivers, in the cañon of the Truckee, and narrow strips bordering the Carson and the Walker. Some portions of the



Julius Bien & Co. Lith.

MAP SHOWING LAND CLASSIFICATION OF THE LAHONTAN REGION.

Scale 20 miles 1 inch

Arid | Agricultural | Forest | Grazing

Carson Desert, so situated as to be conveniently watered from the Carson River, are also under irrigation. At a limited number of localities on the borders of the Black Rock Desert and in Quinn River Valley the water from springs and small mountain streams is used to irrigate gardens or a few acres of grain. In Mason and Honey Lake valleys there are swampy meadows of considerable extent adjoining irrigable lands where abundant harvests are annually secured.

The Central Pacific Railroad passes for 165 miles through the desiccated bed of the extinct lake, entering it a few miles east of Golconda and leaving it, on the west, in the Truckee Cañon about 15 miles west of Wadsworth. Nearly all the villages in the basin are located along this highway, which furnishes supplies for a wide extent of country. The traveler in crossing western Nevada by rail for the first time will perhaps be impressed with its barren nature and perhaps conclude that it is unfit for human habitation. With the exception of Mason and Honey Lake valleys, however, it is the most fruitful portion of the Lahontan basin. A typical example of the deserts of Nevada may be seen from the track of the Central Pacific Railroad between Humboldt Lake and the Truckee River, including a glimpse of the Carson Desert to the southward of Humboldt Lake, which was once covered by 500 feet of water.

The Carson and Colorado Railroad also passes through a portion of the basin once occupied by Lake Lahontan. On going south from Dayton the traveler by this route follows a narrow valley formed in part by the erosion of the Carson River, and subsequently occupied by Lake Lahontan. Opposite the site of Camp Churchill the road bends abruptly southward and traverses a narrow pass leading to Mason Valley; from there it follows Walker River and the eastern shore of Walker Lake and crosses the southern extremity of the old lake margin at a point a short distance south of Hawthorn. Throughout this entire distance, with the exception of a short space in the Walker River Cañon, the road is below the level of the highest beach of the old lake.

MOUNTAINS.

The numerous narrow and rugged mountain ranges of the Lahontan basin, excepting in a few instances where they are scantily clothed with cedars and pine, are nearly as barren and desolate as the intervening sage-brush valleys. The Sierra Nevada, as is well known, supports varied and beautiful coniferous forests that are valuable for the timber and wood which they supply. The trees are mainly confined to the moderately elevated portions of the range, their upper limit or the "timber line" having an elevation of about 10,000 feet. The lower extent of arborescent vegetation, more especially of the pines, is apparently determined by lack of moisture, and along the eastern base of the Sierra Nevada occurs at an elevation of about 5,000 feet. The upper limit of timber-growth is invariably occupied by pines, which, owing to the severe winter climate of the elevated regions, are dwarfed and gnarled, and, at their extreme upper limit, extended prone on the mountain side. At widely separated points in the High Sierra, where exposed to the full fury of the winter storms, the branches and trunks of the pines are stripped bare of leaves and bark, and even eroded by the drifting ice-crystals to a considerable depth, thus recording a recent climatic change that has produced more severe storms than were experienced during the earlier history of the trees. King states that this recent climatic oscillation began previous to 1870, and was the first of its kind for over 250 years.[15]

In the northern part of the Lahontan basin the most conspicuous ranges are the Santa Rosa, Jackson, and Pine Forest. The first two of these are scantily clothed with cedars, above which rise the bare and rugged mountain crests; the third, on the western border of the northern extension of the Black Rock Desert, is covered over a limited area with a forest of yellow pine, from which the range derives its name. The mountains bordering on the Carson Desert on the east are dark with piñon, and afford to the Pahute Indians an abundant harvest of pine-nuts during certain seasons. On the precipitous mountains overshadowing Walker Lake on the west, there is a timber band, composed almost entirely of piñon, commencing about 1,000 or 1,500 feet above the lake, and extending upwards to within

[15] U. S. Geological Exploration of the Fortieth Parallel, Vol. I, p. 527.

1,000 feet of the highest summits. When seen from the eastern shore of the lake, this girdle of vegetation appears like a dusky cloud-band encircling the mountain; above which rise the bare and rugged peaks forming the crest of the range. Besides the coniferous trees the mountain mahogany and the cottonwood are common in some portions of the old lake basin. The former grows in the cañons and ravines of the mountains, while the latter is found mostly along the streams, whose courses it renders conspicuous by deep green foliage in summer, and the brilliant yellow of ripened leaves in autumn.

With the few exceptions we have mentioned, the mountains of the Lahontan basin are desert ranges, frequently brilliant in color, and present a diversity of tints that are astonishing to one reared beneath more humid skies, but lacking in the shades and shadows that vegetation alone can impart. In this region the mountains are nearly all of volcanic rocks, among which the deeply colored rhyolites are conspicuous. Still more diversified are the purple trachytes of many hues, and volcanic tuffs that vary through all shades and tints, from a pure white to a deep, luminous red. In contrast with these harlequin colors are sombre mountains and rugged cliffs of basalt, sometimes veiled and partially buried beneath dunes of soft, creamy sand. The traveler over the Carson and Colorado Railroad, while passing along the eastern shore of Walker Lake, cannot fail to be impressed with the gorgeous coloring of the rhyolite hills bordering the valley on the east, especially if his journey be made in the deepening twilight, when the splendor of the western sky is rivalled by the brilliant coloring of the silent and lifeless mountains. The West Humboldt Mountains, bordering Humboldt Lake on the east, are also remarkable for the great variety of beautiful tints that are inherent in the rhyolites and tuffs composing the range. The absolutely desert mountains stretching northward from Black Rock Point, and known as the Black Rock Mountains, are so gorgeous and varied in color that they merit the name of the Chameleon Hills. The nearly parallel range to the west of these mountains has been called the "Harlequin Hills," by Mr. Webster. The aptness of the name will no doubt be appreciated by every one who has seen those naked towers and domes of rhyolite and tuff at sun rise or at sunset, when their glories are fully revealed.

RIVERS.

The rivers that enter the Lahontan basin are the Humboldt, from the east, Quinn River, from the north, and the Truckee, Carson, and Walker, from the west and southwest. All these streams flow through partially filled cañons which bear evidence of having been excavated by stream erosion previous to the first rise of Lake Lahontan. These rivers, like most others in the Great Basin, vary greatly in volume during the year. In winter and spring they become broad, rapidly flowing floods of muddy water that overspread their banks, but during the dry season, from May to November, they shrink greatly in volume, and sometimes become dry for a large part of their course.

THE HUMBOLDT RIVER.

This river[16] rises on the eastern border of Nevada and flows westward for approximately 200 miles, and enters the Lahontan basin through a pass in the Sonoma Mountains, in latitude 41°. From this point it continues its course through Lahontan lake-beds for nearly 100 miles to Humboldt Lake. Throughout the dry season this is usually its terminus, but during the winter months the lake frequently overflows, and the river continues to North Carson Lake ("Carson and Humboldt Sink"), where its waters are evaporated. The Humboldt before entering the Lahontan basin receives a number of tributaries, the largest being Reese River, which enters from the south. During the summer and fall many of these streams, including Reese River, fail to reach the main channel, their waters being dissipated by evaporation or absorbed by the thirsty soil. In its course through the Lahontan lake-beds between Golconda and Humboldt Lake, the river has carved a cañon, in places 200 feet deep, since the recession of the former lake. The material removed in cutting this channel has been deposited in the northern part of Humboldt Lake, and has contributed largely to the formation of a broad low-grade delta that is already partially converted into rich meadow-lands.

[16] Named Humboldt by Frémont, but was previously known as Mary's, or Ogden River. See Frémont's Geographical Memoir upon Upper California, Washington, 1848, page 10.

Two measurements were made of the volume of the Humboldt, one on September 10, 1881, the second July 17, 1882; the former gave 48 and the latter 750 cubic feet per second. When the first measurement was taken the river was at its lowest stage for the year. At the time of the second measurement it was flooded, and heavy with sediment, but had fallen three feet below the line that recorded its highest rise; two weeks later its discharge had decreased nearly one half.

An analysis by Dr. T. M Chatard of the water of the Humboldt, collected November, 1882, near Stone House, just before the river enters the Lahontan basin, is given below.

Constituents.	One liter of water contains, in grammes—	Per cent. in total solids.	Constituents.	Probable combination (in grammes per liter).
Silica (SiO_2)	0.0326	9.03	Silica (SiO_2)	0.0326
Alumina (Al_2O_3)	0.0013	0.37	Alumina (Al_2O_3)	0.0013
Calcium (Ca)	0.0489	13.53	Calcium carbonate ($CaCo_3$)	0.1222
Magnesium (Mg)	0.0124	3.46	Magnesium carbonate ($MgCo_3$)	0.0434
Potassium (K)	0.0100	2.77	Potassium chloride (KCl)	0.0157
Sodium (Na)	0.0467	12.92	Potassium carbonate (K_2CO_3)	0.0046
Sulphuric acid (SO_4)	0.0477	13.12	Sodium sulphate (Na_2So_4)	0.0705
Chlorine (Cl)	0.0075	2.08	Sodium carbonate (Na_2Co_3)	0.0550
	0.2071	57.28	Total (95.52 per cent. accounted for)	0.3453
Carbonic acid (CO_3) by difference	0.1544	42.72		
Total	0.3615	100.00		

If excess of CO_3 above amount required for Na_2Co_3 be calculated as $NaHCo_3$, we will have 0.3453 less Na_2Co_3 (0.0550) = 0.2903
Na_2Co_3 = 0.0200
$NaHCo_3$ = 0.0512

Total..0.3615

An analysis of the water of Humboldt Lake is given on page 67.

QUINN RIVER.

Quinn River is formed by the union of many brooks that have their sources on the Santa Rosa Mountains and on the eastern slope of the Quinn River Range. It flows south for about fifty miles down Quinn River Valley and then turns abruptly westward, and continues its course until the northern end of the Jackson Range is passed; it then flows southward again and enters the Black Rock Desert. During the spring months, while the snow on the mountains is melting, this is a good-sized river, and has a swift muddy current. At Mason's Crossing, some 75 miles from its source, it is reported to be impassable for horsemen for a number of days together during the high-water stage. At this season its waters form a shallow lake of variable size, on Black Rock Desert, that is said, at times, to be 50 or 60 miles long by 20 broad. As the dry season advances, this playa lake evaporates, leaving a vast mud-plain; the river at the same time shrinking back 75 or 100 miles. During the highest stages of Lake Lahontan, Quinn River had no existence, the greater part of its valley being occupied by an arm of the lake.

TRUCKEE RIVER.

The Truckee River has its source in the overflow of Lake Tahoe and is of greater purity and subject to less fluctuation than any other stream that enters the Lahontan basin. The lake which gives it birth is situated at an elevation of 6,247 feet[17] amid the peaks of the Sierra Nevada; from this reservoir the water descends with a fall of 2,466 feet,[18] to Pyramid and Winnemucca lakes, where it is evaporated, leaving the lower lakes alkaline and saline. The river is quite largely used for irrigation in the neighborhood of Reno, and to a small extent between Reno and Wadsworth. A few miles from Pyramid Lake a good-sized ditch has recently been constructed for the irrigation of the lands of the Indian reservation.

An analysis of the waters of Lake Tahoe, by Prof. F. W. Clarke, which may be considered as representing the normal condition of the Truckee River, is given herewith:

Constituents.	One liter of water contains, in grammes—	Per cent. in total solids.	Constituents.	Probable combination (in grammes per liter).
Silica (SiO_2)	0.0137	18.77	Silica (SiO_2)	0.0137
Magnesium (Mg)	0.0030	4.11	Magnesium carbonate ($MgCo_3$)	0.0105
Calcium (Ca)	0.0093	12.74	Calcium carbonate ($CaCo_3$)	0.0232
Sodium (Na)	0.0073	10.00	Sodium chloride (NaCl)	0.0012
Potassium (K)	0.0033	4.52	Potassium chloride (KCl)	0.0034
Chlorine (Cl)	0.0023	3.14	Sodium sulphate (Na_2So_4)	0.0052
Sulphuric acid (SO_4)	0.0054	7.40	Potassium sulphate (K_2So_4)	0.0034
	0.0443	60.68	Sodium carbonate (Na_2Co_3)	0.0117
Carbonic acid (CO_3) by difference	0.0287	39.32	Total (99.04 per cent. accounted for)	0.0723
Total	0.0730	100.00		

[17] Determined by Pacific Railroad surveys.

[18] Elevation of Pyramid Lake, 3,781 feet. See *postea*, page 101.

The sample, the analysis of which is reported, was collected in October, 1882, on the eastern border of the lake near Glen Brook, one mile from shore and one foot below the surface.

The most interesting feature to the geologist in the present condition of the Truckee River is its bifurcation shortly before reaching Pyramid Lake. As represented on Plate IX, the stream divides so as to deliver a part of its waters to Pyramid Lake and a part to Winnemucca Lake. The branch entering Pyramid Lake has the ordinary features of a river winding through an alluvial bottom, and has formed a low-grade delta of broad extent, as shown on the map. The waters that are tributary to Winnemucca Lake leave the main stream at nearly a right angle and flow through a deep narrow channel carved in Lahontan sediments. This stream, or "slough," when measured in September, 1882, had a volume of 2,400 cubic feet per second From the manner in which the bifurcation takes place it cannot be considered as the breaking up of a stream on a delta or an alluvial slope, as in the case of the Carson River after entering the Carson Desert, but must have been originated by the waters overflowing from Pyramid to Winnemucca lakes, or *vice versa.* This matter, however, will receive further consideration in connection with the fluctuation of Pyramid and Winnemucca lakes (page 63).

CARSON RIVER.

The Carson River rises on the eastern slope of the Sierra Nevada, south of Carson City, and, after flowing 60 or 70 miles, enters the Lahontan basin through a deep cañon at Dayton. From this point to the Carson lakes its course is through a channel carved in Lahontan lake-beds. Near its mountain source its waters are fresh and pure, as mountain streams usually are, but in passing through Carson and Eagle valleys, once occupied by Quaternary or late Tertiary lakes, its waters become somewhat impregnated with soda salts, and in its course through Lahontan lake-beds this percentage is increased. The waste from a large number of stamp-mills now pollutes the river to such an extent that it was not thought desirable to have its waters analyzed. The valley of the Carson from Eagle Valley to Carson Desert was largely excavated by stream erosion in pre-Quaternary times, as is shown by the fact that from Dayton to the Carson Desert it was occupied by the waters of Lake Lahontan. During the existence of the lake the valley became deeply filled with lake sediments and delta deposits, which were re-excavated as the lake fell. The present gorge is the work of the second period of excavation. The structure of the cañon between Churchill Valley and the Carson Desert is represented in the following ideal section, which shows the older cañon in volcanic rock partially filled with lacustral sediment, and the second carved out of stratified lake-beds.

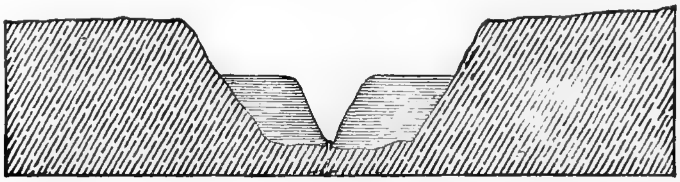
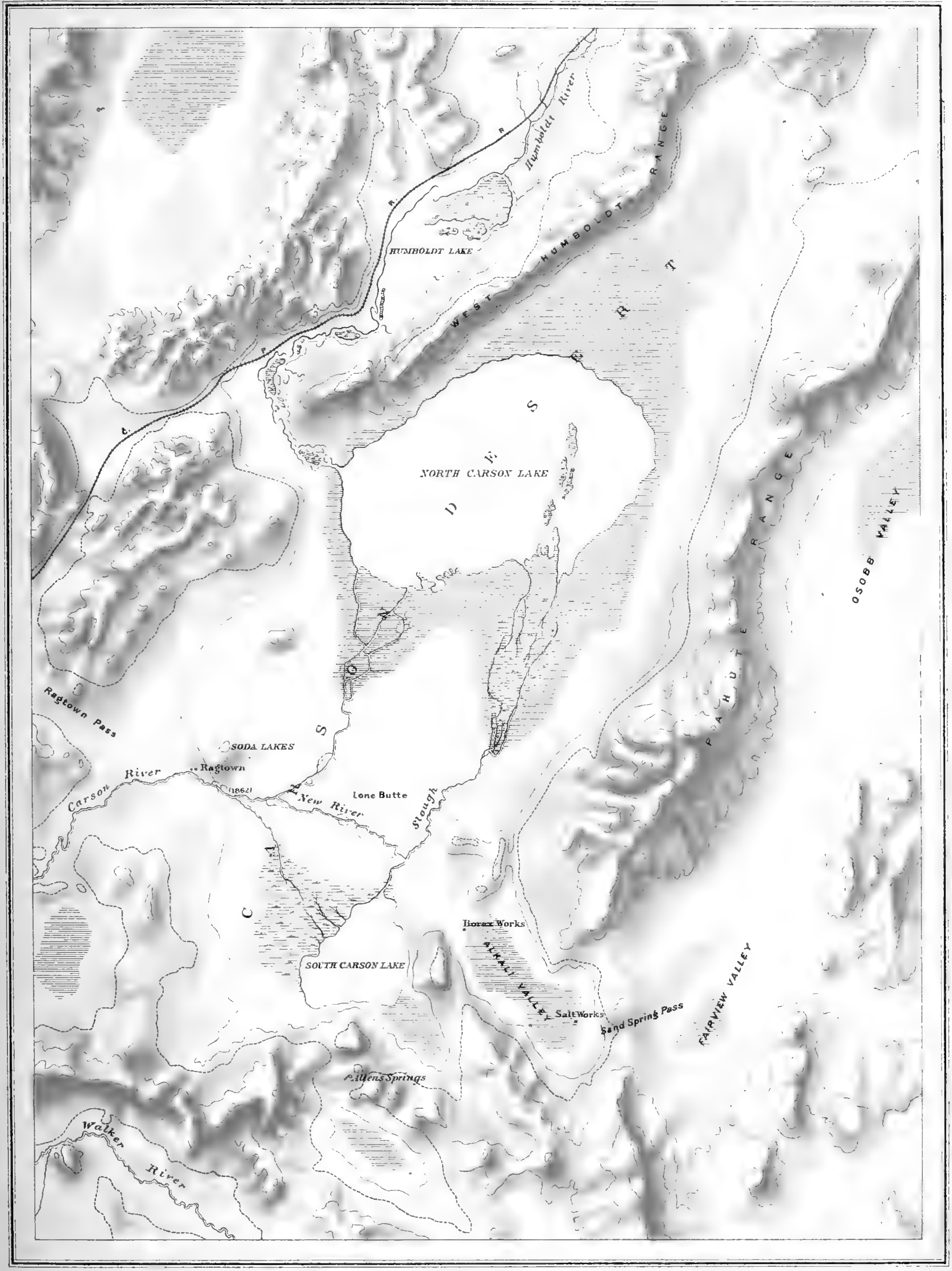


FIG. 5.—Ideal cross-section of Carson River Cañon, Nevada.

Measurements of the volume of the Carson River at Old Camp Churchill, July 1, 1881, gave between 450 and 500 cubic feet per second as the volume of the stream; in September, 1883, the discharge was less than half this amount.

The bifurcation of the Carson River after entering the Carson Desert is represented on the accompanying map (Plate VII). For the history of the changes that the river has undergone during the last few years I am indebted to some of the early pioneers, who made this region their home. Previous to 1862 it flowed into the South Carson Lake, but there was an abandoned channel branching from it and leading northward. During a time of unusually high water in the spring of 1862 the river bifurcated, the old channel was reoccupied, and a branch flowed to each lake. The point at which the river divided is indicated on the map by the date 1862. Previous to that time there was a "slough" connecting the North and South Carson lakes through which the waters flowed northward. After the forking of the stream the South lake was lowered so that it no longer overflowed, and the water in the slough became stagnant. Another flood occurred in the spring of 1867 or 1869, which caused the arm emptying into North Carson Lake to branch and send a stream eastward to the slough. The last-



Julius Bien & Co. Lith.

Lahontan Beach
Playas

CARSON DESERT, NEVADA.

Scale of Miles.
5 4 3 2 1 0 5 10 15 20

Interval between Contours 1000 feet.

formed channel is still occupied, and is known as "New River." This distribution of the waters of the Carson still continues, but is regulated, at least in part, by slight willow dams at the points of bifurcation. Since 1862 the slough connecting the two lakes is reported to have reversed its current in some instances, according as the water in the North or South Lake was the higher. In June, 1859, the water in the slough was reported by Captain Simpson to be 50 feet wide and 3 or 4 feet deep, and flowing northward with a strong current.[19] In September, 1866, Lieut. R. Birnie[20] states that the waters were sluggish, with scarcely a perceptible flow. In June, 1881, I found the volume of water about the same as reported by Simpson in 1859, and flowing northward with a well-marked current. In September, 1883, the slough was low, and did not exhibit any motion; South Carson Lake at the same time was very shallow, much of it presenting the appearance of a swamp.

While viewing the Carson Desert from the surrounding mountains one may trace, as on a map, the various branches of the river meandering through the monotonous plain, by the lines of vivid green cottonwood trees that mark their courses.

WALKER RIVER.

This stream rises on the eastern slope of the Sierra Nevada in two main branches between which there is a grand mountain mass known as the Sweetwater Range. The east fork of the Walker River receives the drainage from the eastern slope of the Sweetwater Range, and from the western slope of the less picturesque Wassuck or Walker River Range. The west fork flows at the base of the main range of the Sierra Nevada, and once formed a chain of small lakes, probably of Tertiary age, which cut deep channels of discharge and were drained dry. These basins are now level-floored valleys, connected by narrow and almost impassable cañons. The two branches of Walker River unite a little below the point where they formerly entered Lake Lahontan, and thence flow through Mason and Walker River valleys to Walker Lake. At the north

[19] Exploration Across the Great Basin of Utah, Washington, D. C., 1876, p. 85.
[20] Annual Report of the Chief of Engineers, U. S. A., 1877, p. 1264.

end of Mason Valley the river bends abruptly southward, at the same time increasing the depth of its channel, which soon becomes a cañon through lake-beds similar to the ones carved by the Humboldt and the Truckee. Captain Simpson reports the Walker River near its mouth to have been about 100 yards wide and from 6 to 10 feet deep on June 7, 1859.[21] A measurement of the volume of the river about 3 miles from its mouth, June 4, 1881, gave 400 cubic feet per second as the rate of flow. In October of the following year its bed was dry, and little, if any, water reached the lake from this source. This decrease during the dry season is evidently due in a great measure to the extensive use of its waters for irrigation in Mason Valley. As a rough average, the data at hand being inexact, I have assumed 200 cubic feet per second, or 700,000,000 cubic yards annually, as the approximate discharge. An analysis of a sample of water collected October, 1882, at a point just below where the main branches of the river unite, is reported by Prof. F. W. Clarke, as follows:

Constituents.	One liter of water contains, in grammes—	Per cent. in total solids.
Silica (SiO_2)	0.0225	12.50
Calcium (Ca)	0.0228	12.66
Magnesium (Mg)	0.0038	2.12
Potassium (K)	Trace.	
Sodium (Na)	0.0318	17.67
Chlorine (Cl)	0.0131	7.28
Sulphuric acid (SO_4)	0.0284	15.77
	0.1224	68.00
Carbonic acid (CO_3) by difference	0.0576	32.00
Total	0.1800	100.00

Constituents.	Probable combination (in grammes per liter).
Silica (SiO_2)	0.0225
Calcium carbonate ($CaCO_3$)	0.0570
Magnesium carbonate ($MgCO_3$)	0.0133
Sodium chloride (NaCl)	0.0216
Sodium sulphate (Na_2SO_4)	0.0421
Sodium carbonate (Na_2CO_3)	0.0224
Total (99.39 per cent. accounted for)	0.1789

The measurements of the volumes of the rivers of the Lahontan basin at different seasons indicate the great fluctuations to which the drainage in a desert country is subject. The rivers are flooded during the winter and spring—which includes the rainy season, and also the time when the mountain snows are melting most rapidly—and diminish greatly in volume during the parched and arid summer months. The Truckee River is an exception to this rule, as it is the overflow of a great reservoir, Lake Tahoe,

[21] Explorations Across the Great Basin of Utah, Washington, D. C., 1876, p. 87.

which serves to equalize its volume, as well as to clear its waters of impurities in suspension. A knowledge of the composition of the rivers entering the Lahontan basin and their average volume enables one to estimate roughly the amount of mineral matter in solution that these streams are now contributing to the lakes that they supply. This subject will be reverted to in discussing the chemical history of Lake Lahontan.

SPRINGS.

Springs have been grouped with reference to their mode of occurrence, in two convenient classes: (*a*) Hillside springs and (*b*) Fissure springs.

Hillside springs are usually formed by the gathering of percolating meteoric waters in inclined porous strata, which alternate with less pervious beds, and outcrop on a hillside or among mountains in such a manner as to afford an escape for the subterranean waters. The source of the water forming hillside springs is in the rainfall of the immediate neighborhood. They are commonly small, and their temperature is approximately the same as the mean temperature of the locality at which they are found. Springs of this class are usually agreeable to the taste and useful for domestic purposes, for the reason that they are seldom highly charged with mineral matter.

In western Nevada the conditions favoring the formation of hillside springs are almost entirely absent. The rocks throughout the region are very largely volcanic without definite stratification, and the rainfall is limited to a few inches annually. Owing to these unfavorable conditions, there are no springs of this class in the Lahontan basin to claim our attention.

Fissure springs occur where the earth's crust has been broken, usually with some displacement, to a great depth. Their water supply, as in the first instance, is from meteoric sources, but is derived from regions remote from the point of discharge. Owing to the depth to which the water of fissure springs frequently descends during its subterranean passage, it is commonly highly heated and not unfrequently reaches the surface with the temperature of boiling water. The heat and the great pressure to which the water is subjected during its underground passage render it an active solvent. Hot springs are therefore frequently charged with a great variety of mineral substances in solution.

The Lahontan basin, in common with the entire northern half of the Great Basin (the southern portion not being so thoroughly explored), is remarkable for the number of springs which rise from a great depth through fissures. These almost invariably occur along lines of displacement, and range in temperature from 50° or 60° F. up to the temperature of boiling water for the elevation at which they occur.

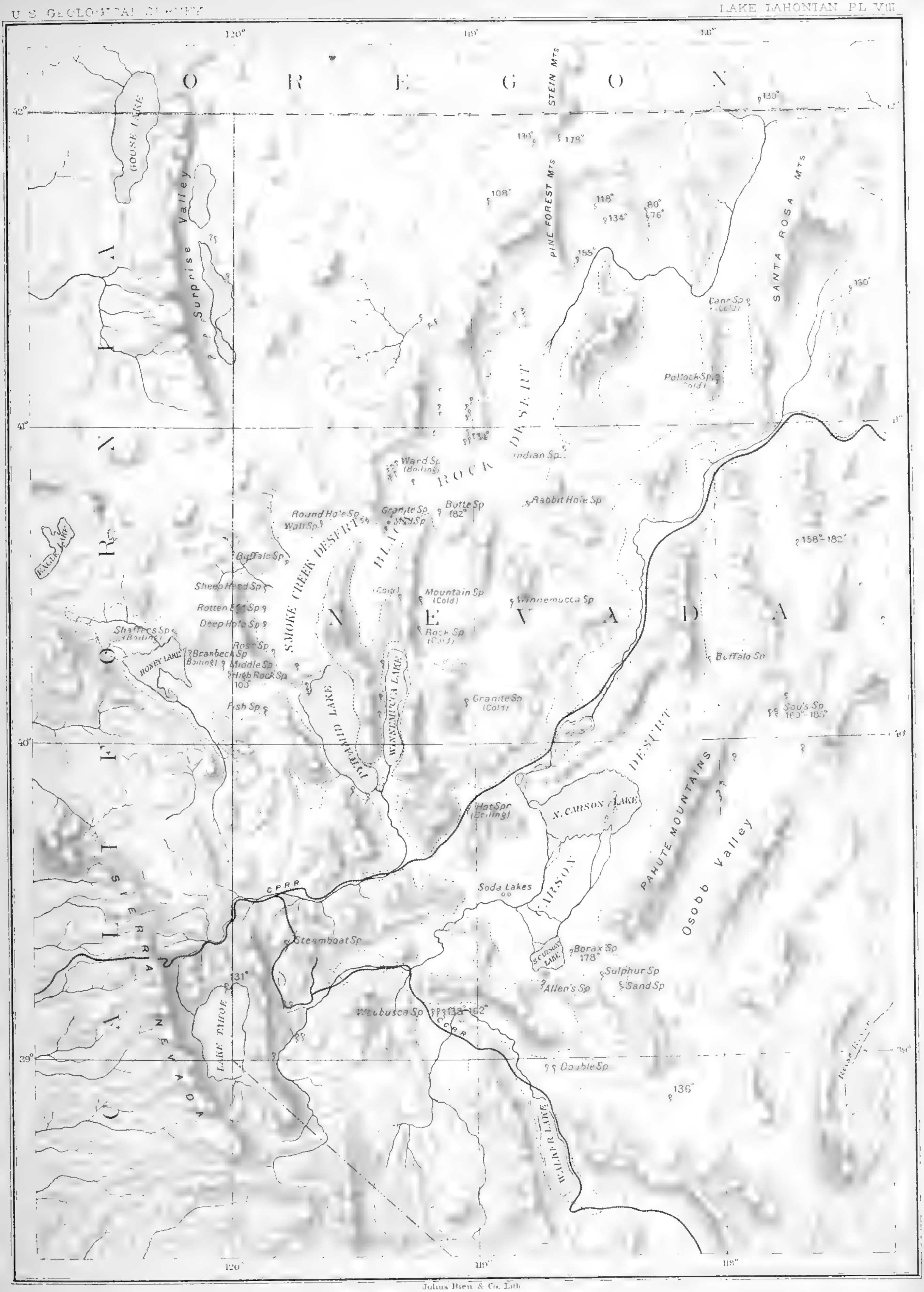
The springs of the Lahontan basin are indicated on the accompanying map, Plate VIII; their maximum temperature when known being shown by figures in red.

As springs performed an important part in the history of Lake Lahontan, we shall devote a few pages to the description of those now rising in its basin. A knowledge of the phenomena they now present will assist in interpreting the records of the similar springs that flowed long ago.

Beginning at the south, the first group of springs requiring notice is found in the northern part of Mason Valley, about one mile northward of Wabusca station. These springs occur in circular basins, sometimes at the tops of low mounds, and are of all degrees of temperature, from about the mean of the region up to 162° F. The water flowing from them is clear and sparkling, but is somewhat alkaline to the taste, and contains a small percentage of sulphate and carbonate of soda, common salt, etc. The water collecting in small basins on the desert is evaporated, and has formed a saline deposit of considerable extent, a section of which is given below:

White, hard crust of sulphate of soda, with common salt, some calcium carbonate, etc	inches	1–2
Soft, mealy or clayey deposit of sodium sulphate, calcium carbonate, calcium sulphate, etc	inches	2–7
Clear transparent crystals of sodium sulphate, with some earthy impurities, resting on saline clay	feet	6–8

The surface of the desert about the more abundant accumulation of salts is covered over a large area with a white saline efflorescence. These springs occur in an east and west line, that coincides with the course of a



Julius Bien & Co. Lith

Existing Springs

SPRINGS OF THE LAHONTAN REGION.

Fahrenheit Temperature

Scale 20 miles = 1 inch

post-Lahontan fault which is plainly shown by an irregular scarp, in some places 20 feet high.

Allen's Springs are situated on the southern border of South Carson Lake at the base of a high basaltic butte which once formed an island in Lake Lahontan. These springs at present are very small, the discharge at the surface being less than half a gallon per minute. In this desert country even this meager supply is important, as it is the only drinkable water within a radius of over twenty miles. These springs are of interest to the geologist because of their antiquity. The amount of yellowish, porous, tufa deposited about them indicates that the flow of water was formerly more copious than at present, and at various times has issued from a number of orifices. Much of the tufa that is plainly a spring deposit is incrusted with thinolite and dendritic tufa which we know was precipitated from the waters of Lake Lahontan, and shows that the springs were in existence at least as early as the middle Lahontan period.

The Hot Spring, at Hot Spring station on the Central Pacific Railroad, as shown by Dr. T. M. Chatard's analysis, has the following composition:

Constituents.	One liter of water contains in grammes—	Per cent. in total solids.	Constituents.	Probable combination (in grammes per liter).
Silica (SiO_2)	0.2788	11.14	Silica (SiO_2)	0.2060
Aluminum (Al)	0.0010	0.04	Sodium silicate ($NaSiO_3$)	0.1480
Calcium (Ca)	0.0305	1.23	Aluminum sulphate ($Al[SO_4]_3$)	0.0063
Magnesium (Mg)	0.0010	0.04	Calcium sulphate ($CaSO_4$)	0.1037
Potassium (K)	0.0669	2.69	Magnesium sulphate ($MgSo_4$)	0.0050
Lithum (Li)	Trace.	Trace.	Sodium sulphate ($NaSo_4$)	0.4039
Sodium (Na)	0.7743	31.04	Sodium chloride (NaCl)	1.4946
Chlorine (Cl)	0.9679	38.79	Potassium chloride (KCl)	0.1278
Sulphuric acid (SO_4)	0.3555	14.25	Total	2.4953
Oxygen* in SiO_3	0.0194	0.78		
Total	2.4953	100.00		

* Extra oxygen in silicate.

No carbonic acid in residue left by evaporation.

At a number of orifices the waters of this spring issue in a state of active ebullition. When the openings become obstructed the steam escapes with a hissing and roaring sound. The spring occurs in a line of recent faulting, and has evidently been crowded southward as the deposits from the waters closed the previous channels of discharge. On cooling, an abundant deposit, consisting principally of common salt and sodium sulphate, is found. At one time these waters were thought to contain sufficient boracic acid to be of economic importance, and an attempt was made to separate it, but the experiment was a failure. There is no evidence to show that this spring was active during the existence of Lake Lahontan.

A number of small springs, some of which are warm, occur on the west side of Winnemucca Lake. Farther northward small springs of pure cold water have been found on both sides of the Selenite Range.[22] Near the north end of this range, but isolated from it, stands Hot Spring Butte, once a small island in Lake Lahontan. The butte derives its name from a copious spring with a temperature of 180° F. which discharges about 20 gallons per minute. The water flows northward for about a mile, and forms a shallow pool in the desert, where it is evaporated. Other hot springs occur northward of Hot Spring Butte, near the southern end of the Jackson Range.

Numerous copious springs of all temperatures, from the mean of the region up to the boiling point of water, come to the surface along the western border of the Lahontan basin, from Honey Lake Valley to the Oregon boundary. The majority of these have formed circular basins that are filled with beautifully clear water, and are sometimes of great depth, as in the case of Deep Hole, Round Hole, and the group at the east end of Granite Mountain. The bottoms of the basins are usually of flocculent mud, through which the water issues, frequently accompanied by bubbles of gas. In common with very many other hot springs, these basins are lined with deep green confervoid growths. Many of the springs in the belt indicated exhale sulphurretted hydrogen, and deposit amorphous, calcareous tufa In one instance silicious sinter is precipitated as the water cools. All the springs in this belt occur either on fault lines that have been disturbed by orographic movement since the withdrawal of the waters of Lake Lahontan, or are very closely related to such lines of displacement.

[22] This range is about 30 miles long and extends from the north end of Winnemucca Lake to Hot Springs Butte; it is structurally distinct from the Natches or Truckee Range, which follows the eastern shore of Winnemucca Lake. I have named it in reference to extensive deposits of crystallized gypsum or selenite that outcrop along its western border.

The character of these recent faults will be described in the chapter devoted to post-Lahontan orographic movements.

The springs in this belt are too numerous to receive detailed description, and we can only notice a few of the most important ones. The most copious single spring in the series occurs near the northern shore of Honey Lake, designated as Schaffer's Spring on the accompanying map, and discharges about 100 cubic feet of boiling water per minute. The ebullition is so energetic that the water is thrown in a column to the height of 3 or 4 feet. An analysis of this water by Dr. T. M. Chatard shows the following composition:

Constituents.	One liter of water contains in grammes—	Per cent. in total solids.	Constituents.	Probable combination (in grammes per liter).
Silica (SiO_2)	0.1310	12.83	Silica (SiO_2)	0.1008
Calcium (Ca)	0.0121	1.18	Sodium silicate (Na_2SiO_3)	0.0613
Magnesium (Mg)	0.0004	0.04	Calcium sulphate ($CaSO_4$)	0.0409
Sodium (Na)	0.3040	29.78	Magnesium sulphate ($MgSO_4$)	0.0020
Potassium (K)	0.0094	0.92	Sodium sulphate (Na_2SO_4)	0.4715
Chlorine (Cl)	0.2070	20.27	Potassium chloride (KCl)	0.0180
Sulphuric acid (SO_4)	0.3492	34.19	Sodium chloride (NaCl)	0.3266
Oxygen* (O)	0.0080	0.79	Total (99.93 per ct. accounted for)	1.0211
Total	1.0211	100.00		

* Oxygen necessarily added to form Na_2SiO_3. A slight trace of Co_2 in residue left on evaporation.

This spring occurs at the southern end of a long row of tufa crags, fully 50 feet high and somewhat greater in breadth, a few of which still have small springs issuing from their bases. The tufa at the base of the crags, and forming the nucleus of the deposit, is amorphous, but is coated with a heavy deposit of the dendritic variety hereafter to be described. The former was a direct precipitate from spring water, but the latter was as plainly deposited from the former lake. The evidence is such as to lead to the conclusion that this spring was fully as copious during the existence of Lake Lahontan as now, and that its point of discharge was crowded southward along a fissure as its former outlets became filled with calcareous tufa deposited from its own waters.

About 5 miles southeastward of the spring described above occurs a group of springs covering several acres and discharging a very large volume of heated water, which issues at so many orifices that no estimate of the total outflow could be obtained. At a number of points the temperature of the water approximates to the boiling point, and, on cooling, deposits a limited quantity of calcareous tufa. A qualitative examination indicates that these springs have about the same chemical composition as the water of Schaffer's Spring, an analysis of which is given above.

High Rock Spring, situated 5 miles eastward of the group described in the last paragraph, occurs at the base of large tufa crags of Lahontan date, and has a temperature of 100° F. Its waters are used for irrigation, and are inhabited by both fish and mollusks. This spring is evidently of considerable antiquity, as the tufa crags deposited from its waters are coated with heavy layers of calcium carbonate that have a dendritic structure and were without question deposited from the lake waters which once flooded the valley.

None of the numerous springs on the western border of Smoke Creek Desert are remarkable for their high temperatures, but a number are thermal, and nearly all bear indications of having been hot springs at some former time There is no evidence that any of these springs were in existence during the time when Lake Lahontan covered the desert

On the border of the desert at the eastern end of Granite Mountain a group of circular basins filled with heated waters from a subterranean source covers a considerable area. A number of these basins furnish water of wonderful transparency, which overflows to the eastward, and on evaporating leaves a saline incrustation that covers many acres. Others occur in the tops of low mounds and are caldrons of boiling mud that occasionally erupt and discharge their tenacious contents to a distance of 30 or 40 feet. This group is known as the Mud Springs.

The most copious outflow of hot water in the Lahontan basin occurs in a small embayment of the ancient lake a few miles north of Granite Mountain. This is a group of springs several acres in extent which fill circular basins in the tops of low mounds that have been formed to some extent by spring deposits, but are largely composed of vegetable growths mingled with æolian sand and dust. These springs vary through all degrees of temperature, from 50° to 60° F. up to that of boiling water, and their discharge forms a creek of heated water of considerable size that pours into a deep basin and becomes ponded before spreading out over the desert and evaporating. Many of the basins in this group are lined with amorphous calcareous tufa; and one, filled with boiling water, is depositing both silica and tufa. The siliceous sinter precipitated from these waters is gelatinous at first, but soon hardens and forms mushroom-shaped scollops which fringe the sides of the basin and the margins of the channel of discharge. The deposition of silica takes place quite rapidly as the water cools, and in some instances imprisons insects that have been killed by venturing into the boiling waters.

An analysis by Dr. T. M. Chatard of one of the most typical of the springs in the group described briefly above, from which calcareous tufa is being deposited, is given below:

Constituents.	One liter of water contains in grammes—	Per cent. in total solids.	Constituents.	Probable combination (in grammes per liter).
Silica (SiO_2)	0. 1136	9. 60	Silica (SiO_2)	0. 0180
Calcium (Ca)	0. 0367	3. 10	Sodium silicate (NO_2SiO_3)	0. 1942
Magnesium (Mg)	0. 0034	0. 29	Calcium sulphate ($CaSO_4$)	0. 1247
Sodium (Na)	0. 3554	30. 03	Magnesium sulphate ($MgSO_4$)	0 0170
Potassium (K)	0. 0191	1. 61	Sodium sulphate (Na_2SO_4)	0. 4267
Lithium (Li)	Trace.	Trace.	Potassium chloride (KCl)	0. 0363
Chlorine (Cl)	0. 2396	20. 25	Sodium chloride (NaCl)	0. 3665
Sulphuric acid (SO_4)	0. 3901	32. 97	Total (99.43 per ct. accounted for)	1. 1834
Oxygen* (O)	0. 0255	2. 15		
Carbonic acid (CO_3)	Trace.	Trace.		
Total	1. 1834	100. 00		

*Oxygen necessarily added to form Na_2SiO_3.

Hot springs of considerable volume occur in groups near the southern end of Black Rock Point and along both the eastern and western borders of the Black Rock Range, and also on the borders of the desert at the eastern base of the Pine Forest Range. Continuing northward, the belt of hot springs we have been tracing is represented in Pueblo Valley by two steaming caldrons, and at the eastern base of Stein Mountain other outlets of a similar nature have been examined. Nearly every spring throughout the entire region between Honey Lake Valley, California, and Alvord Valley, Oregon, a distance of over 200 miles, has been observed to occur on a line of recent displacement.

In all, there are at present between fifty and sixty groups of hot springs in the Lahontan basin; the total number of individual outflows cannot be estimated at less than two or three hundred. It is impossible to estimate the amount of water entering the basin from subterranean sources with even an approximation to accuracy, but if gathered in a single stream it would form a river comparable in size with the Humboldt during the summer season, the volume of which would remain practically constant from year to year. The temperature of this imaginary river would be far above the normal for the region; and in composition it would be much richer in dissolved minerals than ordinary surface streams, as is indicated by the accompanying analyses.

It is certain that many of the hot springs now flowing were in existence during the time that Lake Lahontan flooded the valleys of northwestern Nevada; and it is believed that the three analyses given above not only represent approximately the average composition of the springs now flowing, but also indicate the character of the thermal waters that entered the ancient lake through fissures in its bottom.

EXTINCT SPRINGS.

At many points in the Lahontan basin, as mentioned in the preceding pages, we find deposits made by springs which are now extinct. The majority of these are composed of calcareous tufa that was precipitated about sublacustral springs, and will be described in the chapter devoted to the chemical history of the former lake. A group of spring-mounds about half a mile southward of Humboldt House and on the west side of the Central Pacific Railroad track, are, however, of a different nature. They are low domes composed principally of calcareous tufa, open at the top and filled within with crystallized gypsum impregnated with sulphur. The presence of sulphur has led to some exploration, but the supply is evidently too limited to be of much economic importance.[23] The mounds in this group are broad and comparatively low domes, formed of thatch-like layers of calcareous tufa with considerable quantities of siliceous sinter, especially about

[23] These sulphur deposits were the only ones that could be found by the writer in the neighborhood of Humboldt House, and are thought to be the ones described in the reports of the United States Geological Exploration of the Fortieth Parallel, Vol. II, p. 742.

their bases. These deposits are unlike the greater part of the old tufa structures occurring abundantly in the same basin, especially in the neighborhood of Pyramid Lake, but agree in form and structure with the rings and domes now forming about many subaërial hot springs; thus indicating that the deposits in question are of post-Lahontan date. The presence of siliceous sinter also indicates that these deposits were of subaërial origin, as no precipitates of this nature from sublacustrine springs are known.

LAKES.

At present there are seven lakes in the Lahontan basin. These are Honey Lake, California; Pyramid, Winnemucca, Humboldt, North Carson, South Carson, and Walker lakes, Nevada. To these we may add the two Soda lakes near Ragtown, Nevada, as occurring in the same basin, but these are of a decidedly different character from those enumerated above, and will receive special attention. These lakes are of assistance to the geologist in interpreting the history of the great lake which formerly flooded all their valleys; we shall, therefore, describe them somewhat minutely.

HONEY LAKE.

Honey Lake Valley was occupied by the western arm of Lake Lahontan, and became deeply filled with lake sediments. At present it is a broad, level-floored, sage-brush-covered plain, with fruitful areas on its western and northern borders where water is available for irrigation, and has an absolutely barren playa of considerable extent on its eastern margin near Fish Spring. The lake occupies a shallow depression in the western part of the valley, and may be classed as a playa lake, as it is without outlet and becomes completely desiccated during seasons of unusual aridity. It is supplied principally by Susan River, which enters it from the northwest; but it receives some tribute during the rainy season from Long Valley. The hot springs along its northern border also furnish considerable quantities of water. The area of the lake varies with the seasons, as well as from year to year, as is common with all inclosed lakes. As mapped by the survey in charge of Captain Wheeler, in 1867 it covered an area of approximately

90 square miles. In the summers of 1859 and 1863 it is reported by the settlers in the valley to have become completely desiccated, leaving a broad smooth plain of cream-colored mud. Its average depth in the summer of 1877 is reported by Lieutenant Symonds[24] to have been about 18 inches. In 1882 its greatest depth was 4 feet, but the average, as nearly as could be judged, did not differ much from the figures given for 1877. The outline of the lake is indefinite, as its shores are usually low and marshy, and in places form broad tule swamps. Its waters are quite strongly alkaline, unfit for human use, and always of a greenish-yellow color, due to the impalpable mud held in suspension. A preliminary examination of the water shows that it contains 0.0784 per cent. of saline matter in solution. Qualitative tests show the water to be alkaline and charged with chloride of sodium, and carbonate and sulphate of soda, together with some potash and magnesia.

PYRAMID LAKE.

Pyramid Lake was discovered January 10, 1844, by General Frémont, who first saw it from the mountains at its northern end. From the remarkable form of an island near its eastern shore its discoverer gave it the name which it now bears.[25]

The accompanying map of Pyramid and Winnemucca lakes (Plate IX) was made in August and September, 1882, by Mr. Johnson, and shows an accurate outline of the lakes as they existed at that time. The soundings indicated are from actual observation, the position of the boat at the time of measuring the depth being determined with instruments stationed on shore. The sublacustrine contour lines, drawn at intervals of 50 feet, are in part conjectural, but are believed to represent approximately the topography of the lake bottom. The north and south axis of Pyramid Lake is 30 miles in length; in the widest part, near the northern end, its breadth is 12 miles; farther southward between Anaho Island and the southern end of the lake it is contracted to about 5 miles. Its area in September, 1882, was 828 square miles. Our soundings determined that the greatest depth occurs

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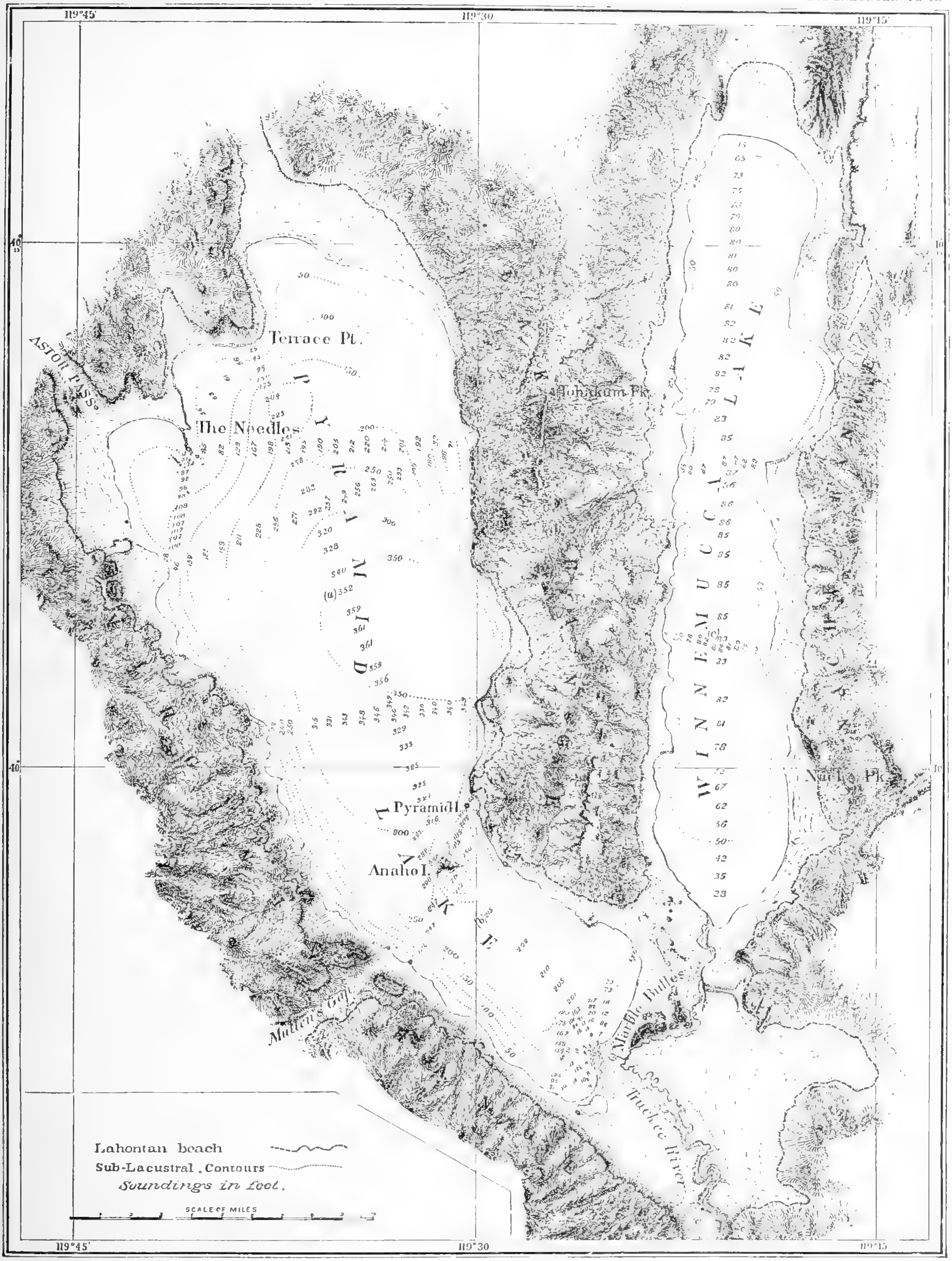
[24] Ann. Rep. U. S. Geographical Surveys West of the 100th Meridian for 1878, p. 115.

[25] Frémont's First and Second Expeditions, 1842–'43–'44, p. 216.



W. D. Johnson, Topographer. *I. C. Russell, Geologist.*

PYRAMID AND WINNEMUCCA LAKES, NEVADA.

a few miles north of Anaho Island where the water is 361 feet deep over a very considerable area; showing that the bottom in this portion is a nearly uniform plain. As the Lahontan beach is 525 feet above the 1882 level of Pyramid Lake, the former lake had a depth of 886 feet, without considering, however, the amount of sedimentation that has since taken place. This was the deepest point in Lake Lahontan.

Pyramid Lake is without outlet. It receives almost its entire supply from the Truckee River, which enters it at its southern end. During the rainy season the surrounding mountains send down some tribute, supplied principally by two small brooks from the western side of the valley, which are living streams for a portion of the year; but the supply from these sources is extremely small. As nearly all of the fresh water entering the lake is delivered at its southern end the lake varies in salinity as one follows it northward. Near the mouth of the Truckee River the waters are sufficiently fresh to be used for camp purposes; at the northern end it is far too saline and alkaline for human use, but may be drunk by animals without injury. The waters of Pyramid Lake from two localities and at different depths have been analyzed by Prof. F. W. Clarke, who reports their composition as follows:

Water of Pyramid Lake collected in August, 1882, at b, *south of Anaho Island (see Plate IX).*

Constituents.	One liter of water contains, in grammes per liter—		Per cent in total solids.		Constituents.	Probable combination (in grammes per liter).	
	Sample from 1 foot below surface.	Sample from 200 feet below surface.	Sample from 1 foot below surface.	Sample from 200 feet below surface.		Sample from 1 foot below surface.	Sample from 200 feet below surface.
Silica (SiO_2)	0.0425	0.0300	1.22	0.86	Silica (SiO_2)	0.0425	0.0300
Magnesium (Mg)	0.0752	0.0832	2.17	2.38	Magnesium carbonate ($MgCO_3$)	0.2632	0.2912
Calcium (Ca)	......	......	......	......	Calcium carbonate ($CaCO_3$)	......	......
Sodium (Na)	1.1826	1.1809	34.06	33.84	Potassium chloride (KCl)	0.1374	0.1387
Potassium (K)	0.0719	0.0726	2.07	2.13	Sodium chloride (NaCl)	2.2466	2.2428
Chlorine (Cl)	1.4288	1.4271	41.15	40.99	Sodium sulphate (Na_2SO_4)	0.2621	0.2757
Sulphuric acid (SO_4)	0.1772	0.1864	5.10	5.34	Sodium carbonate (Na_2CO_3)	0.4940	0.4834
	2.9782	2.9802	85.77	85.54	Total*	3.4458	3.4618
Carbonic acid (CO_3) by difference	0.4943	0.5098	14.23	14.46			
Total	3.4725	3.4900	100.00	100.00			

* 99.23 per cent. accounted for in the sample from 1 foot below surface, and 99.19 per cent. in remaining sample.

Water of Pyramid Lake collected in August, 1882, at a, north of Anaho Island (see Plate IX).

Constituents.	One liter of water contains, in grammes per liter—		Per cent. in total solids.	
	Sample from 1 foot below surface.	Sample from 350 feet below surface.	Sample from 1 foot below surface.	Sample from 350 feet below surface.
Silica (SiO_2)	0.0412	0.0200	1.17	0.57
Magnesium (Mg)	0.0800	0.0805	2.29	2.31
Calcium (Ca)	0.0179	0.0179	0.51	0.51
Sodium (Na)	1.1731	1.1817	33.53	33.92
Potassium (K)	0.0766	0.0723	2.19	2.07
Chlorine (Cl)	1.4298	1.4342	40.87	41.17
Sulphuric acid (SO_4)	0.1803	0.1850	5.15	5.31
	2.9989	2.9916	85.71	85.86
Carbonic acid (CO_3) by difference	0.4998	0.4921	14.29	14.14
Total	3.4987	3.4837	100.00	100.00

Constituents.	Probable combination (expressed in grammes per liter).	
	Sample from 1 foot below surface.	Sample from 350 feet below surface.
Silica (SiO_2)	0.0412	0.0200
Magnesium carbonate ($MgCO_3$)	0.2800	0.2818
Calcium carbonate ($CaCO_3$)	0.0447	0.0447
Potassium chloride (KCl)	0.1474	0.1381
Sodium chloride (NaCl)	2.2411	2.2550
Sodium sulphate (Na_2SO_4)	0.2667	0.2737
Sodium carbonate (Na_2CO_3)	0.4738	0.4756
Total*	3.4949	3.4889

* 99.94 per cent. accounted for in sample from 1 foot below surface, and 100.15 per cent. (error 0.15 per cent.) in the remaining sample.

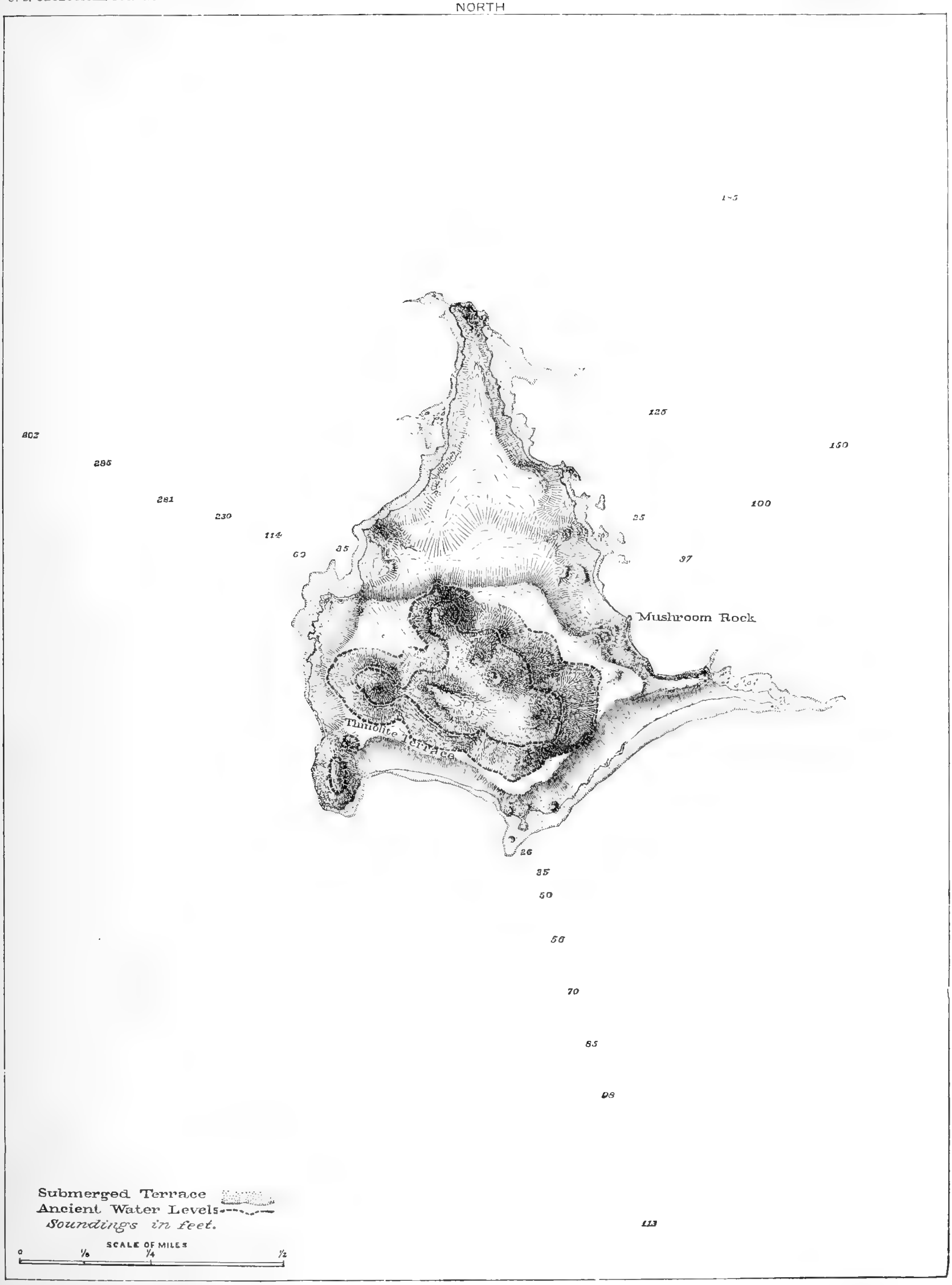
All the water samples from Pyramid Lake when analyzed contained a small quantity of suspended flakes of calcareous and siliceous matter, which had separated since the samples were bottled.

These analyses show much less difference in the composition of the water near the northern and near the southern ends of the lake than was anticipated; and the examination of top and bottom samples fails to indicate an increase in salinity with increase in depth, such as was found by Lartet in the case of the Dead Sea.[26] The bearing of the present composition of Pyramid Lake on the interpretation of the history of the ancient lake which flooded the same basin will be considered in connection with the chemistry of the other lakes of the basin. Standing alone, the analyses of the water of the present lake are of geological interest as showing the composition of waters that are now depositing calcareous tufa of the same general character as that first found in Lake Lahontan.

During our measurements of the depth of the lake the cup at the end of our sounding lead seldom failed to bring up a specimen of the bottom. From the samples thus obtained we learn that the bottom near shore is usu-

[26] Exploration Géologique de la Mer Morte, Paris, 1877, p. 278.

NORTH



W. D. Johnson, Topographer. *I. C. Russell, Geologist.*

ANAHO ISLAND, PYRAMID LAKE, NEVADA.

ally composed of sand or gravel in which the shells of fresh water gastero-pods were frequently obtained. At a distance of a few rods from land the bottom invariably became muddy, excepting in sheltered bays, where the littoral deposits had a greater breadth than when the lake margin was precipitous. In all the central portions of the lake the bottom is of fine tenacious mud, either gray in color or intensely black, and having the odor of sulphuretted hydrogen The samples of black mud when dried in the open air lost their inkiness as well as their odor, and became identical with the gray mud occurring in other localities.

In the southern portion of the lake the water is slightly discolored, and is charged with a multitude of shining particles that are rendered visible when a ray of light is passed through it. The lack of transparency is apparently due to the suspended silt brought down by the Truckee River. In the northern part of the lake the water becomes wonderfully clear, and at some distance from land of a deep blue color. On looking down into the waters from the neighboring hills the color appears almost black, or black tinged with deep blue. Near shore, especially where the bottom is of white sand, the water presents a clear greenish-blue tint, as is the case on nearly all lake shores where the bottom is light colored. When thrown into breakers by strong winds it exhibits a play of colors that is only rivaled in beauty by the surf of the ocean.

The largest and most attractive islands in the lake are Pyramid and Anaho, which rise in its southern portion near the eastern shore. Anaho Island, as determined by engineer's level, is 517 feet above the water level of 1882, and is surrounded by water from 150 to 300 feet deep. We present an accurate map of it, prepared in August, 1882 (Plate II), from which future changes in lake level may be determined. When seen from a distance the island presents a convex outline due to the deposition of vast amounts of tufa at certain horizons. A broad terrace has been carved all around it at an elevation of about 100 feet above the lake, and forms a pediment for the extremely rugged crags that are piled upon it. The contour formed by the water line of this terrace is indicated by the lower of the three dotted lines on the map; the next above marks the water level at the dendritic stage; and the highest of all is the Lahontan beach. This island, although without fresh water, and but scantily clothed with vegetation, is one of the most instructive points about Pyramid Lake, and will well repay a visit from the geologist or the artist. During the time that Lake Lahontan had its greatest extent, Anaho Island rose but a few feet above its surface.

Pyramid Island, as determined by sights with an engineer's level from Anaho Island, rises 289 feet above the lake; the water near its base is from 150 to 175 feet deep. As remarked by Frémont, its regular pyramidal form and precipitous sides give it a striking resemblance to the great pyramids of Egypt. Its sides are somewhat convex owing to the immense accumulation of tufa deposited upon them, and are difficult to scale. On the accompanying plate this island is represented as it appears from the neighboring shore.

The most picturesque portion of the shores of Pyramid Lake is at the northern end, where a rugged cape, known as "The Needles," projects a mile or more from the main land, and has near it many small islands of peculiar and sometimes fantastic form. This group of spires, domes, and crags exhibits rock forms of the most rugged description, and furnishes the grandest display of tufa in all their varieties that is to be found in the Lahontan basin. A general view of this picturesque point is given on the accompanying plate, which is sketched from a photograph taken on the lake shore to the westward of The Needles. The highest of the spire-like masses, rising 300 feet above the lake, is shown somewhat in detail in the illustration forming Plate XIII. A photograph of one of the islands near The Needles, taken from the peninsula, is given on Plate XXXVIII. Plate XXXIX also illustrates the remarkable towers and domes that the tufa deposits here simulate.

On the northern side of the peninsula a number of hot springs rise from the bottom of the lake and along the base of the tufa crags, and are forming a deposit of calcareous tufa beneath the lake surface. This accumulation is soft and creamy white, and forms a more or less regular layer over considerable areas. The hot water of the submerged springs rises from many orifices, a number of which have built up tubular chimney-like growths 5 or 6 inches high that sometimes look not unlike mushrooms, but always have one or more openings at the top, through which the spring-water issues. The carbonate of lime is deposited when the hot spring-water

SKETCH OF PYRAMID ISLAND, PYRAMID LAKE, NEVADA

comes in contact with the colder and more dense waters of the lake. A few of the deposits from these springs are represented, half natural size in the following figure:

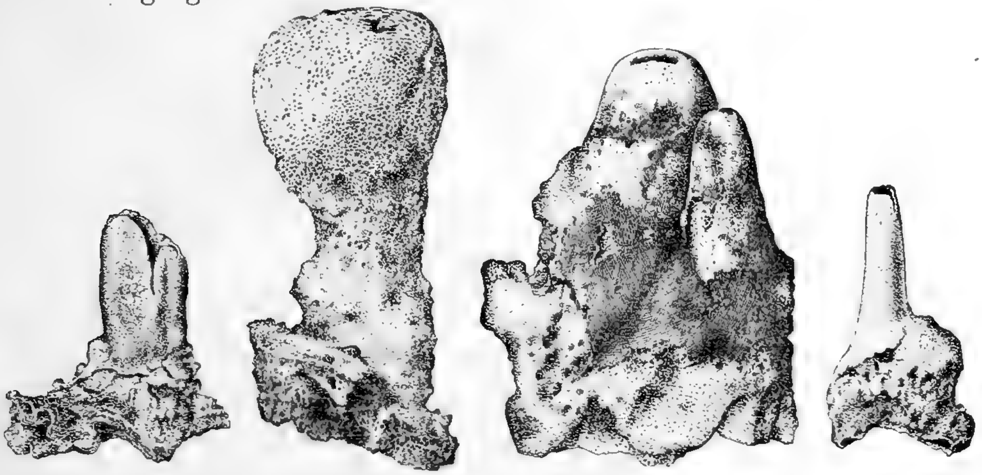


FIG. 6.—Deposits of calcium carbonate from sub-lacustral springs.

Among The Needles the rocky capes are connected by crescent-shaped beaches of clean, creamy sands, over which the summer surf breaks with soft murmurs. These sands are oolitic in structure, and are formed of concentric layers of carbonate of lime which is being deposited near where the warm springs rise in the shallow margin of the lake. In places these grains have increased by continual accretion until they are a quarter of an inch or more in diameter, and form gravel, or pisolite, as it would be termed by mineralogists. In a few localities this material has been cemented into a solid rock, and forms an oolitic limestone sufficiently compact to receive a polish. No more attractive place can be found for the bather than these secluded coves, with their beaches of pearl-like pebbles, or the rocky capes, washed by pellucid waters, that offer tempting leaps to the bold diver. The tufa forming The Needles is gray in tone, with a light-colored band, 10 or 12 feet broad at the base, consisting of a coating of very recent calcareous deposit, similar to that forming the oolitic sands, but probably not dependent on spring action. On the cliffs the nucleus about which the lime crystallized was immovable, and became coated with a continuous layer of calcium carbonate; on the beach the sands were washed about by the waves, and grew into little spheres of polished marble. A band of recently-formed tufa, like that surrounding the base of The

Needles, occurs around the borders of all the islands in the lake, and may be distinguished at many points on the shores of the mainland. By comparing a photograph of "The Domes," near Pyramid Island, taken in the summer of 1882, with the photograph of the same locality taken in 867, as published in the report of the United States Geological Exploration of the Fortieth Parallel (Vol. I, Plate XXIII), we learn that the surface of Pyramid Lake in the older photograph is 10 or 12 feet higher than when the later picture was taken. As this difference in the levels of the lake corresponds with the breadth of the band of recently-formed tufa, we are led to believe that the deposition of the calcareous deposit took place during the recession of the lake thus recorded The shores of Pyramid Lake, like those of all the lakes in the lower portions of the Great Basin, are without trees or shrubs, and clothed only with a scanty growth of desert vegetation. Although the scenery about this lake impresses one with its desolation and want of life, yet the rugged mountains surrounding it and the clear, bright blue of its waters combine to form a picture of more than ordinary grandeur. Like the ocean, its surface appears bright and blue in the sunshine and cold and gray in the storm. Even in summer the gales rise suddenly, without warning, and sweep down upon the lake with the fury of a tempest. Sometimes within a few moments the lake is changed from a placid mirror to a sea of frothing billows that break on the shore in long lines of foam. The suddenness with which the wind changes, and the bleak, inhospitable character of the shores, make the navigation of this lake somewhat dangerous, even to experienced boatmen. Many tales of adventure, sometimes accompanied by loss of life, are related by those who have experienced the sudden storms of this inland sea.

The lake is abundantly supplied with splendid trout, *Salmo purpuratus Henshavi*, Lord, and, as stated by Prof. E. D. Cope,[27] is also inhabited by *Leucus olivaceus*, *Leucus dimidiatus*, *Siphateles lineatus*, *Squalius galtiæ*, *Chasmistes cujus*, *Catostomus Tahoensis;* of mollusks, three species—*Pompholyx effusa*, Lea, var. *solida*, Dall.; *Pyrgula Nevadensis*, Stearns; and *Pyrgula humerosa*, Gould—are living in its waters, and their dead shells occur in abundance along the shore.

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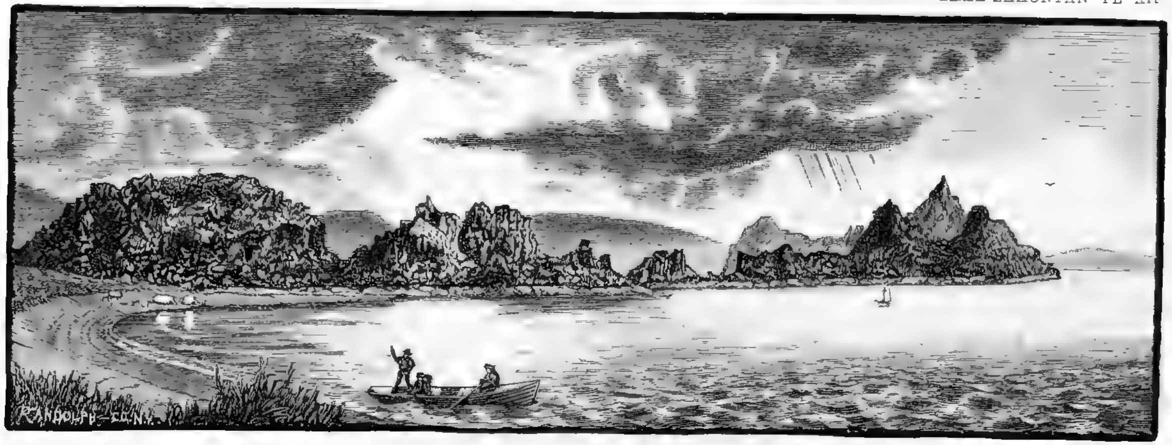
[27] Proceedings Acad. Nat. Sci. Philadelphia, 1883, p. 1?2.



THE NEEDLES, PYRAMID LAKE, NEVADA

The resemblance of Pyramid Lake to an arm of the sea is enhanced by the presence of numerous sea-birds. About The Needles especially one sees large numbers of gulls, terns, cormorants, pelicans, together with geese, ducks, swans, herons, bitterns, etc. Many of these find convenient nesting places in the hollows of the calcareous tufa. During our visit to Anaho Island in August, 1882, there were two large pelican "rookeries," in each of which there were 600 or 800 young birds.

WINNEMUCCA LAKE.

This, like its sister lake, occupies a long, narrow valley, formed by orographic displacement, and is a fair illustration of a lake occupying a fault basin. It is 26 miles long, with an average breadth of about 3½ miles, the longer axis being due north and south. As in the case of Pyramid Lake, its waters are alkaline and brackish. The following analysis by Prof. F. W. Clarke is of a sample collected in August, 1882, near the center of the lake (at *c*, Plate IX) and 1 foot below the surface:

Constituents.	One liter of water contains in grammes—	Per cent. in total solids.	Constituents.	Probable combination (in grammes per liter).
Silica (SiO_2)	0.0275	0.76	Silica (SiO_2)	0.0275
Magnesium (Mg)	0.0173	0.48	Magnesium carbonate ($MgCO_3$)	0.0494
Calcium (Ca)	0.0196	0.54	Calcium carbonate ($CaCO_3$)	0.0254
Sodium (Na)	1.2970	36.00	Potassium chloride (KCl)	0.1310
Potassium (K)	0.0686	1.90	Sodium chloride (NaCl)	2.6877
Chlorine (Cl)	1.6934	47.01	Sodium sulphate (Na_2SO_4)	0.1972
Sulphuric acid (SO_4)	.1333	3.70	Sodium carbonate (Na_2CO_3)	0.4065
	3.2567	90.39	Total (98.44 per ct. accounted for)	3.5247
Carbonic acid (CO_3) by difference	.3458	9.61		
Total	3.6025	100.00		

Nearly all of the water that supplies the lake enters at its southern end, and consequently causes this portion to be fresher than the northern part. As stated while describing the Truckee River, the water supplying this lake is a branch of the main stream. The only published account known to us of the bifurcation of the Truckee River, so as to supply two lakes, is given by Mr. King,[28] who states that—

At the time of our first visit to this region, in 1867, the river bifurcated; one half flowed into Pyramid Lake, and the other through a river four or five miles long into Winnemucca Lake. At that time

[28] U. S. Geological Exploration of the Fortieth Parallel, Vol. I., pp. 505–6.

the level of Pyramid Lake was 3,890 feet above the sea, and of Winnemucca about 80 feet lower. Later, owing to the disturbance of the balance between influx and evaporation already alluded to as expressing itself in Utah by the rise and expansion of Great Salt Lake, the basin of Pyramid Lake was filled up, and a back water overflowed the former region of bifurcation, so that now the surplus waters all go down the channel into Winnemucca Lake, and that basin is rapidly filling.

Between 1867, the time of my first visit, and 1871, the time of my last visit, the area of Winnemucca Lake had nearly doubled, and it has risen from its old altitude about 22 feet, Pyramid Lake in the same time having been raised about 9 feet. The outlines as given upon our topographical maps are according to the survey of 1867, and form interesting data for future comparison.

The differences in elevation between Pyramid and Winnemucca lakes, as reported by Mr. King, and as determined by the present survey in August, 1882, are as follows: In 1867 Pyramid was 80 feet higher than Winnemucca (U. S. Geol. Expl. 40th Parallel, Vol. I, p. 505); in 1872 Pyramid was 67 feet higher than Winnemucca (U S. Geol. Expl. 40th Parallel, Vol I, p. 506); in 1882 Pyramid was 12 feet higher than Winnemucca, as determined by engineer's level.

We know of no accurate means of determining how much each lake individually has varied since 1872, but the decrease in the difference of the levels of the two lakes is certainly due in part to the lowering of the waters of Pyramid Lake, as is indicated by recent tufa deposits and lines of bleached sea-weed at an elevation of about 12 feet above the present surface of the lake. From the data now in hand, providing that all the measurements are correct, it is evident that Winnemucca Lake has risen over 40 feet since 1872, and over 50 feet since 1867.

The history of the fluctuations of these lakes is supplemented and enlarged by the statements of Mr. George Frazier, who has been familiar with the region since 1862 In his judgment Winnemucca Lake has risen about 40 feet in the last twenty years. In 1862, the branch of the Truckee River that supplies Winnemucca Lake was so low that a person could cross it by stepping from stone to stone, at a point where it is now not less than 25 feet deep. The lake was then confined to the northern extremity of its basin, and the stream reached it after meandering through meadow lands that are now 15 or 20 feet under water. At that time the channel of the stream could be traced along the bottom of the lake for some distance, and dead cottonwood trees were standing in the water, showing that the lake had previously been much lower. Dead trees standing in Pyramid Lake, some distance from the shore, bore similar evidence to the rise of that lake

AMONG THE NEEDLES, PYRAMID LAKE, NEVADA

previous to 1862. This lake, however, is thought by Mr. Frazier to be much higher at present than when he first saw it. During the spring and summer of 1868 the Truckee delivered more water than usual, and Pyramid Lake rose 10 or 15 feet. This rise continued throughout the following year, and during these two years Pyramid overflowed into Winnemucca Lake. The water in the "slough" at that time was brackish and unfit to drink. In the summer of 1876 all the water of the Truckee River emptied into Winnemucca Lake, its outlet into Pyramid Lake having been closed by a gravel bar; but the annual rise of the river the following spring removed the obstruction. These observations, although not of scientific accuracy, are yet of value, and have been confirmed by other people who have been acquainted with these lakes for a number of years.

We may note here that the rise of Pyramid and Winnemucca lakes during the last fifteen or twenty years is synchronous with a similar increase observed in Goose, Horse, and Mono lakes, California; Walker and Ruby lakes, Nevada; Great Salt and Rush lakes, Utah.

In determining future fluctuations of level in Pyramid and Winnemucca lakes, the accompanying map, Plate IX, may be considered as of approximate accuracy; the soundings, too, were made with care. Besides these data we have determined the elevation of certain points above the surface of the lake, which will serve as bench-marks for future measure-

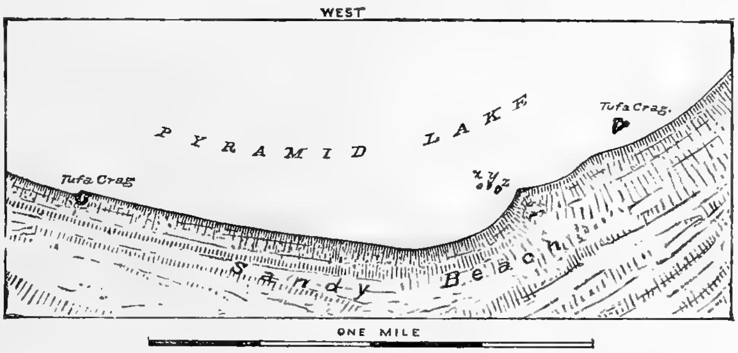


FIG. 7.—Portion of the east shore of Pyramid Lake, showing position of measured rocks.

ments. In the southern end of Pyramid Lake, and to the eastward of the Truckee delta, rise a group of tufa crags, indicated on the map by the letters *x*, *y*, *z*. An enlarged plat of this portion of the lake shore is given in the accompanying figure. The height of these crags above the surface of the lake, September 9, 1882, was as follows: *x*, 21.0 feet; *y*, 9.8 feet; *z*, 23.7 feet.

This record may be increased by adding the following elevations above the lake level as determined in September and October, 1882:[29]

Summit of Anaho Island	517 feet
Summit of "Mushroom Rock," on the north shore of Anaho Island (see Plate XIV)	17 feet 3 inches
Rock to the south of Mushroom Rock (beneath bird on Plate XIV)	8 feet 5 inches
Summit of Pyramid Island (Plate XI)	289 feet
Highest spire among The Needles (Plate XIII)	300 feet

HUMBOLDT LAKE.

Humboldt Lake is but an expansion of the river that supplies it, and is held in check by an immense gravel embankment that was thrown completely across the valley by the currents of the former lake, at one time 500 feet deep at this point. An accurate map of this structure is given on Plate XVIII, and a detailed description on page —. As there described, the embankment has been cut across by the overflow of the lake and the breach partially filled during the past few years by an artificial dam, which has greatly increased the area of the lake. During the dry season the lake seldom overflows and is then the limit of the great drainage system of the Humboldt River, but in winter and spring the waters escape southward, and spreading out on the desert form Mirage Lake. Farther southward on the northern part of the Carson Desert they again expand and contribute to the formation of North Carson Lake.

In the summer of 1882, Humboldt Lake covered an area of about 20 square miles, did not overflow, and although somewhat alkaline was inhabited by both fish and mollusks, and was sufficiently pure for human use. The following analysis of its waters by Prof. O. D. Allen, of Yale College, is taken from the reports of the United States Geological Exploration of the Fortieth Parallel, Vol. II, p 743.

[29] All these measurements were made with an engineer's level.

MUSHROOM ROCK, NORTH SHORE OF ANAHO ISLAND

Constituents.	1.	2.	Average.
Specific gravity, 1.0007.			
Fixed residue in 1,000 parts	0.9015	0.9045	0.9030
Constituents found in 1,000 parts:			
Carbonic acid	0.1065	0.1075	0.1070
Sulphuric acid	0.0257	0.0248	0.0253
Phosphoric acid	0.00069	....	0.00069
Chlorine	0.2954	0.2949	0.2952
Silica	0.0320	0.0330	0.0325
Magnesia	0.0281	0.0268	0.0274
Lime	0.0180	0.0172	0.0176
Sodium	0.2786	0.2783	0.2785
Potassium	0.0612	0.0605	0.0609
Lithia	trace.	....	trace.
Boracic acid	trace.	....	trace.
			0.84509
Oxygen			0.04273
			0.88782

There is probably a loss of carbonic acid.

The theoretical combination of bases and acids would give—

Carbonate of soda	0.24944
Sulphate of soda	0.04498
Chloride of sodium	0.39571
Chloride of potassium	0.11617
Carbonate of lime	0.03143
Carbonate of magnesia	0.05768
Silica	0.03250
Phosphoric acid	0.00069
	0.92860
Less carbonic acid added to the amount found	0 04254
	0.88606

A series of soundings made in Humboldt Lake, in July, 1882, gave a nearly uniform depth of 12 feet for the central part. Near the western shore quite extensive mud-banks rise a few feet above the surface and nearly divide the lake; westward of these the water is still more shallow than in the main body. The lake is being rapidly filled by the silt from the Humboldt River, and is destined to early extinction.

Owing to the orographic structure of the valley it occupies, the eastern shore of the Humboldt Lake is bordered by a precipitous cliff of displacement, the western shore is low and marshy, in places covered with a saline efflorescence. A sample of the incrustation from the surface of the desert near Brown's Station was found by Mr. R. W. Woodward to have the following composition:[30]

Constituents.	Per cent.
Soluble in water	27.71
Chloride of sodium	49.67
Sulphate of soda	20.88
Sesquicarbonate of soda	18.15
Borate of soda	11.30
	100.00

NORTH CARSON LAKE.

This lake is situated on the northern part of the Carson Desert (see Plate VII) and receives its waters from both the Humboldt and the Carson rivers. Having no outlet, the waters flowing into it have been supposed to sink, and for this reason it is generally spoken of as the "Humboldt and Carson Sink." As this term is based on an error, we have used the name "North Carson Lake" instead.

During the winter and spring it receives a considerable supply of water from both the Humboldt and Carson rivers, and becomes a shallow playa-lake, between 20 and 25 miles in length, by 14 miles in breadth. In unusually arid summers the water supply fails, and the lake evaporates to dryness. As desiccation becomes more intense the salts impregnating the lake-beds are brought to the surface and form an efflorescence several inches in thickness.

This was the case when the Carson Desert was visited by the writer in October, 1881. The lake had then wholly evaporated, leaving a broad mud-plain covered in places with a white alkaline crust that looked like patches of snow.

SOUTH CARSON LAKE.

Situated on the southern border of the Carson Desert lies South Carson Lake. This, like the larger lake to the northward, is a playa-lake and occupies a very shallow depression in the lake-beds flooring the desert. Like other lakes of its class, it has indefinite boundaries and varies in size

[30] U. S. Geological Exploration of the Fortieth Parallel, Vol. II, p. 744.

and depth with the alternation of seasons. In 1882 its area was about 40 square miles, with a depth of four feet throughout its central portion. Its waters are alkaline, and contain 1.4725 grammes of solids in solution to the liter; of which 0.2135 gramme is silica, as reported by Prof. F. W. Clarke from a partial analysis of a sample collected in October, 1863.

The lake is supplied almost entirely by the Carson River and usually overflows through a slough into North Carson Lake.[31]

The low muddy shores are strewed with the dead shells of *Anodonta Planorbis*, *Limnæa*, etc., but, so far as known, no mollusks are now living in the lake.

WALKER LAKE.

The southern extremity of the Lahontan basin is occupied by Walker Lake, which, next to Pyramid Lake, is the most picturesque and attractive of the desert lakes in the Lahontan basin.

A correct outline of the lake, as it existed in 1882, is given on Plate XV. As may be gathered from the map, the lake is 25.6 miles in its longer, or north and south axis, and has an average width of between 4.5 and 5 miles. Its area is 95 square miles As on the map of Pyramid Lake, the actual soundings are given in figures, and the somewhat conjectural topography of the bottom is represented by dotted contour lines. Over a large area in the central and western portions it has a remarkably uniform depth of 224 feet; but as a rule the depth increases as one approaches the western shore, which is overshadowed by rugged mountains. The bottom throughout the central portions is composed of fine tenacious mud, which in many places is black in color, and has the odor of hydrogen sulphide. Coarser deposits, consisting of sand and gravel, mingled with the empty shells of *Pyrgula*, *Pompholyx*, etc., were found only in the immediate neighborhood of the shore. No mollusks were found living in the lake; but the conditions of environment being so similar to what has been observed in Pyramid Lake, it is thought that a more careful search would show that Walker Lake is also inhabited by a few species. Analyses of the water, collected in September, 1882, one foot and 215 feet below the surface

[31] See *ante*, page 44.

where the depth was 224 feet, as shown on the accompanying map, are reported by Prof. F. W. Clarke as follows:

Constituents.	One liter of water contains, in grammes—		Per cent. in total solids.	
	Sample from 1 foot below surface.	Sample from 215 feet below surface.	Sample from 1 foot below surface.	Sample from 215 feet below surface.
Silica (SiO_2)	0.0075	0.0075	0.29	0.30
Magnesium (Mg)	0.0391	0.0375	1.55	1.51
Calcium (Ca)	0.0267	0.0176	1.06	0.71
Sodium (Na)	0.8577	0.8530	34.11	34.29
Potassium (K)	Trace.	Trace.	Trace.	Trace.
Chlorine (Cl)	0.5875	0.5800	23.36	23.32
Sulphuric acid (SO_4)	0.5275	0.5125	20.96	20.69
	2.0460	2.0081	81.33	80.73
Carbonic acid (CO_3) by difference	0.4695	0.4794	18.67	19.27
Total	2.5155	2.4875	100.00	100.00

Constituents.	Probable combination (expressed in grammes per liter).	
	Sample from 1 foot below surface.	Sample from 215 feet below surface.
Silica (SiO_2)	0.0075	0.0075
Magnesium carbonate ($MgCO_3$)	0.1369	0.1313
Calcium carbonate ($CaCO_3$)	0.0667	0.0440
Sodium chloride (NaCl)	0.9681	0.9558
Sodium sulphate (Na_2SO_4)	0.7803	0.7580
Sodium carbonate (Na_2CO_3)	0.5157	0.5339
	2.4752	2.4305
Loss	0.0403	0.0570
Total	*2.5155	†2.4875

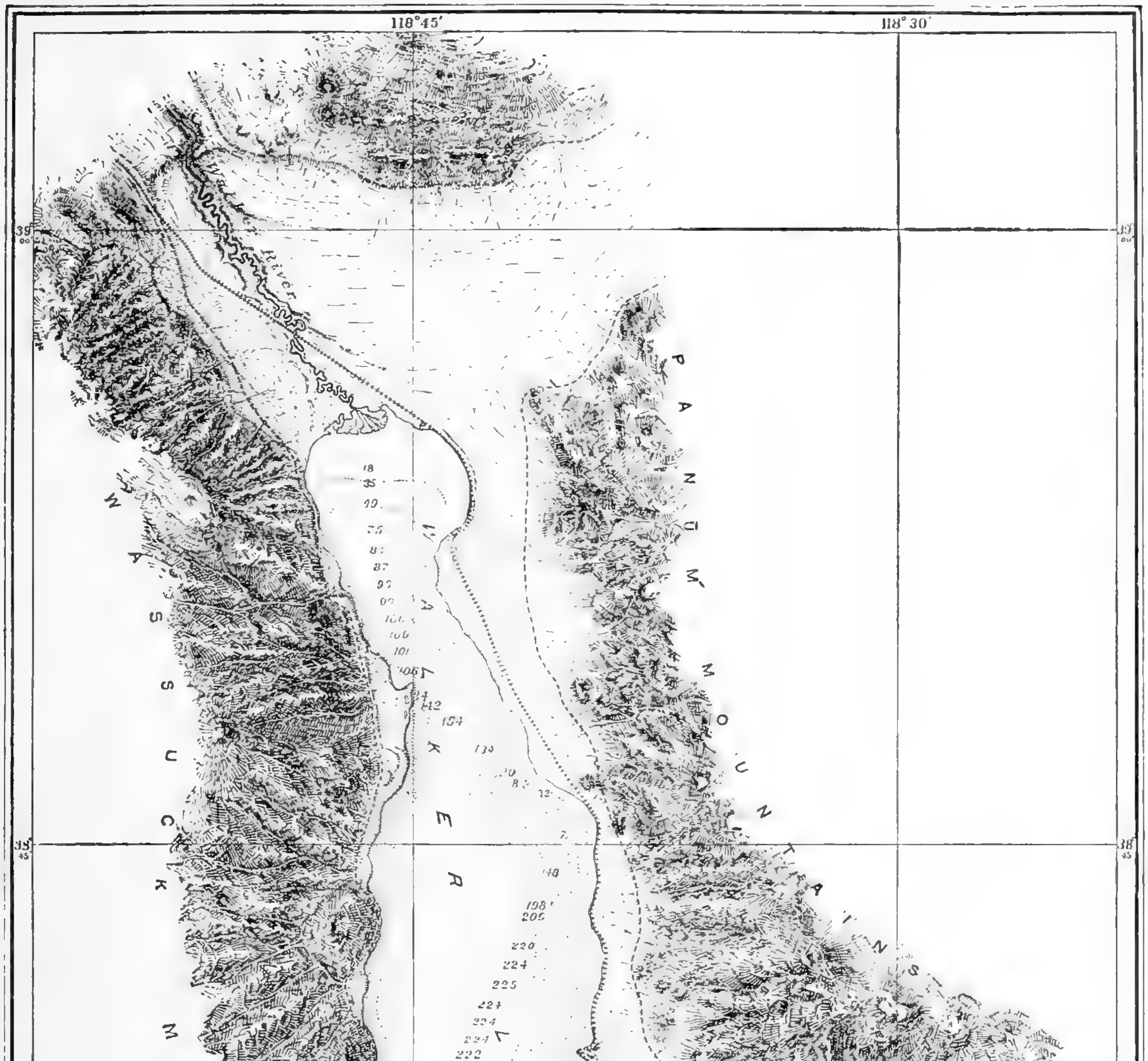
* 98.39 per cent. accounted for.

† 97.66 per cent. accounted for.

As in the case of the other lakes of the Great Basin, situated at an elevation of less than 5,000 feet, the shores of Walker Lake are totally lacking in arboreal vegetation except at the river mouth, and are clothed only with desert shrubs. At the northern end, and following the immediate shores of the Walker River for many miles, are luxuriant cottonwood groves, together with willow-banks and meadow-lands.

At the northern end, the river is building out a low delta of fine silt, and remnants of similar deltas, at higher levels, may be seen as one follows up the river. A change in the level of the lake is recorded by dead trees standing in the water, which show that it has risen at least four or five feet in recent years.

The waters at a distance from the river mouth are of a clear deep blue, changing to a bright green tint near the shore, as in Pyramid Lake. They are charged with saline matter to such an extent that carbonate of lime is now being deposited. The calcareous tufa now forming cements the gravel and sands of the shore into compact strata or forms rosette-shaped masses, with isolated pebbles for nuclei.



W. D. Johnson, Topographer.

I. C. Russell, Geologist.

In the study of the recent and fossil lakes of the Far West it is frequently desirable to know the present rate of evaporation, and the character of the seasonal and secular variations in precipitation that are taking place. Attempts have been made to determine the rate of evaporation by experimenting with artificial evaporating pans, but owing to the difficulty of imitating the conditions of nature, these observations have been of little value. Gauges have been established in Great Salt Lake, and accurate records of its annual and secular fluctuations have been secured for a number of years, but in this instance the variations of the lake are influenced by irrigation, and the sources of supply for the waters of the lake are too numerous to be definitely measured. Of all the lakes of the Far West with which we are acquainted, excepting Abert Lake, Oregon, the most favorable for determining the questions indicated above is Walker Lake. As this lake receives its entire supply from a single source and is without outlet, the rate of evaporation from a large water surface could be determined with great accuracy. Observations intended to show the secular variations in precipitation would be more difficult because the waters of Walker River are largely used for irrigation.

LAKE TAHOE.

As Lake Tahoe is the grandest of the Sierra Nevada lakes, and the largest that discharged into Lake Lahontan, we insert a brief account of it, compiled principally from the investigations of Prof. John Le Conte, of the University of California.[32]

The lake is situated in latitude 39° N., and lies part in California and part in Nevada, at an elevation of 6,247 feet, as determined by railroad surveys. Its drainage area, including the lake surface, is about 500 square miles. The water surface is 21.6 miles long from north to south, with an extreme breadth of 12 miles; its area being between 192 and 195 square miles. Its outlet is the Truckee River, which leaves the lake through a magnificent gorge, at a point on its northwestern shore.

[32] "Physical Studies of Lake Tahoe," published in the Free Press and the Mining and Scientific Press of San Francisco, during 1880 and 1881. Reprinted in the Overland Monthly for November and December, 1883, and January, 1884.

Soundings made by Professor Le Conte, beginning at the northern end, near the "Lake House," and advancing along the longer axis of the lake directly north towards the "Hot Springs," at the northern end, give depths of from 900 to 1,645 feet

Between the 11th and the 18th of August, 1873, Professor Le Conte made a large number of temperature measurements at different depths in the lake, an abstract of which is here copied:

No.	Depth in feet.	Depth in meters.	Temperature: Fahr.	Temperature: Cent.
1 (surface)	....	....	67	19.44
2	50	15.24	63	17.22
3	100	30.48	55	12.78
4	150	45.72	50	10.00
5	200	60.96	48	8.89
6	250	76.20	47	8.33
7	300	91.44	46	7.78
8 (bottom)	330	100.58	45.5	7.50
9	400	121.92	45	7.22
10	480	146.30	44.5	6.94
11 (bottom)	500	152.40	44	6.67
12	600	182.88	43	6.11
13 (bottom)	772	235.30	41	5.00
14 (bottom)	1,506	459.02	39.2	4.00

Professor Le Conte's paper also contains many valuable observations on the transparency and color of the lake water, and on rhythmic variations of level. An analysis of the water of Lake Tahoe has already been given on page 42.

Besides Lake Tahoe, there was another lake among the mountains of Northern California during Quaternary times which was tributary to Lake Lahontan. This was a comparatively shallow water body that occupied the basin now known as the Madeline Plains. A small stream from Horse Lake Valley joined that draining the Madeline Plains; as did also the waters escaping from Eagle Lake, which, without evidence to the contrary, we may consider to have discharged, then as now, through beds of gravel beneath a lava coulée.

SODA LAKES, NEAR RAGTOWN, NEVADA.

On the Carson Desert, about 2 miles northeast of Ragtown, are two circular depressions that are partially filled with strongly alkaline waters and known as the Soda Lakes or Ragtown Ponds By reference to the accompanying map (Plate XVI), on which the contour lines are drawn at intervals of 20 feet, it will be seen that the lakes occupy deep depressions in low cones. The larger lake is 268.5 acres in area, and the smaller is a pond of variable size.[33] The form of the larger depression is still farther illustrated by the cross-section given at the bottom of the plate, which has been constructed from actual measurements with an engineer's level and a sounding line. The rim of the larger lake in its highest part rises 80 feet above the surrounding desert, and is 165 feet higher than the surface of the lake which it incloses. The outer slope of the cone is gentle and merges almost imperceptibly with the desert surface; but the inner slope is abrupt and at times approaches the perpendicular. A series of careful soundings gives 147 feet as the greatest depth of the lake. The total depth of the depression is therefore 312 feet, and its bottom is 232 feet lower than the general surface of the desert near at hand.

The walls encircling the lake exhibit well exposed sections of stratified lapílli, mingled with an abundance of angular grains, kernels, and masses of basalt, some of which are 2 and 3 feet in diameter and scoriaceous, especially in the interior. Mingled with this angular and rough material is a great quantity of fine dust-like lapílli, and some rounded and worn pebbles of rhyolite. Interstratified with the lapílli occur marly lake-beds containing fresh-water shells and dendritic tufa, as is indicated in the accompanied generalized section of the crater walls (Plate XVII, Fig. A). Both the lapílli and the lake-beds are evenly stratified, and exhibit diverse dips. On the interior of the larger crater, on the south side, the dip is towards the lake at an angle of about 30°. On the east side the stratification appears quite horizontal, but may, perhaps, be inclined away from

[33] The smaller lake, when the accompanying map was made, had been so changed by excavation and the construction of evaporating vats that its original form had been destroyed. Its surface is 20 feet higher than the larger lake, and 65 feet below the general desert surface. The highest point on the crater rim is 80 feet above the bottom of the depression.

the crater; near the surface of the lake there are two planes of unconformability, as well as a number of small faults. In the crater walls on the opposite side of the lake a number of displacements may be seen, as indicated in Fig. E, Plate XVII.

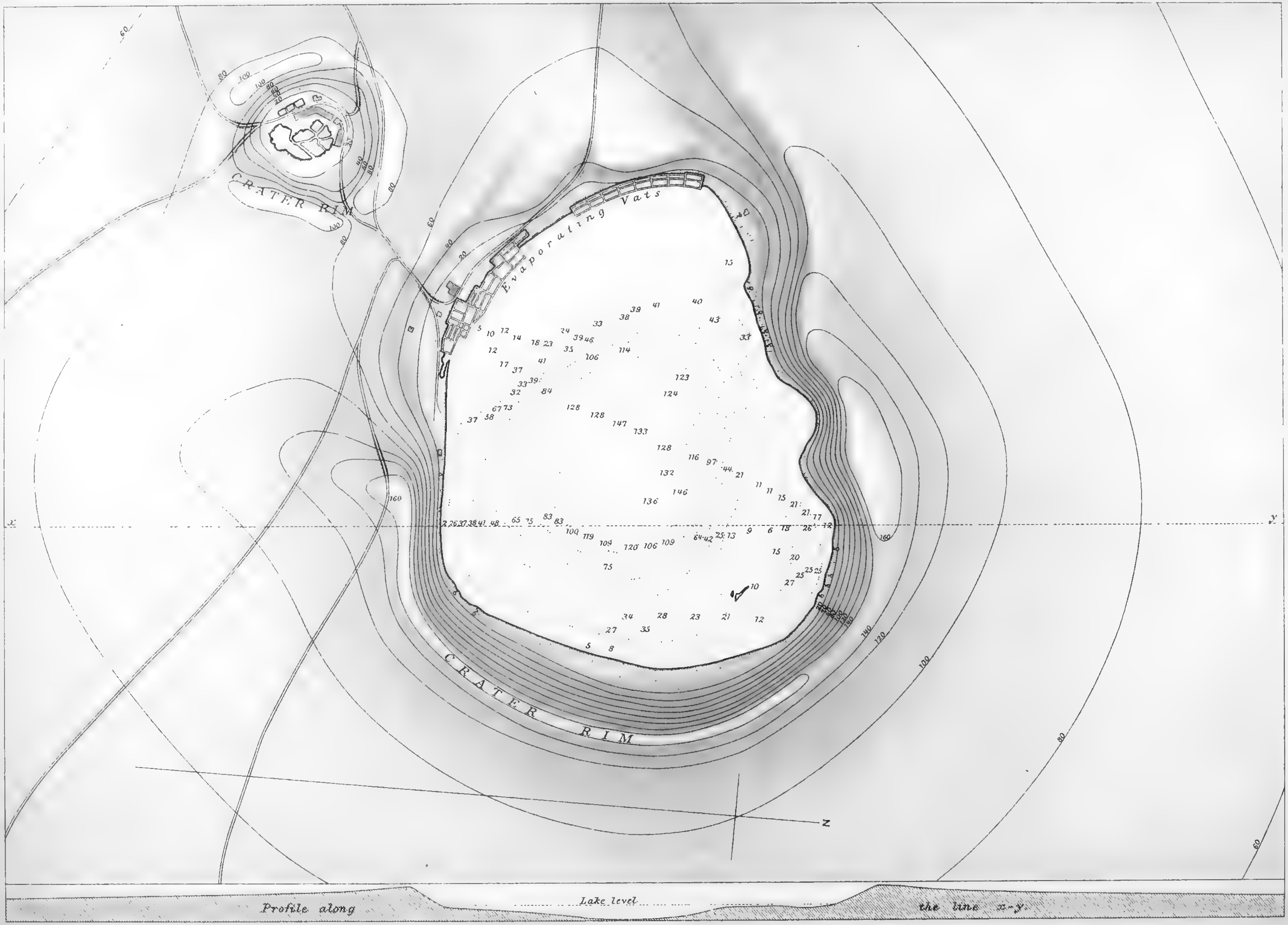
The form of the cones and the nature of the material of which they are composed leave no doubt that these are crater-rings, *i. e.*, low cones of eruption containing large craters. The evidence sustaining this conclusion is abundant In the stratified beds of yellowish lapílli, which are always angular and sometimes as fine as dust, are many fragments of basalt, rhyolite, and masses of hardened lake-beds,[34] that are evidently ejected fragments that have been dropped from a considerable height to the positions which they now occupy. The strata of lapílli beneath these "bombs" are bent down, as shown in the accompanying sketch (Figs. B, C, and D, Plate XVII) the disturbance being visible for 6 or 8 inches below the included rock. The strata of loose cinders covering the inclosed fragments are horizontal and undisturbed. That the cones were not formed during a single eruption, but have a long and complicated history, and are perhaps sublacustrine in their origin, is shown by the alternation of ejected and sedimentary materials in the crater walls.

From the presence of fossiliferous lacustral clays in the midst of lapílli, it seems evident that volcanic eruption was interrupted by periods during which the lake covered the craters. The presence of dendritic tufa in the midst of the section proves that the volcano was active both before and after the dendritic stage of Lake Lahontan. The wall of the larger lake is somewhat open on the south side, while the western rim has been prolonged southward (see Plate XVI) in such a manner as to suggest that the erupted material was in part removed by currents at the time it was ejected and deposited in the form of an embankment, connecting with the crater rim.

The hypothesis that the craters were formed by the action of extremely powerful sublacustrine springs, as advanced by King,[35] would not account for the nature of the material forming the crater walls, nor the presence of

[34] The rhyolite pebbles and fragments of lacustral sediments thrown out by this volcano were evidently derived from the superficial strata through which it opened a passage. The basalt, on the other hand was erupted in a semi-fused condition and formed slaggy masses on cooling.

[35] U. S. Geological Exploration of the Fortieth Parallel, Vol. I, p. 512.



W. D. Johnson, Topographer.

Julius Bien & Co. Lith.

I. C. Russell, Geologist.

SODA LAKES NEAR RAGTOWN, NEVADA.

the numerous volcanic bombs that depress the strata on which they rest. If the cavities owed their origin to springs of very great magnitude rising in the bottom of Lake Lahontan, it is evident that the out-flowing waters would have cut channels of overflow when the lake evaporated to a horizon below the rim of unconsolidated material that surrounded them; but the crater walls are now continuous and unbroken by stream channels. On the other hand, had the springs become extinct before the evaporation of the lake the cavities they formerly occupied would be buried beneath lake-beds. This, as our observations show, is not the case, but both the inner and outer surfaces of the cones are free from lake sediments The last addition of lapílli to the walls of the crater must have been of post-Lahontan date.

The least diameter of the larger crater at the water surface is 3,168, and its greater 4,224 feet. Its area, as stated on a previous page, is 268.5 acres. A sublacustral spring of these dimensions, rising with sufficient force to carry blocks of basalt 1 or 2 feet in diameter to the height of 150 feet, would be a phenomenon without parallel. That the lakes occupy extinct craters is recognized by Mr. Arnold Hague in his description of the Carson Desert.[36]

There are no streams either tributary to or draining these lakes; their total water supply, excepting the small amount derived from direct precipitation, is supplied from subterranean sources. Around the immediate shores of the larger lake there are a number of fresh-water springs; the largest of these is situated on the northern border of the basin, and issues from a small fault at an elevation of about 15 feet above the water surface. As the lake, by aneroid measurements, is 50 feet below the level of the Carson River at its nearest point, we may safely look to this stream as the probable source of the water supply which reaches the craters by percolating through the intervening marls and lapílli deposits. The bottom of the lake, as determined by many soundings, is a continuation of the slope of the inner walls of the crater, excepting that the conical form has been modified by shore action and sedimentation, which has resulted in the formation of the terrace about the present water margin. In the northern part of the lake a reef of rock projects above the surface, and soundings show that this is continuous from

[36] U. S. Geological Exploration Fortieth Parallel, Vol. II, p. 746.

shore to shore, thus indicating that two craters are combined in the formation of the present depression.

The bottom, as shown by the samples obtained by the cup at the end of our sounding lead, is a fine tenacious black mud having a strong odor of sulphuretted hydrogen. When exposed to the air for some time this material loses its inky color and shows itself to be of the same nature as the fine dust-like lapílli that form a large part of the crater walls. The organic matter impregnating these sediments is evidently derived from the millions of brine shrimps (*Artemia gracilis*) and the larvæ of black flies that swarm in the dense alkaline waters.

Near the shore the rock and pebbles, as well as bits of organic matter are coated with beautiful crystals of gaylussite which form about any solid nucleus that chances to be available. The crystals are white, with transparent edges, monoclinic in form, and thin in the direction of the orthodiagonal, as illustrated by Figure 607, Dana's System of Mineralogy, 5th edition. The small island in the northern part of the lake is completely coated with gaylussite crystals and trona. An analysis of a crystal of gay-lussite from this locality by Prof. O. D. Allen gave the following composition:[37]

Lime	19. 19
Soda	19. 95
Carbonic acid	29. 55
Water	31. 05
Sulphuric acid	Trace.
Chlorine	Trace.
Insoluble residue	0. 20
	99. 94

Trona also occurs along the shore of the lake up to an elevation of 10 or 12 feet, and not unfrequently contains casts of the larval cases of a fly which now lives in the lake in immense numbers. An analysis of a sample of trona from this locality, by Prof. O. D Allen is here copied.[38]

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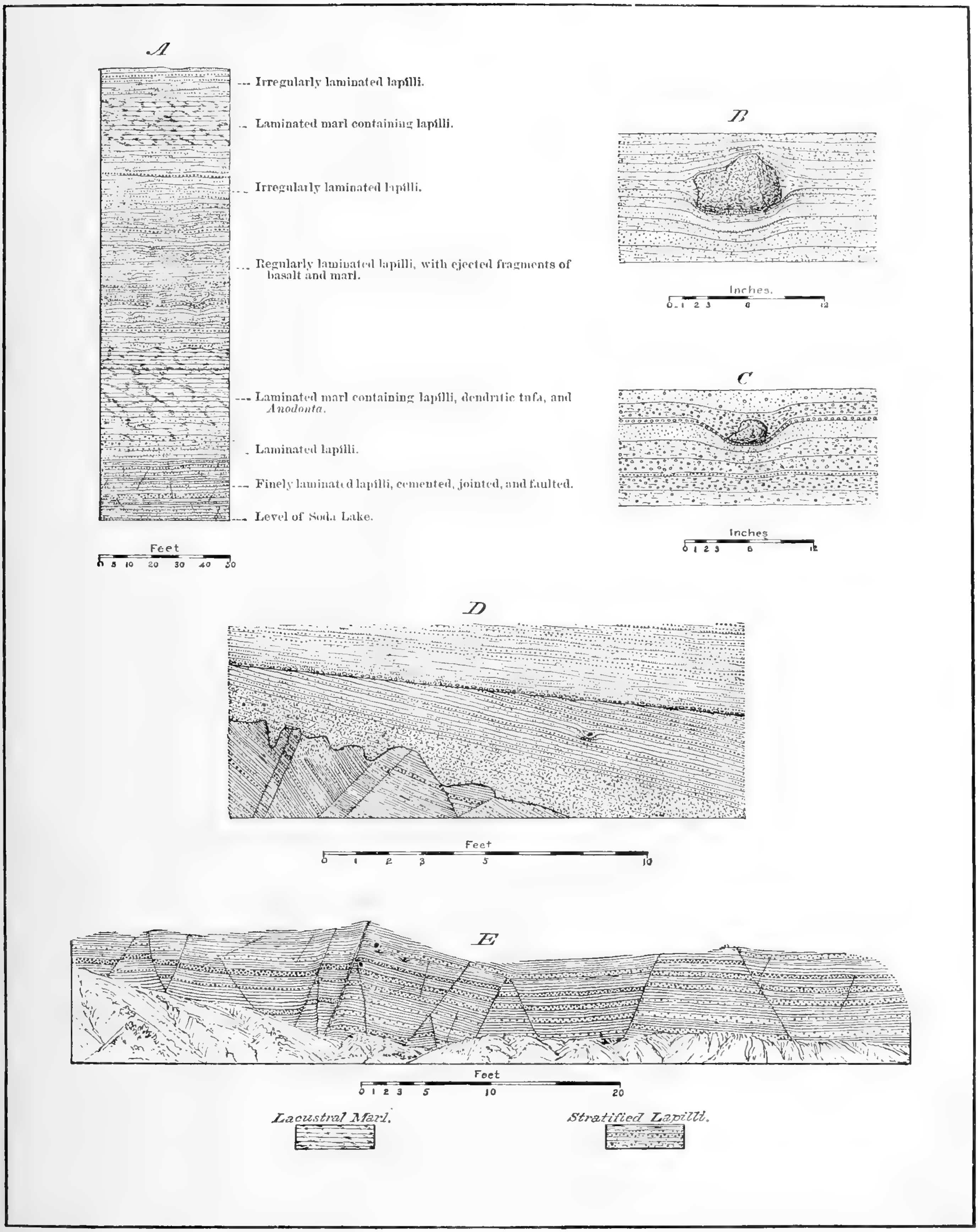
[37] U. S. Geological Exploration of the Fortieth Parallel, Vol. II, p. 749.

[38] U. S. Geological Exploration of the Fortieth Parallel, Vol. II, p. 748.



W J McGee, Del. I. C. Russell, Geologist.

SECTIONS OF THE CRATER WALLS INCLOSING THE SODA LAKES, NEVADA.

	Per cent.
Soda	40.55
Carbonic acid	36.86
Sulphuric acid	0.73
Chlorine	0.98
Water	19.90
Insoluble residue	0.80
	99.82
Oxygen equivalent to chlorine	0.22
	99.60

"The deposit is thus nearly a pure trona, or sesquicarbonate of soda, mixed with small quantities of sulphate of soda and common salt. It contains also traces of phosphoric and boracic acids. The insoluble residue consists of fine sand and carbonate of lime."

Samples of water collected in September, 1882, in the central portion of the lake, at the depths of 1 foot and 100 feet, have been analyzed by Dr. T. M. Chatard, who reports their composition as follows:

Constituents.	One liter of water contains in grammes—		Per cent. in total solids.		Constituents.	Probable combination (expressed in grammes per liter).	
	Sample from 1 foot below surface.	Sample from 100 feet below surface.	Sample from 1 foot below surface.	Sample from 100 feet below surface.		Sample from 1 foot below surface.	Sample from 100 feet below surface.
Silica (SiO_2)	0.304	0.310	0.24	0.25	Silica (SiO_2)	0.304	0.310
Magnesium (Mg)	0.270	0.270	0.22	0.21	Magnesium carbonate ($MgCO_3$)	0.940	0.940
Potassium (K)	2.520	2.670	2.01	2.13	Potassium chloride (KCl)	4.820	5.110
Sodium (Na)	45.840	44.270	36.63	35.38	Sodium chloride (NaCl)	71.470	68.930
Chlorine (Cl)	45.690	44.270	36.51	35.38	Sodium sulphate (Na_2SO_4)	19.170	19.450
Sulphuric acid (SO_4)	12.960	13.150	10.36	10.50	Sodium borate ($Na_2B_4O_7$)	0.404	0.417
Boracic acid (B_4O_7)	0.314	0.327	0.25	0.26	Sodium carbonate (Na_2CO_3)	26.410	24.840
	107.898	105.267	86.22	84.11		123.518	119.997
Carbonic acid (CO_3) by difference	17.232	19.883	13.78	15.89	Loss *	†1.612	‡5.153
Total	125.130	125.150	100.00	100.00	Total	125.130	125.150

* If the excess of CO_3 above the amount required for Na_2CO_3 be calculated as $NaHCO_3$, we will have in the sample from 1 foot below the surface: 123.518 less Na_2CO_3 = 97.108
Na_2CO_3 = 23.64
$NaHCO_3$ = 4.382
125.130

and in the remaining sample: 119.997 less Na_2CO_3 = 95.157
$NaCO_3$ = 16.04
$NaHCO_3$ = 13.953
125.150

† 98.71 per cent. accounted for.
‡ 95.98 per cent. accounted for.

A water sample collected from the south side of the lake in August, 1867, and analyzed by Prof. O. D. Allen, had a specific quantity of 1.0975, and gave a fixed residue of 114.7 parts per thousand, and on spectroscopic examination was found to contain lithia in addition to the elements given in the above analyses.[39]

In obtaining carbonate of soda from the waters of the larger lake two methods are in use. One is known as the "cold weather" and the other as the "warm weather" process. In the former the water of the lake is conducted into vats along its shore, and has a density of about 12° of Beaumé's areometer As it evaporates beneath the heat of the summer sun its density increases until it approaches 30° B. At this point more water is added from the lake. This process is continued until cold weather approaches; the vats are then so adjusted as to have a density approaching 30° B. The lowering of the temperature on the approach of winter causes sodium carbonate and sodium sulphate to be precipitated at the bottom of the vats in a hard crystalline layer, which, when removed to the drying sheds, crumbles to a fine white powder. The "soda" formed by this process contains about equal portions of sulphate and carbonate, as shown by the following analysis by Dr. F. W. Taylor of a sample of the material as it is sent to the market:

	Per cent.
Silica	0.449
Iron and aluminum	.011
Calcium sulphate	.038
Magnesium sulphate	.040
Sodium chloride	2.193
Sodium sulphate	49.437
Sodium carbonate	40.714
Water	7.118
	100.000

While concentrating the waters in the soda vats during the summer, if the density increases beyond about 30° B., carbonate of soda and sulphate of soda are precipitated, and, if concentration continues, is soon followed by the deposition of common salt. In this process the water is conducted from vat to vat, becoming gradually concentrated as it progresses. When in the last

[39] U. S. Geological Exploration of the Fortieth Parallel, Vol. II, p. 747.

of the series it has reached the desired density, sodium carbonate, together with sodium sulphate, is deposited. The mother liquor is afterward returned to the lake. The soda thus obtained is called "summer soda," and has about the composition given in the above analysis, as is indicated by qualitative tests. The vats in which the evaporation is conducted are formed by levees built along the shallow border of the lake, and are usually about 80 feet long by 50 feet broad; the water when evaporation commences is usually from 12 to 14 inches deep. (Plate XVI.)

When the waters of the lake are evaporated until a density of about 15° B. is reached, they assume a reddish tint, which increases as the concentration is carried forward, until at 30° B. they become of a bright cherry-red color. Chemical tests show that this color is not due to the presence of manganese or iron, but is probably produced by organic substances.

The manufacture of soda at the larger lake was commenced in 1875, and is yet in its experimental stage, although two or three hundred tons of impure soda carbonate have been produced. The smaller lake when first discovered is reported to have been dry, and presented the appearance of an ordinary mud-playa. Excavations carried to the depth of about 25 feet have shown that the material filling the basin is composed of layers of soda salts, separated by strata of dust and mud. As the layers of soda in these beds have the character of the "summer soda" now formed in the vats, it is evident that the crater has served as a natural evaporating pan, in which the water accumulated during the wet season was entirely evaporated before the dry season had passed.

For the manufacture of soda in this basin, vats have been excavated in the material composing its bottom. They are filled by water seeping from its sides, which, as it enters the vats, has a density of from 10° to 15° B. Concentration is carried on until the carbonate of soda begins to crystallize, when a new supply of brine is added, and the process carried forward until cold weather sets in, when an abundant crop of beautiful soda crystals is formed during the first cold nights of autumn. After all the soda is precipitated that a lowering of temperature will produce, the mother liquor is conducted back into lower depressions, and allowed to leach through the soda-bearing strata once more The crust of soda obtained at the bottom of the vats is usually about 10 inches thick and shows two divisions, the upper layer, or "winter soda," being the more crystalline. The salt thus obtained is removed to drying sheds, where it loses its excess of water, at the same time crumbling to a fine powder, and is then ready for the market. A sample of this material was found on qualitative examination to consist principally of sodium carbonate, together with considerable quantities of chloride and sulphate of soda, and traces of phosphoric and boracic acid and potash.

The manufacture of soda in the smaller pond has been carried on for about eighteen years, with an annual production of between four and five hundred tons, as I am informed by Mr. B. F. Gray, the present superintendent.

The walls of the smaller crater are of the same nature as those that surround the larger lake, and exhibit sections of stratified tuff containing ejected blocks of basalt that depress the strata on which they rest. An illustration of the smaller Soda Lake will be found on Plate XXII, Vol. II, and of the larger lake on Plate XXVI of Vol. I, of the reports of the U. S. Geological Exploration of the Fortieth Parallel.

The mineral matter now dissolved in the water of the Soda Lakes is unquestionably derived from the springs that supply them, and has been dissolved from the lacustral beds and lapilli deposits through which their waters percolate during their subterranean passage.

The data given on Plate XVI enable one to calculate approximately the volume of the larger of the Soda Lakes; and from the analyses of its waters that have been made we can determine the quantity of the various salts it contains. Making these calculations for the salts of greatest economic importance, we find that the lake contains nearly 428,000 tons of sodium carbonate; sodium sulphate amounts to nearly four-fifths of this quantity; while the sodium chloride is somewhat less than three times as great. The total of all salts dissolved in the lake is in the neighborhood of two million tons.

PLAYA-LAKES AND PLAYAS.

The name "playa-lake" has been applied to inclosed water bodies of dry climates which have little depth and frequently evaporate to dryness, leaving mud-plains, or playas. In the typical examples found throughout the Great Basin, their waters are somewhat alkaline and saline, and almost always turbid with fine silt, and, probably, chemical precipitates. This material is retained in suspension not only because the shallow lakes are frequently agitated to the bottom by the wind, but, also, for the reason that in waters containing alkaline salts the precipitation of suspended matter is greatly retarded. Lakes of this class exhibit great variety, and are the most irregular of water bodies. In many instances they hold their integrity for a number of years, and only evaporate to dryness during exceptionally arid seasons. Again, desiccation is apparently the normal condition, and the basins are only flooded during times of unusual humidity. Many lakes of this class exist only during the humid season, and are dry throughout the summer. In the spring and fall, as already mentioned in describing the general features of the Great Basin, they appear with every storm that gathers and vanish when the heavens are again bright. Their outlines consequently fluctuate with the humidity of the season, and, owing to the extreme shallowness of their basins, a variation of an inch or two in depth may make a difference of many square miles in area.

Examples of the more permanent playa-lakes of the Lahontan basin are furnished by Honey Lake and the lakes of the Carson Desert. Another, of less permanence, on the Black Rock Desert, has been noticed on page 10. The positions of others, some of which are many miles in extent during the winter, but disappear completely when the breath of summer touches them, are indicated on the accompanying pocket-map. Examples might be multiplied, and the curious effects that these ephemeral lakes exert on the scenery of arid lands might be dwelt upon, but this would perhaps carry us beyond their geological interest.

The lakes described above are commonly uninhabited by fish, but frequently afford a congenial abode for mollusks, especially for the Limnæidæ and allied forms.

The water reaching playa-lakes is commonly derived from the surface drainage of the basins in which they occur; the larger ones, however, are supplied by streams more or less permanent. The sediment contributed to lakes of this description is commonly in a state of minute subdivision, and when derived from the surrounding surface is rich in saline matter. When evaporation takes place both the suspended and dissolved matter is deposited and forms a peculiar light-colored saline clay, which, when desiccation is complete, forms a smooth mud-plain, or playa.

The mud-plains originating in the manner described above are characterized by the evenness of their surfaces and their light creamy-yellow color, which is independent of the nature of the surrounding rocks. These deposits have the same characteristics and apparently about the same composition whether surrounded by sedimentary rhyolites or basaltic rocks. In area they vary from a fraction of an acre up to many square miles. They are entirely destitute of vegetation, and are in fact the only absolute deserts in this country. During the rainy season they are rendered soft and impassable, and very frequently covered with water, as mentioned in describing a playa-lake, but with the advance of summer they lose their moisture and become so completely desiccated beneath the intense heat of the summer's sun that they resemble a pavement of cream-colored marble, which, on the broader deserts, stretches away to the horizon without a shrub or spear of grass to break the monotony of the glossy surface. Owing to the contraction of the mud on drying a playa becomes broken by a vast system of intersecting "sun cracks," which frequently cover the surface with an intricate network of narrow fissures. While the mud is soft it sometimes becomes impressed with the foot-prints of animals and rippled by the winds, thus receiving markings that are usually considered characteristic of shores.

Typical examples of playas of broad extent occur in the Lahontan basin, on the Black Rock, Smoke Creek, and Carson deserts; others of less size are met with in various minor basins, as has been indicated in describing playa-lakes.

The scenery on the larger playas is peculiar, and usually desolate in the extreme, but yet is not without its charms. In crossing these wastes the traveler may ride for many miles over a perfectly level floor, with an unbroken sky-line before him, and not an object in sight to cast a shadow on the ocean-like expanse. Mirages may be seen every day on these heated deserts. Similar optical illusions give strange fanciful forms to the mountains, and sometimes transfigure them beyond all recognition. At such times a pack-train crossing the desert a few miles distant frequently appears like some strange caravan of grotesque beasts fording a shallow lake, the shores of which advance as one rides away. The monotony of midday on the desert is thus broken by delusive forms that are ever changing, and suggest a thousand fancies which divert the attention from the fatigues of the journey. The cool evenings and mornings in these arid regions, when the purple shadows of distant mountains are thrown across the plain, have a charm that is unknown beneath more humid skies. The profound stillness of the night in these solitudes is always impressive.

When the heat of summer drives every drop of moisture from these deserts a white saline efflorescence appears, which is formed by the crystallization of various salts brought to the surface in solution by the action of capillary attraction, and left as the water that dissolved them is evaporated. Incrustations of this nature sometimes cover areas many miles in extent, especially along the borders of the playas, and render the surface as dazzling as if covered by snow.

An analysis of a typical specimen of playa mud from the southern part of the Carson Desert is reported by Dr. F. W. Taylor, as follows:

Portion soluble in water 15.16 per cent.

Constituents.	Soluble portion.	Constituents.	Insoluble portion.
	Per cent.		*Per cent.*
Silica	14.05	Silica	48.33
Iron sesquioxide	2.37	Iron sesquioxide	3.93
Alumina	2.17	Alumina	14.36
Magnesium carbonate	2.90	Lime (CaO)	11.23
Calcium carbonate	0.79	Magnesia (MgO)	2.82
Sodium carbonate	14.36	Soda	5.00
Sodium sulphate	4.28	Potassa	2.58
Sodium chloride	53.16	Carbonic acid	6.88
Water (by difference)	5.92	Water	4.55
	100.00		99.68

An examination of a sample from another playa gave less than 3 per cent. soluble in water, consisting principally of sodium carbonate, calcium carbonate, and common salt.

It is not to be expected that all deposits of this character would have even approximately the same composition, but the conclusion arrived at in the field, that they are the result of both mechanical and chemical processes, is strengthened by the analyses that have been made. In some instances easily soluble salts form a large percentage of the deposit, which then becomes a salt-field, a bed of gypsum, or is largely composed of other similar salts. At times these deposits become covered with mechanical sediments, and perhaps buried so deeply that they are not again dissolved when the basin is reoccupied by a lake. All stages in this process, which, in fact, is the closing chapter in the history of many lakes, may be observed in the arid region of the Far West.

Playas in which the mechanical deposits greatly predominate are the most common, and may be studied in a large number of the desert-valleys of Utah and Nevada. Examples of salt-playas are numerous, especially in Southern Nevada, where they are of economic importance, and, besides common salt, frequently contain large quantities of sodium sulphate and carbonate, borax, etc. In some instances the lower portions of earthy playas are saturated with brine—as is the case in Diamond Valley, Nevada—which, when raised to the surface and evaporated, is capable of supplying an almost unlimited quantity of salt. One of the most instructive playas in the Great Basin is situated in Utah, a few miles southward of Fillmore. In this instance the water entering the basin and partially flooding it during the rainy seasons is probably charged with calcium sulphate in excess of all other salts, and on evaporating leaves a deposit of crystallized gypsum, or selenite, which is now approximately 12 square miles in extent, and has been penetrated to the depth of 6 feet without revealing its entire thickness. The salts more soluble than gypsum, which must have been deposited by the waters covering the playa at various times, have apparently been flooded out by an overflow of the basin, thus leaving the selenite in a remarkably pure condition. The small crystals of selenite swept from the surface of the deposit by the wind have been accumulated in immense dunes, especially along the northern border of the playa, and have nearly buried a rhyolitic butte beneath snow white drifts, thus acquiring for it the local name of the "White Mountain."

A stratification of the various salts found in playas in the order of their solubility, as commonly occurs from the slow evaporation of brines, is not usual, for the reason, apparently, that they owe their accumulation to repeated desiccations. In some instances, however, as at Rhode's salt marsh in Nevada, the more soluble salts are gathered most abundantly in the central part of the basin.

A study of the playas of the Far West renders it evident that saline deposits of great extent may result in the manner described above, and sustains the suggestion that beds of rock-salt, gypsum, etc., found in various geological formations may have been accumulated in interior basins by the evaporation of ordinary surface waters, and are not in all cases, as frequently inferred, the result of the evaporation of isolated bodies of sea-water.

Besides the playas proper, the formation and characteristics of which we have sketched, there are other desert areas in the Far West that are frequently designated by the same name, but which are of a somewhat different nature. These are mud-plains left by the evaporation of large lakes, and composed of ordinary lake sediments. Deserts of this nature are in many instances nearly as desolate as the true playas. Their borders are commonly poorly defined, being more or less covered with shrubs; their surfaces, too, are commonly uneven and irregular. In substance, they are usually composed of tenacious greenish clay of the same character as the sediments now forming in many large lakes. Usually the deserts of this character occupy nearly the entire breadth of an ancient lake-bed, and are overlaid by playas proper in their lowest depressions. In a deep section of such a playa the light-colored saline clays, of which they are almost invariably composed, would be found to pass into the more tenacious and darker clays beneath. The strata at the base of such a section were deposited in a deep lake of broad extent, while the playa-beds proper are the record of frequent desiccations.

The freshening of lakes by complete evaporation is one of the most interesting results of the processes we have been tracing. Perhaps the strongest proof that the burial of desiccation products beneath earthy sediments is competent to convert a lake from a saline to a fresh condition is furnished by a number of the existing lakes of Nevada and Oregon, which are either fresh to the taste, or else hold but a fraction of 1 per cent. of saline matter in solution, but occur in comparatively broad drainage-basins that have not overflowed since the beginning of the Quaternary. This is illustrated especially by the present condition of the lakes of the Lahontan basin, as will be shown in treating the chemistry of the former lake (*postea*, page 229).

CHAPTER IV.

PHYSICAL HISTORY OF LAKE LAHONTAN.

SECTION 1.—SHORE PHENOMENA IN GENERAL.

The examination of the shores of recent and fossil lakes has shown that there are a number of characteristic topographic features, resulting from the action of waves and currents, which are of geological interest, and frequently enable one to determine much of the history of a lake that has passed away. The dynamics of lake waters may be studied in any existing lake, but the topography of shores is best seen in lake basins that have been emptied of their waters at a recent date.

If we stand on a shelving lake shore during a gale that is blowing landward, and watch the waves breaking on the beach, it will be noticed that they apparently become accelerated on entering shallow water, and, as their crests break into foam, they rush up the beach or shore-terrace, carrying stones and pebbles with them. As each wave retires we may hear the sharp rattle of this material, even above the roar of the waters, as it rolls and slides down the beach, only to be caught up by the next inrush, and the process repeated again and again. Outside the line of foam fringing the shore the water is frequently discolored, perhaps for several rods, by suspended sediment derived from the comminution of shore *débris;* farther lakeward the waves are clear and blue, or perhaps streaked with long lines of foam. The most superficial observations tend to assure us that vast quantities of stones, pebbles, sand, and silt are constantly carried up and down lake beaches and become rounded and smoothed by the process. This conclusion is also sustained by the worn appearance of the *débris* on every shore. A little attention also enables one to ascertain that the beach material greatly assists the waves in cutting away the coast so as to form terraces and sea-cliffs, and is subsequently utilized in building bars and embankments. The modifications of lake shores due to chemical action need not receive attention at this time.

The principal features entering into shore topography are terraces, sea-cliffs, bars, embankments, and deltas. These, as will be shown below, result from the action of waves and currents on the shores that confine them, and differ so widely from the topographic forms produced by sub-aerial erosion and other geological agencies that the nature of their origin may be determined at a glance.

TERRACES.

The most characteristic forms resulting directly from wave action are sloping terraces bounded by a steep scarp, termed a sea-cliff, on the landward margin, and a second scarp, less abrupt, on the lakeward border. These forms are illustrated in the following diagram, which represents the profile of a lake shore so carved by waves as to form a cut-terrace and sea-cliff. The line *ab* represents the original slope of the shore before its modification by waves; *ac* the profile of the sloping terrace; and *cb* the sea-cliff.

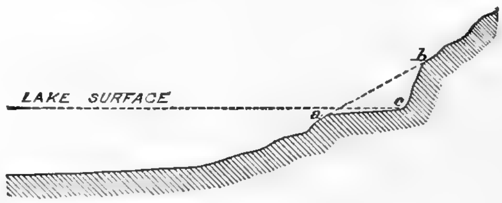


FIG. 8.—Ideal profile of a cut-terrace.

In the desiccated lake basins of Utah and Nevada terraces of this nature frequently occur that are hundreds of feet in breadth and overshadowed by cliffs which at times are a thousand feet high.

The material derived from the formation of a cut-terrace at first encumbers the shelf formed, but is soon removed by the waves and currents and its place supplied by fresh *débris*. The finest of the waste from the land is carried lakeward by the undertow and finally deposited as lacustral beds;

portions less finely comminuted fall on the outer slopes of the terrace and serve to broaden it. The coarsest of all the shore débris usually remains on the terrace and is swept along by the currents until it finds a resting-place in some embankment or wave-built bar. The portion falling on the outer margin of the terrace is frequently consolidated by the precipitation of calcium carbonate in its interstices, thus forming a conglomerate, which adds to the breadth of the structure. In this manner a terrace may become in part a work of destruction and in part a work of construction, as indicated in the following diagram, which represents a cut-terrace, as in the last figure, with the addition of an accumulation of *débris* on its outer slope.

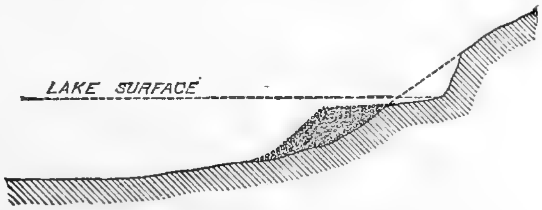


FIG. 9.—Ideal profile of a cut-and-built terrace.

Observations have shown that this is the most characteristic form of lake terrace, and illustrates the fact that the action of waves and currents in modifying shores may be divided into erosion and deposition, or the processes of destruction and construction.

SEA-CLIFFS.

The steep scarps rising above terraces are termed sea-cliffs, whether formed on lake or ocean shores. They occur especially where the borders of a lake are abrupt; but when the bluffs approach the perpendicular and form cliffs with deeply submerged bases, the action of the waves in carving terraces is reduced to a minimum, for the reason that the shore *débris* falls into deep water beyond the reach of the waves and can no longer be used as a tool in cutting away the land. On the other hand, sea-cliffs are seldom formed when the slope of the beach is very gentle. In such localities the waves lose their force before reaching the land, and deposition rather than erosion takes place. Sea-cliffs are most pronounced in rocks of heterogeneous composition, which are easily eroded, but yet sufficiently durable to stand in perpendicular escarpments.

BARS.

In the illustrations given above the effects of waves that result from winds blowing directly on-shore are alone considered. When the wind blows obliquely to the beach we have another modification of wave action. Currents are established in each instance by the friction of the wind on the water, but in the first they are at right angles to the beach and return lakewards as an undertow; in the second case, however, *i. e.*, when the wind blows obliquely to the land, the currents formed move more or less nearly parallel with the shore, as may be illustrated along any lake margin by placing floats in the water or by watching the movements of the shore-drift. It will require but little attention to assure one that during a gale strong currents are thus established along lake margins, which in some respects are similar to the flow of rivers. They carry with them a band of shore-drift, consisting of sand, gravel, bowlders, etc., the width of which depends mainly on the slope of the shore and the character of the material moved. As in the flow of streams, the transported material is carried partly in suspension and partly by rolling along the bottom. The upward wave movements tend to lift the stones and the onward movement to carry them forward. When the force of the current is checked the coarser *débris* is first deposited and the finer transported to greater distances. The movement of such current-borne streams of *débris* along a lake shore necessitates friction, which results in the comminution of the *débris* itself and the abrasion of the base of the sea-cliff against which it impinges. Shore currents are even more powerful than on-shore waves as agents of erosion, but their distinctive property is the power to transport shore-drift. In this manner the *débris* supplied by the sapping of sea-cliffs is removed and formed into new structures at the same time that it causes the detachment of fresh material from the shore, thus supplying fresh tools with the aid of which the waves remodel their boundaries.

Shore currents are usually strongest at some distance from the actual lake margin. In some instances this distance amounts to several rods or perhaps half a mile. As the maximum transportation takes place where the current is most rapid, the result is the formation of a ridge of gravel in the path of the current. Deposits of this nature are molded by the waves into long, narrow, level-topped ridges, with rounded crests, which follow the broader curves but not the minor irregularities of lake shores. They are composed of water-worn *débris* which has been assorted by currents, and when exposed in cross-section they present an irregular anticlinal of deposition. Gravel ridges of this nature have received the name of *barrier-bars*.

The altitude of the horizontal crest of a barrier bar is determined by the storm limit of the waves and currents that built it. Each such structure therefore furnishes a record of the horizon of the water's surface in which it was formed. Should a lake vary in level, it is evident that barrier bars may be constructed at many different altitudes. In the desiccated lake basins of Utah and Nevada bars of this nature frequently occur in concentric and symmetrically curved ridges, which may be followed for miles and sometimes furnish natural highways of a most excellent character.

An ideal plat of an arm of an ancient lake in which barrier bars were formed at three different levels is given in the following figure. Below

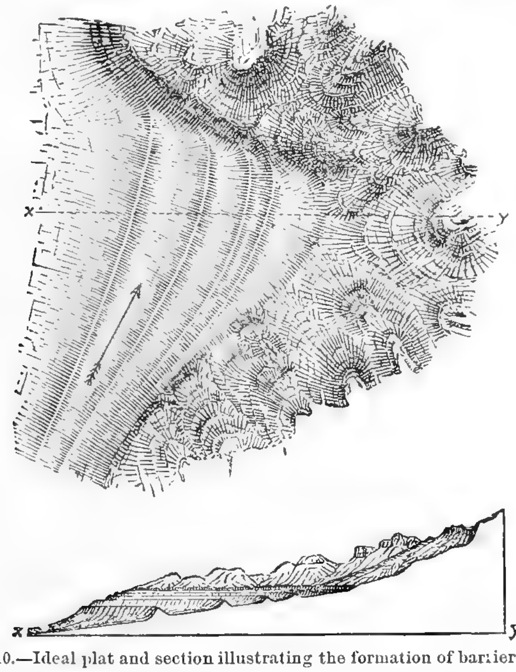


FIG. 10.—Ideal plat and section illustrating the formation of barrier bars.

the sketch is a section through the valley on the line *xy*, in which the level of the surface of the lake at the time the various bars were formed is indicated by dotted lines.

The conditions most favorable for the formation of barrier bars obtain when shelving shores occur adjacent to steep banks where sea-cliffs are forming; in such instances the *débris* derived from the sapping of the sea-cliff is swept along by shore currents, and furnishes the material for works of construction.

Sometimes a current is deflected from the shore and returns to it at another point. In this manner a looped bar inclosing a lagoon is formed. The lakeward portion of such a bar sometimes forms a definite angle; the structure then becomes V-shaped, and is known as V-bar. Bars with this peculiar form are not uncommon, and sometimes obtain great magnitude. It frequently appears as if structures of this nature had been begun in a rising lake, and that the forms of the shore deposits first made were retained and carried upwards as the lake rose, by the addition of fresh material to their surfaces. Barrier bars present other variations, some of which will be noted in the succeeding pages, which may frequently be seen in process of formation on the shores of existing lakes.

Bars of another character are also formed along lake margins, at some distance from the land, which agree in many ways with true barrier bars, but differ in being composed of homogeneous, fine material, usually sand, and in not reaching the lake surface.

The character of structures of this nature may be studied about the shores of Lake Michigan, where they can be traced continuously for hundreds of miles. There are usually two, but occasionally three, distinct sand ridges; the first being about 200 feet from the land, the second 75 or 100 feet beyond the first, and the third, when present, about as far from the second as the second is from the first. Soundings on these ridges show that the first has about 8 feet of water over it, and the second usually about 12; between, the depth is from 10 to 14 feet. From many commanding points, as the summit of Sleeping Bear Bluff, for example, these submerged ridges may be traced distinctly for many miles. They follow all the main curves of the shore, without changing their character or having their continuity broken. They occur in bays as well as about the bases of promontories, and are always composed of clean homogeneous sand, although the adjacent beach may be composed of gravel and boulders. They are not shore ridges submerged by a rise of the lake, for the reason that they are in harmony with existing conditions, and are not being eroded or becoming covered with lacustral sediments.

In bars of this character the fine *débris* arising from the comminution of shore drift appears to be accumulated in ridges along the line where the undertow loses its force; the distance of these lines from the land being determined by the force of the storms that carried the waters shoreward. This is only a suggested explanation, however, as the complete history of these structures has not been determined.

EMBANKMENTS.

The combined action of waves and currents along shores of moderate slope results, as we have seen, in the formation of cut terraces, sea-cliffs, built terraces, and barrier bars. When the shore becomes steep or any abrupt change in its direction takes place, as when the mouth of a bay is reached or a promontory projects from the shore, the current does not follow the sinuosities of the land but continues its course, and, on entering deeper water, loses its power of transportation and deposits its load. Fresh material is carried along in a more or less continuous stream by the shore current and added to that previously deposited, thus forming a subaqueous embankment. This process is continued until the deposit is raised to the level of the barrier bar or terrace, as the case may be, along which the current-borne *débris* is carried. This process continuing, the embankment increases in length but not in height; its crest, like that of a barrier bar, has its height determined by the horizon of the lake surface. It is evident from their mode of formation that embankments are but prolongations of built terraces and barrier bars; in fact one form merges into the other in such a manner that it is not always possible to determine in which list a given structure should be placed.

The formation of embankments will, perhaps, be rendered more intelligible by referring to the accompanying topographic sketch, in which a portion of a gently sloping lake margin adjacent to a bay is represented. The current in sweeping along the shelving shore in the direction indicated by

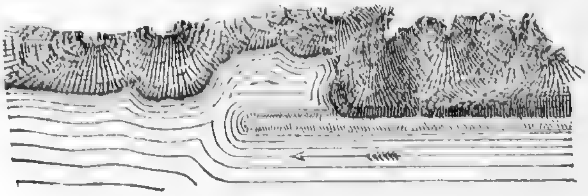


FIG. 11.—Ideal plate illustrating the formation of embankments.

the arrow, will carry with it a narrow band of shore drift; when the entrance to the bay is reached the direction of the current is but little changed; it consequently enters deeper waters where its velocity is checked and its load of *débris* deposited. Fresh material continues to be swept along the shore terrace and is added to that already accumulated until a long, narrow, level-topped embankment is built up. Current-formed structures of this nature have the character of a railroad embankment, and sometimes grow to be miles in length and perhaps several hundred feet high. Should the conditions represented in the sketch continue long enough, it is evident that the bay will eventually be cut off from the lake and form a lagoon; in such an instance it is frequently convenient to speak of the structure as a bay-embankment. In case the bay chances to be at the mouth of a stream, the embankment may become breached by the outflowing waters and repaired again by the currents, thus complicating the stratification of the deposit.

Embankments, like barrier bars, when exposed in cross section present a more or less perfect anticlinal structure due to the mode of their deposition. When buried beneath subsequent deposits, as lacustral beds, for example, and dissected by erosion, they sometimes simulate a true anticlinal formed by the folding of the strata; an instance of this nature is illustrated on Plate XXV.

Simple embankments, like that shown in the above illustration, are usually either straight or but slightly curved, and end at the distal extremity in a semicircular scarp the slope of which depends on the angle of stability in water of the material of which the structure is composed. Beyond the end of the embankment sand-banks are commonly formed by the subsidence of the finer particles carried along by the current and held in suspension for some time after the coarser material has been deposited; as the structure is prolonged this fine *débris* becomes buried beneath the gravel and stones composing the major part of the embankment, and many times becomes folded and crumpled owing to the weight of the superimposed mass.

The action of waves and currents in forming embankments is subject to a multitude of variations dependent on the topography of the shores, on the character of the material moved, on changes in the direction of winds and currents, and on many other conditions. As may be imagined, the resultant forms are equally diverse. Should a lake be also subject to great fluctuations of level, the structure and grouping of the embankments will be still more complicated. When a lake rises, new embankments and built-terraces are formed above older ones; when it falls, previously formed structures are cut away and remodeled into new forms. In the first instance, a line of division or an unconformability will mark the junction of the older and the newer deposits; such an example is shown in cross section at *a* in the following figure, which represents contiguous built-terraces of different date: the altered conditions may also be recorded by changes in the character of the material of which the embankments are formed. In the second instance,

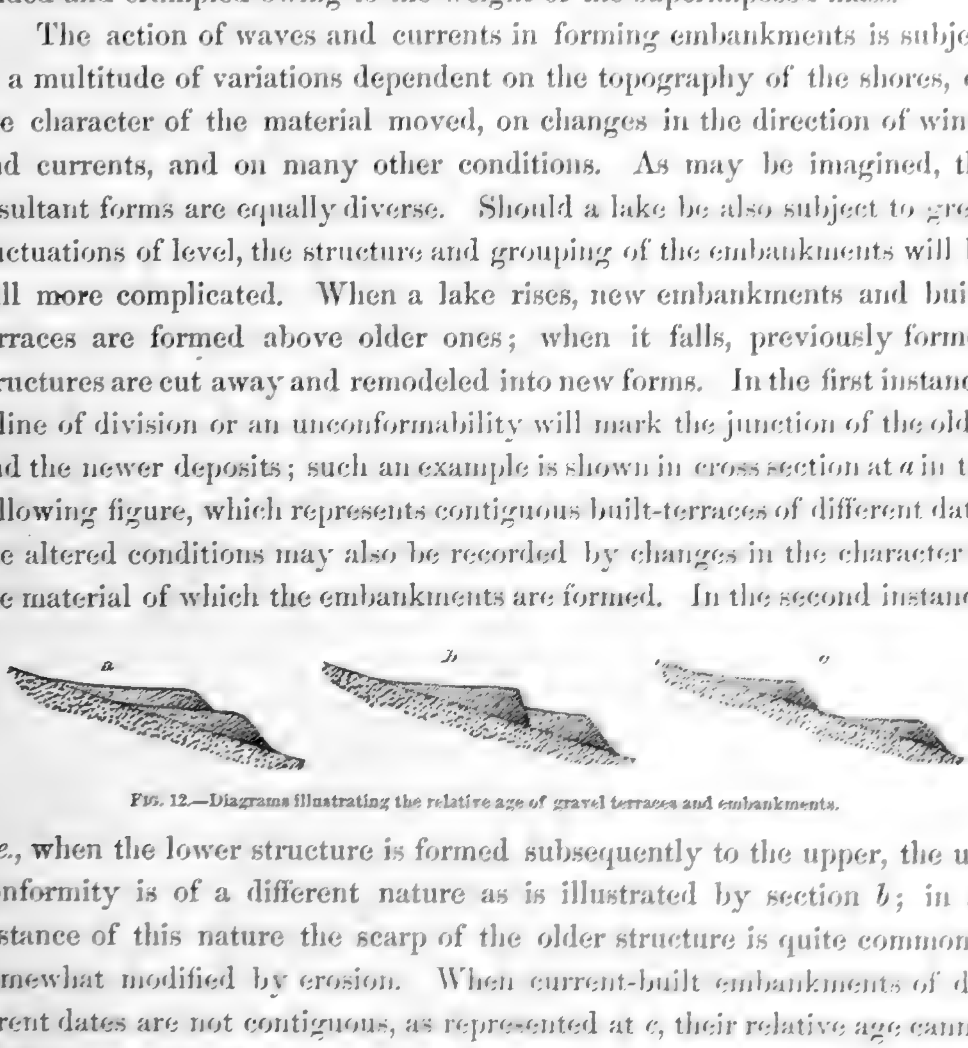


FIG. 12.—Diagrams illustrating the relative age of gravel terraces and embankments.

i. e., when the lower structure is formed subsequently to the upper, the unconformity is of a different nature as is illustrated by section *b*; in an instance of this nature the scarp of the older structure is quite commonly somewhat modified by erosion. When current-built embankments of different dates are not contiguous, as represented at *c*, their relative age cannot be determined in the same manner as in the previous examples.

Sometimes a current in sweeping past a promontory will build embankments tangent to it, which become curved or sickle-shaped at their free extremities, as is illustrated on Plate XIX; again, such embankments may curve abruptly at the end so as to resemble the letter J, and are conveniently designated as J-bars. Other modifications of gravel-built structures will be noticed in the descriptions of the shores of Lake Lahontan which follow.

Water at rest having no power to erode, it is evident that lakes modify their shores but little during calm weather; it is when storms are raging that the potency of waves and currents reaches a maximum, and the greater part of terrace cutting and bar building takes place. The level of the highest water line as recorded by works of construction, is the storm level; in some instances this is several feet above the normal lake surface, for the reason that the water is raised to an abnormal height along a shore against which a gale is blowing. The topography of a coast may cause the storm waves to reach a higher level in some portions than in others, as, for example, where a funnel-shaped bay opens out into a broad lake. In such an instance the water will be driven into the bay during on-shore storms and forced to a greater height than on a more open coast. For these reasons the highest beach-lines of a lake at various points are not always in the same plane; a fact that should be borne in mind while measuring the depth of fossil lakes and in studying the effects of orographic movement.

DELTAS.

The general forms of the fan-shaped accumulations of gravel, sand, and silt deposited about the mouths of streams which enter still water, are too well known to require a detailed description.

When a stream bringing silt and sand in suspension and rolling pebbles and larger rock masses along its bed debouches into still water, its momentum is checked and the greater part of its load is deposited. When the structure thus begun is undisturbed by currents it is built out equally in all directions from the mouth of the stream and thus acquires a semicircular or fan-shaped topographic form. When a high-grade stream enters a valley it commonly deposits a heap of *débris* about the point of discharge, which has received the name of an alluvial cone; a delta may be considered as an alluvial cone that has been formed with its base below water. The part of a delta that is above the reach of the waves has the irregular structure characteristic of alluvial deposits, but the submerged portion acquires a more or less well-defined oblique stratification, which may be called a "delta structure." During the building of a delta the stream meanders over all parts of its surface that are not submerged, and, in irregular succession, discharges at all points of its periphery; in this manner the stream-borne *débris* is carried to all points on the edge of the deposit and allowed to roll down the submerged slope. The strata thus formed are inclined, the amount of their inclination depending upon the angle of stability in water of the material deposited. Observation has shown that the slope of a delta scarp commonly is from 20 to 25 degrees. The fine sand and mud held in suspension is carried farther than the stones and gravel, and is deposited about the base of the delta scarp, decreasing in quantity and becoming finer the farther it is carried from the point of discharge. The stream-borne silt thus tends to build up a secondary cone outside the base of the main delta, which, on its outer margin, merges with the lacustral sediments deposited in the central portion of the lake. In the growth of a delta the scarp of coarse *débris* is gradually advanced on all sides and consequently overplaces the secondary cone at its base; this added weight frequently causes the fine sediment to be crumpled into folds and perhaps broken by small faults.

A delta deposited at the mouth of a high-grade stream will have three well marked divisions, as shown in the following diagram:

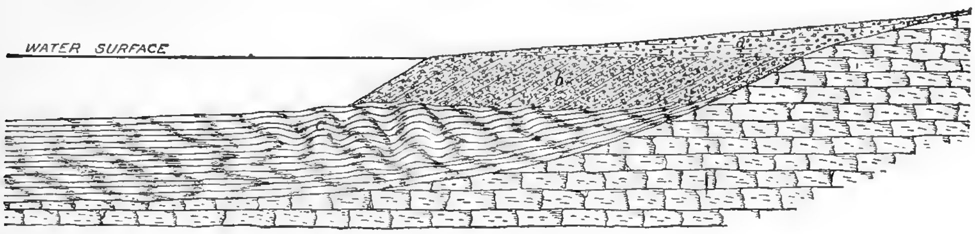


Fig. 13.—Ideal section of a high-grade delta.

At the top is an alluvial cone (*a*) of unassorted material, resting on (*b*) a deposit of obliquely stratified gravel, which in turn is built out over a secondary cone (*ca*) of sand and silt. As a delta grows, *a* becomes thickened, and is built out over *b*, which at the same time is carried forward over *c*. In this manner the characteristic tripartite structure of deltas originates. In low-grade streams, which all long rivers necessarily are, the material transported to their mouths is fine silt, and in their deltas the divisions described above are obscure and indeterminate.

A fluctuation of lake level during the formation of deltas produces even greater modifications in their forms and structure than the same change of conditions would in the nature of current-formed embankments. When the waters of a lake rise and submerge a delta, a new one is at once commenced and carried forward in the same manner as the first, which it may eventually bury so completely that only a deep section would reveal its presence. In some ancient deltas that have been dissected by erosion a stratum of lacustral sediments is found separating two delta deposits. In such an instance the included sheet of fine material is thickest near the outer margin of the structure; the formation of the higher delta and the deposition of the fine sediments took place at the same time, the latter being finally overplaced by the former. The lowering of a lake causes its tributary streams to erode channels through their previously formed deltas and to commence the building of new ones, either in the gap thus formed, or altogether below the former structure. In some instances in the Bonneville and the Mono basins this action was carried forward at a number of successive stages until a series of small deltas were formed, each starting in the channel cut through its predecessor. In the formation of deltas, as in the construction of terraces and embankments, one of the most important conditions requisite for the production of typical examples on a large scale is permanence of lake level. The finest deltas are formed in lakes that maintain a constant horizon for a considerable time and receive the influx of high-grade streams which are abundantly loaded with *débris.*

In the above sketch attention has only been given to the modifications of lake shores and tideless seas; the action of the waves, currents and tides of the ocean receiving no consideration, because they are foreign to the scope of the present essay.

RECAPITULATION.

Cut terraces are shelves carved in the shores of lakes by the action of waves and currents; they are bounded on both their shoreward and lakeward margins by steeper slopes; the former inclines upward and forms a sea-cliff, the latter slopes downward and forms a terrace scarp. Their upper limit is a horizontal line marking the level of the water at the time they were formed; their surfaces slope gently lakeward.

Built terraces are shelves of *débris* formed along shores and are usually adjoined to or combined with cut terraces. As in the previous instance, they are limited on their lakeward borders by terrace-scarps, and may or may not occur at the bases of sea-cliffs. Their shoreward margins are horizontal.

Sea-cliffs are scarps formed by the erosion of cut terraces; their bases are horizontal and coincide with the upper limit of terraces.

Barrier bars are ridges usually composed of water-worn gravel, deposited by currents in shallow water at some distance from land. Their crests are horizontal, and mark the storm limit of the waves and currents that built them. In cross-section they exhibit anticlinals of deposition. Aberrant forms are V-bars, J-bars, looped bars, etc.

Embankments are deposits formed by the transportation of shore drift along terraces and barrier bars, of which they are continuations, to localities where the water deepens. Like built terraces and barrier bars, they are composed of water-worn *débris*, but are frequently of great size; their tops are horizontal, and in cross-section they exhibit anticlinals of deposition.

Deltas are accumulations of stream-borne *débris* deposited about the mouths of streams that debouch into still water; topographically they are semicircular or fan-shaped, and, when seen in radial section, exhibit a tripartite structure.

Since the present chapter was written, a graphic and comprehensive summary of lake shore phenomena has been published by Mr. Gilbert in the Fifth Annual Report of the United States Geological Survey, to which the reader is referred for a more complete discussion of the geological effects of waves and currents than is contained in the present sketch.

SECTION 2.—SHORE PHENOMENA OF LAKE LAHONTAN.

In considering the question of outlet in a previous chapter, it was shown that the shores of Lake Lahontan are unbroken by a channel of overflow. It was therefore an inclosed lake, and, like others of its class, must have been subject to repeated fluctuations of level. That such was its history is also evident from the multitude of terraces still remaining as records of its former changes. The Lahontan water-lines are lacking in strength as compared, for example, with those of Lake Bonneville, the reason being in part, evidently, that the ancient lake margins were precipitous throughout a large portion of their extent, and the water-surface was greatly broken by islands and headlands which must have retarded the force of the waves and currents; but the main reason why the old shore lines are poorly defined is that the lake surface was not held at any definite horizon for a considerable time. The records of wave action still remaining are sufficiently distinct, however, to be easily traced, except on some gently-sloping shores where the waters were shallow, and at the heads of deep narrow bays where all shore phenomena are frequently absent. In the Lahontan basin, as in all fossil lakes, the elements of shore topography to which we turn for the history of the ancient water-body are terraces, sea-cliffs, bars, embankments, deltas, etc.

TERRACES AND SEA-CLIFFS.

The most common of the records inscribed on the borders of the Lahontan basin are cut terraces. These may be traced throughout a very large portion of the basin, but are most distinct on the borders of the larger deserts. About the southern margin of the Carson Desert the ancient lake was limited by mountains of soft, volcanic rock, which yielded easily to both wave action and subaërial erosion. The result is a group of Gothic-like mountains rising from a broad, horizontally scored base. The contrast between rain-sculpture and wave-sculpture is here well marked.

In traveling over the Central Pacific Railroad between Golconda and Wadsworth, one is seldom out of sight of the long horizontal lines drawn by the waves of the ancient lake on the shores that confined them. Records of the same character may be traced continuously about the borders of the Black Rock and Smoke Creek deserts, and are strongly defined along the bases of the mountains overlooking Pyramid and Winnemucca lakes. They are again plainly legible on the steep slopes bordering Walker Lake, as may be observed by the traveler over the Carson and Colorado Railroad.

The highest of these numerous shore lines we have named the "Lahontan Beach," as it records the highest water stage of the former lake. Its elevation above the sea, as shown by lines of level connecting with the Central Pacific Railroad surveys, is 4,343 feet at Mill City, and from 4,418 to 4,427 feet at the lower end of Humboldt Lake.[40] Barometric measurements of the altitude of Pyramid Lake, for which I am indebted to Messrs. J. S. Diller and M. B. Kerr,[41] determine its 1882 level to have been 3,783 feet above the sea. The Lahontan beach in the vicinity of the lake, as measured by several lines of leveling, is 530 feet above its 1882 level, and therefore 4,313 feet above the sea. The altitude of the surface of the former lake, as determined by Clarence King, was 4,388 feet.[42] These results, together with many measurements with the aneroid barometer and by angulation, show that the old shore lines are not now horizontal, owing to the orographic movement that has taken place since their formation, as will be described in Chapter X. What their original horizon may have been is not now susceptible of accurate determination. An average of the various measurements that have been made of the present elevation of the Lahontan beach gives 4,378 feet, which is the nearest approximation we can make to its original altitude.

Besides the Lahontan beach there are three other water-lines of sufficient importance in the history of the lake to deserve special designation. One of these is a strongly defined terrace, 30 feet below the Lahontan beach, and at the upper limit of a calcareous deposit, precipitated from the waters of the ancient lake, which we have named "Lithoid Tufa"; we therefore call this the "Lithoid Terrace." Its elevation is 500 feet above the 1882 level of Pyramid Lake.

Another chemical deposit, known as "Dendritic Tufa," occurs in great quantities in the same basin, and at its upper limit is bounded by a water-line, usually but poorly defined, which we name the "Dendritic Terrace." Its elevation is 320 feet above the datum plain just mentioned.

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[40] See profile in Plate XVIII.

[41] Its elevation was determined by barometric readings at Reno and at the lake surface in June, 1884, and gave a difference of level of 715.5 feet. The elevation of Reno, as determined by the Central Pacific Railroad surveys, is 4,497 feet.

[42] U. S. Geological Exploration of the Fortieth Parallel, Vol. I, p. 507.

Between the dendritic terrace and the surface of Pyramid Lake there is a broad platform, which is the strongest and best defined of all the Lahontan water-lines. It marks the upper limit of a third variety of tufa, known as "Thinolite"; we call it, therefore, the "Thinolite Terrace." Its elevation is about 110 feet above the level of Pyramid Lake in 1882. This terrace has been found to extend entirely around the valleys occupied by Pyramid and Winnemucca lakes, and may also be followed, though with less certainty, along the borders of Black Rock, Smoke Creek, and Carson deserts.

The terraces we have named, together with the present level of Pyramid Lake, furnish four definite horizons that will be found convenient reference plains in tracing the Quaternary history of the basin. It is only at exceptional localities, however, that these terraces can be followed for any considerable distance, and at only a few points could a sequence like the one shown below be obtained from actual measurements. Our diagram is a generalized profile of the Lahontan shores.

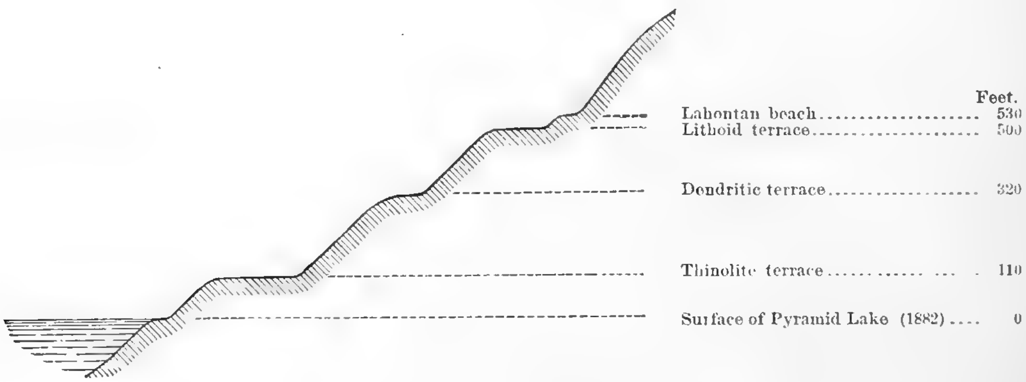


FIG. 14.—Generalized profile of Lahontan shores.

The relative age of the various water-lines shown in the diagram will be discussed in connection when the chemical history of the lake is considered.

The highest terrace of all, the Lahontan, is an inconspicuous feature in itself, but it is important as forming the boundary between subaërial and subaqueous sculpture on the sides of the valleys. It usually appears as a terrace of construction a few feet wide, resting on the broad lithoid terrace 30 feet below. Where the shore records are unusually well displayed, as along the western margin of Pyramid Lake and on the south side of the Carson Desert, the lithoid terrace sometimes has a width of 200 or 300 feet. Resting on it we sometimes find two built terraces of gravel and rolled stones, the water-line of one being the highest of all the shore records; the second is intermediate between the Lahontan beach and the lithoid terrace. This arrangement is illustrated in the accompanying diagram, which exhibits a generalized profile of the shore:

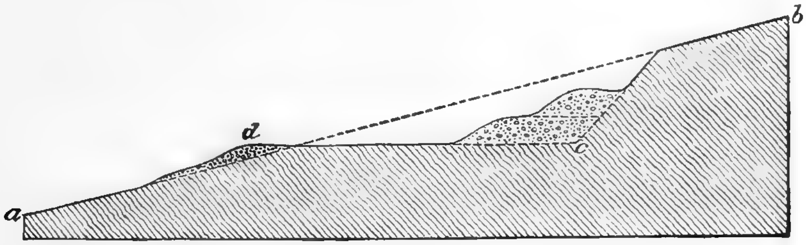


FIG. 15.—Profile of Lithoid Terrace and Lahontan beach.

The line *ab* represents the original slope of the mountain side before it was modified by the waves of the lake. The lithoid terrace *cd* was first formed, the outer edge being built of detritus. The magnitude and persistence of this terrace indicate that the water stood for a long time at a nearly constant level, allowing the waves to carve out a broad shelf from the solid rock. As we shall see further on, the terrace became coated with calcareous tufa, and its gravel was cemented into a conglomerate. At some later period in the history of the lake the water rose and built the two small embankments, or terraces, that rest upon it, but it remained at these horizons only a comparatively short time.

Besides the more definite and strongly marked terraces to which we have given names, there are a large number of less deeply engraved lines on nearly every portion of the former shore. Each of these scorings, as we well know, is the record of a pause in the fluctuations of the water surface; collectively they indicate numerous changes in the lake level. The obscurity and want of strength in many of the terraces is no doubt due in a great measure to the fact that the slopes on which they are traced have been brought within the reach of wave action many times. In this way the records first made have been erased or obscured by subsequent additions.

One of the best localities in the basin for the observation of ancient lake-margins is at Terrace Point, near the northern end of Pyramid Lake.[43] The water-lines at this locality are drawn at nearly equal intervals, and are approximately of the same strength. Even at a distance of several miles they continue to form a conspicuous and striking feature in the scenery of the region. These terraces are the result of both the destructive and constructive action of waves and currents, and are largely composed of basaltic *débris* mingled with worn and rounded fragments of the different varieties of tufa that sheath the interior of the basin. The presence of tufa in the terraces renders it evident that they were formed subsequent to the deposition of the main tufa deposits, and, therefore, at least in part, belong to a very recent chapter in the history of Lake Lahontan. These facts will receive further consideration in the discussion of the chemistry of the tufas.

The topography of terraced shores is well illustrated on Anaho Island, Pyramid Lake, a map of which forms Plate X. The broad bench formed by the lithoid terrace extends completely about the island and forms the base for the tufa-coated crags that are apparently piled in huge pyramids upon it. At an elevation of 320 feet above the lake surface the poorly defined dendritic terrace may be seen, and nearly at the top of the island is a faint line marking the position of the Lahontan beach. At the time when the ancient lake reached its greatest extension, Anaho Island stood but 15 or 20 feet above its surface, and during severe storms must have been completely buried by the dash of the waves. The modifications of topography produced by terraces may also be seen on the Marble Buttes at the southern end of Pyramid Lake, which at one time formed a group of small islands in Lake Lahontan; and, again, about the shores of Humboldt Lake, a portion of which are shown in Plate XVIII.

Although the terraces in the Lahontan basin are sufficiently distinct to enable one to trace the outline of the ancient lake with accuracy, yet they are by no means so well defined as the similar records made by the waters of Lake Bonneville. In the former instance we have the result of the action

[43] See Plate IX.

of the waves and currents in an inclosed lake, the surface of which must have fluctuated with the seasons, and become of broad extent during long periods of more than usual humidity, only to contract again and perhaps be divided into separate water bodies with the return of arid conditions. Hence the comparative indefiniteness of its water lines. In the case of the ancient Utah lake the horizons of the most strongly defined terraces were determined by overflow; the water surface was thus maintained at a constant level for long periods, and the shore phenomena at these favored stages became the grandest that have yet been studied.

BARS AND EMBANKMENTS.

The deposits in the Lahontan basin that owe their origin wholly to the constructive action of waves and currents are far more important and instructive than the associated terraces, and are deserving of the most careful attention. Accumulations of gravel in the form of bars and embankments occur at many points along the ancient shores which we are studying, but in many cases these structures are indefinite or complicated, and their bearing on the history of the former lake is difficult to trace. We have therefore selected a few of the more typical examples to serve as illustrations of the various phenomena observed. The maps accompanying the following descriptions were drawn by Mr. Johnson from plane-table surveys made by himself, and are so truthful and graphic that they require but little interpretation.

EMBANKMENTS AT THE WEST END OF HUMBOLDT LAKE.

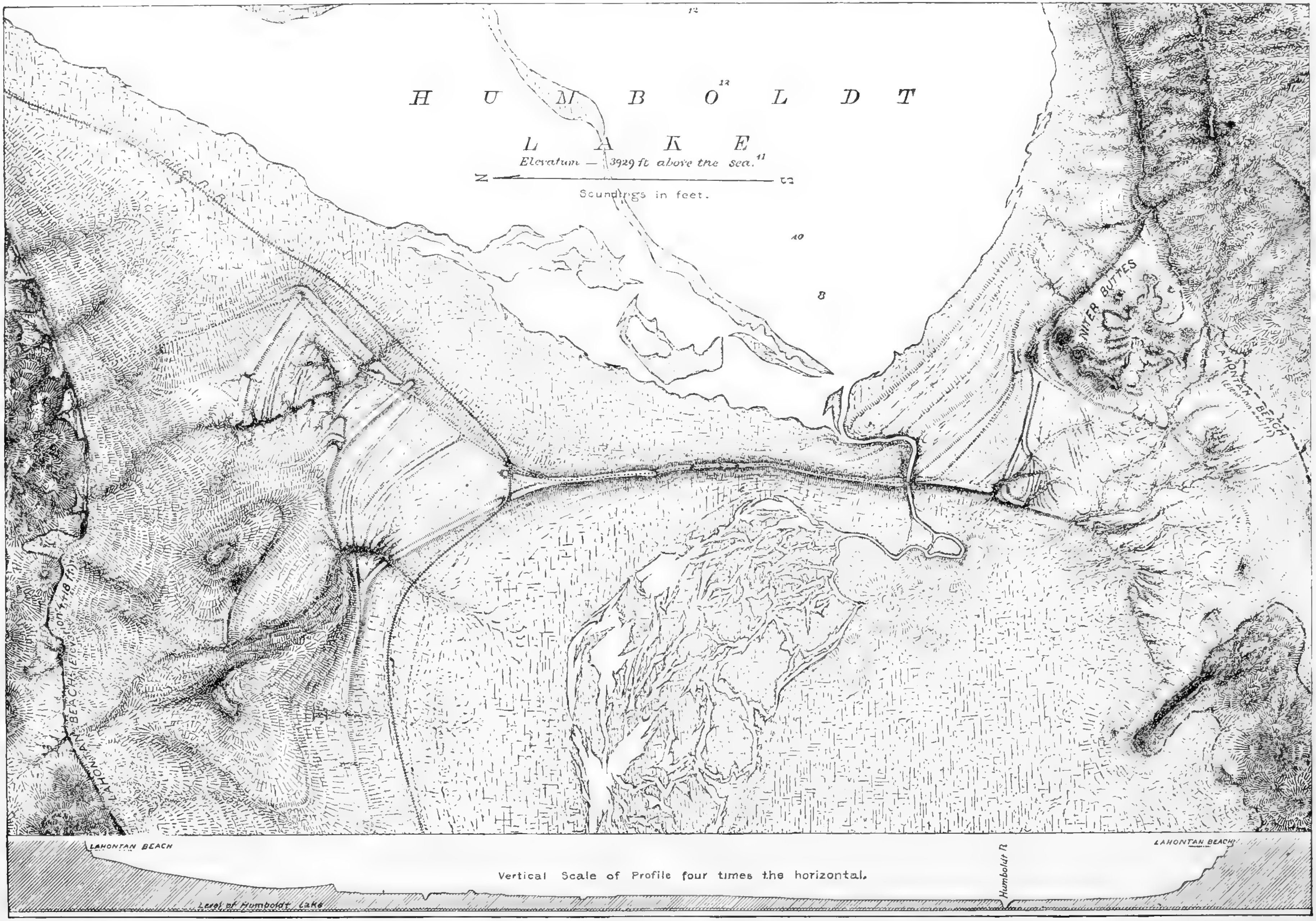
Humboldt Lake owes its existence to the damming of the Humboldt River by extensive gravel embankments which were thrown completely across its channel during the time that Lake Lahontan occupied the valley. The topography about the west end of the lake is represented with accuracy on the accompanying map, Plate XVIII, which embraces the entire breadth of the former lake in this portion of the valley. The highest level of the ancient water surface is represented on the map by a heavy broken line, and appears in the topography of the country as a gravel embankment, or a wave-cut terrace at the base of a sea-cliff that is sometimes a hundred feet or more in height. On the western side of the valley this ancient water line is rendered especially noticeable by the cliffs of deep purple that mark its course.

The narrow valley in which Humboldt Lake is situated was a strait at the time of the higher stages of Lake Lahontan, and connected the Carson body of the former lake with the waters that occupied the northern part of the Humboldt Valley. In its topographical relations it was similar to the constriction in the valley at the southern end of Winnemucca Lake, and is paralleled in the Bonneville basin by the narrow passage, now known as the Narrows of the Jordan, which connected the main body of Lake Bonneville with the Utah Lake body. In all these localities, and in many others similarly situated that have been studied by the writer in the basins of the extinct lakes of Utah and Nevada, the beach phenomena are greatly intensified, and bars and embankments of gravel are unusually well displayed.

At the southern end of Humboldt Lake a single embankment of gravel from 50 to 125 feet in height[44] has been carried completely across the valley in such a manner as to suggest that it is an artificial structure intended to confine the drainage. At either end the main embankment widens as it approaches the shore and forms heavy triangular masses of gravel, on the surface of which appear many smaller bars built of clean, well-worn shingle. These secondary bars form ridges with rounded crests which vary from a few feet up to thirty or forty feet in height, and are nearly level-topped for long distances. These are seldom straight, but curve with beautiful symmetry, each gracefully bending ridge marking the course of a current in the waters of the ancient lake in which it was formed.

The main embankment, *i. e.*, the one crossing the valley, declines gently in height from either end towards the center, and has been cut through at its lowest point by the overflow of Humboldt Lake. The gap carved by the outflowing waters is shown in the profile at the bottom of Plate XVIII. The diagram was constructed from a line of levels run from the Lahontan beach on the Niter Buttes to the highest water line on the west side of the valley; the points selected for the beginning and the end of the line were free

[44]The base of this structure is deeply buried beneath lacustral sediments; the figures given above indicate its elevation above Humboldt Lake.



W. D. Johnson, Topographer.

I. C. Russell, Geologist.

SCALE OF MILES

Line of levels for constructing profile shown by dotted line.

GRAVEL EMBANKMENTS AT WEST END OF HUMBOLDT LAKE NEVADA.

bars with rounded crests, thus securing the highest records of wave action in this portion of the former lake. One result of these measurements is the proof that the beach lines on the sides of the valley, although formed at the highest water stage of the former lake, and therefore originally in the same horizontal plane, no longer have the same elevation. On the east side, the highest water line is now 498 feet above the level of Humboldt Lake, while on the west its elevation is 489 feet. Humboldt Lake, as shown by connecting our line of levels with the profile of the Central Pacific Railroad, is 3,929 feet above the sea.

In studying these wave-built structures more minutely, we find that the one which crosses the valley is composed of worn and rounded pebbles of basalt, rhyolite, granite, and quartzite, together with fragments of black slate and occasional masses of cemented pebbles. The granite and quartzite and the volcanic rock forming some of the pebbles are only found in place in the vicinity on the north side of Humboldt Lake; consequently, the currents which carried them to their present positions must have come from the northeast and followed the western border of the valley until deflected by the topography of the coast. The direction of the currents that built this embankment is also indicated by its form; to the westward it presents a steep escarpment, but the eastern slope is quite gentle and, especially near its extremities, merges gradually with the alluvial slopes in the sides of the valley. The more gentle slope indicates the general direction from which the current-borne *débris* was derived. In the following section a profile of the bar is given, constructed with the same vertical and horizontal scale, from a line of levels run at right angles to the trend of the structure at a point about two miles west of the gap cut by the overflow of Humboldt Lake.

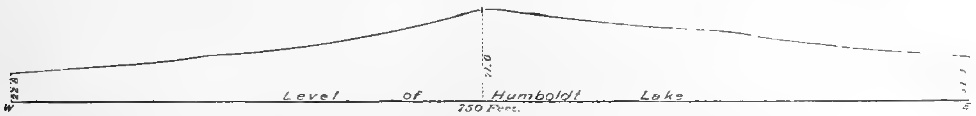


FIG. 16.—Profile of gravel embankment at west end of Humboldt Lake.

The topography of the embankment, therefore, as well as the material of which it is composed, indicates that it was built very largely by currents from the north. It is highest at the northern end, near where the railroad crosses it, but maintains a nearly horizontal crest for at least a third of the way to the point where the river has cut through; it then falls off with an abrupt descent to a level six or eight feet lower, the crest of the structure at the same time becoming broadened and curved slightly westward. Continuing southward, one descends three more similar scarps of less height before reaching the lowest point in the embankment. Each of these descents is formed by the end of a comparatively thin layer of gravel that was added by the currents to the surface of the structure, and would no doubt have been carried along its whole extent had not a rise in the lake caused the currents to begin the formation of another similar sheet of gravel near the shore and at a higher level. Each of the steps in the crest of the embankment represents a pause in the rise of the waters of the ancient lake. The highest in the series was the last formed. The incompleteness in this instance furnishes the suggestion that similar embankments which seem from their form to be homogeneous may in reality be highly compound. The irregular stratification of the embankment retaining Humboldt Lake is illustrated by the following sketch of the section exposed on the right side of the channel that has been eroded through it The general inclination of the strata on the west side of the embankment is much greater than on

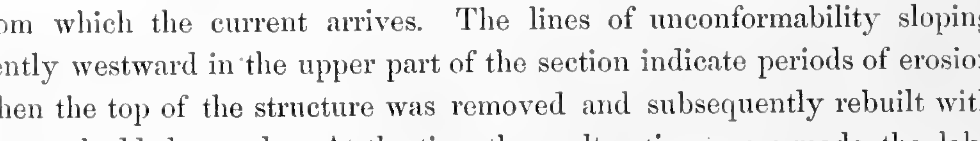


FIG. 17.—Section of gravel embankment at west end of Humboldt Lake.

the east, the reason being that in deposits of this nature the scarps sloping with the current are usually steeper than those inclined in the direction from which the current arrives. The lines of unconformability sloping gently westward in the upper part of the section indicate periods of erosion when the top of the structure was removed and subsequently rebuilt with current-bedded gravels. At the time these alterations were made, the lake surface in each instance must have been nearly on a level with the top of the embankment.

The embankment crossing the valley is older than the branching structures forming the surface at either end, as is shown by the superposition of the latter. This is well exhibited in the left side of the gap cut by the Humboldt, where the homogeneous black gravel composing the end bars rests directly on the more heterogeneous material forming the main embankment. Its greater age is also shown by its being incrusted on its western slope by the three main varieties of Lahontan tufa hereafter to be described, while the end bars are almost entirely free from these deposits.

In a terrace of black gravel on the northern slope of the Niter Buttes, dendritic tufa between heavy beds of gravel indicates that there were periods of bar building both before and after the formation of the tufa. On the north side of the valley, northeast of the north end of the main embankment, an arroyo has cut the gravel deposits so as to reveal an interbedded stratum of white marl; this again marks a division between two periods during which embankments were formed. These interruptions in the gravel deposits are noted now as a part of the facts observed in the region we are describing, but their connection with the history of the lake will be described in a future chapter.

The embankments on the south side of the valley, as shown on Plate XVIII, appear, topographically, to be branches of the main structure, but in reality they were formed at a later date by currents sweeping westward along the southern border of the valley. This is shown not only by their being tangent to the projection formed by the Niter Buttes, but is also evident from the nature of the material of which they are composed. The Niter Buttes and Mopung Hills are rhyolite, while the mountains skirting the southern shore of Humboldt Lake are largely composed of black slate. The gravel forming the symmetric embankments at the base of the Niter Buttes is composed almost wholly of water-worn pebbles of black slate, and could only have been derived from cliffs of the same material to the eastward; the gravel of which the bars are composed may, in fact, be traced continuously to the quarries from which it was obtained.

On the steep western slope of the Niter Buttes are a number of terraces, each of which records a pause in the fluctuation of the lake in which they were formed. The most conspicuous of these is a broad shelf of black gravel which girdles the promontory at an elevation of 220 feet above Humboldt Lake. The gravel forming this shelf consists of well-rounded fragments of black slate identical with those composing the bars at a lower level, and derived from the same source. As the rock composing the buttes has a bright reddish tint, the position of this terrace is rendered conspicuous by contrast in color. At the southern side of the buttes this terrace leaves the steep slope and crosses an alluvial cone, changing at the same time from a terrace to a barrier bar with a rounded crest. In cross-section, like nearly all gravel bars, it exhibits an oblique stratification which is most pronounced on the lakeward slope.

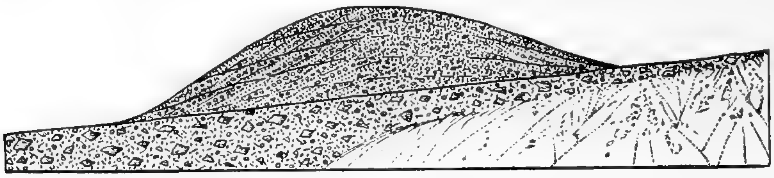


FIG. 18.—Section of bar on the Niter Buttes.

The angular alluvium on which the bar rests is largely composed of brightly-colored rhyolite, derived from the cliffs above, while the bar, like the terrace of which it is a continuation, is almost wholly formed of pebbles of black slate, which indicate by their rounded forms and polished surfaces that they have traveled a long way since leaving their parent ledges in the cliffs on the southern border of Humboldt Lake. On following these gravels still farther southward, we find that they again form a terrace, which soon loses its identity, however, on approaching the Mopung Hills.

The group of bars on the north side of the valley, like the corresponding structures at the base of the Niter Buttes, are level-topped ridges of clean, well-worn gravel, forming graceful curves; but the gravel in this instance was very largely contributed by currents from the west. The spaces inclosed by these ridges are in almost all cases floored with light-colored mud, forming playas, which are converted into shallow lakelets by every storm. The relative age of these bars may be determined in some instances by the superposition of one upon another, and by the fact that some are partially covered with tufa, while others, of later date, are free from that deposit.

The complexity of these embankments, arising from the fact that they were formed at many horizons and at various stages in the former lake, together with the erosion and rebuilding that has taken place, renders their structure complex and their bearing on Lahontan history, *i. e.*, their value as records of Quaternary climate, exceedingly difficult to trace. From the occurrence of Lithoid tufa[45]—the oldest variety found in the basin—on the western slope of the main bar, it is evident that the deposit of gravel at this locality was commenced early in the existence of the old lake, perhaps at the very first rise of its waters; and, as we have seen, enlargement and reconstruction have taken place at many subsequent periods and at many stages in the vertical range of the lake's surface.

The trifling changes that have occurred in the area embraced by the accompanying maps, since the withdrawal of the waters of Lake Lahontan, are indicated by the arroyos or small water-courses cutting the embankments, and by the gap eroded by the overflowing waters of Humboldt Lake; with these exceptions, the structures are as fresh in appearance and as perfect in form as if they had been exposed to subaërial degradation for only a few years.

The contrast in the topography above and below the Lahontan beach, in the region about Humboldt Lake, is so pronounced that it at once attracts the attention of the observer. The mountains above the level of the former lake have the rugged and angular aspect characteristic of the subaërial erosion of arid climates, while below that horizon the topography is remarkable for its sweeping curves and flowing outlines. In the former instance the direction of the lines of erosion is controlled by the flow of rills and rivulets, and approaches the perpendicular; in the latter the predominating lines in the landscape are modeled by the waves and currents of a level water surface, and are therefore horizontal. The characteristics of the topography in one instance are due to subaerial, and in the other to subaqueous, conditions.

Orographic movement has taken place on a grand scale in the region represented on Plate XVIII. This is illustrated by the great fault, with a throw of several thousand feet, which determines the northwestern face of the west Humboldt Range. This fault passes between the Niter Buttes and the main range to the southward, and a curving branch determines the western face of the promontory formed by these buttes. The nearly perpendicular

[45] Thinolite and dendritic tufa also occur in abundance at this locality.

northern face of the Mopung Hills was also formed by the same displacement. The greater part of the orographic disturbance in this region took place previous to the rise of Lake Lahontan, and gave origin to the main features in the structure of the basin now occupied by Humboldt Lake. Movements must have taken place along this line of fracture during the inter-Lahontan time, as is indicated by sloping terraces on the western face of the Niter Buttes. Since the withdrawal of the waters of the former lake the fault at the immediate base of the west Humboldt Range has increased its displacement 50 or 60 feet, and formed fresh scarps in Lahontan gravels (see Plate XLV). There has also been some recent movement in the branching faults about the base of the Niter Buttes, which may be traced for a considerable distance across the alluvial slopes to the westward, and appears again at the base of the Mopung Hills. The displacements, noticed above in explanation of the accompanying map, will receive further attention in Chapter X, which is devoted to post-Quaternary orography.

EMBANKMENTS ON THE SOUTHERN BORDER OF THE CARSON DESERT.

On the south shore of South Carson Lake there stands a bold, rugged promontory of basaltic rock that is girdled with terraces and incrusted with tufa about its base. During the existence of Lake Lahontan, this butte formed a high, rocky island, that was separated from the mainland to the southward by a narrow strait, partially obstructed by small islands, through which the currents must have swept with great force. On the southern or mainland border of the strait, the group of gravel bars represented on Plate XIX were formed.

The changes wrought by waves and currents are marked with unusual distinctness all along the southern margin of the Carson Desert. This was the shore of the largest open water area of the former lake, and was exposed to the full force of storms from the north. The conspicuous sea-cliff on the southern margin of the Carson Desert may be followed all the way to the pass near Allen's Springs, where it is bold and rugged, as represented by the heavy hachuring at the top of the accompanying plate. During the higher stages of the lake the currents swept southward through the pass, carrying with them the *débris* of the sea-

W. D. Johnson, Topographer. 330 FEET ONE HALF MILE I. C. Russell, Geologist.

GRAVEL EMBANKMENTS ON SOUTH BORDER OF THE CARSON DESERT, NEVADA.

cliffs, and depositing it in less exposed situations under the lee of the promontory where the shore receded and formed a bay. The sickle-shaped bars with free extremities, which resulted from this action, indicate by their forms, as well as by the character of the pebbles and stones composing them, the direction followed by the currents to which they owe their origin. The hill represented at the top of the accompanying map is of white rhyolite, with a high, narrow spur of black anamesite projecting from its southern border. The latter rock also composes the hills represented in the southwestern portion of the map. Between these rugged outcrops there is a gentle slope of alluvium, cut by miniature drainage lines. The striking contrast in the color of the rock in place at either end of the embankments enables one to determine at a glance the localities from which the stones composing them were derived.

The broad, lightly shaded bands on the right of the map, having a southeast bearing, are low gravel bars that form the crest of the divide in the pass, or ancient strait, and are now separated by a smooth playa. The drainage north of these bars is into South Carson Lake, while the rill-lines south of them combine to form a water-course that leads eastward past Allen's Springs into the desert valley which opens southward. The curved bars, shown in the central portion of the map, are thus confined in vertical range between the highest water-line of the former lake, *i. e.*, the Lahontan beach, and the highest part of the pass in which they occur. This interval measures 114 feet, or, in other words, the water was 114 feet deep in the shallowest part of the strait at the time the highest embankment was formed.

The highest of this series of gravel structures are shown at A and B on the map. A is a short, curved bar, 3 or 4 feet higher than the long, sickle-shaped embankment on which it rests, and is composed of well-worn stones and gravel of anamesite and rhyolite. That this bar was built subsequent to the much longer embankment beneath is proven by the stratification to be observed at its terminus. Its outer or lakeward slope is regular, with a curved contour that is the result of deposition. Had the lower embankment been built last, the outer slope of the higher structure would have been cut away by shore erosion, so as to form a sea-cliff. The embankment at B is at the same horizon as the smaller one at A. It leaves the shore and returns to it, thus forming a loop inclosing a cup-shaped depression 5 or 6 feet deep, now smoothly floored with playa mud. The long, curved bar C has a smooth, evenly rounded top and a nearly horizontal crest-line, which decreases slightly in height, however, as we approach its southern end, where the curvature is more abrupt. Like all the embankments in the series, this is composed largely of rhyolite, with some anamesite, all rounded and well worn, but coarsest near its northern end. At its southern end it becomes broader, as well as more sharply curved, and shows three or four minor divisions, thus indicating that it is a compound structure throughout. The area to the westward of this embankment, once a lagoon, is now a playa, floored with smooth, horizontal, light-colored mud, that is unclothed with vegetation of any kind. That the embankment C is of a later date than the platform on which it rests is shown by the same kind of evidence that proves it to be of older date than the bars superimposed upon it. This is an interesting conclusion, as the bar below C is incrusted and cemented with lithoid tufa, thus showing that the higher bars were constructed after the formation of the calcareous deposit. The bar C is a portion of the water-line designated as the lithoid terrace on page 101. The highest exposure of tufa is here about 25 feet below the Lahontan beach. A corresponding relation of the lithoid terrace to the highest beach line has been observed at a number of other localities in the Lahontan basin, and will again claim attention when the oscillations of the lake are considered. The outer margin of the platform on which the bar C rests has been cut away by waves and currents so as to expose a steep sea-cliff of cemented gravel, and furnishes the only example in the group of a gravel structure that has suffered erosion by the waters of the lake in which it was formed. Below this horizon are other curved and sickle-shaped embankments, the relative age of which is indicated by the manner in which they overplace each other. The topography of these structures, and the playas they contain, are faithfully represented on the accompanying map.

The bars described above, with the exception mentioned, are unaffected by erosion, and are as smooth and regular as if their elegantly curved ridges were formed but yesterday. They afford beautiful examples of the symmetry of water-built structures.

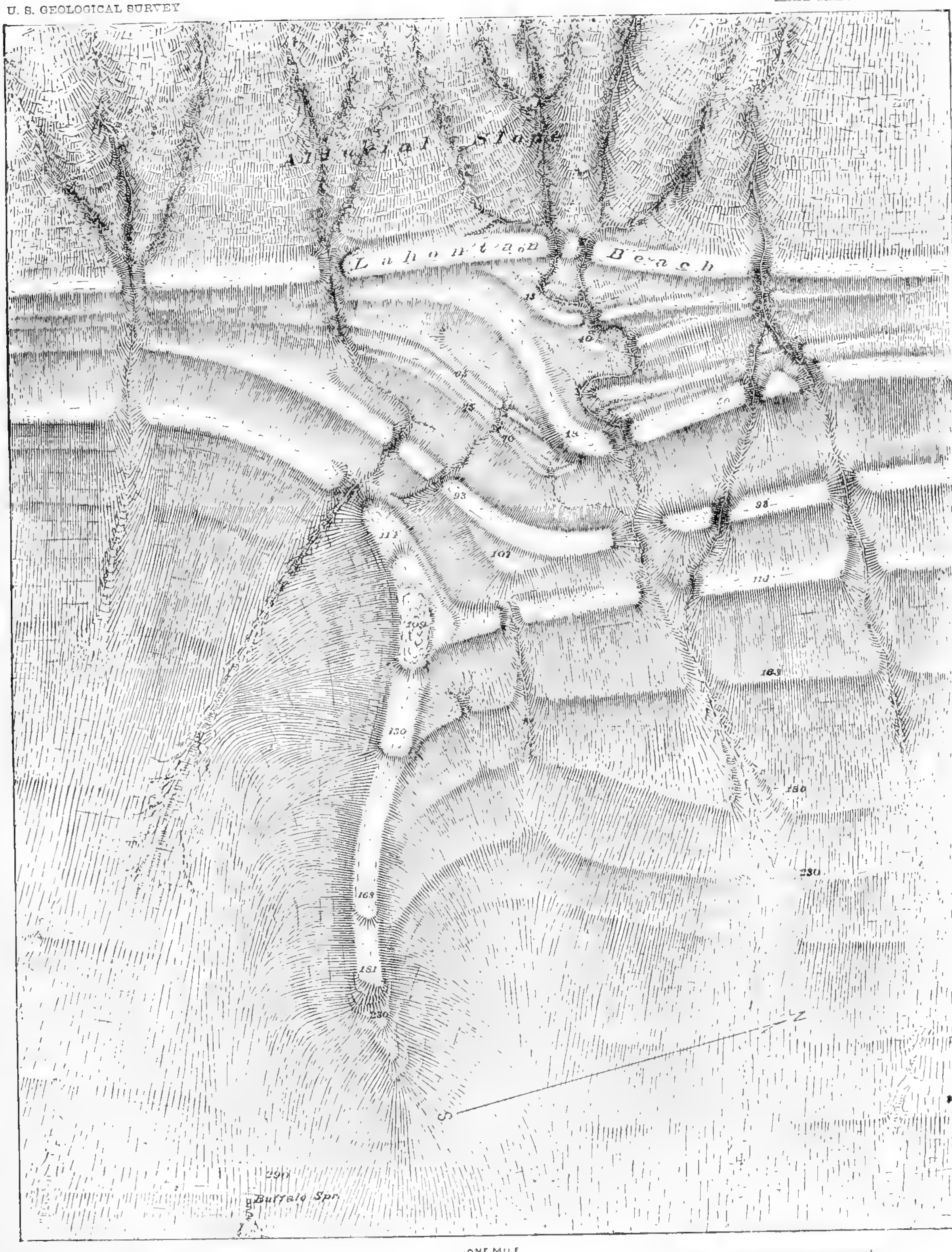
The sea-cliff marking the horizon of the highest water-line is a conspicuous feature on the more exposed shores in the area embraced by the accompanying map, but cannot be distinguished on the alluvial slopes of the bays, where the water was shallow and sheltered from waves and currents. The material cut away to form the sea-cliffs shown in the lower part of Plate XIX was carried southward and built into a series of looped and V-shaped bars, inclosing deep cups, at another angle of the shore, a few hundred yards away.

EMBANKMENTS AT BUFFALO SPRINGS, NEVADA.

Passing north from Carson Desert, one crosses a low, narrow divide, once a strait in Lake Lahontan, and enters a valley having a broad playa in its central portion and surrounded on all sides by alluvial slopes, above which rise angular mountain crests. Around the borders of the valley, at an elevation of about 300 feet above the playa, the Lahontan beach can be traced with distinctness. The lowest point on the pass at the north end of the valley is higher than the Lahontan beach, and was never crossed by the waters of the old lake. The valley was therefore a typical *cul-de-sac* at the time it was flooded by Lake Lahontan. Owing to the abundance of loose material furnished by the alluvial slopes, the shore phenomena in the valley consist almost entirely of works of construction. The most common of the structures due to shore action are rounded beaches of gravel, looped bars, and peculiar embankments, not designated by a special name, that extend out nearly at right angles to the general trend of the ancient shore and form conspicuous features in the topography of the basin. A locality near Buffalo Springs, at which these various features are well displayed, is represented on Plate XX. On the map the crests of the bars are light and the slope of their sides represented by hachures. The figures at various points represent vertical distances in feet below the Lahontan beach, which is taken as zero. They may be considered as soundings made in the ancient lake during its highest stage. Each of the bars has the form of a railroad embankment, with a somewhat rounded crest; they are even more clearly defined when examined in the field than they appear on the map, as the nature of their material and the general absence of vegetation from their surfaces serve to accent the topographic forms.

Buffalo Springs are situated on the western border of the valley, at an elevation approximately 25 feet above the playa and 300 feet below the Lahontan beach. On Plate XX a portion of the border of the valley is represented which extends from Buffalo Springs to an elevation a short distance above the highest water line of the former lake. If the map had been continued a mile or two westward, it would have shown a greater portion of the sloping pediment of alluvium that surrounds the valley; and if extended for an equal distance east, it would have embraced a portion of a much gentler slope which finally merges with the playa in the bottom of the basin. The alluvial slope represented on the map above the highest beach shows a few of the numerous drainage lines which during the infrequent rains conduct the surface waters to the bottom of the valley. The influence of the beaches in deflecting the water-courses is indicated, as is also the manner in which streams shift their channels, and sometimes bifurcate, on alluvial slopes.

The first feature to attract attention on inspecting this group of embankments is the fact that they were built from the bottom up. The oldest in the series, so far as now exposed, is the lowest. The last formed is the Lahontan beach. Another division in reference to age is also possible, as a portion of the bars is coated with tufa, while other portions are free from that deposit. On referring to the plate it will be seen that the lowest well-defined beach occurs at a horizon 114 feet below the highest water line. This is a gravel ridge, forming an irregular V-bar, from the apex of which a somewhat curved embankment of gravel extends into the valley for about half a mile. The projecting bar is coated with lithoid and dendritic tufa, but the structures at a higher level are free from such deposits. The projecting bar has also suffered from erosion much more than those at a higher level, and, besides, is coated with fine sediments. It thus appears that the structures below the level of the lowest well-defined beach were formed before the deposition of the lithoid and dendritic tufas, while the bars and beaches above that horizon were built at a subsequent date. From data afforded at other localities we conclude that the construction of the higher



W. D. Johnson, Topographer.

I. C. Russell, Geologist.

GRAVEL EMBANKMENTS AT BUFFALO SPRINGS, NEVADA.

beaches took place during the last high-water stage of the lake. This determination, however, will appear more clear to the reader as we advance with our studies.

An inspection of the map shows that all the structures there represented were built in a rising lake, and were but little, if at all, modified by the waves and currents as the waters receded. This statement requires qualification however. We may be certain from the perfection of the ridges that the retiring waters did not tend to destroy them, but, on the other hand, they may have received additions. It is probable that gravel structures like those under discussion, when formed in a rising lake, would induce deposition at the same horizons during a recession of the waters. The sections of the structures at Buffalo Springs fail to give information on this point.

The only modifications that have taken place in these deposits in post-Lahontan times are due to the erosion of the rills that cross them and the partial removal of the fine sediment deposited over the older bars.

At the extreme distal end of the embankment that projects into the valley there are considerable accumulations of sand, illustrating the fact that fine material is carried farthest by currents when structures of this character are found, and showing why the bottoms of gravel embankments are frequently composed of sand. On either slope of the embankment the gravel of which it is composed is concealed beneath fine sediments, which must have been deposited when the lake stood over the structure. The looped bars high in the series at one time contained lagoons in which mollusks found a congenial habitat, as is shown by the multitudes of shells, principally of *Pompholyx*, that crowd the marls in the miniature playas behind a number of the embankments.

Three miles south of Buffalo Springs there is another group of embankments similar to that described above. These are represented on the sketch-map forming Plate XXI.[46]

[46] This map is less accurate than the one forming Plate XX, but it indicates the main features of the structures as well as could be desired. The figures on Plate XXI are from aneroid measurements, and indicate approximately the depth of water at the highest water stage of Lake Lahontan. The figures on Plate XX are from measurements with an engineer's level, and may be considered accurate.

All the structures in this group were formed mainly by currents from the south, which swept along the lake shore, carrying shore drift with them, and were deflected from the land upon arriving at the place where deposition had been initiated. This is shown not only by the curvature of the terraces as they approach the bars, but also by the fact that the structures are much the steeper on the north side.

In these beaches and embankments, as in those at Buffalo Springs, two clearly defined divisions may be seen, which are of different age. The long bar projecting into the valley and marked with the numbers 95 to 100—indicating depth of water in feet at the highest stage of the former lake—is of older date than the group of V-shaped structures at a higher level.

The main embankment has a broad, smooth top, which is covered in places with lithoid and dendritic tufa, and is partially coated, especially on the sides, with fine lacustral sediments. Below the point marked with the figures 190, there is a steep scarp nearly a hundred feet high, from the base of which the bar continues on in the same direction as at the higher levels, but is more deeply covered with sediments, and finally becomes so completely inclosed that its presence is only indicated by the rise of the lacustral beds as they arch over the buried structure. The main embankment is thus older than the stages of the lake during which lithoid and dendritic tufa was precipitated, and was formed previous to a high-water period, during which the lacustral beds covering the structure were deposited.

Considering next the group of V-shaped bars at the north of the main structure, we find that the base of this compound group, so far as is revealed by the topography, is older than the highest portion of the main embankment, which was built upon it. The structures that occur from the Lahontan beach down to a horizon 75 feet below that level are of later date than the bar which is prolonged into the valley, as is shown by their freedom from both lacustral sediments and tufa deposits.

The difference in age of the two main divisions of this group thus furnishes evidence similar to that presented at the Buffalo Springs locality. The higher structures in each case are the younger. These two groups are the complement of each other, however, in the fact that the one at Buffalo Springs was built principally by currents from the north, while the second

W. D. Johnson, Topographer. I. C. Russell, Geologist.

GRAVEL EMBANKMENTS THREE MILES SOUTH OF BUFFALO SPRINGS, NEVADA

group, three miles south along the same shore, was constructed almost entirely by currents from the south.

The manner in which a gravel structure once started on the margin of a lake continues to induce deposition in case the waters rise, is well illustrated by the group of bars at the right on Plate XXI, which is literally a pile of V-bars, the lowest in the series being the oldest. The thickness of gravel in this compound structure exceeds a hundred feet, and, as shown by the topography, the material composing it was nearly all brought from the south.

Besides the embankments that have been specially examined, there are many others in the Lahontan basin of equal magnitude and perhaps equally instructive, which illustrate the variety of topographic forms produced by the action of waves and currents.

On the east shore of Walker Lake are two localities where gravel embankments of large size have been built out from the old lake shore and form capes the ends of which are washed by the waves of the present lake. These may be distinguished on Plate XV by the manner in which the railroad curves about them, close to the water's edge. At each of the localities there are a number of V-shaped gravel deposits that have been built one above another from a common base, so as to produce an exceedingly complicated structure.

In Alkali Valley, about three miles west of Sand Spring Pass, is another locality where the gravel accumulated along the shores of the former lake may be studied to advantage.

Other deposits of the same character may be seen on the east side of Humboldt Valley, between Rye Patch and Humboldt House, and again at the south end of Winnemucca Lake. A plat of the gravel structure at the last named locality is given below, which will serve as an illustration of the manner in which an embankment of large size may be thrown across a narrow strait so as to obstruct the drainage when the waters retire.

The deposits at this locality are very similar to the embankment at the west end of Humboldt Lake, represented on Plate XVIII, and find a parallel in the Bonneville basin in the immense bar at Stockton, Utah. In the instance before us, the gravel forming the embankment was brought by shore currents from the north, along the east side of Winnemucca Valley, and deposited, when the current was deflected from the shore, so as to build the structure still remaining. This is a remarkably uniform embankment,

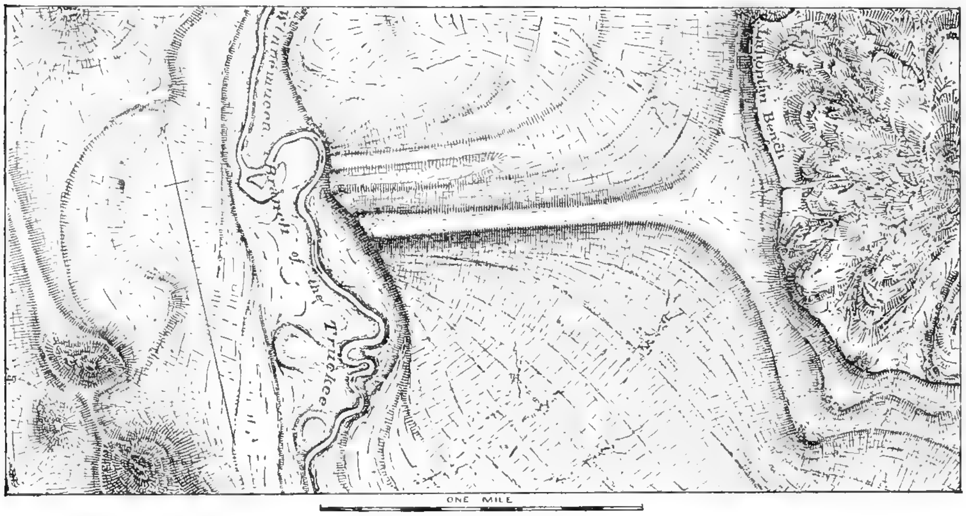
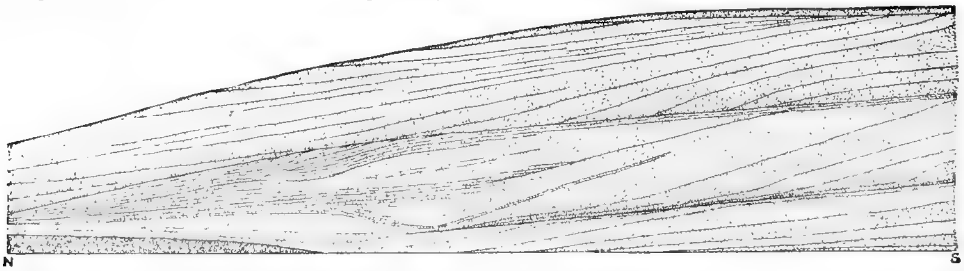


FIG. 19.—Gravel embankment at south end of Winnemucca Lake, Nevada.

about 250 feet high, which has all the features of an artificial structure intended to dam the valley of Winnemucca Lake. Its western end does not reach quite to the west shore of the strait, and since recession of the waters in which it was formed it has been truncated by the erosion of the branch of the Truckee River which flows into Winnemucca Lake. A portion of the section exposed by the removal of the end of the embankment is accurately shown in the following diagram.



Scale of feet—vertical and horizontal the same.

0 50 100 150 200

FIG. 20.—Section of gravel embankment at south end of Winnemucca Lake, Nevada.

On the west side of the gap through which the Carson River leaves Churchill Valley there is a group of curved bars that were built out from a small butte, once an island in Lake Lahontan, by currents flowing out of Churchill Valley. A note-book sketch of these structures is reproduced below, on a scale of about 500 feet to 1 inch, which will serve to indicate the character of the phenomena found at this locality.

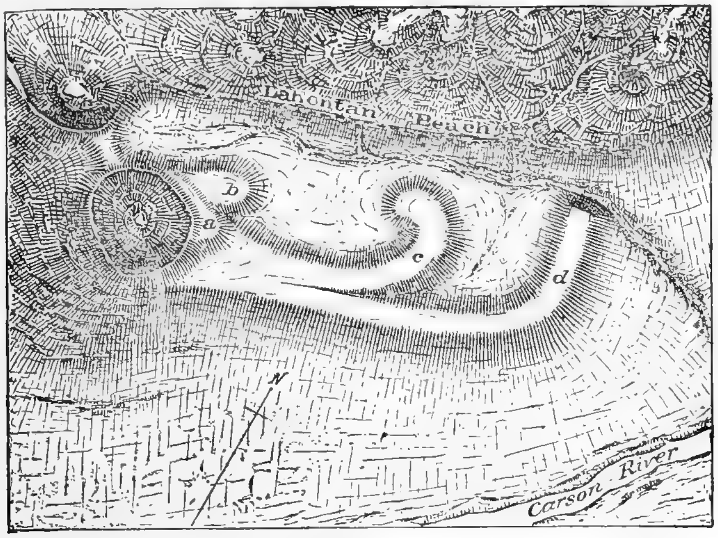


FIG. 21.—Sketch of gravel embankments in Churchill Valley, Nevada.

These bars or embankments are quite similar to those near Allen's Springs (see Plate XIX), and, as is so frequently the case, have been built from the bottom up; the highest in the series is the youngest. In examples of this nature, however, the deposits made as the waters fell may have been added to the surfaces of the older structures. This is indicated in the example shown in the sketch, by the fact that the outer scarp of the higher terrace *a* has been cut away, the material removed being spread out over the embankments *c* and *d*. In the illustration, *a* is about 20 feet below the Lahontan beach, while *b* is 20 feet lower. The surface of *c* is 25 feet lower than *b*, and on the same general level as *d* Both *c* and *d* decline gradually in elevation towards the distal extremity. The longest of the bars has been truncated by the erosion of the waters which sometimes flow down the arroyo shown in the sketch

In the northern part of the Lahontan basin, fine examples of water-built gravel embankments may be seen at the northern end of the Slumbering Hills, and at the corresponding extremity of the Jackson Range; also, at the southern terminus of the Quinn River Mountains, and about Black Rock Point. All these localities were prominent headlands in the ancient lake, and were swept by strong currents which brought gravel and sand from the adjacent shore and deposited it on the salients of the land when the currents were forced into deep water.

A note-book sketch of the embankment at the south end of the Quinn River Mountains is reproduced in the following diagram:

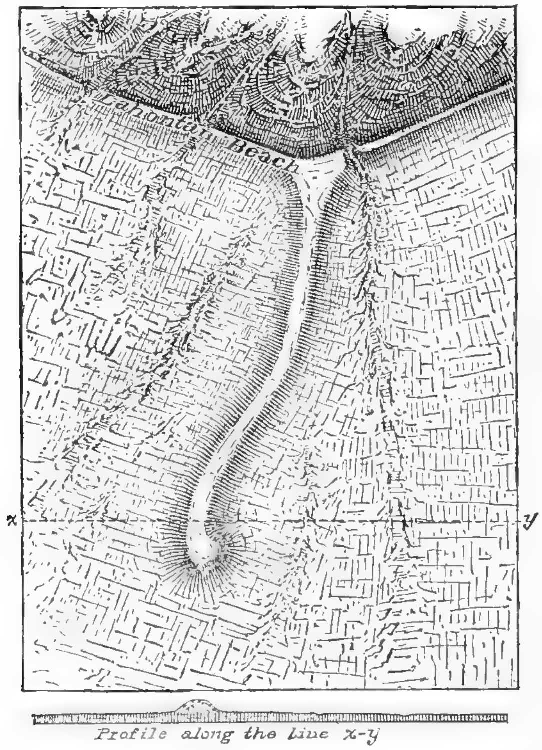


FIG. 22.—Sketch of gravel embankments at south end of Quinn River Mountains, Nevada.

The embankment is about 1,500 feet long, and at the point where the profile was sketched is 100 feet broad and 40 feet high. It projects from a salient where the current from Quinn River Valley left the shore on entering the strait between the Quinn River Mountains and the Slumbering Hills. The valley at this point is about 4 miles broad, and, during the existence of the ancient lake, formed a strait connecting two comparatively large water-bodies. The embankment was built by currents from both the north and the west, and was carried out over horizontal lacustral beds, as represented in the sketch.

The buttes in King's River Valley were islands in Lake Lahontan and became surrounded by terraces, bars, and embankments that were built by the currents sweeping past them.

The topographic forms produced by the deposition of gravel in the paths of currents are extremely varied, and usually present curving contours and smooth, rounded crests, that are in marked contrast to the angular mountain slopes rising above them. Wherever the current-built structures of ancient lakes occur, one is sure to find an illustration of the striking contrast exhibited by the angular reliefs produced by subaërial erosion, and the rounded and flowing outlines resulting from the action of waves and currents. Aside from the bearing that these gravel embankments have on the geological history of the basin, one may always derive aid from them in determining the action of currents in existing lakes. The hydraulic engineer will do well to study the processes employed by nature to accomplish results that are frequently analogous to the works desired by man for improving navigation or providing a haven for shipping.

DELTAS.

The study of the records left by Lake Lahontan has added but little to our knowledge of deltas, for the reason that the lake was too inconstant in level to favor their formation, and also because nearly all the tributary streams entered the lake at the heads of narrow bays and estuaries, which were unfavorable localities for the development of structures of this nature. The Humboldt River entered the Lahontan basin at the head of a long, narrow arm of the old lake, which became deeply filled with *débris*, but is not now exposed in section. Farther southward in the same valley, between Mill City and Oreana, the Lahontan strata are well exposed, and will receive attention under the section devoted to sedimentary deposits. In the southern portion of the section to be seen in the banks of the Humboldt River there are inclined strata that have a striking resemblance to delta structure, but after a careful examination it was concluded that they owe their inclination to their having been deposited by currents on the steep slopes of gravel embankments. That much of the material now filling the Humboldt Valley was brought down by the river, and is in reality of the nature of a delta deposit, there can be little doubt, but it has mostly been rearranged by currents and the topographic form of a delta is wanting. The same is true also of the accumulations at the points where the Truckee and Carson rivers entered the lake; about the ancient mouths of these streams there is a thickening of the river-borne *débris*, but no distinct delta forms are visible. The cañons of Buffalo and Smoke creeks were excavated to their present depth before the existence of the lake, and during the time the basin was flooded each of these channels formed a long narrow inlet which became deeply filled with sediments. When the lake's surface was lowered, the greater part of this material was removed by stream erosion; and so far as the history of their deltas is concerned, there is no more to be said than in the case of the larger rivers.

Nowhere in the Lahontan basin are deltas to be found that are comparable with those formed along the bold eastern shore of Lake Bonneville, or those deposited in the Mono Lake basin by streams that descended the eastern slope of the Sierra Nevada.

SECTION 3.—SEDIMENTS OF LAKE LAHONTAN.

The tributaries of lakes—disregarding organic substances—contain two classes of impurities, (a) mineral matter in suspension, and (b) mineral matter in solution.

Besides holding fine silt in suspension, streams also roll pebbles and stones along their beds. On entering a lake all this material subsides more or less quickly, forming lake-beds, gravel-deposits, etc. In the sedimentation of lakes the coarser and heavier *débris* is invariably dropped near shore, while the finer and lighter substances are floated to a greater distance before subsiding. In this manner coarse shore and fine off-shore deposits originate. The shore deposits of Lake Lahontan have already received

LAHONTAN SEDIMENTS, HUMBOLDT CAÑON, NEAR RYE PATCH NEVADA.

some attention. In the present division the off-shore sediments, or lake-beds proper, together with certain interstratified gravels, will be described. The mineral substances contributed to the lake in solution will be studied in connection with its chemical history.

The sedimentary deposits of Lake Lahontan exhibit three definite divisions, viz.:

Upper lacustral clays.

Medial gravels.

Lower lacustral clays.

Wherever any considerable section of Lahontan sediments is exposed these three divisions appear in unvarying sequence.

The upper and lower members of the series are composed of marly clays, which show by their fineness and the evenness of their lamination that they were deposited in deep still water. The middle member, on the other hand, usually consists of well-rounded gravel and sand, in some instances becoming coarse and including bowlders a foot or more in diameter. This deposit is current-bedded, and exhibits many variations, indicating that it was deposited in shallow water.

It is apparent, therefore, that the evenly stratified beds at the base and summit of the series are the records of a deep lake of broad extent, and mark periods of comparatively abundant precipitation or of greatly decreased evaporation. It is also evident that the medial gravels were deposited when the lake was sufficiently lowered to allow stream and current-borne *débris* to be carried far out over the previously formed lake-beds, recording an interval of low water in the history of the lake. The significance of these deposits in reference to Quaternary climatic changes will appear more clearly in the sequel.

Sections of Lahontan sediments are well exposed in those portions of the cañons of the Humboldt, Truckee, Carson, and Walker rivers that are below the highest water-line of the former lake; and as the sections observed present facts of interest in tracing the Quaternary history of the region, together with many illustrations of geological structure, we shall give somewhat detailed descriptions of the principal exposures.

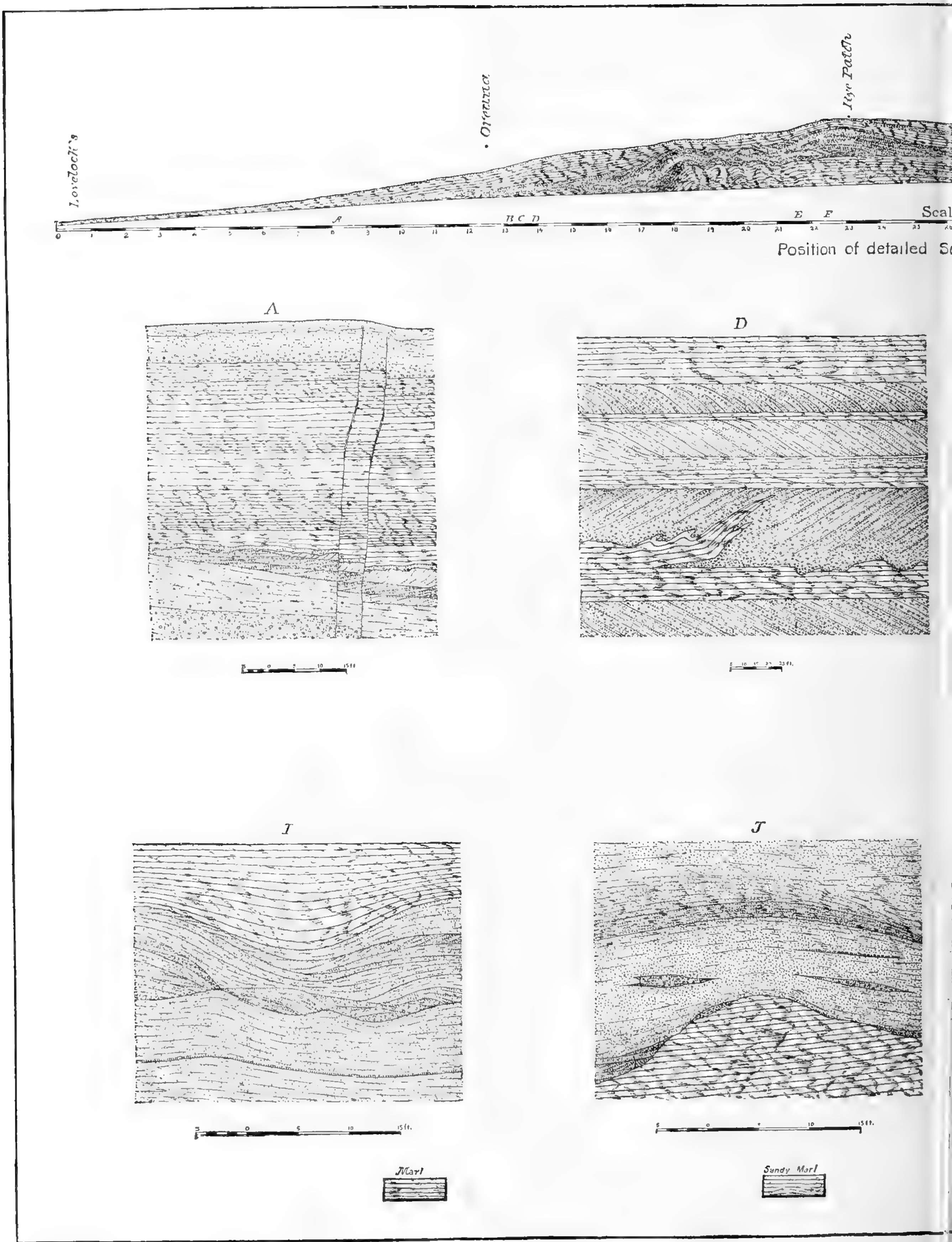
The illustrations of sections accompanying the following pages were drawn by Mr. W J McGee, to whom I am also indebted for a number of the observations here included.

EXPOSURES IN THE CAÑON OF THE HUMBOLDT.

Between Golconda and Humboldt Lake the Humboldt River flows in a channel that it has excavated in Lahontan sediments since the last desiccation of the ancient lake. For a number of miles below Golconda the river is practically a surface stream, with low banks of marly clay belonging to the upper lacustral series. At Mill City its channel commences to deepen, and at Rye Patch the river flows a little more than two hundred feet below the general level of the desert. The general appearance of the gorge excavated by the river through the plain formed of lacustral sediments is shown in the accompanying illustration, Plate XXII, which is a reproduction of a photograph taken on the brink of the cañon, opposite Rye Patch. Throughout this portion of the cañon the tripartite division of the strata exposed in the steep banks is easily distinguished where not obscured by *débris* slopes. Below Rye Patch the banks decrease in altitude, and south of Oreana they are seldom more than 40 or 50 feet high, and only exhibit sections of the upper lacustral clays, with traces here and there of the medial gravels.

A section of the beds exposed in the sides of the Humboldt Cañon between Mill City and Lovelock Station, a distance of over 50 miles, is represented at the top of Plate XXIII. This section was compiled from about 25 detailed sections, which were first drawn at their proper place on the general diagram and then united in the manner that a somewhat extended study of the exposures seemed to dictate.[47] A few local sections, drawn with the same vertical and horizontal scale, are represented in the lower portion of the plate, and illustrate the diversity that prevails throughout the exposures. The most striking feature in the general section is the thickening of the deposits near Rye Patch, where they form an arch that once completely dammed the valley and was subsequently dissected by the river. The hypothesis framed by the writer in explanation of the phenomena ob-

[47] This illustration is perhaps open to the criticism that too much prominence has been given to the apparent plication of the strata.



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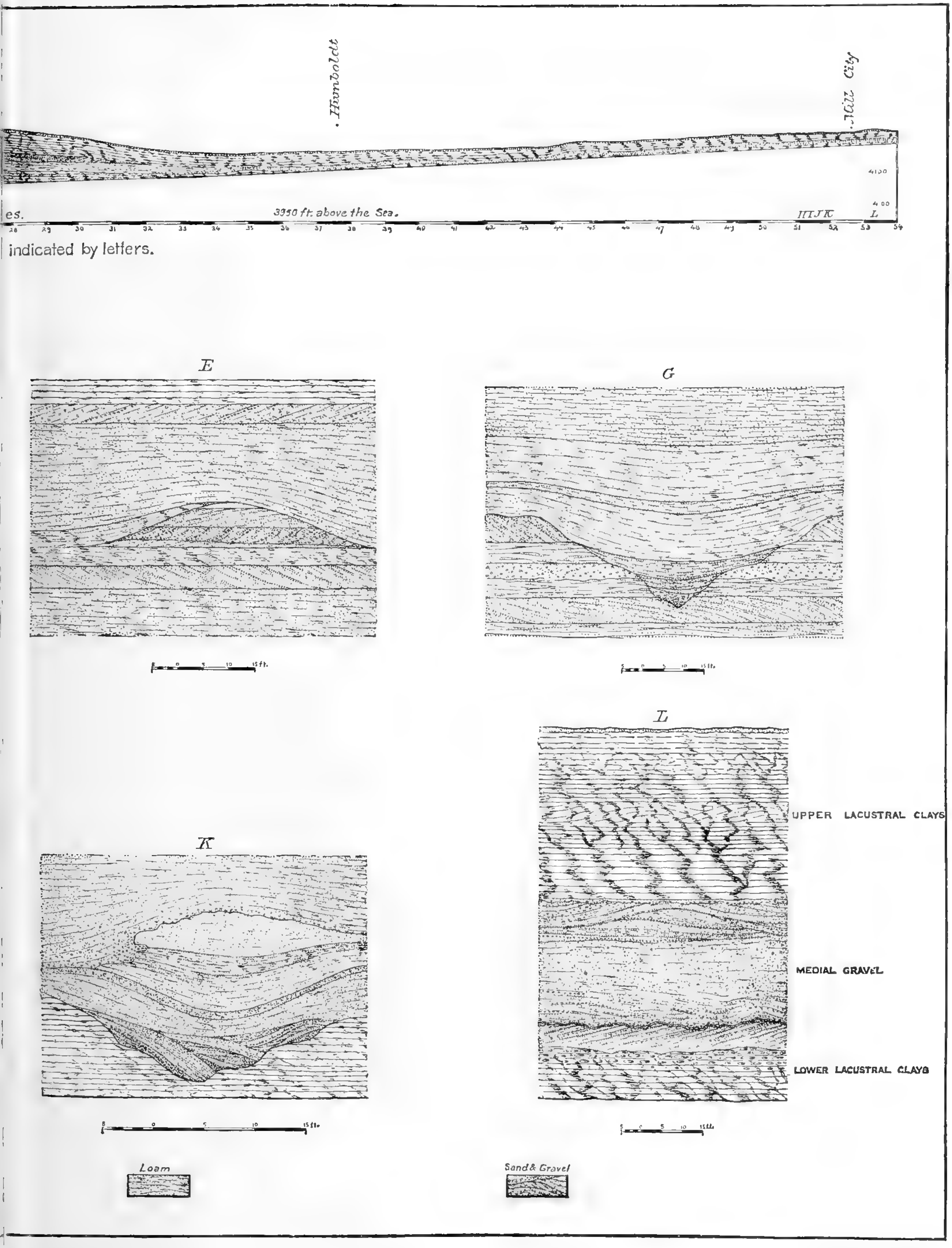
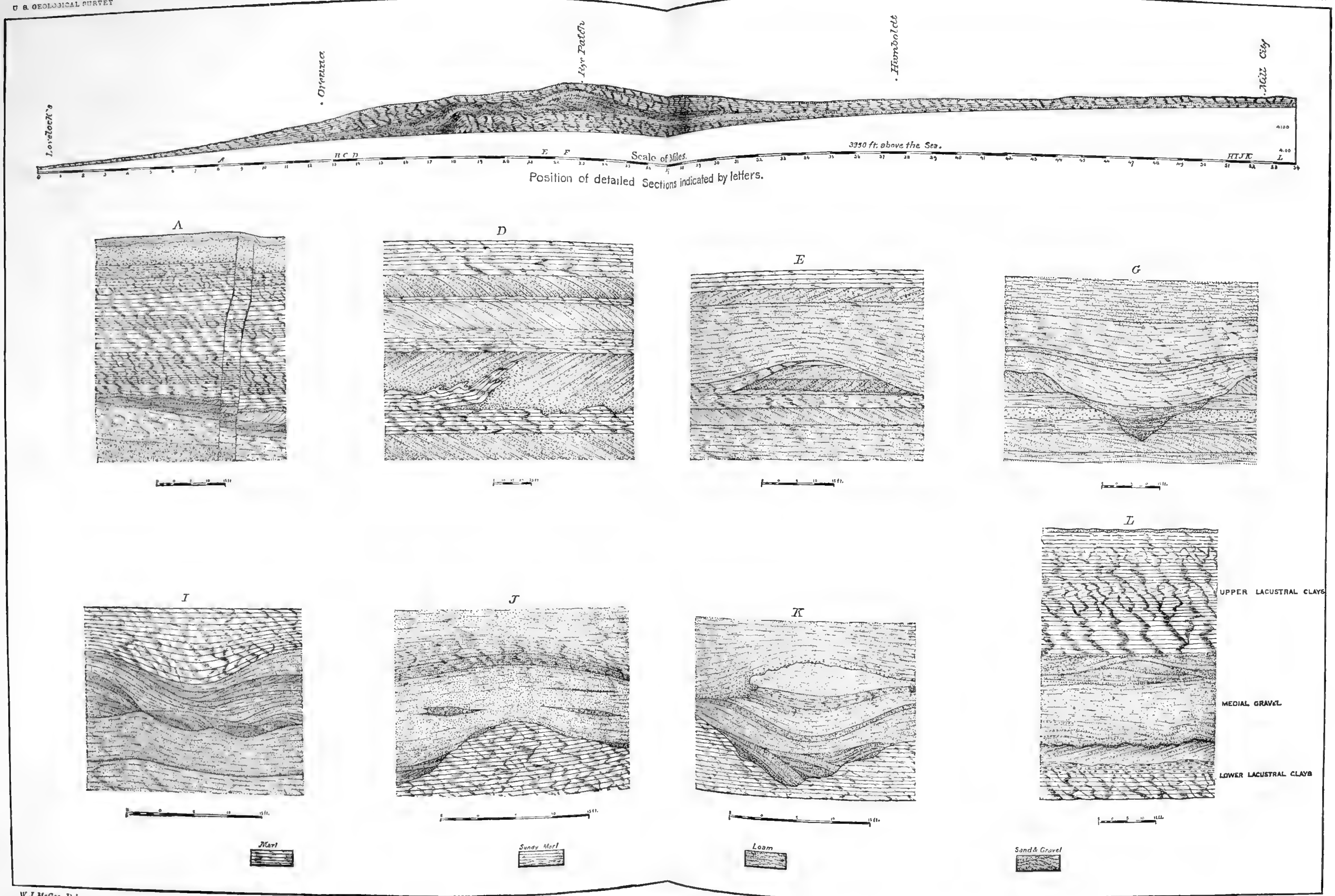
SECTIONS OF LAHONTAN SE



I. C. Russell, Geologist.

N HUMBOLDT CAÑON, NEVADA.



W J McGee, Del.

I. C. Russell, Geologist.

SECTIONS OF LAHONTAN SEDIMENTS IN HUMBOLDT CAÑON, NEVADA

served is that the beds were deposited by currents in the position they still retain during the time that the Humboldt Valley was occupied by the waters of Lake Lahontan. In other words, the inclined strata seen in the cañon walls are sections of current-formed embankments that have been buried beneath the upper lacustral marls. They are arches of deposition, and not plications due to orographic disturbance.

The formation of gravel embankments across narrow straits in such a manner as to completely close them has already been referred to in describing a structure of this nature at the lower end of Humboldt Lake (*ante*, page 108). The study of current-formed gravel deposits in a large number of the desiccated lake-basins of the Far West strongly favors the conclusion that the inclination of the strata exposed in the walls of the Humboldt Cañon is due entirely to their mode of accumulation. Could the gravel embankments familiar to us in many narrow valleys become buried beneath lake sediments and then exposed in cross-section by erosion, they would furnish examples of strata increasing in thickness at the same time that they became inclined and arched, which would in many ways be the counterpart of the phenomena illustrated by the section on Plate XXIII.

The hypothesis that the dip in the sections we are considering was due to plication, in the manner common to many older rocks, suggested itself early in the investigation, but did not find support in the facts observed.

The contacts of the lower and upper clays with the medial or gravel member of the series are nearly always unconformable. In many instances the surface of the lower marls was eroded into hollows and channels previous to the deposition of the gravels, and these are now filled with current-bedded *débris* in the manner illustrated by section K, Plate XXIII. Similar unconformities by erosion are also to be observed at many points where the contact of the medial gravels with the upper marls is exposed, as shown at I, on the same plate. Other illustrations of unconformity in the contact of the medial gravels with the evenly stratified beds above and below them are shown in the remaining detailed sections of Plate XXIII.

A comparison of the upper and lower clays indicates that they are very similar in their nature and were probably accumulated under nearly identical conditions; they are both evenly laminated, fine-grained, drab-colored clays, that are usually marly and saline, and frequently exhibit a well-marked jointed structure. An analysis of a typical example of each, as reported by Dr. T. M. Chatard, shows that they do not differ more widely in composition than might be expected in two samples taken at different points in the same stratum.

Constituents.	Upper clays.	Lower clays.
Loss by ignition (water)	9.78	13.03
Silica (SiO_2)	56.30	50.70
Alumina and ferrous oxide (Al_2O_3, and Fe_2O_3)	21.60	19.01
Lime (CaO)	5.45	10.26
Magnesia (MgO)	2.64	3.19
Potassa (K_2O)	2.17	2.16
Soda (Na_2O)	2.60	1.91
Total	100.54	100.26

The upper clays differ from the lower, however, in the fact that at some localities they include interstratified beds of homogeneous, white, pumiceous dust, forming even layers from a fraction of an inch to several feet in thickness; and also a deposit of tufa in peculiar mushroom-shaped forms. The layer of fine marly clays on which the tufa stratum rests frequently teems with *Cypris* cases, and sometimes contains the shells of *Pompholyx effusa* in immense numbers; above the tufa the shells of *Anodonta nuttalliana* are frequently abundant. In the lower clays the relics of molluscan life are comparatively rare; and, so far as has been observed, they contain no deposits of volcanic dust; this, however, may be considered as an accidental circumstance dependent on the periods of eruption of distant volcanoes. The layer of tufa in the upper clays is a widely spread deposit indicating chemical conditions that so far as is known—the entire thickness of the lower clays not being exposed—did not occur previous to the formation of the medial gravels; although lenticular masses and thin sheets of tufa of a somewhat similar nature are not uncommon in the lower portion of the Lahontan section.

The medial gravels are in many places plainly divisible into two portions; the lower, composed of clean, well-worn, current-bedded sand and gravel, has all the structural characteristics of stream-bed and shore formations; the upper is of a homogeneous, earthy character and has a striking resemblance to recent flood-plain deposits. The remarkable similarity of the middle member of the Lahontan section, as exposed in certain localities, to the bipartite—stream-bed and flood-plain—deposit formed by meandering streams, leads us to refer its origin with considerable confidence to similar causes. In some instances the earthy or flood-plain portion of the medial gravels is overlaid by current-bedded *débris*, which may reasonably be considered as the sheet of shore material spread out by the waves and currents during the rise of the lake that followed the formation of the middle member of the series.

The accuracy with which the accompanying detailed sections have been drawn, leaves little room for description; but in order to present still more definitely the facts on which they were based, descriptions of a few of the more instructive exposures are inserted. The lettering of the following sections indicates their position on Plate XXIII:[48]

SECTION A.—*West bank of Humboldt River, 2 miles south of Oreana.*

	Feet.	
1. Æolian sand and dust, forming surface of the desert	1	
2. Sand and gravel, massive	3	Uppe lacustral clays
3. Loam, sandy, laminated	2	
4. Marly clay, laminated and jointed	18	
5. Sand and gravel, cross-stratified	1	Medial gravels.
6. Loam and sand, obscurely cross-stratified	5	
7. Sandy loam, massive; to river	3	
	33	

A double fault-line extends through the series, as shown on Plate XXIII. A similar double fault occurs 300 feet northward of the first, in the same vertical cliff (see Fig. 26, page 165), but the throw is in the opposite direction, showing that the whole included block, 300 feet long, has been bodily depressed 2 or 3 feet. The marly clays forming the upper portion of the section are, as usual, markedly unconformable to the gravels underlying them.

[48]In making the drawings of detailed sections represented on Plate XXIII, the entire vertical range of the exposures observed was not represented.

SECTION B.—*West bank of Humboldt River, ½ mile above Oreana.*

	Feet.
1. Marly clay, light colored, sandy	30
2. Marly clay, yellowish, fine-grained, laminated	4
3. Marly clay, light colored, sandy, like No. 1	4
4. Gravel, cross-bed, ferruginous	1
5. Marly clay, drab-colored	1
6. Gravel, cross-bedded, ferruginous	1
7. Marly clay, finely laminated, jointed	5
8. Marly clay, more sandy than No. 7, thick-bedded; to river	15
	61

The exposures in this portion of the cañon walls vary greatly as one follows them up or down stream. The middle member especially changes in both the character of the strata and their inclination.

SECTION C.—*West bank of Humboldt River, 2½ miles above Oreana.*

	Feet.	
1. Sand and gravel	12	
2. Marly clays, white, laminated	12	Upper lacustral clays.
3. Marly clays, brownish, loams	10	
4. Marly clays, white	25	
5. Gravel and sand, cross-stratified	25	Medial gravels.
6. Marly clays and loam; to river	10	Lower lacustral clays
	94	

SECTION F.—*West bank of Humboldt River, at Rye Patch.*

	Feet.	
1. Æolian sand and alluvial gravel, variable	1 to 6	
2. Loam, sandy, light-colored, fine	12	Upper lacustral clays.
3. "Tufa mushrooms" (dendritic tufa)	0.9	
4. Ostracoid and gasteropod shells	0.2	
5. Sand, loamy, buff-colored, with small concretions of gypsum	16	
6. Gravel, rounded, cross-stratified	18.5	Medial gravels.
7. Marl, buff-colored	6	
8. Gravel, cross-stratified	9	
9. Loam, with some cross-bedded gravel	7	
10. Gravel, cross-stratified	3	
11. Sand, cemented by carbonate of lime	0.4	
12. Loam, fine, cross-stratified	2	
13. Sand, white, marly (much thicker in east wall of cañon)	4	
14. Loam, with irregular strata of gravel	40	
15. Gravel, cemented	1	
16. Loam and fine gravel; to river	75	Lower lacustral clays.
	196 to 201	

The separation of the three members is more difficult to trace in this locality than is usual; the above divisions are somewhat arbitrary.

SECTION H.—*North bank of Humboldt River, 6 miles below Mill City.*

	Feet.	
1. Æolian sands, with some gravel, irregular in thickness		
2. Marly clay, white, regularly laminated, jointed	15	Upper lacustral clays.
3. Loam, sand, and gravel, massive medially, cross-stratified above and below	12	Medial gravels.
4. Marls, regularly laminated, light drab; to river	10	Lower lacustral clays.
	37	

The medial gravels are markedly unconformable by erosion to both the upper and lower lacustral beds.

SECTION L.—*South bank of Humboldt River, Mill City.*

	Feet.	
1. Weathered marl, æolian sand at summit	2.5	
2. Marly clays, obscurely stratified, gray	3.0	Upper lacustral clays.
3. Marly clays, white, laminated	3.0	
4. Marly clays, sandy, brownish, obscurely cross-stratified	2.5	
5. Marly clay, white, laminated, jointed	9.0	
6. Sand and gravel, somewhat ferruginous, fossiliferous	0.5	Medial gravels.
7. Sand, gravel, and pebbles, cross-stratified	5.0	
8. Sand and loam, massive, with pebbles	5.0	
9. Sand and loam, obscurely and irregularly stratified	4.0	
10. Sand and gravel, with ferruginous current	0.3	
11. Sand, cross-stratified, fine	3.0	
12. Marly clays, regularly laminated, ash colored, jointed, with some tufa at summit; to river	3.0	Lower lacustral clays.
	40.8	

The tufa in the lower lake-beds occurs in uniform lenticular nodules, in places forming a continuous layer an inch or two thick. Dendritic tufa, in the form of mushrooms, occurs in the upper lake-beds above No. 5, near where this section was taken.

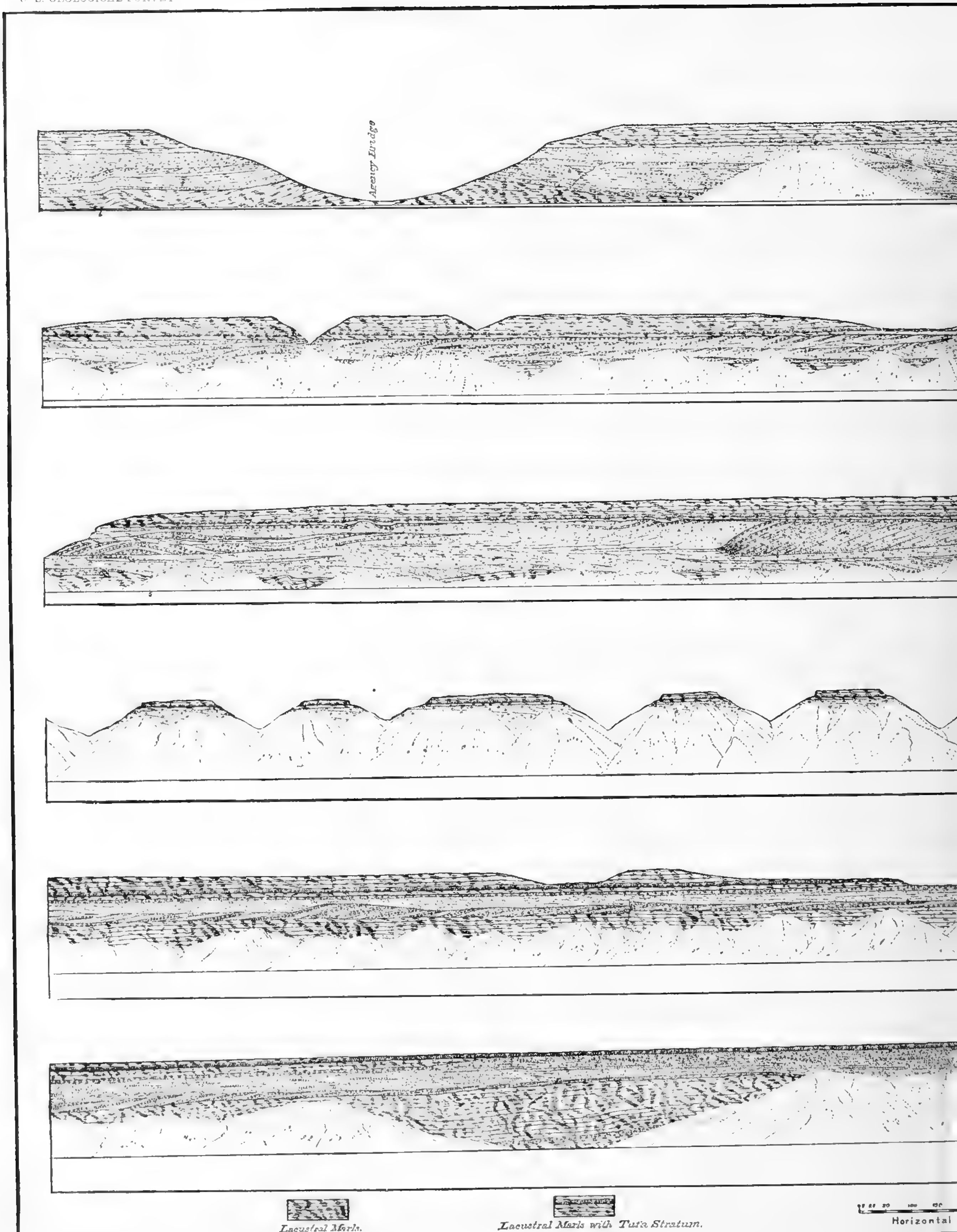
EXPOSURES IN THE CAÑON OF THE TRUCKEE.

The sedimentary deposits accumulated in Lake Lahontan are also well exposed in its precipitous banks of the Truckee River from the point where it enters the basin of the former lake, about 15 miles westward of Wadsworth, to its termini in Pyramid and Winnemucca lakes. Above Wadsworth the exposures are entirely of upper lacustral clays, which occur in fragmentary masses on the sides of the cañon in places where they have been sheltered from erosion. The western bank of the Truckee just below Wadsworth, and 2 or 3 miles from the gorge through which the river enters the valley, is about a hundred feet high and exposes the following diversified sections:

	Feet.
1. Æolian sands	5 to 18
2. Sandy clay, fine, evenly stratified	12
3. Clay, drab-colored, fine-grained, homogeneous	6
4. Clay, evenly stratified, ferruginous	1.5
5. Sand, argillaceous, in contorted strata	3
6. Sand, fine, clean, sharp	2.5
7. Clay, sandy, ferruginous, jointed	2
8. Sand, coarse and pebbly	5
9. Clay, argillaceous	2
10. Sand, ferruginous	10
11. Clay, drab-colored, with seams of fine sand	2
12. Sand and gravel, micaceous	10
13. Gravel, well rounded, with seams of sand and occasional boulders sometimes 2 feet in diameter	6
14. Sand, evenly stratified, micaceous, ripple-marked	2
15. Sand, sharp, clean, micaceous	12
16. Sand, evenly stratified, micaceous, ripple-marked and current-bedded; passing into—	3
17. Clay, fine, evenly stratified, drab-colored, sometimes sandy; jointed by two systems of fractures nearly at right angles, and resting unconformably upon—	6
18. Gravel, well rounded, current-bedded, and containing boulders 2 feet in diameter; to river	20
	110 to 123

The numerous changes recorded by this section are no doubt to be accounted for by the proximity of the former mouth of the river, from which the greater part of the *débris* forming the beds was derived.

A noticeable feature of the section is the fine exhibition of double jointing to be seen in bed No. 17. This stratum is of compact and nearly homogeneous, sandy clay, resting on a thick deposit of unconsolidated gravel and bowlders, and overlain by similar material. As the inclosing beds are too loose and incoherent to exhibit jointed structure it seems evident that the forces producing the joints must have originated in the clays themselves; for it is difficult to understand how external agencies, as an earthquake shock for example, could have been transmitted through the loose gravel deposits inclosing the clays. The jointed stratum to which we have called attention apparently represents the lower lacustral clays, but as the section is rendered abnormal by its proximity to the ancient mouth



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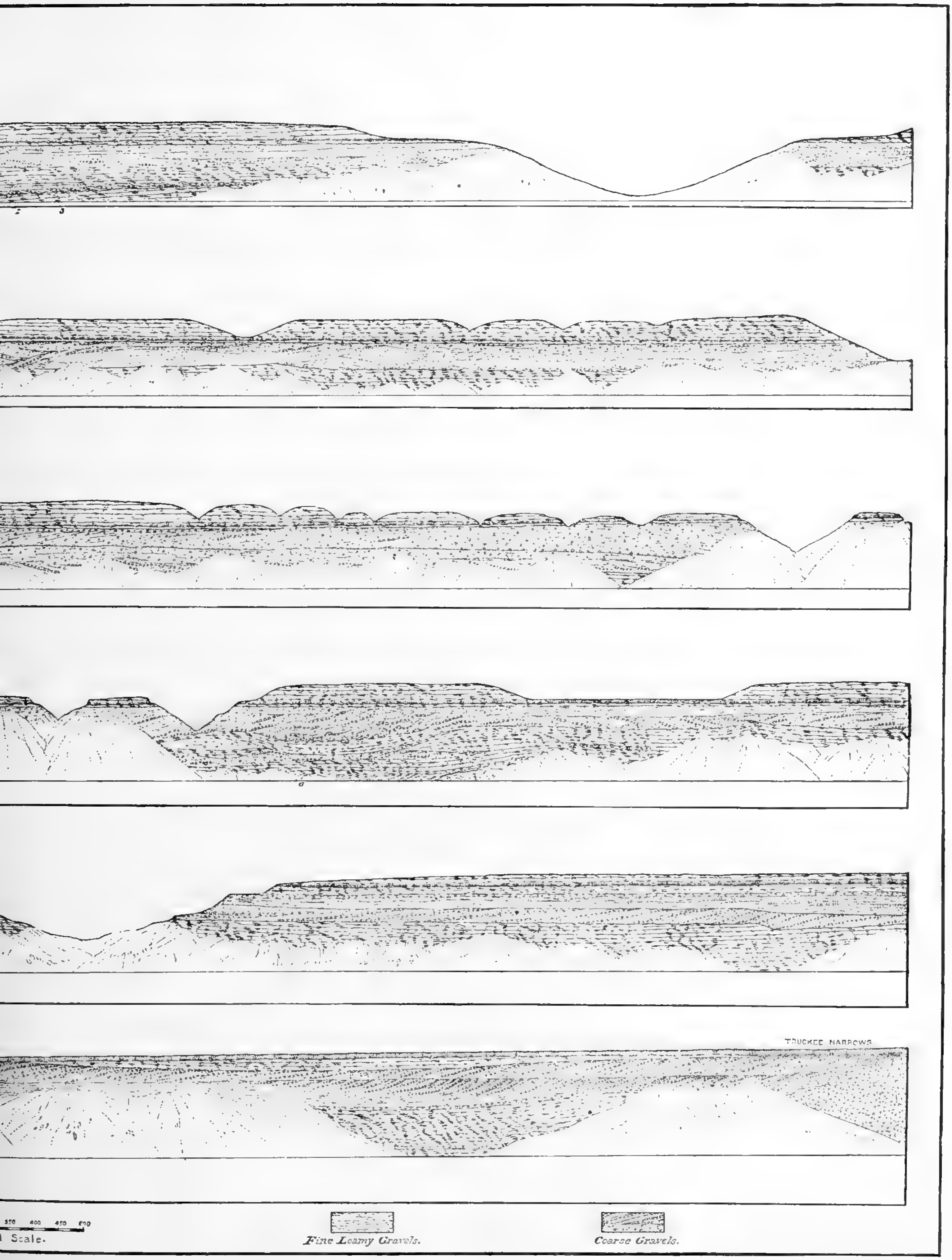
SECTIONS OF LAHONTAN SE



I. C. Russell, Geologist.

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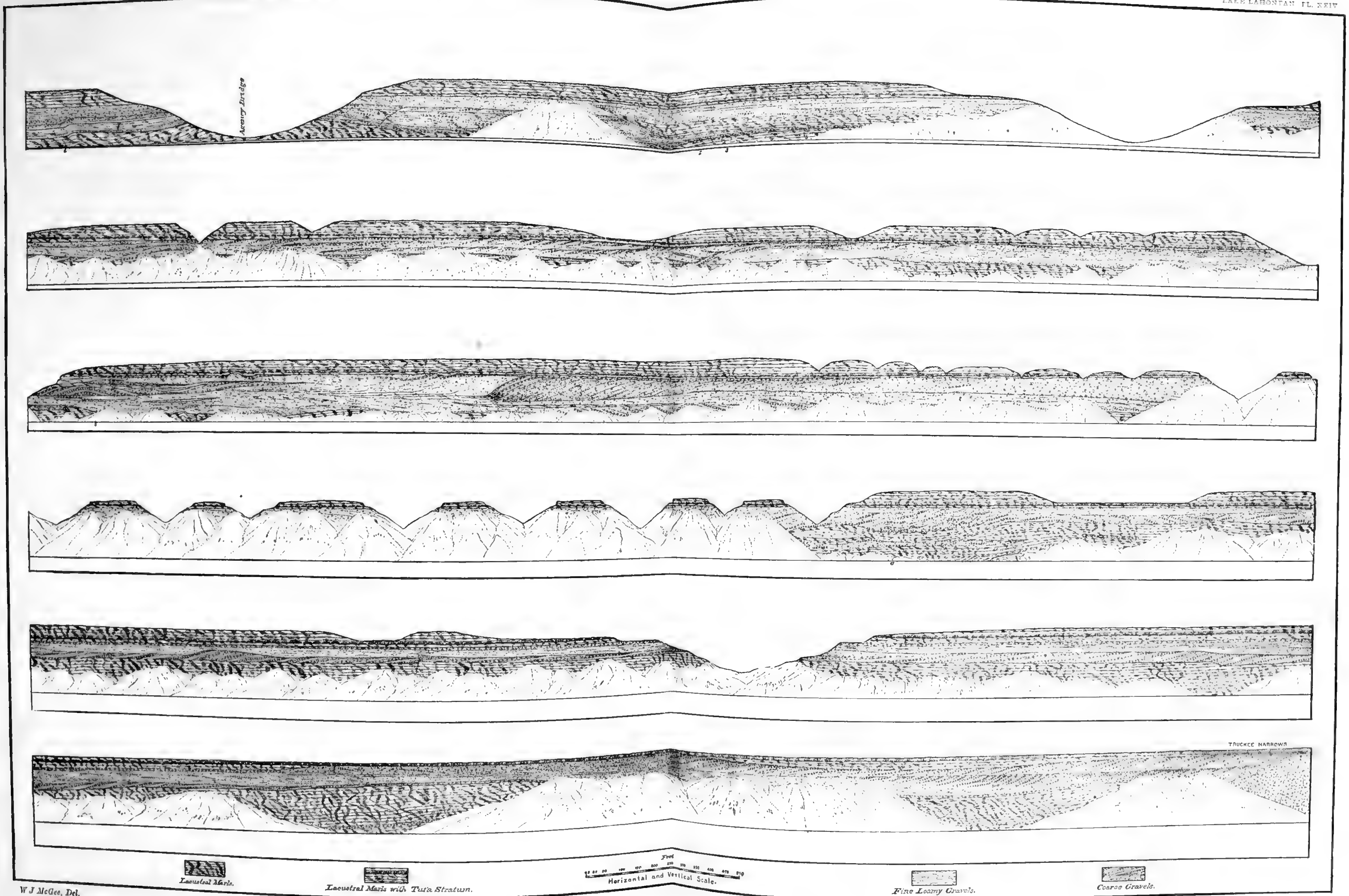


W J McGee, Del. I. C. Russell, Geologist.

SECTIONS OF LAHONTAN SEDIMENTS IN TRUCKEE CAÑON, NEVADA

of the Truckee River, the three divisions of Lahontan sediments so easily recognized in many localities are here indefinite.

Continuing towards Pyramid Lake with our study of the exposures in the river banks, we find the section changing in its details and losing the complex character observed at Wadsworth. Beginning a mile or two below the position of the section given in detail above, and continuing for four or five miles down the river, the exposures are almost entirely of upper lacustral clays, including a few irregular strata of current-borne material. This is indicated by the following section observed on the west side of the river about four miles below Wadsworth:

	Feet.
1. Æolian sand	1 to 2
2. Dendritic tufa in mushroom-forms	1 to 1.5
3. Clay, fine, sandy, ferruginous	4
4. Clay, compact, drab-colored	12
5. Sand, fine, ripple-marked	1
6. Clay, fine, evenly stratified	2
7. Sand and gravel, current-bedded	1
8. Clay, drab-colored	8
9. Sand, ripple-marked	1
10. Clay, evenly stratified, with some sandy layers; to river	100

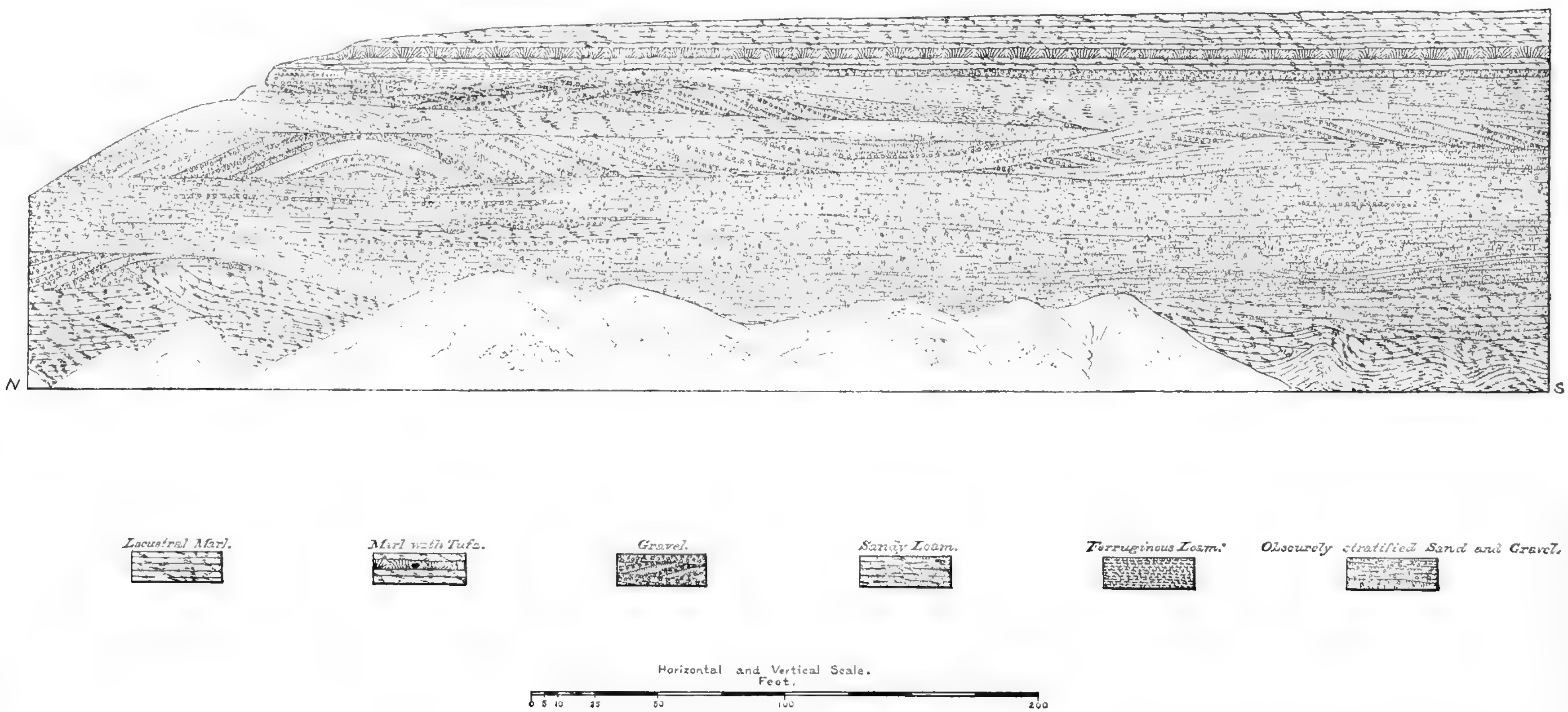
Near the locality where this section was observed, but on the opposite side of the stream, the lower fifty feet of the cañon wall are composed of coarse gravel which evidently represents the middle member of the Lahontan series; half a mile down stream, however, the entire section is again composed of lacustral clays.

Other abrupt changes of this nature are common and seem to indicate that the medial gravels occupy an old eroded channel in the lower clays, which is crossed irregularly by the present stream channel.

Continuing down stream, one finds good exposures of the upper clays resting on coarse current-bedded gravels which are without question a portion of the middle member of the series. The medial gravels are here probably represented in part by a heavy deposit of reddish-brown *débris*, somewhat coarser than the normal lacustral clays and having a close resemblance to the upper or flood-plain portion of the medial gravels observed in the Humboldt section. On the east side of the river this deposit becomes thinner as we follow it westward, and at length disappears in a thin wedge, at the same time increasing in thickness in the west bank of the cañon, until it finally composes the entire section of more than a hundred feet.

Just before the Truckee Cañon opens out into the valley occupied by Pyramid and Winnemucca lakes, it becomes quite narrow, and is bounded on either side by rocky walls; for convenience of reference we have called this the "Truckee Narrows." From this point to the Agency Bridge, a distance of about four and a half miles, the walls of the cañon exhibit a continuous section in which the tripartite character of the Lahontan sediments is strikingly displayed. The exposures actually observed on the east side of the stream have been sketched by Mr. McGee and form Plate XXIV. The most instructive feature illustrated by this section, as is the case of the exposures along the Humboldt, is the fact that it consists of two series of fine homogeneous strata, separated by a heavy deposit of heterogeneous, current-bedded gravels. A generalized section of the beds here exposed agrees in a remarkable way with the similar sections observed in the Humboldt Cañon. The upper and lower lacustral clays occurring in the Truckee section, like those exposed in the banks of the Humboldt, show but little variation. They are composed of fine, evenly laminated, drab-colored, marly clays, that are somewhat saline and alkaline as indicated by chemical tests. On the west side of the river near the Agency Bridge, however, the upper clays show some variation, especially near their contact with the underlying gravels, as is exhibited with considerable detail in the section forming Plate XXV.

One of the most instructive portions of the Truckee section is a stratum of dendritic tufa interbedded with the upper clays. At the northern end of the section, *i. e.*, towards the deeper portion of the lake in which the sediments of tufa were deposited, the tufa-stratum is but 3 inches thick and is buried beneath 25 or 30 feet of laminated clay; when followed shoreward, or up stream in reference to the present drainage, the tufa gradually increases in thickness, at the same time approaching nearer the surface of the section, until at the Narrows of the Truckee it forms a sheet of huge mushroom-shaped masses at the top of the bank, which are from 10 to 15 feet in diameter and so thickly planted that they form a continuous pavement fully 10 feet thick. The rocks at the Narrows above the level of the lacustrine deposits are



W J McGee, Del.

I. C. Russell, Geologist.

SECTION OF LAHONTAN SEDIMENTS NEAR AGENCY BRIDGE, TRUCKEE CAÑON, NEAVDA.

coated with a continuation of the same tufa sheet, the upper limit of which is about 200 feet below the highest of the ancient water-lines engraved on the sides of the valley. The tufa interstratified with the upper clays almost invariably starts from small nuclei, and, forming dendritic branches, spreads out above into dome or mushroom-shaped growths; in some instances the tufa is prolonged downward below the general level of the stratum to which it belongs, and forms irregular vase-shaped masses below the continuous tufa layer. Immediately below the tufa, and sometimes adhering to it, are great quantities of *Cypris* and gasteropod shells, and occasionally bones of fishes, indicating that the waters from which the calcium carbonate forming the tufa was precipitated were far from being concentrated saline solutions.

Throughout the section, the contact of the medial gravels with both the underlying and the overlying clays is unconformable, owing, in each case, to the erosion of the lower member, as is well shown in Figs. A, C, and D, Plate XXVI, which are accurate sketches of observed exposures, and illustrate the filling of channels, formed principally by erosion, with current-bedded gravel.

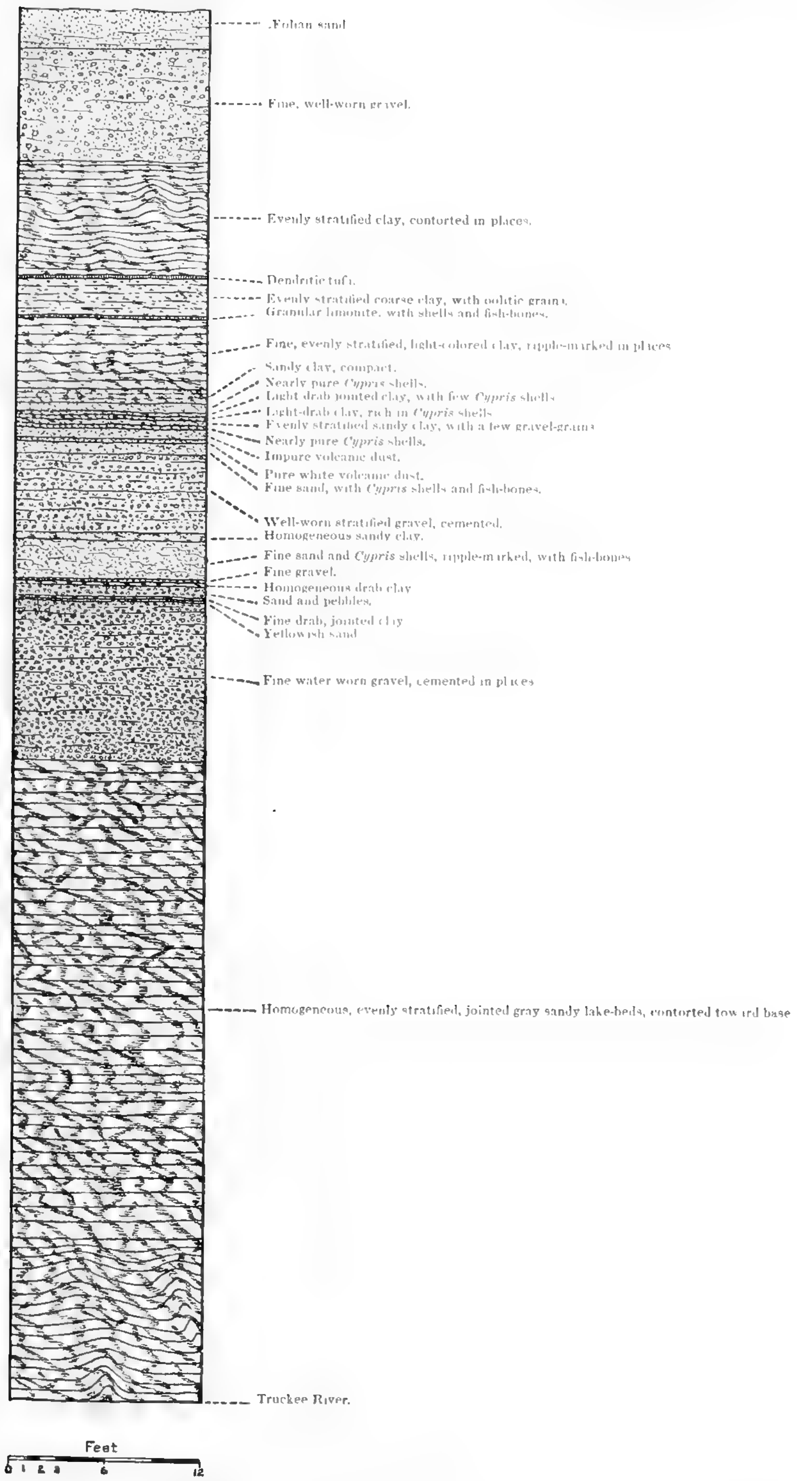
The lacustral clays forming the lower portion of the section are, in places, exposed to the depth of 100 feet, but what their total thickness may be it is not possible to determine from the present exposures. When examined at some distance from the shore of the basin, they exhibit little variation, and are normally finely laminated, marly clays An exception is found, however, a short distance above the Agency Bridge, on the east side of the river, where a rounded boulder of hard volcanic rock from 2½ to 3 feet in diameter occurs several feet below the top of the lower clays. This is a much larger block than any seen in the medial gravels, and evidently must have been floated to its present position, probably through the agency of ice. Although rounded and worn it did not exhibit striations or planed surfaces, and gave no proof that it had ever been subject to glacial action.

In places, the lower clays exhibit contortions which in some instances can only be accounted for by a movement of the beds since their deposition, caused apparently to the weight of the superimposed masses of gravel and clay. In other exposures the contortions and convolutions of the laminated deposits are apparently due to their having been formed in agitated waters; just how the intricate folds and contortions were produced, however, it is extremely difficult to explain.

In a few localities the lacustral clays, especially below the medial gravels, are faulted; and at times the strata on one side of a fault have been thrust over the beds forming the opposite wall, as indicated at the left on Plate XXV. In this instance the projecting strata seem to have been removed by erosion previous to the deposition of the superimposed clays.

The medial gravels in the Truckee section vary from 25 to 100 feet in thickness, and exhibit great diversity both in composition and structure, thus indicating many variations in their mode of formation. Examples of cross-bedding are abundant, and the presence of arched strata and lines of unconformability, as well as the irregularity of the beds and the manner in which they wedge-out and are replaced by others of a somewhat different nature, all tend to show that the entire middle member of the Lahontan series here exposed was deposited in shallow, current-swept waters. The arches seen in the cañon walls are, apparently, cross-sections of current-built embankments, while the irregular layers of fine sediment are proof, on the other hand, of more quiet condition during which the fine silt held in suspension was allowed to subside. The general conclusion that the medial gravels were formed during a time of low water, separating two periods when the lake was broad and deep, cannot be questioned by any one who has examined the records exposed in the Truckee section, which, as previously stated, are in harmony with the similar evidence furnished elsewhere in the basin of the ancient lake.

On following the Truckee River from the Agency Bridge to its mouth, one finds its banks becoming low, and exposing, for the most part, only portions of the upper clays; in a few localities, however, limited sections of the medial gravels may be seen, thus showing that the valley could not have held a lake much, if any, larger than that of the present day during the time that the medial member of the Lahontan series was being deposited.



... BRIDGE, TRUCKEE RIVER, ...

EXPOSURES IN THE CAÑON OF THE CARSON RIVER.

During the highest stages of Lake Lahontan its waters extended up the Carson River Valley as far as Dayton, and occupied it long enough to allow large quantities of lacustral beds to accumulate. When the lake evaporated and the river regained its ancient channel, these beds were deeply dissected by erosion. The remnants of Lahontan sediments to be seen in the valley belong mostly to the upper lacustral clays, but in places they were observed to rest on gravel deposits. The sections obtained, however, were imperfect and far less satisfactory and instructive than those described in the preceding pages. The lacustral beds exposed along the banks of the Carson, and flooring Churchill Valley, are fine, light-colored marly-clays, similar in all respects to the corresponding beds observed at many localities throughout the Lahontan basin. Interstratified with these sediments is a deposit of dendritic tufa, sometimes 3 or 4 feet in thickness, which is well exposed in the narrow channel connecting Churchill Valley with the Carson Desert. This deposit corresponds both in structure and position to the interstratified tufa-layer observed in the Humboldt and Truckee cañons.

So far as known, the lacustral beds observed along the Carson River are undisturbed by post-Lahontan movement, and have nowhere been dissected sufficiently deep to lay open the sediments accumulated during the first rise of the lake.

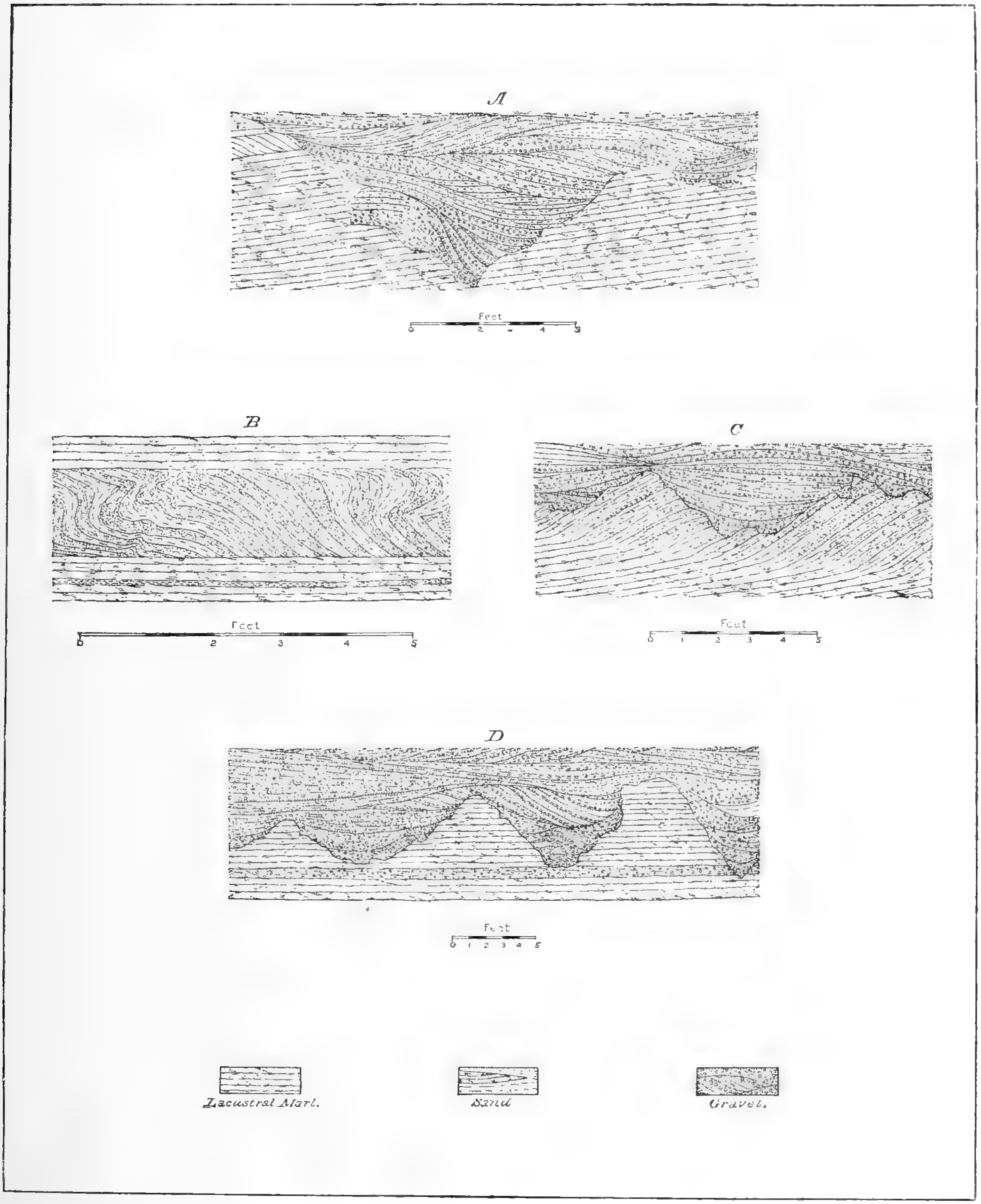
The Carson River rises on the eastern slope of the Sierra Nevada and flows northward through Carson and Eagle valleys, which are in reality a single basin, and enters a deep and all but impassable cañon, through which it flows with a rapid descent as far as Dayton. It then enters a valley 2 or 3 miles broad—once an arm of Lake Lahontan—which contracts again to a narrow cañon at its southern end. In the course of a few miles this cañon again expands and forms Churchill Valley, which in its turn connects with the Carson Desert through a narrow channel now occupied by the Carson River. The contractions in the lower portion of the river channel are probably due in a great measure to erosion, but are less plainly stream-carved channels than the deep gorge above Dayton. Since Lake Lahontan during its highest stages occupied the valley as far as Dayton, we are safe in concluding that the river channel was carved in pre-Lahontan times, and also that the lake which occupied Eagle-Carson Valley must have overflowed and cut down its channel of discharge so as to drain that basin to the bottom previous to the existence of Lake Lahontan. We make this departure from our immediate subject for the purpose of showing that the sediments of the Eagle-Carson Lake, in which a variety of foot-prints have recently been discovered at the Nevada State Prison, are older than Lake Lahontan, and probably belong to early Quaternary or late Tertiary times.

EXPOSURES IN THE CAÑON OF WALKER RIVER.

The Walker River, in its course between Mason Valley and Walker Lake, flows through a comparatively narrow valley, which was deeply filled with Quaternary lake sediments and is now a desert, sage-brush-covered plain, dissected through the center by a cañon eroded by the present stream since the evaporation of the former lake. Like the Humboldt, the Truckee, and the Carson, the Walker River has exposed sections of Lahontan sediments, in which the tripartite division is well displayed. As in the former instance, the upper and lower members are fine, evenly laminated, marly-clays, which were evidently accumulated in quiet waters, and are separated by a heterogeneous accumulation of sand and gravel that records an interval of low water.

The tendency of current-borne *débris* to accumulate in narrow straits connecting broad water-bodies has already been discussed in connection with the descriptions of the gravel deposits observed in the Humboldt and Truckee cañons. A gravel embankment similar to those already described occurs a few miles northward of Walker Lake and forms the divide between Walker Lake and Walker River valleys. In this instance a large embankment was built completely across the mouth of the narrow strait that formerly connected the open waters of Walker Lake and Mason valleys; subsequently this structure was cut through by waters flowing from the northward, thus revealing a section of the inclined and arched strata in which the gravels were deposited.

A generalized section compiled by Mr. W J McGee, from many detailed observations, is reproduced in Fig. C, Plate XXVIII, which represents the



W J McGee, Del.

I. C. Russell, Geologist.

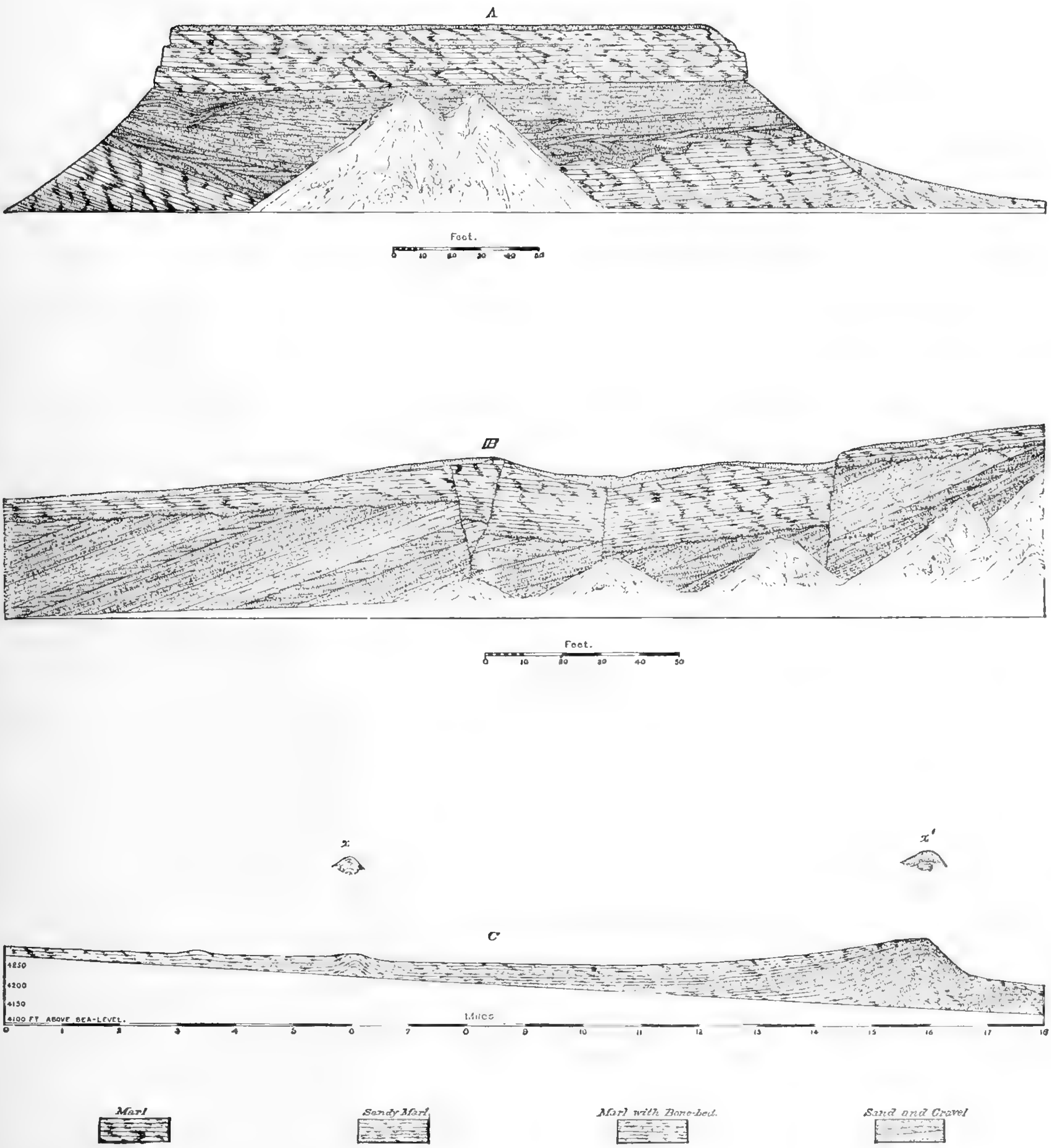
DETAILED SECTION OF LAHONTAN SEDIMENTS, TRUCKEE CAÑON, NEVADA.

structure of the Lahontan sediments exposed in the cañon walls for a distance of 18 miles. The highest point in the section is at the crest of the embankment, which crosses the valley and marks approximately the level of the highest water stage of the former lake. Between the embankment mentioned above and Walker Lake, a distance of 8 miles, the river banks vary from zero at the lake to 50 or 60 feet in the neighborhood of the embankment. In this interval the exposures are almost entirely of upper lacustral clays, with intercalated beds of volcanic dust, but at a few localities, in the northern portion of the section, the medial gravels and underlying clays may be seen at the base of the escarpment bordering the river. Where the stream-channel crosses the embankment, the entire exposure, 200 feet high, is composed of inclined and arched strata of sand and gravel inclosing irregular and loamy beds. The entire series has a characteristic pinkish tint due to the presence of iron oxide. This embankment occurs unconformably between the upper and lower clays, and, like many similar structures when seen in section, exhibits anticlinals of deposition. Its base is not exposed to view, but as the clays of the lower series occur near at hand, both to the north and south, it seems probable that the gravels composing the embankment were, at least in part, accumulated during the time the lower clays were being deposited. Like the embankment at the southern end of Humboldt Lake, this structure was probably begun early in the history of Lake Lahontan, and has been enlarged many times since. The last addition was contemporaneous with the deposition of the upper clays, or perhaps in part subsequent to it; in the main, however, it is composed of the medial gravels of the Lahontan series. Northward from the crest of the embankment the cañon walls decrease in height, as represented in Fig. C, Plate XXVIII, all the way to Mason Valley, where the river becomes a surface stream. The medial gravels are exposed for about 8 miles north of the embankment, and appear again at a point where they have suffered some local disturbance about 4 miles below the point where the river leaves Mason Valley.

Throughout the entire exposure of lower lacustral clays observed in the Walker River Cañon, the strata are of light-colored, laminated, marly clays, of the same nature as the corresponding beds occurring in the Humboldt and the Truckee cañons, and therefore do not require farther description. The medial gravels, in common with lacustrine shore deposits in general, are heterogeneous accumulations of worn and rounded sand, gravel, and boulders, with occasional inclusions of finer *débris;* cross stratification prevails, and many of the beds were deposited in an inclined position.

The upper lacustral clays in the Walker River section are more varied and indicate more complex conditions of deposition than the similar exposures that have been described in the preceding pages. The upper and lower portions of the upper clays have the normal features of the deposit, but an intermediate portion, varying 20 to 30 feet in thickness, is of a more diversified character, and includes strata of sand and gravel which are frequently iron-stained and in many places form contorted and folded layers.

This portion of the upper clays obtained the name of the "bone-bed" in our field notes, from the numerous mammalian remains that it contains (see Chapter VI). It is exceptional in the Lahontan series, and evidently must have been formed under peculiar conditions. The only hypothesis which seems to furnish assistance in interpreting the phenomena observed assumes that the embankment dividing Walker River and Walker Lake valleys formed a dam in late Lahontan times that obstructed the free circulation of the waters occupying the two basins and caused the region above the obstructions to become a swamp or a shallow lake in which the iron-stained deposits of varying character containing mammalian remains were accumulated. Afterwards the lake rose sufficiently to flood the valley and allow homogeneous, fine-grained clays to accumulate. In this portion of the deposit the shells of *Margaritana margaritifera* are abundant. The surface of the upper clays over large areas both in Walker Lake and Walker River valleys is coated with an abundance of dendritic tufa, which occurs both in mushroom-shaped masses that have formed about small nuclei and in irregular vertical sheets which penetrate the clays and in some instances inclose considerable areas. These sheets of tufa seem to have formed on the sides of fissures, or perhaps on eroded surfaces which had been submerged, in such a manner as to take an accurate cast of the beds against which they were deposited. The upper clays in the Walker River section correspond not only in their composition and arrangement



W J McGee, Del.

I. C. Russell, Geologist.

SECTIONS OF LAHONTAN SEDIMENTS IN WALKER RIVER CAÑON, NEVADA.

with the similar beds in other parts of the Lahontan basin, but they contain the same species of fossils. Their tufa deposits in various parts of the old lake basin record similar chemical conditions.

The following section observed in the left bank of the Walker River, about two miles above the gravel embankment shown on Plate XXVIII, represents the prevailing character of the exposures to be seen in this region:

		Feet.
Upper lacustral clays	Æolian deposits forming desert surface	1 to 10
	Light-colored marly clays, passing into ferruginous sandy beds, sometimes contorted, containing detached mammalian bones; changing to marly clays at the base	40 to 50
	Contact unconformable.	
Medial gravels	Gravels and loam, colored with iron	25 to 30
	Contact unconformable.	
Lower lacustral clays	Light-colored marly clay; to river	75

The sections taken at various points along the Walker River show great variation, but the differences are caused almost entirely by the want of constancy in the medial gravels; the upper and lower members of the series are remarkably uniform throughout. In the majority of cases where the upper or lower contacts of the medial gravels could be seen they were found to be unconformable with the adjacent beds.

The most difficult problems presented by the superficial geology of the Walker River Valley are in connection with the orographic disturbances that have affected the region in post-Lahontan times. The valleys occupied by Walker Lake and Walker River are of the Great Basin type, and owe their formation to pre-Lahontan faulting; the main displacement that gave origin to the depressions—which are structurally a single basin—follows its western border and determines the extremely precipitous eastern face of the Walker Lake or Wassuck Mountains. Other faults, less plainly distinguishable, occur on the eastern border of the valley, especially near its northern end, and connect with the displacements to be seen in Mason Valley. Some of these ancient fault lines, including the largest of all—that following the western border of the valley—appear at the surface within the basin of the former lake; in such instances a post-Lahontan movement of the ancient displacements is usually indicated by fresh scarps in lacustral clays and gravels. Since the desiccation of Lake Lahontan there has been considerable movement along some of these ancient lines of fracture, and the Lahontan beaches and terraces no longer retain their normal position, but in places have been carried far above the horizon which they originally occupied. If we consider the crest of the gravel embankment separating Walker Lake Valley from the valley occupied by Walker River as approximately the original level of the Lahontan beach, we find that the eastern end of the structure, as determined by Mr. McGee, is now fully 200 feet above its original position, as indicated at x′, Plate XXVIII. The only explanation of this phenomenon the writer can offer is that the fault following the eastern border of the valley has increased its displacement in post-Lahontan times and carried the shoreward portion of the bar above its normal position. Similar disturbances may be seen in the northern part of the same valley, where a post-Lahontan fault occurs on each side of the basin exposing characteristic sections of Lahontan sediments. The altitude of the beach on the eastern side of the valley is indicated at x, Plate XXVIII. In the bottom of the valley and near the northern end, the strata are arched as indicated in the generalized section. From the limited section open to examination, this seems to be a variable anticlinal, and, if so, it is the only post-Lahontan arch of this nature that has been observed. The movements that produced the disturbances in the northern part of the Walker River Valley are connected with the recent displacements to be seen in the vicinity of the hot springs in Mason Valley, and are so indicated on Plate XLIV.

Local faults affecting the Lahontan sediments are of frequent occurrence, especially in the lower portion of the Walker River Valley; the throw of these displacements is seldom over 40 or 50 feet, and they have caused but little change in the topography of the valley. They are of different dates, as is illustrated by figures A and B, Plate XXVIII; in the former, the displacement took place previous to the deposition of the medial gravels; and in the latter, after the upper clays had been deposited.

We have described the orographic movements in this region in somewhat general terms, for the reason that it is difficult to describe the facts on which our conclusions rest with as much accuracy as could be desired, and also because the subject will claim further attention in connection with other orographic disturbances that have affected the Lahontan basin.

GENERALIZED SECTION OF LAHONTAN SEDIMENTS.

On grouping the numerous sections of Lahontan sediments observed in the Humboldt, Truckee, Carson, and Walker cañons, we have the following generalized section of sedimentary deposits formed in the ancient lake:

	Average thickness, in feet.
Upper lacustral clays:	
Evenly laminated marly clays, fine and homogeneous, usually saline; with interstratified bands of dendritic tufa near the top; in places containing intercalated layers of volcanic dust. In some places this member is divisible into three parts, the upper and lower being normal clays, while the intermediate member is more sandy, and usually contains iron-stained lyse, that are frequently contorted	50 to 75
Fossils: *Cypris, Anodonta, Margaritana, Sphærium, Pisidium, Helisoma, Gyraulus,* etc., together with mastodon or elephant, horse, and camel.	
Contact uncomformable.	
Medial gravels:	
Cross-stratified sand, gravel, and loam, in beds that are irregular both in thickness and inclination, frequently forming arches of deposition. At times exhibiting two plainly marked divisions; the upper being a compact, earthy, homogeneous, flood-plain deposit; the lower clean, well-rounded sand and gravel, at times strongly cross-bedded	50 to 200
Fossils: *Anodonta, Gyraulus, Lymnophysa, Pompholyx.*	
Contact unconformable.	
Lower lacustral clays:	
Laminated marly clays, very similar to the clays at the summit of the section. The clays throughout the section frequently exhibit two systems of joints at nearly right angles to each other (full thickness not exposed)	100
Fossils: *Pompholyx.*	

The interpretation of this section gives an outline of the later Quaternary history of the Lahontan basin; but as the base of the lower clays is nowhere exposed, all the changes that may be recorded by the lower strata remain unknown. From the sedimentary deposits observed we learn that there have been two high-water periods in the history of the Lahontan basin, during which fine clays were deposited. Separating these two periods was a time when the lake was low and allowed current-borne gravels to be carried far out over the previously formed lake-beds. During the second flooding the waters underwent long concentration, and at a certain period deposited a vast quantity of tufa; the lake during this stage also received large quantities of pumiceous dust, which must have been thrown out by some volcano in the state of violent eruption. The second rise of the lake was followed by the present period of desiccation, which witnessed the evaporation of its waters and the exposure of its sediments to subaerial erosion. The rivers in flowing across the exposed lake-beds carved the deep channels we have described, and are now spreading stream and current borne gravels far out in the central portions of the valleys, thus in many ways repeating the conditions that characterized the time during which the medial gravels were deposited.

In order to represent the sediments of Lake Lahontan on a geological map of the region one has but to color the area once occupied by the lake with the appropriate tint. The older rocks throughout the area are not completely concealed by the sediments of the lake, however, the exceptions occurring along the borders of the basin and about isolated buttes; but these portions being usually precipitous, the belt left unconcealed is so narrow that it would be scarcely possible to represent it on a geological map of the scales ordinarily used.

To prevent confusion it seems appropriate to indicate at this time some discrepancies that exist between the published reports of the United States Geological Exploration of the Fortieth Parallel and the conclusions presented in the present volume. On map V of the atlas issued for that exploration a large portion of Lahontan basin is included. The area covered by the sediments of Lake Lahontan, as determined by the present survey, are there indicated in four different ways. Some portions are represented as Truckee Miocene, others as Humboldt Pliocene, while the greater part is divided between Upper and Lower Quaternary.

The areas colored as Truckee Miocene are situated at the lower end of Humboldt Lake and at the southern end of Winnemucca Lake. The deposits at these localities are similar, consisting, if the writer's determinations are correct, of gravels that were accumulated in the form of bars or embankments through the action of the currents of the Quaternary lake. The some deposits about the south shore of Humboldt Lake have been described at length in the preceding pages (105 to 112), and a detailed map of the area presented on Plate XVIII. The embankments near the south end of Winnemucca Lake are described on page 120. The discrepancy in reference to the nature of the gravel deposits bordering Humboldt Lake may be seen by comparing the pages referred to above with the description given on page 742 of Vol. II of the reports of the United States Geological Exploration of the Fortieth Parallel.

The entire area represented as Humboldt Pliocene, on map V of the atlas cited, has been considered throughout the present volume as of Quaternary age, and as furnishing the most typical exposures of Lahontan sediments, as will be seen by referring to the descriptions of the Humboldt and Truckee cañons.

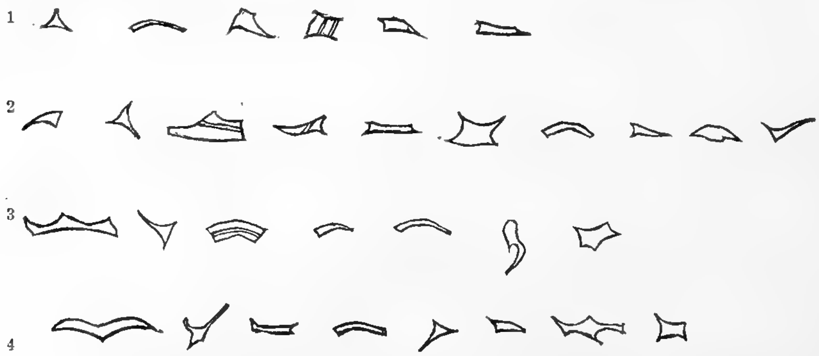
The areas colored as Lower Quaternary on map V, of the atlas named, are mostly playa-deposits; while the areas designated as Upper Quaternary are largely covered with alluvial gravel, especially near the mountains, but in the broader valleys within the Lahontan area large portions thus designated are floored with Lahontan sediments. In the present report Upper and Lower Lahontan clays have been recognized; these might with propriety be termed Upper and Lower Quaternary, but cannot be correlated with the Upper and Lower Quaternary of King. The exposures of upper and lower Lahontan sediments are so limited, occurring mostly in cañon walls, that they could scarcely be represented on a map of the scale used in that atlas, and if mapped they would not agree with the classification of the Quaternary there used. As the facts are interpreted by the present writer, the lake beds there mapped as Lower Quaternary belong to Upper Quaternary, while the playas also mapped as Lower Quaternary are recent. The alluvial deposits, there mapped as Upper Quaternary, are deep formations whose accumulation began at least as early as the Tertiary and has been continued to the present time. Their surface layers are in part modern, but other areas have received no recent additions and are superficially Upper Quaternary.

EXCEPTIONAL SEDIMENTARY DEPOSITS.

PUMICEOUS DUST.

In describing the section of upper lacustral clays observed in the Humboldt, Truckee, and Walker River cañons, strata of fine silicious material, varying in thickness from a fraction of an inch to five or six feet, were noted at a number of localities; it is now our intention to describe these abnormal deposits more fully.

In all the exposures of this material the same characteristics were observed. The beds are composed of a white, unconsolidated, dust-like, silicious substance, homogeneous in composition, and having all the general appearance of pure, diatomaceous earth. When examined under the microscope, however, it is found to be composed of small, angular glassy flakes, of a uniform character, transparent and without color, but sometimes traversed by elongated cavities. When examined with polarized light, it is seen to be almost wholly composed of fragments of glass, with scarcely a



1. Volcanic dust which fell in Norway, March 29 and 30, 1875.
2. Volcanic dust emptied from Krakatoa, August 27, 1883.
3. Volcanic dust from the Truckee River, Nevada. Quaternary.
4. Volcanic dust from Brakleast-Hill in Saugus, Mass., pre-Carboniferous.

FIG. 23.—Volcanic dust.

trace of crystal or of foreign matter. On comparison with volcanic dust that fell in Norway in 1875, derived from an eruption in Iceland, with the dust erupted in Java in 1864, and the similar material ejected in such quantities from Krakatoa in 1883, it is found to have the same physical characteristics; but it is much more homogeneous, and, unlike the greater part of the recent dust examined, is composed of colorless instead of brown or smoky glass. In the following figure, which we copy from

Mr. J. S. Diller's instructive article on the volcanic sand which fell at Unalaska, October 20, 1883,[49] the microscopic appearance of volcanic dust, from various localities and of widely different geologic age, is shown with accuracy. The peculiar concave edges and acute points of the shards of glass render it evident that they were formed by the violent explosion of the vesicles produced by the steam generated in the viscid magma from which the glass was formed, and were not produced by the mere attrition of the fragments during the process of eruption. It is noteworthy that the dust erupted from Krakatoa but yesterday is undistinguishable in its main characteristics from the material of a similar origin which fell in the waters of Lake Lahontan during the Quaternary, or from the dust thrown out by some unknown and long since extinct volcano in the vicinity of the Atlantic coast, which fell near the site of Boston during pre-Carboniferous or possibly in pre-Cambrian time. The volcanic phenomena of to-day are governed by the same laws as obtained at the dawn of geologic history.

Farther study revealed that even the finest of the dust obtained from the basin of Lake Lahontan has identically the same physical properties as pumiceous rhyolite forming the Mono Craters, ground in a mortar to a corresponding fineness; under the microscope the two powders were very similar.

The dust deposits are rich in silica, as shown by the following analysis, by Dr. T. M. Chatard, of a sample collected in the bank of the Truckee River near Pyramid Lake; for comparison we give also an analysis, by the same chemist, of a specimen of pumiceous rhyolite from the Mono Craters:

Constituents, etc.	Volcanic dust.	Pumiceous rhyolite.
Loss by ignition (water)	3.91	2.20
Silica (SiO_2)	71.15	74.05
Alumina (Al_2O_3) and iron (Fe_2O_3)	15.95	13.85
Lime (CaO)	0.85	0.90
Magnesia (MgO)	0.41	0.07
Magnesia (MnO)	Trace.	.....
Potash (K_2O)	3.36	4.31
Soda (Na_2O)	4.94	4.60
	100.57	99.98

The striking similarity in the composition of the above samples (especially when allowance is made for the greater percentage of moisture

[49] Science, Vol. III, p. 652.

in the specimen of dust, and the fact that it has been exposed to the action of solvents much more than the rock remaining in the crater walls) strongly favors the assumption that they had a common origin.

More extended operations in the field revealed that beds like those described above are not confined to the Lahontan basin, but are found as superficial deposits above the Lahontan beach at many localities and at points far distant from the old lake margins. Accumulations of the same nature occur in the Mono Lake basin, interstratified with lacustral deposits, and were also found in the cañons about Bodie at a considerable elevation above the level of the Quaternary lake that formerly occupied Mono Valley. About Mono Lake these deposits are frequently of a coarser texture than those found farther northward, and, at times, graduate into strata which reveal to the eye the fact that they are composed of angular flakes of obsidian.

The Mono Craters form a range some 10 or 12 miles long, which extends southeastward from the southern shore of Mono Lake, and in two instances attains an elevation of nearly 3,000 feet above the lake. A few coulées of dense, black obsidian have flowed from them, but the great mass of the cones is formed of the pumiceous obsidian which occurs both as lava-flows and ejected fragments, the latter forming a light lapilli which gives a soft gray color to the outer slopes of the craters. Fragmental material of the same nature has been widely scattered over the mountains and on the ancient moraines that occur in the Mono basin, while fine dust, unquestionably derived from the same source, may be traced to a still greater distance.

From the evidence given above we conclude that the strata of fine, siliceous, dust-like material occurring in the Lahontan sections, as well as the similar beds found about Mono Lake and scattered as superficial deposits over the neighboring mountains, are all accumulations of volcanic dust, which was probaly erupted from the Mono Craters.[50] The greatest

[50] This material could not have been erupted from the craters in which the Soda Lakes, near Ragtown, are situated, as these volcanoes are formed of quite different and more heterogeneous material. The fragments of scoria ejected from these vents are composed of basalt in which grains of olivine are conspicuous.

distance from the supposed place of eruption at which these deposits have been observed is about 200 miles.

The resemblance between the volcanic dust described above and very pure diatomaceous earth is so close that it is difficult to distinguish one from the other by a cursory examination; with the aid of the microscope, however, the difference is at once apparent, as the dust seldom shows even a trace of any organism mingled with it.

WHITE MARL.

At a number of localities in the Lahontan basin there are exposures of white, chalky marl which does not appear in the cañon sections we have described, but is exposed locally, mostly on the sides of the basin, and evidently indicates peculiar conditions of the waters in which it was accumulated.

White marls were first observed in the Lahontan basin at the southern end of the desert valley, which is connected with the Carson Desert by the narrow pass in which Allen's Springs are situated; during the higher stages of the ancient lake this valley formed a land-locked bay. That the waters did not extend through the pass at the southern end is shown by a series of barrier-bars at about the horizon of the Lahontan beach, which sweep about this portion of the ancient shore in graceful curves. These concentric gravel ridges, or barrier-bars, record a gradual recession of the waters which once filled the valley, and are especially noticeable from the neighboring hills when the slanting, afternoon light brings out their symmetric forms in bold relief. Modern drainage has cut a channel through them in a direction at right angles to their general trend, and exposed the following section:

	Feet.
Well-worn gravel, forming barrier bars	15 to 25
Fine sand, cross-bedded	8 to 10
Finely laminated, white, chalky marl	
Gravel, well rounded, ferruginous	1 to 2
Fine sand; to bottom of exposure	1 to 2

The marl at this locality is by aneroid measurement 175 feet below the Lahontan beach, and may be traced for a hundred yards or more along the sides of the arroyo. At both its lakeward and shoreward margin it becomes impure from the intermingling of sand and gravel, and finally wedges out and is replaced by water-worn *débris* like that forming the bars. It seems to form a lenticular mass, filling a local basin, but the section does not give complete proof that such is the case. Our observations would apply equally well to a low off-shore embankment built by gentle currents, and subsequently buried by ordinary shore-drift. The gravel bars resting on the marl were formed during a subsequent rise of the waters and were never afterwards submerged; consequently the marl must have been deposited previous to the last high-water stage of Lake Lahontan This will be of interest when the oscillations of the lake are more fully described.

Passing to other localities where white marl has been observed, we find that in sheltered ravines on the sides of the basaltic buttes overlooking the southern shore of the South Carson Lake there are fine, mealy deposits of this nature, 20 or 30 feet thick, and some distances below the highest of the Lahontan terraces, which contain gasteropod shells in abundance. Similar beds were also observed about 2 miles north of Allen's Springs, in the bottom of the ancient channel leading to the Carson Desert. The exposure is here imperfect, and as the beds are but little elevated above the general desert-surface it is with doubt that they are referred to the same period in the history of the lake as the similar deposits observed at higher levels. White marl may also be seen at a number of indefinite exposures at a uniform horizon, some distance below the Lahontan beach, along the steep bluffs which border the Carson Desert on the south. In Alkali Valley, 2 or 3 miles west of Sand Springs, similar marls filled with gasteropod shells occur in a group of embankments that project into the valley. Another locality of the same nature was observed on the west side of Humboldt Lake at an elevation of four hundred feet above the lake surface.

In the Truckee Cañon, about a mile below the Truckee Narrows, there are beds of pure, white, chalky marl not less than 50 feet in thickness, that are grouped about a butte of volcanic rock which was formerly completely buried beneath Lahontan sediments, but is now exposed by the erosion of the river. These beds are in part overlain by Lahontan deposits, but the exposure is obscure and the relation of the marls to the associated clays not easily determined; no fossils were found, and it is not impossible that the marls are of much older date than the associated Quaternary beds; possibly they are of Tertiary age.

The best localities of all for observing the deposits we are considering are about Pyramid Lake. In this basin they frequently appear as a conspicuous white band along the borders of the valley at an elevation of 320 feet above the 1882 level of the lake, and form a well defined built-terrace which we have named the "White Terrace." Measurements with an engineer's level, as well as many observations with an aneroid barometer and hand level, show this terrace to have a nearly uniform height and to be coincident in elevation with the water-line which marks the upper limit of the dendritic tufa. About the Marble Buttes, and at many points along the steep western shore of Pyramid Lake, the White Terrace is well exposed in sheltered ravines, which were coves and bays when the waters occupying the valley stood 320 feet higher than at present, but it is wanting on projecting spurs. Northward of Mullen's Gap the terrace becomes more continuous, and when cut by arroyos exhibits the sequence represented in the following section:

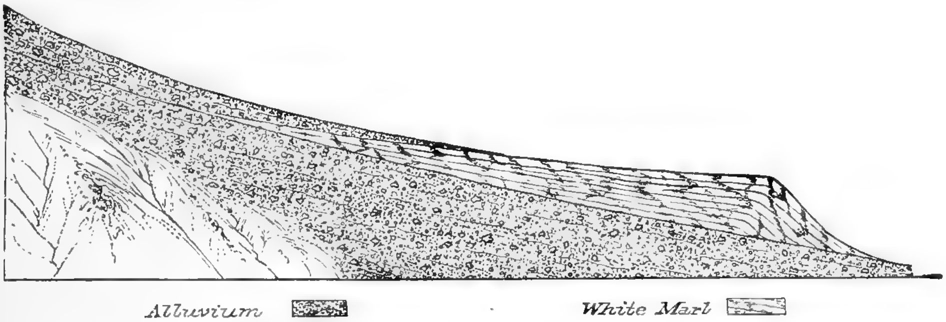


FIG. 24.—Section of White Terrace, west side of Pyramid Lake, Nevada.

In some instances the outer border of the terrace has been removed so that the steep lakeward dip of the strata is not always observable. At a number of localities the terrace is from 200 to 400 yards broad, with a plane or slightly concave upper surface which usually slopes gently lakeward; the outer scarp is steep and at times 30 or 40 feet high, but the deposit diminishes rapidly in thickness towards the shoreward margin. The marly beds are usually underlain by alluvium, as shown in the figure, and are overplaced along the shoreward margin by similar material that has been swept down from the slopes above. Sometimes the marls are deeply eroded and present typical "bad land" topography in miniature.

The White Terrace may be seen at a number of places about the northern end of Pyramid Lake, and in the pass leading to Honey Lake Valley. At the southern end of Smoke Creek Desert it was again observed, with its normal elevation of 320 feet above Pyramid Lake. Further northward, it occurs at a number of localities on the steep borders of the Black Rock Desert. From the numerous exposures observed it is evident that this terrace occurs all about the deeper portions of Lake Lahontan, and may be considered as co-extensive with the dendritic terrace with which it coincides in elevation. The occurrence of the marl as a shore deposit is independent of the character of the rock against which it rests; it occurs with equal purity on alluvial slopes and on shores of limestone, basalt, rhyolite, etc. It is found in abundance about isolated buttes that formed small islands in the former lake, as well as along the shores of the mainland, and is therefore evidently not a product of erosion. Occasionally, however, the marl is mingled with sand and pebbles, and when it takes the form of a free bar the proximal end will be found to contain more foreign material than the distal extremity, thus indicating the assorting power of the currents that transported the material.

At all the numerous localities where the White Terrace is exposed it is composed of fine, incoherent, chalky marl, which is often richly charged with the shells of fresh-water mollusks. In places the deposit is 40 or 50 feet thick, and homogeneous throughout. An analysis of a typical sample collected on the western border of Pyramid Lake Valley, as reported by Dr. T. M. Chatard, is given below, and shows that the material is essentially an impure calcium carbonate containing a high percentage of silica:

Water (H_2O)	3.32
Calcium carbonate ($CaCO_3$)	64.82
Silica (SiO_2)	22.00
Alumina (Al_2O_3)	5.14
Iron (Fe_2O_3)	2.04
Lime (CaO)	0.93
Magnesia (MgO)	1.89
	100.14

When examined microscopically the marl reveals a great quantity of crystallized and amorphous calcium carbonate, very similar in appearance to the same substance obtained by precipitation in the laboratory, together with other bodies which appear more clearly when the material is treated with diluted acid. On examining the residue insoluble in acids under the microscope, is found to contain many diatoms, especially in the finer and more flocculent portion of the sediment; the coarser portion, which subsides most quickly, also contains diatoms, but is mainly composed of crystalline grains and many glassy flakes similar to those composing the volcanic dust described on page 146. The chemical and microscopical examinations render it evident that the material in question is mainly a chemical precipitate, but is also, in part, of mechanical and organic origin.

It seems probable that the calcium carbonate forming the principal portion of the marl was precipitated from the waters of Lake Lahontan in a microcrystalline and amorphous form at about the time the dendritic tufa was being accumulated; and became mingled with the siliceous exuviæ of the microscopic organisms that lived in abundance in the lake waters; it also received some contributions of volcanic and æolian dust, but, in the main, was free from the products of ordinary stream erosion. The deposit thus formed, when near the shore, was assorted and rearranged by currents so as to form the terrace and embankments we now find. In the deeper portions of the lake the lime precipitated from the waters was mingled with clay and sand and now appears as marly-clay. The abundant precipitation near the shore may also have been due, in part, to the greater abundance of nuclei which tended by their presence to induce crystallization

ÆOLIAN SANDS.

The accumulations to be described under this head consist mainly of sand that has been blown about by the wind and finally deposited in banks or dunes which sometimes cover large areas.

The first acquaintance the explorer in the Great Basin usually makes with the material forming these deposits is when it is in motion and fills the air with clouds of dust, sand, and gravel, which are blinding and irritating, especially on account of the alkaline particles which saturate the atmosphere at such times. Dust-storms are common on the deserts during the arid season, and impart to the atmosphere a peculiar haziness that lasts for days and perhaps weeks after the storms have subsided. Whirl-winds supply a characteristic feature in the atmospheric phenomena of the Far West especially during calm weather, as noted already, and frequently form hollow dust-columns two or three thousand feet or even more in height, which may many times be seen in considerable numbers moving here and there over the valleys. The loose material thus swept about at the caprice of the winds tends to accumulate on certain areas and forms dunes or drifts that at times cover many square miles of surface. During its journey across the country the material which finds a resting place in the dunes becomes assorted with reference to size and weight, so that the resulting sand-drifts are usually homogeneous in their composition, but are characterized by extreme irregularity of structure when seen in section. In the Lahontan basin the subaërial deposits are usually composed of fine, sharp quartz sand, but in some instances small drifts are principally formed of the cases of ostracoid crustaceans.

A large area buried beneath sand dunes of post-Lahontan date occurs a few miles north of Winnemucca and extends westward from the lower part of Little Humboldt Valley to the desert between Black Butte and the Doña Schee Hills. This belt of drifting sand is about forty miles long from east to west by eight or ten miles in width. The drifts are fully seventy-five feet thick and present their steeper slopes to the eastward, thus indicating the direction in which the whole vast field of sand is slowly travelling. No measurements of the rate at which these drifts advance has been made, but their progress is evidently quite rapid, as it has necessitated a number of changes in the roads in the southern part of Little Humboldt Valley during the past few years. In some places in the same region the telegraph-poles have been buried so deeply that they required to be spliced in order to keep the wires above the crests of the dunes. The sand is here of a light creamy-yellow color, and forms beautifully curved ridges and waves that are covered with fret-work of wind-ripples, and frequently marked in the most curious manner by the foot-prints of animals, thus forming strange hieroglyphics that are sometimes difficult to translate.

Another area of drifting sand occurs to the southward of the Carson Desert and covers portions of Alkali Valley and the desert basins south of Allen's Springs. This train of dunes commences somewhat to the eastward of Sand Spring Pass, at the east end of Alkali Valley, and may be traced westward for at least twenty miles to the mountains on the east side of Walker River Valley. The width of the belt is not more than four or five miles. In a sheltered recess in Alkali Valley, a mile or two northwest of Sand Springs, the sand has been accumulated by eddying wind-currents so as to form a veritable mountain, rising, by estimate, two or three hundred feet above the plain. This ever-changing mountain of creamy sand varies its contours from year to year, while every zephyr that blows is busy in remodeling the rounded domes and gracefully curving crests and in altering the details of the tracery that gives grace and elegance to the structure. The dunes in this train, like those northward of Winnemucca, are traveling eastward across mountains and deserts and seem little affected in their ultimate course by the topography of the country. In the desert valley south of Allen's Spring the sand is carried up the steep eastern border of the basin and finds temporary resting places on the terraces cut by the waves of Lake Lahontan in the black basalt of its shores. The yellow sands loading these ancient terraces bring out the horizontal lines in strong relief by reason of their contrast in color and accent the minor sculpturing of the cliffs.

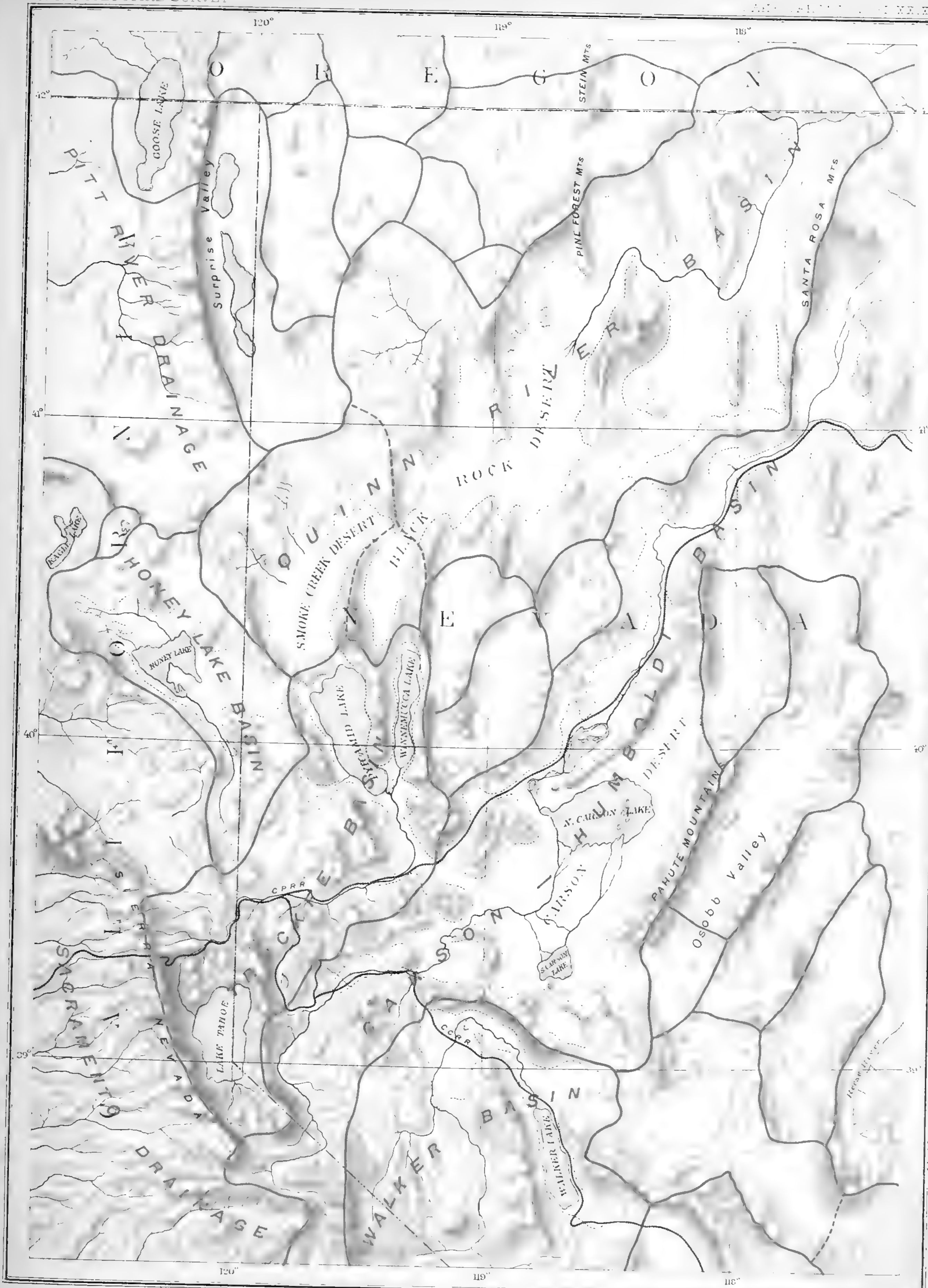
Another region of sand dunes covering an area a few square miles in extent is located at the southern end of Winnemucca Lake and threatens to obstruct the only stream that supplies that water body.

It is impossible to trace the sands forming these various dunes to their sources, but we may be sure that they have traveled far and were not derived from the waste of the rocks in their present neighborhood. Similar areas of drifting sand occur at many localities throughout the region west of the Rocky Mountains, a number of which are known to be traveling in the same direction as those of the Lahontan basin. It is possible, as has been suggested by previous writers, that these various areas all belong to a single series, and are formed of the beach sands of the Pacific which have been blown inland by the prevailing westerly winds. It seems more probable, however, that they owe their origin to the subaërial disintegration of the granites of the Sierra Nevada.

SECTION 4.—ANCIENT STREAM CHANNELS.

When the waters of Lake Lahontan subsided during inter- and post-Lahontan periods its basin became divided into separate water bodies or independent lakes, some of which were connected by streams that overflowed from one to another. The channels eroded by these streams are interesting not only as examples of erosion, but because they contribute to the interpretation of the history of the former lake. When a large inclosed lake is reduced so far by evaporation that the inequalities of its bottom divide it into independent areas, it is evident that this fact in itself is a record of an important climatic change; when the ridges or embankments that divide a lake in this manner are cut by channels of overflow, it is evident that they may furnish some index of the length of the period of desiccation or perhaps of the date at which it occurred. The multiplication of hydrographic basins by desiccation is illustrated by the present condition of the Lahontan region, as shown on Plate XXIX. The ancient lake basin is now divided into six independent drainage areas.

Old channels now abandoned and dry occur in the Lahontan basin, between the larger areas of the former lake and the neighboring valleys that once formed bays along its shore. The Carson Desert is united with the desert valley south of Allen's Springs by a deeply eroded channel of this nature, which appears to have been cut by a stream flowing northward; a moderate rise of the waters of the Carson Desert would flood this pass and reconvert it into a strait This channel is about 5 miles long, and has precipitous walls composed of lacustral sediments, which are lined with the form of tufa we have called dendritic, while in the bottom of the pass there are crags of thinolitic tufa; from these records we learn that the channel was excavated previous to the rise of the lake during which tufa deposits were formed. As the sequel will show, these tufas were deposited during that



Julius Bien & Co. Lith.

Hydrographic Boundaries

PRESENT DRAINAGE AREAS OF THE LAHONTAN REGION.

Lahontan Beach

Scale 20 miles = 1 inch

portion of Lahontan history that witnessed the accumulation of the upper clays; and since the walls of the channel are composed of lacustral sediments, the inference is drawn that it was excavated during an inter-Lahontan period of desiccation. It will appear, as we progress with our history, that this is but one of a number of independent lines of proof which show that Lake Lahontan had two high-water stages, separated by a time when it was greatly lowered by evaporation, and perhaps reached absolute dryness.

The ancient channels, now dry and abandoned, similar to the one connecting Carson Desert and the desert basin south of it, occur at the northern end of Pyramid Lake Valley; one of these leads to Honey Lake Valley and the other to Smoke Creek Desert. The former, known as Astor Pass, was never deeply excavated, showing that the valley in which Honey Lake is situated must have been an independent water-body during a large part of the Quaternary. The second, however, is a pass, now partially obstructed by gravel embankments, which must have been a narrow strait during the greater part of the Lahontan period. The bottom of this pass is on a level with the thinolite terrace in Pyramid Lake Valley, as shown by aneroid measurements, and is thought to have regulated the water in that valley in such a manner as to bring it frequently to the same level. This would be accomplished by allowing it to escape, at a certain horizon, on to the Smoke Creek Desert. It may be that this is the reason for the great strength of the thinolite terrace about Pyramid Lake. Another channel of a similar character, now known as the Ragtown Pass, connects the Carson Desert with the desert valley in which the Eagle Salt Works are situated. All these channels were in existence before the deposition of dendritic tufa, but the proof that they were excavated in lacustral clays is less definite. It is probable that some of them were occupied by streams before the first rise of the ancient lake. In some instances they have become partially re-excavated during the present period of desiccation, but usually they are still occupied by the upper clays.

Other channels of this character have been examined in the Lahontan basin, but their features are not so clearly defined as in the examples described above, and their bearing on the history of the former lake is consequently less definite.

Section 5.—ILLUSTRATIONS OF GEOLOGICAL STRUCTURE.

It is customary to consult the older and usually the more thoroughly consolidated stratified rocks for illustration of geological structure, but as such features are in many cases the records of the manner in which the beds were deposited, it is evident that they should occur in the newest as well as the oldest formations. It is well known that the history of the earth is a continuous record, however fragmentary it may seem at the present day, and that the processes of nature have been the same throughout the geological ages. Nowhere are these axioms more thoroughly sustained than in the recently desiccated lake basins of the Far West. As the gravels and finer sediments deposited in Lake Lahontan afford many instructive records of the circumstances under which they were accumulated, we have prepared the following brief summary of observations relating to geologic structure due to deposition, erosion, etc., believing that it will assist in interpreting similar phenomena when observed in older rocks, where they are frequently obscured by metamorphism and other changes.

STRATIFICATION AND LAMINATION.

The sediments forming the upper and lower portions of the Lahontan section consist of fine, homogeneous, evenly-stratified marly-clays, which show a distinct lamination parallel with the planes of bedding. Attention is called to the lamination of these deposits in connection with other features due to deposition, as it has manifestly resulted from the slow accumulation of fine sediments in thin layers, and does not owe its existence to pressure, as is the case in many older rocks. This is evident since both the upper and lower clays are alike laminated, while the higher members of the series at least have never been subjected to the pressure of superimposed deposits.

CURRENT BEDDING.

The gravels separating the upper and lower Lahontan clays are characterized by extreme irregularity, and afford many illustrations of structure due to deposition. They were deposited in the shallow waters and were much agitated by waves and currents, and among other features present typical examples of "current bedding," sometimes called "cross-bedding" and "false-bedding," as is abundantly illustrated in the walls of the Humboldt, Truckee, and Walker cañons. The beautiful curves presented by these irregular beds when seen in section are represented with much accuracy in the detailed sections illustrating the exposures observed. From the thousands of examples examined in various portions of the basin, those presented on Plates XXIII, XXIV, XXV, and XXVII, have been selected as types of this phenomenon. Not only is this structure remarkable for the grace and elegance of the curves produced, but each sweeping line and each curving stratum has an individual structure and varies through all degrees of fineness, and through very many shades and tints, which serve to distinguish it from adjacent deposits. The accuracy of the illustrations to which we have directed attention renders farther description of the forms presented by current-bedded gravels when seen in section unnecessary.

Examples of what may be properly designated as "drift bedding" are abundant, especially in the walls of the Truckee Cañon, which furnish fine examples of the oblique stratification produced when currents sweep sand and gravel along the bottom until the edge of a scarp is reached and then deposit them in inclined layers. Under favorable circumstances this action may continue until a stratum is formed that is obliquely stratified from top to bottom, perhaps several feet in thickness, and of wide extent, as illustrated in the central portion of the section exposed in the Truckee Cañon.

The deposition of current-borne *débris* in inclined strata sometimes takes place on a grand scale, as is illustrated by the section of the gravel deposits at the southern end of Humboldt Lake, shown in Fig. 17, and again by Fig. 20, which represents a section of a similar structure at the southern end of Winnemucca Lake. In the cañon of the Walker River, evenly-bedded strata inclined at an angle of from 15° to 20° are exposed in a section that is fully 200 feet high, as represented on Plate XXVIII. In all these examples, and in many others that have been studied, the current-borne gravels composing the strata were deposited in the inclined position they now occupy, and do not owe their inclination to a movement of the beds subsequent to their deposition. Stratified beds deposited at an incline are usually composed of water-worn gravel, but instances are not rare in the Lahontan basin of fine clays and marls that were formed in even layers inclined at an angle of from 10 to 20 degrees.

CONTORTED STRATA.

The folded and contorted appearance presented by many sedimentary beds may originate in two ways; either they were deposited in a horizontal position and subsequently disturbed, or they were laid down in agitated waters in the contorted forms we now find. The Lahontan sediments afford illustrations of each of these modes of origin.

Examples of contortion and deformation in the lower lacustral clays, obviously due to motion produced by the weight of the superimposed deposits, were observed at many localities. In the Truckee Cañon, disturbances of this nature occur, as shown in the lower portion of the illustration forming Plate XXV. At the left of the section the stratum of marly clay has been broken in an irregular manner and one part thrust over the other; at the right, in the same section, the strata are crumpled and folded in such a manner as to form anticlinals and synclinals in miniature. Other illustrations of similar disturbances may be seen in the section exposed along the Humboldt, Truckee, and Walker rivers. At the top of the section shown on Plate XXV, but weathered back so as not to appear in the drawing, there is a deposit of fine yellowish sand in contorted strata resting on the upper clays. This deposit contains crystals and rosette-like masses of selenite, and is evidently water-laid—not æolian as perhaps might be fancied—and from its position at the top of the section could never have been subjected to pressure or mechanical disturbance. The contortions and foldings of the thin sheets of sand composing this deposit are rendered especially distinct, when seen in section, by the presence of iron-stained lines and bands, which indicate a character of contortion that can only be explained by assuming that the beds were deposited in the irregular forms they now present. Similar contorted beds were observed in the Quaternary strata of the Mono Lake basin, California, in a bed of sand and pebbles 18 inches thick, inclosed between horizontal, evenly-bedded, ripple-marked clays and sand. In this instance the iron-stained lines marking the edges of contorted sheets, form a most intricate pattern when seen in section, and inclose pockets and cells sometimes four or five inches in diameter, that are without openings and packed full of gravel and stones; in some instances the pebbles thus enclosed are an inch or more in diameter and are all well waterworn. The presence of these cells filled with material of a different nature from the contorted sheets of sand, while the strata above and below the contorted layer are of fine sand and clay in even horizontal beds which show no crumpling, is evidently proof that the disturbance causing the irregularities of the deposit took place during the deposition of the strata and cannot be referred to subsequent mechanical movement. The conditions under which these contorted sands were accumulated are difficult to determine, but in some instances deposition seems to have taken place in shallow lakes that were greatly disturbed by winds and currents. The hypothesis which attributes the contortion of superficial strata to the action of advancing glaciers and grounded icebergs is not here admissible, as the relation of the lakes and glaciers is well known. The action of a moving ice sheet, formed by the freezing of a lake, might perhaps under certain conditions disturb the sediments beneath, and might even transport pebbles from the shore and drop them in offshore deposits; thus forming strata analogous to the exposure observed near Mono Lake. It is impossible, however, to account completely for all the phenomena observed by any of the hypotheses that have been suggested.

ARCHES OF DEPOSITION.

The finest example of an arch of deposition that has been observed in the Lahontan s ediments is represented in the section forming Plate XXV, and has already been noticed in describing the exposure to be seen along the Truckee River. This, with scarcely any doubt, is a section of a gravel bar, the top of which was removed previous to the deposition of the superimposed gravels. Similar arches, but less complete, may be seen in other portions of the Truckee section, and occur in greater or less perfection wherever a cross-section of a current-formed embankment or bar is exposed. That the arch represented on Plate XXV is the result of deposition and not of mechanical disturbance is clearly shown by the horizontal stratification of the material above and below it.

UNCONFORMABILITY BY EROSION AND DEPOSITION.

Wherever the junction of the medial gravels with the lower or upper clays is exposed, one is nearly always sure to find evidence of unconformability, resulting usually from the erosion of the older strata. Examples of this phenomenon are shown in nearly all the accompanying illustrations which include the junctions in question. On Plate XXVII, the cross-stratification of the gravels filling eroded hollows in the lower clays is admirably shown by Figs. A, C, and D. On Plate XXIII, Fig. G illustrates the manner in which the strata filling eroded hollows are sometimes thickened; while Fig. J shows a thinning of similar beds when deposited over a protuberance of the bottom on which they were laid down. Figure K, of the same plate, furnishes an example of current-bedded gravels covering the eroded surface of the lower clays, while a second line of unconformity, also resulting from erosion, parts the gravels themselves. Sometimes the variations due to erosion and deposition are complicated by the effects of subsequent lateral movement, as appears to have taken place in D, Plate XXIII. Unconformability by deposition alone, where erosion has but little effect, is shown in Fig. B, Plate XXVIII, which illustrates the contact of horizontal lacustral beds resting upon gravels that were deposited in inclined strata. Other examples of a similar character may be found in many of the accompanying illustrations.

JOINTING.

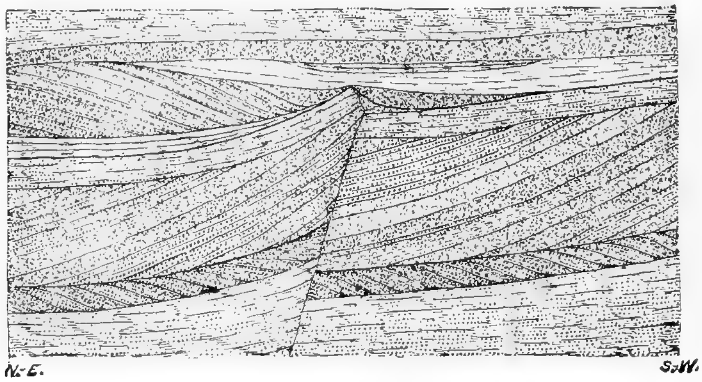
The marly clays forming the upper and lower members of the Lahontan series usually break into prismatic and cubical blocks on weathering; the vertical faces of the blocks are determined by joint planes, and the horizontal by planes of lamination. In many localities a more pronounced jointing occurs, forming two approximately vertical systems that are nearly at right angles to each other. Judging from the number of instances observed, at widely separated localities, the joints in question may be traced through the entire series of lacustrine beds. The occurrence of two distinct and well-marked systems of joints in a bed of marly clay 6 feet thick, lying between unconsolidated gravels, has been noticed on page 132. This may be taken for an example of what may be seen at numerous localities. The most striking exhibition of jointing that we have observed in the Lahontan strata occurs in the upper clays on the west side of the Humboldt River, near Saint Mary's. An arroyo has there exposed a vertical cliff 25 feet high, of homogeneous, marly clay that is cut from top to bottom by joints which divide the material into small pentagonal prisms that bear a superficial resemblance to basaltic columns. Specimens of these prisms may be collected that are 2 or 3 feet in length and not over 3 or 4 inches in diameter, with sharply-defined edges; in some instances the diameter of the columns is much less than here indicated, the prismatic form being still well preserved. The jointing of the Lahontan sediments is of the same nature as the similar phenomena observed in the Bonneville basin, the origin of which has been the subject of some discussion.[51]

FAULTS.

Two systems of faults have affected the sediments of Lake Lahontan; the first is of wide extent and due to a recent movement along the ancient lines of displacement which gave origin to the structural features of the region; the second is of local origin, and seems to be entirely independent of orographic disturbances. Displacements of the first class will be described in a future chapter devoted to the description of post-Lahontan orographic movements. The local faults in which we are interested at present are common in the soft, unconsolidated sediments of the ancient lake, but even in the most typical instances their displacement does not exceed a few feet, and, as indicated by several observations, they appear to have small vertical range, *i. e.*, their throw diminishes and finally disappears when

[51] G. K. Gilbert, "Post-Glacial Joints," American Journal of Science, Vol. XXIII, 1882, pp. 25–27. G. K. Gilbert, "On the Origin of Jointed Structures," American Journal of Science, Vol. XXIV, 1882, p. 50. John Le Conte, "Origin of Jointed Structure in Undisturbed Clay and Marl Deposits," American Journal of Science, Vol. XXIII, 1882, p. 233. W. O. Crosby, "On the Classification and Origin of Joint-Structure," Proceedings Boston Soc. Nat. Hist., Vol. XXII, 1882, pp. 72–85. H. F. Walling, "On the Origin of Joint Cracks," Proceedings American Association for the Advancement of Science, Vol. XXXI, 1882, p. 417.

traced downwards. Their hade usually approaches the perpendicular, and, as is common with the displacements in older rocks, slopes to the downthrow. In the instance represented below, however, the hade is reversed; this example occurs in unconsolidated gravels and clays of the Lahontan series at Mullen's Gap, on the western border of Pyramid Lake.



Scale of feet—vertical and horizontal the same.

0 5 10

FIG. 25.—Reverse fault in Lahontan gravels.

The upward bend of the strata on the heaved side of this fault may perhaps be accounted for by assuming that the displacement has undergone double movement. During the first, the block to the left of the plane of fracture, as it appears in the figure, was the thrown block; its downward movement caused the ends of the strata of which it is composed to bend upwards, as is common in similar displacements in older rocks; afterwards the movement was reversed, and what was previously the thrown side was upraised beyond its former position. The faulting took place in this instance previous to the deposition of the cross-stratified gravels represented in the diagram above the line of unconformability, as is proven by the fact that the plane of fracture does not extend through them. The interval between the disturbance causing the fault and the deposition of the superimposed beds was short, as is evident from the absence of erosion along the surface of unconformability.

Another illustration of the minor displacements that occur in the Lahontan sediments is given on Plate XXIII, Fig. A, which is remarkable for the narrowness of the block cut out by the double dislocation; this double fault is one of a pair, as is shown in the following figure, which is drawn to the same vertical and horizontal scale, and represents with considerable accuracy the exposure observed in the cañon wall.

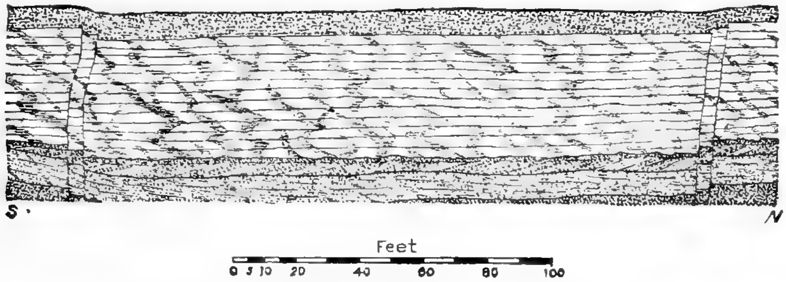


FIG. 26.—Faults in lacustral clays, Humboldt Cañon, Nevada.

This section includes the upper portion of the medial gravels, the upper clays, and the subaërial accumulations forming the surface of the desert.

In the walls of the Walker River Cañon, between Mason Valley and Walker Lake, there are many examples of faults which shear the lacustral deposits of the Lahontan series; two illustrations of the displacements there observed are given in Figs. A and B, Plate XXVIII. In the former, the actual fault is concealed by an alluvial slope, but the dip of the strata proves that it was formed previous to the deposition of the upper clays and probably before the medial gravels were accumulated. In the latter instance (Fig. B) the faulting occurred after the last rise of the ancient lake, and affected both the medial gravels and the upper clays. The inclination of the strata in the lower portion of this section is mainly due to their having been deposited in an inclined position. In this instance, as is usually the case in the faults we are considering, the general inclination of the beds due to deposition is but little disturbed. On Plate XVII, Fig. E, a number of faults belonging to the class we are considering are represented, which cut the stratified lapílli composing the ancient craters now occupied by the Soda Lakes near Ragtown, Nevada.

The faults noticed in the preceding paragraphs can only be studied to advantage when fresh sections of the Lahontan beds are exposed, and in no instance is their presence indicated by a scarp crossing the surface of the deserts.

The existence of faults shearing unconsolidated strata of sand and clay can scarcely be accounted for by the hypothesis of tangential strain, as has so often been done in the case of displacements in older and more consolidated rocks, as these beds are still horizontal and have not been subjected to the pressure of superimposed accumulations. The strata on either side of the planes of fracture are undisturbed. As the displacements are local and unconnected with any general orographic movements and in some instances die out as we trace them downwards, it seems safe to conclude that they have resulted from some change in the strata themselves, as is perhaps the case also with the joints occurring in the same beds. The Lahontan sediments were water-laid and are now desiccated. It may be that the contraction produced on drying will be found a sufficient explanation of the faulting and jointing that has been observed. The drying of heterogeneous stratified beds must result in unequal contraction of the various members of the series, at the same time that the unequal desiccation of various portions of the basin would complicate the resultant stress. In the Lahontan basin changes of this nature have taken place and have been accomplished by jointing and faulting. That these facts stand in the relation of cause and effect, however, is but a provisional hypothesis.

STRUCTURE OF TERRACES AND EMBANKMENTS.

While describing the formation of terraces and sea-cliffs it was shown that the loose material occurring on lake shores is sometimes swept along by currents and deposited so as to form a horizontal shelf bounded by a steep scarp on the lakeward slope. Owing to the mode of its formation, the structure of such gravel-built terrace is necessarily irregular, but as a whole is characterized by oblique stratification, especially on its lakeward margin, and abounds in examples of current bedding. Its material varies from accumulations of bowlders, sometimes two or three feet in diameter, through all degrees of comminution to the finest of silt and marl, and is usually of a heterogeneous character, dependent on the nature of the rock forming the lake shores. The general structural features of a built terrace are shown in the section inserted on page 151.

When a shore current bearing *débris* enters deep water, as illustrated by a simple instance on page 94, it commences the formation of an embankment, which is increased by the addition of gravel, sand, etc., in inclined strata at its end and along its sides. A cross-section of a regularly formed embankment should show a series of more or less perfect arches of deposition.

CONGLOMERATES AND BRECCIAS.

In many of the bars and terraces described in this report the gravel of which they are composed is firmly cemented by calcium carbonate into a compact conglomerate. A similar action has taken place in some of the alluvial slopes once submerged beneath the waters of the ancient lake, which at times has resulted in the formation of typical breccias. On the west shore of Pyramid Lake, near Mullen's Gap, the immediate lake margin is formed of sand and pebbles that have been consolidated into a firm conglomerate by the deposition of calcium carbonate. Similar beds were observed on Anaho Island and about the Needles at the northern end of the lake. In all these instances the conglomerate slopes lakewards at a low angle, sometimes amounting to ten degrees. This in all cases is evidently of a very recent date and in places is still being deposited. Although the youngest of the rock series, yet it is sufficiently consolidated to acquire a polish from the constant attrition of the sand that is washed over it and compact enough to be used for the ruder kinds of masonry. Similar conglomerates which appear also to be still in process of formation were observed on the shores of Walker, Winnemucca, and Mono lakes.

Breccias cemented by calcium carbonate are formed in alluvial slopes of the Great Basin above the limits of the Quaternary lakes. These deposits are usually less firm than the lacustral conglomerates, and frequently differ in the fact that the cementing material is accumulated most abundantly on the lower surfaces of the stones forming the deposit. The precipitation of calcic carbonate in the interstices of alluvial slopes apparently results from the evaporation of the percolating waters and the consequent deposition of the salts held in solution, which act as a cement and sometimes change a loose *débris* heap to a compact conglomerate or breccia. Subaërial deposits of this nature are common throughout the arid region of the Far West.

OOLITIC SAND.

The presence of oolitic sand on the shore of Pyramid Lake has already been referred to in connection with the general description of the lake. This material is evidently now forming, and in places has been cemented into a compact oolite by the deposition of a paste of calcium carbonate between the grains, and forms irregular layers several inches in thickness that slope lakewards at a low angle. The oolitic grains composing the beach sands are frequently a quarter of an inch or more in diameter, and would, perhaps, more properly be designated as pisolite. When examined in thin sections under the microscope each grain is seen to be made up of a large number of concentric layers of calcium carbonate surrounding a particle of sand or other foreign body which furnished the original nucleus. The spherical form of the grains and the uniform thickness of the concentric layers evidently indicates that the kernels were in motion during the slow deposition of the concentric shells of which they are principally composed. Oolitic sands occur also at a number of localities near the base of the dendritic tufa, thus indicating that the conditions necessary for the formation of a deposit of this nature were then prevalent throughout the entire area covered by Lake Lahontan. That the chemical conditions favoring the formation of oolitic sands vary through wide limits is shown by the fact that they are now forming both in Pyramid Lake and in Great Salt Lake. The former contains less than half of one per cent. of solids in solution, while the latter has varied from over twenty-two to about thirteen per cent. during the past twenty years.[52]

SURFACE MARKINGS.

The surfaces of lacustrine deposits when laid bare and subject to desiccation become covered with a net-work of shrinkage cracks and are not infrequently impressed with the foot-prints of animals; sometimes, too, the

[52] See table of analyses at C, page 180.

muddy surfaces are pitted by falling rain-drops or covered with ripple marks. When the waters again cover such an area, all these records may be concealed beneath superimposed strata and thus preserved for an indefinite time. They are, in fact, as well suited to become fossilized as the records of a similar nature so common among the Triassic rocks of the Atlantic slope. The markings inscribed on the surfaces of lake beds are identical with many records that are made on the sands and mud along the ocean's shore, and if fossilized, would in themselves give no indication of the character of the water-body on the borders of which they were formed.

COLOR OF LACUSTRAL SEDIMENTS.

From the study of the Triassic, Old Red Sandstone, and other formations of Europe,[53] Professor Ramsay was led to the conclusion that sediments deposited in inland waters were usually iron-stained. The reverse of this conclusion would probably have been reached had lake deposits been first studied in the Great Basin, as all the lacustral beds in that region are light colored and seldom show more than a trace of the presence of iron. Some of the inclined beds in the Walker River section have a pink tinge, due to the presence of iron, while some of the contorted sands we have described have a yellowish color. These features, however, are inconspicuous and do not affect the statement that the sediment in question are a total exception to the rule referred to above.

RÉSUMÉ OF PHYSICAL HISTORY.

To arrive at a satisfactory understanding of the physical history of Lake Lahontan, as recorded in terraces, gravel embankments, deltas, sedimentary deposits, river channels, etc., it is necessary to combine our observations of these phenomena with the records of the chemical history of the lake as furnished by tufa deposits and desiccation products, with reference, also, to the present physiography of the basin. Before considering the

[53] "On the Physical Relations of the New Red Marls, etc.," Quarterly Journal of the Geological Society of London, Vol. XXVII, p. 189. Also: "On the Red Rocks of England of older date than the Trias." *ibid.*, p. 241.

chemical questions connected with the present study, it may be well to see how far our observations relating to the physical history of Lake Lahontan can be correlated.

The presence of vast alluvial slopes of pre-Lahontan date, on which the water-lines of the old lake are traced, leads to the conclusion that the climate of the region was arid for a long time previous to the first filling of the basin of which we have any definite record, viz., the earlier high-water stage of Lake Lahontan. The discussion of this question, however, falls more properly in the chapter devoted to the consideration of Quaternary climate. We assume, for the present, that a change from arid to more humid conditions caused the Lahontan basin to be filled to the level of the lithoid terrace, and to remain at that horizon long enough to enable its waves to excavate a broad shelf in the rocky shores. The terraces above the lithoid are of subsequent date, as is shown by the section of the higher water-lines given on page 103; as there indicated the lithoid terrace is frequently a shelf cut in the rock, on which rest the built terraces that define the Lahontan beach. At other localities the lithoid terrace is represented by gravel embankments that are overplaced by much smaller structures of the same character at the level of the highest water-line. Cumulative evidence of this nature shows that the lake lingered at the horizon of the lithoid terrace for a much longer time than at the higher levels. The lithoid terrace and the Lahontan beach thus record two independent high-water stages. The fluctuations of the lake during the interval between the formation of these water-lines cannot be determined from the physical records alone, but are not difficult to sketch, at least in outline, when the tufas that were precipitated from the waters of the lake are considered. Turning to the stratified beds accumulated in the lake basin, we find two series of fine lacustral sediments separated by a widely-spread sheet of water-worn and current-bedded sands and gravels which were evidently deposited in shallow water. This record of two lake periods, with a time intervening when the basin was at least as nearly desiccated as at the present day, is perhaps the most positive of all the chapters of Lahontan history. That the formation of these two deposits of lake sediments may be correlated in time with the formation of the lithoid terrace and the Lahontan beach remains to be considered in connection with the chemical study of the lake.

The great number of water-lines scoring the interior of the Lahontan basin shows that the main changes in the history of the lake were accompanied by many minor fluctuations. The absence of an outlet renders it evident that the minor oscillations as well as the more permanent horizons recorded by the ancient terraces were due to climatic changes, the nature of which will be considered in a future chapter.

From this brief *résumé* it will be seen that the facts in the physical history of the lake can be correlated but imperfectly, yet give evidence that they have a definite sequence and are in fact fragments of a connected history. In the chemical studies which follow we shall be able to present some of the pages that are here missing and sketch the history of Lake Lahontan with greater completeness.

CHAPTER V.

CHEMICAL HISTORY OF LAKE LAHONTAN.

SECTION 1.—GENERAL CHEMISTRY OF NATURAL WATERS.

The investigation of the chemical history of a lake properly begins with the study of the meteoric waters that supply its hydrographic basin. Lakes are filled to some extent by direct precipitation from the atmosphere, but mainly by tributary streams and springs; it is evident, therefore, that we should look to these channels for the sources of the dissolved mineral matter which all lakes contain. It is true that lakes are sometimes formed by the isolation of portions of sea water, or may occur over beds of salt or other easily soluble rocks; but such cases are exceptional and their abnormal character easily accounted for.

RIVER WATER.

Even rain water and freshly fallen snow are not absolutely pure, but usually contain some organic and saline matter, together with carbonic acid, nitrogen, ammonia, chlorine, etc., which have been dissolved during their passage through the atmosphere. In an arid region, like the Great Basin, where the soil is commonly alkaline, and its surface frequently coated over large areas with saline efflorescences, the dust that is carried high in the air by the winds is richly charged with soluble salts which are dissolved by the falling rain, thus rendering it less pure than the meteoric waters of more humid regions. Rain water on reaching the earth dissolves the more soluble minerals with which it comes in contact, and becoming charged with carbon dioxide (carbonic acid), together with humic and crenic acids, and other organic products, it forms such an energetic solvent that but few substances can entirely resist its action. By the time the surface waters have united to form rills, they contain sufficient mineral and organic matter to have a complex chemical composition. On through their history, as they form brooks, creeks, and rivers, and finally merge with the ocean or some inland sea, they are constantly increasing their sum total of dissolved mineral matter, and are at the same time concentrated by evaporation. The waters of a river when filtered from all suspended matter and evaporated to dryness leave a solid residue which is the principal portion (the more volatile substances escaping) of the foreign matter held in solution. These waters are fresh in the every-day use of the term, but in fact owe their pleasant taste and, to a great extent, their health-giving qualities, to the mineral substances held in solution. In the following table the analyses of the waters of a number of American rivers are given, for the purpose of indicating what salts are contributed to lakes in greatest abundance by their tributaries. The principal impurities in nearly every instance are calcium and carbonic acid, probably combined in the waters as calcium bicarbonate; sometimes, however, calcium sulphate is in excess of any other salt, as in the case of the Jordan River, Utah. Surface waters derive their chemical impurities mainly from the rocks over which they flow, and consequently vary in composition with the geological character of their hydrographic basins. When draining a granitic or volcanic area they are usually rich in potash and soda; when flowing over limestone they are frequently saturated with calcium carbonate. This is illustrated in the Far West by the streams entering the Bonneville and Lahontan basins In the former they have their sources in the Wasatch Mountains where limestones occur, and are usually rich in calcium carbonate; potash is commonly absent, and soda, if present, is comparatively small in amount. In the Lahontan basin volcanic rocks predominate and the streams contain a higher percentage of potash and soda than is usual in a region underlain by sedimentary rocks.

By inspecting the table it will be seen, as stated above, that the most abundant of all the various substances carried in solution by the streams of this country is calcium carbonate. On averaging the amounts given in the tables we have 0.15044 part per thousand as the average of total solids, and 0.056416 part per thousand as the average of the calcium carbonate contained in the waters of American rivers.

In a table of 48 analyses of European river waters given by Bischof,[54] the average of total solids is 0.2127, and the average of calcium carbonate 0.1139 part per thousand. From the analyses of 36 European river waters published by Roth,[55] including some of those tabulated by Bischof, we obtain 0.2033 part per thousand as the average of total solids; and 0.09598 parts per thousand as the average of calcium carbonate. In both American and European river waters, so far as can be determined from the data at hand, the average of total solids in solution is 0.1888, and the average of calcium carbonate 0.088765 part per thousand. These figures may be assumed to represent the average composition of normal rivers. It will be noticed that the average for calcium carbonate amounts to nearly one-half of that for total solids.

Knowing the volume of a stream and the percentage of mineral matter it holds in solution, we can ascertain the amount of dissolved matter that it contributes annually to the ocean or enclosed lake to which it is tributary. To one unfamiliar with such investigations the amount of solid matter thus annually transported in an invisible state from the land to the sea will appear truly astonishing.

The Thames at Kingston, as determined by the Royal Rivers Pollution Commission of Great Britain, has an average daily flow of 1,250,000,000 imperial gallons; the water contains of inorganic impurities 19, and of organic and volatile 1.68 grains per gallon. This is equivalent to 3,364,286 pounds, or 1,682 tons (of 2,000 pounds each), of inorganic matter daily; of this two-thirds, or 1,121 tons, are calcium carbonate, and 271 tons calcium sulphate.

The average flow of the Croton River, which supplies New York City, is 400,000,000 gallons daily, which contain 365,428 pounds; or nearly 183 tons of impurities; of these 47 tons are calcium carbonate.[56]

[54] Chemical Geology, English edition, London, 1854, Vol. I, pp. 76 and 77.
[55] Chemical Geology, Berlin, 1879, Vol. I, pp. 456 and 457.
[56] Rep. American Public Health Association, Vol. I, p. 554.

The Hudson carries daily about 4,000 tons of matter in solution, of which more than 1,200 tons are calcium carbonate.[57]

The Mississippi, as determined by Humphreys and Abbot,[58] discharges annually 21,300,000,000,000 cubic feet of water; from the analyses of the water at New Orleans, by Dr. W. J. Jones,[59] we learn that the total of solids carried annually by the river amounts to 112,832,171 tons; of of which 50,158,161 tons are calcium carbonate. The amount of sediment transported by the river annually, as reported by Humphreys and Abbot, amounts to 887,500,000,000 pounds or 443,750,000 tons. The amount of solids, both in solution and suspension, carried annually to the sea, as determined from the data indicated above, is approximately 556,600,000 tons.

From the very incomplete observations on the discharge of the Humboldt River that have been made, we will assume 500 cubic feet, or, for convenience, 1,700 liters per second, as representing its average flow; each liter contains 0.3615 gram of solid matter in solution, which gives an annual transportation of about 18,000 tons; of this amount somewhat less than one-third, or approximately 5,000 tons, is calcium carbonate. In the same general manner we have estimated that the Carson, Truckee, and Walker rivers, collectively, transport annually about 10,000 tons of calcium carbonate. Not to overestimate we will assume that all the streams now entering the Lahontan basin carry annually 10,000 tons of calcium carbonate in solution. This estimate, although made on very imperfect data so far as the measurements of the streams are concerned, is certainly not too high, and enables one to understand whence the immense amount of calcium carbonate deposited in the form of tufa from the waters of Lake Lahontan was mainly derived.

SPRING WATER.

All the rain that falls does not find its way directly into the surface drainage, but a large portion sinks into the earth, and in many cases has a long underground passage before coming again to the light. During its subterranean course it takes an additional quantity of foreign matter into solution, and has its solvent power augmented by becoming more or less thoroughly charged with certain substances, such as carbon dioxide, which

[57] Report of the American Public Health Association, Vol. I, pp. 542–543.

[58] Report on the Mississippi River, p. 146.

[59] See Table of Analyses A.

act as solvents for many minerals otherwise not easily dissolved by water. Its solvent power is also augmented by the increase of temperature and pressure which it undergoes as it descends into the earth. The waters issuing as springs, frequently with a high temperature, are almost invariably found to have dissolved a great variety of mineral substances. In many instances the less soluble minerals occurring in spring waters are held in solution by the presence of carbon dioxide, or by high temperature or pressure. When such waters reach the surface they lose a large part of their dissolved gases, pressure is relieved, and they are rapidly cooled; the result is that much of the mineral matter they contain is deposited about the orifices through which they discharge. The substances most commonly precipitated under such conditions are calcium carbonate, oxides of iron and of manganese, calcium sulphate, and silica. Accumulations of these substances are frequently of great extent as may be amply illustrated in any of the hot-spring regions of the world. Only a portion of the dissolved matter brought to the surface by springs is thus deposited, however, and in many cases no immediate precipitation takes place. The waters, after losing their dissolved gases and becoming cooled, are usually much richer solutions than ordinary river waters, and, on joining the surface drainage, contribute large quantities of mineral matter to the neighboring streams. The solvent action of subterranean waters is frequently indicated by the porous and cellular character of certain rocks, as well as by the caves, frequently of vast size, that occur, especially in limestones.

The analyses of river waters in all ordinary instances must exhibit the combined result of the solvent action of both superficial and subterranean drainage. Springs frequently rise in the bottom of lakes or beneath the sea and thus contribute directly to the solutions with which rivers eventually mingle. In the case of inclosed lakes, the reaction of mineral waters, rising in dense saline solutions, is followed by interesting results, some of which will be considered in describing the tufa deposits of Lake Lahontan (*postea* page 221).

In illustration of the chemistry of natural waters we have compiled the following table (B) showing the composition of a few of the better known American springs and artesian wells; by comparison with Table A, the greater richness of subterranean waters over surface streams is at once apparent.

ce..	Humboldt	Truckee	Walker	Jordan	Mohawk	Genesee.
oint des.	Battle Mt., Nev.	Lake Tahoe, Nev.	Mason Valley, Nev.	Utah Lake....	Utica, N. Y...	Rochester, N. Y.
63..	Dec., 1872	Oct., 1872	Oct., 1872	Nov., 1873.....		
.... ana- , p.	T. M. Chatard. *Ante*, p. 41	F. W. Clarke. *Ante*, p. 42....	F. W. Clarke. *Ante*, p. 46...	F. W. Clarke. Bulletin No. 9, U. S. Geol. Surv., p. 29.	C. F. Chandler. Johnson's Cyclopedia, Vol. IV.	C. F. Chandler. Johnson's Cyclopedia, Vol. IV.
0513	.0467	.0073	.0318	.0178	.0036	.0044
0115	.0100	.0033	Trace.		.0009	.0023
3233	.0489	.0093	.0228	.0558	.0318	.0417
00585	.0124	.0030	.0038	.0186	.0069	.00896
00242	.0075	.0023	.0131	.0124	.0023	.0024
06836	†.1544	†.0287	†.0576	.0608	.0569	.0646
00831	.0477	.0054	.0284	.1306	.0187	.0431
e.						
03700	.0326	.0137	.0225	.0100	.0067	.0014
e.	.0013					
					.0013	.0014
e.						
e.						
					.0234	.0250
.16055	.3615	.0730	.1800	.3060	.1525	.19526

by difference.

Table A.—*Analyses of American river waters.*

[Reduced to parts per 1,000 by Dr. H. J. Von Hoesen.]

Name of river	Bear	Croton	Cumberland	Delaware	Hudson, N. Y.	James	Los Angeles	Maumee, Ohio	Mississippi
Collected at	Evanston, Wy.	Reservoir, N. Y.	Reservoir at Nashville, Tenn.	Reservoir at Trenton, N. J.		Richmond Water Works, Va.	Hydrant at Los Angeles, Cal.		Hydrant; city water works, New Orleans.
Date	Dec., 1873	1881				Oct. 24, 1876, after light rain.	Sept. 8, 1878		
Analyst	F. W. Clarke	E. Waller	N. T. Lupton	H. Wurtz	C. F. Chandler	W. H. Taylor	W. J. Jones	C. F. Chandler	W. J. Jones
Reference	Bulletin No. 9, U. S. Geol. Survey, p. 30.	Water supply of New York City, 1881.	Am. Chemist, July 16, 1876, p. 16.	Geol. of N. J., 1868, p. 702.	Public Health Papers, Vol. I, Am. Pub. Health Ass.	Ann. Rept. Board of Health, Richmond, Va., 1876.	Rept. Cal. State Board Health, 1878.	Rept. of Toledo Water Works, 1881.	Rept. La. St. Board of Health, 1882, p. 370.
Sodium, Na	.0082	*.00298	.01032	.00072	.00243	.00244	.02968	.00162	.0310
Potassium, K		.00154	.00050	.00178	.00058	.00251		.00309	
Calcium, Ca	.0432	.00905	.02987	.01104	.02220	.01284	.01750	.02645	.0372
Magnesium, Mg	.0125	.00336	.00280	.00435	.00465	.00377	.02097	.00443	
Chlorine, Cl	.0019	.00213	.00299	.00121	.00581	.00105	.01044	.00250	.0480
Carbonic acid, CO_3	†.0982	*.02248	.05727	.02552	.07278	.02054	.05635	.04438	.0383
Sulphuric acid, SO_4	.0105	.00441	.00563	.00175	.01257	.0 363	.05724	.01401	
Phosphoric acid, HPO_4				.00172		Trace.	.02638		
Nitric acid, NO_3			.00511			.00231			
Silica, SiO_2	.0070	.03360	Trace.	.00852	.00698	.01024	.02005	.00724	
Alumina, Al_2O_3				} .00047		.00041	.00171		
Sesquioxide of iron, Fe_2O_3								.00100	
Sesquioxides of iron and alumina, Fe_2O_3 and Al_2O_3		.00078	.00671		.00120				
Sesquioxides of iron and manganese, Fe_2O_3 and Mn_2O_3						.00072			
Carbonates of iron and manganese, $FeCO_3$ and $MnCO_3$							.00143		
Oxide of iron, FeO									
Oxide of manganese, MnO				Trace.					
Hydrogen in bicarbonates, H					.00121				
Chloride and sulphate of sodium, NaCl and $NaSO_4$									
Ammonia, NH_4						.00001			
Organic matter		.00100	.01666	} .01087	.01197	.00299		.00499	
Carbonates and sulphates of, Na, K and Mg									.0154
	.1845	.08433	.13786	.06795	.14238	.07246	.24475	.10971	.1699

Name of river	Ottawa	Passaic	Rio Grande del Norte	Sacramento	St. Lawrence	Humboldt	Truckee	Walker	Jordan	Mohawk	Genesee
Collected at	St. Ann's Lock, Montreal, Can.	4 miles above Newark, N. J.	Fort Craig, New Mexico.	Hydrant, Sacramento, Cal.	S. side, Point des Cascades.	Battle Mt., Nev.	Lake Tahoe, Nev.	Mason Valley, Nev.	Utah Lake	Utica, N. Y.	Rochester, N. Y.
Date	Mar. 9, 1854	1851	1873	Sept., 1878	Mar. 30, 1863	Dec., 1872	Oct., 1872	Oct., 1872	Nov., 1873		
Analyst	T. S. Hunt	E. N. Horsford	O. Loew	W. J. Jones	T. S. Hunt	T. M. Chatard	F. W. Clarke	F. W. Clarke	F. W. Clarke	C. F. Chandler	C. F. Chandler
Reference	Geol. of Canada, 1863, p. 567.	Geol. of N. J., 1868, p. 703.	U. S. Geog. Survey west 100th M., Vol. III, p. 576.	Rep. Cal. State Board Health, 1878.	Geol. of Canada, 1863, p. 567.	*Ante*, p. 41	*Ante*, p. 42	*Ante*, p. 46	Bulletin No. 9, U. S. Geol. Surv., p. 29.	Johnson's Cyclopedia, Vol. IV.	Johnson's Cyclopedia, Vol. IV.
Sodium, Na	.00239	.02357	.03220	.00200	.00513	.0467	.0073	.0318	.0178	.0036	.0044
Potassium, K	.00139	.00163	.00063		.00115	.0100	.0033	Trace.		.0009	.0023
Calcium, Ca	.00992	.01459	.01633	.01279	.03233	.0489	.0093	.0228	.0558	.0318	.0417
Magnesium, Mg	.00161	.00404	.00123	.00121	.00585	.0124	.0030	.0038	.0186	.0069	.00896
Chlorine, Cl	.00076	.03192	.03604		.00242	.0075	.0023	.0131	.0124	.0023	.0024
Carbonic acid, CO_3	.02255	.02634	.01025	.00887	.06836	†.1544	†.0287	†.0576	.0608	.0569	.0640
Sulphuric acid, SO_4	.00194	.01716	.04700	.00397	.00831	.0477	.0054	.0284	.1306	.0187	.0431
Phosphoric acid, HPO_4	Trace.		Faint trace.	.01794	Trace.						
Nitric acid, NO_3			Trace.								
Silica, SiO_2	.02060		Trace.	.03167	.03700	.0326	.0137	.0225	.0100	.0007	.0014
Alumina, Al_2O_3	Trace.	} .01342	Trace.	.00120	Trace.	.0013					
Sesquioxide of iron, Fe_2O_3											
Sesquioxides of iron and alumina, Fe_2O_3 and Al_2O_3										.0013	.0014
Sesquioxides of iron and manganese, Fe_2O_3 and Mn_2O_3											
Carbonates of iron and manganese, $FeCO_3$ and $MnCO_3$				.01088							
Oxide of iron, FeO	Trace.		Trace.		Trace.						
Oxide of manganese, MnO	Trace.				Trace.						
Hydrogen in bicarbonates, H											
Chloride and sulphate of sodium, NaCl and $NaSO_4$				.02431							
Ammonia, NH_4			Trace.								
Organic matter			.01392							.0234	.0250
Carbonates and sulphates of, Na, K and Mg											
	.06116	.13267	.15760	.11484	.16055	.3615	.0730	.1800	.3060	.1525	.19526

* Alkaline carbonates considered as sodium carbonates.

† Carbonic acid by difference.

TABLE B.—*Analyses of American spring waters.*

[Reduced to parts per 1,000 by Dr. H. J. Van Hoesen.]

Waters	Artesian well	Artesian well, "Glacier spouting spring."	Artesian well.*	Manitou Spring.	Opal Spring	Sulphur Spring	Hot Spring	Hot Spring	Boiling Spring.	Warm Spring.
Location	Lexington, Ky.	Saratoga, N. Y.	Sheboygan, Wis.	Manitou, Col.	Yellowstone National Park.	Los Angeles, Cal.	Hot Sp. Station, C. P. R. R.	Ward's Ranch, base of Granite Mts., Nev.	Shaffer's R'ch, Honey Lake Valley, Cal.	Warm Spring Sta., B. & B. R., Mono Basin.
Date		1872	Feb., 1876							
Analyst	R. Peters	F. A. Cairns and C. F. Chandler.	C. F. Chandler.	Oscar Loew	H. Leffman	Oscar Loew	T. M. Chatard.	T. M. Chatard.	T. M. Chatard.	T. M. Chatard.
References	Ky. Geol. Surv., N.S., Vol. V, p. 189.	Am. Chemist, Nov., 1872, p. 164.	Am. Chemist, 1876, p. 370.	U. S. G. S. W. 100th M., Vol. III, p. 618.	U. S. Geol. and Geog. Survey Id., Wyo. Ter., 1878, p. 393.	An. Rep. U. S. G. S. W. 100th M., 1876, p. 195.	*Ante*, p. 49	*Ante*, p. 53	*Ante*, p. 51	Bulletin No. 9, U. S. Geol. Survey, p. 27.
Sodium, Na	.09227	4.72640	2.0398	.45164	.4615	.10424	.7743	.3554	.3040	.6116
Potassium, K	.00919	.35806	.1285	.05980		Trace.	.0669	.0191	.0094	.0630
Calcium, Ca	.02136	.94050	1.0739	.44400	.0344	{ .50600†	.0305	.0367	.0121	.0589
Magnesium, Mg	.01805	.53470	.2352	.05860			.0010	.0034	.0004	.0604
Barium, Ba		.01848	Trace.							
Strontium, St	Trace.‡	.00057								
Lithium, Li	Trace.	.01078	.0003	.00039		Trace.				
Iron, Fe	Trace.§	.00341	.0027	Trace. ‖		Trace.				
Manganese, Mn			.0009			Trace.				
Chlorine, Cl	.07465	7.47400	4.2730	.24850	.7496	Trace.¶	.9697	.2396	.2070	.2272
Bromine, Br		.04661	.0025							
Iodine, I		.00060	Trace.							
Fluorine, Fl		Trace.**								
Carbonic acid, CO_3	.12160	5.82603	.1792	1.11001		.03516		Trace.		
Sulphuric acid, SO_4	.03218	.00234	2.0318	.20696	.0325	.16140	.3555	.3901	.3492	.5787
Phosphoric acid, HPO_4	Trace.	.00005	.0004			Trace.				.3131
Boracic acid, B_4O_7		Trace.	Trace.							
Alumina, Al_2O_3		.00770	.0022			Trace.	.0010			
Silica, SiO_2	.00940	.01174	.0080	.02010	.7680	Trace.	.2788	.1136	.1310	.0618
Hydrogen in bicarbonates, H		.09713	.0030							.1220
Organic substances	Trace.	Trace.	Trace.			Trace.				
Oxygen, O							.0194††	.0255††	.0080††	.0325††
Carbonic acid, CO_2	.37870	20.05910 2.015‡‡	9.9814	2.60000	2.0460	.80680 In excess.	2.4953	1.1834	1.0211	2.0632
Sulphureted hydrogen, H_2S						.05000			Trace.	

*Correction for specific gravity only approximate, as specific gravity was not given in original analyses.

† As carbonates.
‡ As carbonate.
§ As oxide.

‖ As carbonate.
¶ As sodium chloride.
** As fluoride of calcium.

†† Oxygen added to SiO_2 to form SiO_3 of Na_2SiO_3.
‡‡ Liters of gas thrown off per liter of water.

Face page 176.

...iah Lake	Owen's Lake, Cal.	Pyramid Lake,† Nev.	Sevier Lake, Utah.	Walker Lake,‡ Nev.	Winnemucca Lake, Nev.	Van Lake...	Aral Sea.
1.155	1.051	......	......	1.003	1.001	......	......
......	......	Aug., 1882.	1872......	Sept., 1882	Aug., 1882	......	......
...hcock .. ...tet Geo... ...gical Ex... ...loration ...f Dead ...a, p. 284.	O. Loew .... Appendix JJ Ann. Rep. Chief Engineers, 1876, p. 190.	F. W. Clarke *Ante, pp.* 57 and 58.	O. Loew .... U. S. Surv. W. 100 M., Vol. III, p. 114.	F. W. Clarke *Ante, p.* 70.	F. W. Clarke *Ante, p.* 63.	Chancourtois Bischof's Chemical Geology, Vol. I, p. 94.	Roth Chemical Geology, p. 465.
74.890	21.650	1.1796	28.840	.85535	1.2970	8.502§	2.4512
......	2.751	.0733	......	Trace.	.0686	.246	.0584
......	......	......	......	......	......	......	.0022
.529	Trace.	.0089	.118	.02215	.0196	......	.4581
2.914	Trace.	.0797	2.600	.03830	.0173	.157§	.5965
......	Trace.	......	......	......	......	......	......
......	......	......	......	......	......	Trace.¶	.0008
119.496	13.440	1.4300	45.500	.58375	1.6934	5.693	3.8386
......	......	......	......	......	......	......	.0029
......	13.140	.4990**	......	.47445**	.3458**	5.267§	.0918
7.671	9.362	.1822	9.345	.52000	.1333	2.555	3.3368
......	Trace.	......	......	......	......	......	.0011
......	Trace.	......	......	......	......	......	Trace.
......	Trace.	......	......	......	......	......	......
......	.164	.0334	......	.00750	.0275	.180	.0032
......	Trace.	......	......	......	......	......	......
......	......	......	......	......	......	......	......
......	......	......	......	......	......	......	Trace.
......	Trace.	......	......	......	......	......	Trace.
205.500	60.507	3.4861	86.403	2.50150	3.6025	22.600	10.8416

...s peroxide.

** Carbonic acid by diffence.

Table C.—*Analyses of the waters of inclosed lakes.*

[Reduced to parts per 1,000 by Dr. H. J. Van Housen.]

Locality	Abert Lake, Oregon.	Bogdo Lake	Caspian Sea, 2° W.S.W. of Pischina, at 15 feet depth, wind, WSW.	Caspian Sea, near mouth of the Volga.	Dead Sea, Ras Dale, surface.	Dead Sea, near the Island, surface.	Dead Sea, at 393 feet, between Ras Feschkak and Ras Zerka.	Dead Sea, at 656 feet, between Ras Feschkak and Ras Zerka.	Elton Lake
Specific gravity	1023.17				1.0216	1.1647	1.2225	1.2300	
Date	May 3, 1883				Mar. 20, 1864	Apr. 7, 1864	Mar. 15, 1864	Mar. 15, 1864	April
Analyst	F. W. Taylor	Gobel	Gobel	H. Rose	Terreil	Terreil	Terreil	Terreil	Gobel
Reference	Fourth Ann. Rep. U. S. Geol. Survey, p. 454.	Lartet Geological exploration of Dead Sea, p. 284.	Bischof's Chemical Geology, Vol. I, p. 89.	Bischof's Chemical Geology, Vol. I, p. 89.	Lartet Geological Exploration of Dead Sea, p. 278.	Lartet Geological Exploration of Dead Sea, p. 278.	Lartet Geological Exploration of Dead Sea, p. 278.	Lartet Geological Exploration of Dead Sea, p. 278.	Bischof's Chemical Geology, Vol. I, p. 403–405.
Sodium, Na	2.838	74.700	1.4410	.3081	.885	22.400	25.071	25.107	51.590
Potassium, K	10.880	1.041	.0398		.474	3.547	3.090	4.503	1.162
Rubidium, Rb									
Calcium, Ca		3.647	.1854	.1238	2.150	9.094	3.704	4.218	
Magnesium, Mg	.002	13.777	.4005	.0728	4.197	25.529	41.306	42.006	29.971
Lithium, Li									
Iron, Fe					Trace.	Trace.	Trace.	Trace.	
Chlorine, Cl	8.410	163.344	2.7376	.4570	17.628	126.521	166.340	170.425	159.498
Bromine, Br		.043	Trace.		.167	4.568	4.870	4.385	.059
Carbonic acid, CO_3	4.053		.1382	.3740	Trace.	Trace.	Trace.	Trace.	
Sulphuric acid, SO_4	.509	.108	1.3372	.3709	.202	.494	.451	.450	13.320
Phosphoric acid, HPO_4									
Nitric acid, NO_3									
Boracic acid, B_4O_7									
Silica, SiO_3	.004				.066	Trace.	Trace.	Trace.	
Alumina, Al_2O_3					Trace.	Trace.	Trace.	Trace.	
Hydrogen in bicarbonates, H			.0023	.0062					
Ammonium, NH_4					Trace.	Trace.	Trace.	Trace.	
Organic matter					Trace.	Trace.	Trace.	Trace.	Trace.
	27.357	256.750	6.2940	1.6540	25.709	192.153	245.732	251.103	255.600

Locality	Elton Lake	Elton Lake	Great Salt Lake.	Great Salt Lake.	Great Salt Lake.	Humboldt* Lake.	Indevsk Lake.	Soda Lake, near Ragtown, Nev., at 1 foot below surface.	Soda Lake, near Ragtown, Nev., at 100 feet below surface.
Specific gravity		1.27288	1.170	2.4	1.102	1.007		1.101	1.101
Date	August	October	1850	1869	Aug., 1873				
Analyst	Erdman	H. Rose	L. D. Gale	O. D. Allen	H. Bassett	O. D. Allen	Gobel	T. M. Chatard	T. M. Chatard
Reference	Bischof's Chemical Geology, Vol. I, p. 403–405.	Bischof's Chemical Geology, Vol. I, p. 403–405.	Stambury's expedition to Great Salt Lake, p. 419.	U. S. Geol. Expl. 40th par., 1877, Vol. II, p. 435.	Amer. Chemist, 1874, p. 395.	U. S. Geol. Expl. 40th par., 1877, Vol. I, p. 528.	Lartet Geological Exploration of Dead Sea, p. 284.	*Ante* p. 70.	*Ante*, p. 70.
Sodium, Na	29.300	15.060	85.330	49.690	38.3	.27842	94.050	41.632	40.206
Potassium, K		1.204		2.407	9.9	.06083	.529	2.290	2.425
Rubidium, Rb									
Calcium, Ca	.106		Trace ‖	.255	.6	.01257	.123		
Magnesium, Mg	45.508	60.540	.636	3.780	3.0	.01648	5.076	.215	.245
Lithium, Li				Trace.		Trace.			
Iron, Fe									
Chlorine, Cl	166.890	171.936	121.454	83.946	73.6	.29545	158.687	41.496	40.206
Bromine, Br				Trace.					
Carbonic acid, CO_3	.272					.20126		15.650**	18.658**
Sulphuric acid, SO_4	17.734	42.560	12.400	9.858	8.8	.03010	3.065	11.771	11.943
Phosphoric acid, HPO_4						.00009			
Nitric acid, NO_3									
Boracic acid, B_4O_7				Trace.		Trace.		.285	.287
Silica, SiO_3						.03250		.275	.281
Alumina, Al_2O_3									
Hydrogen in bicarbonates, H									
Ammonium, NH_4									
Organic matter	5.080	Trace.							
	264.980	291.300	222.820	149.936	134.2	.92860	261.530	113.641	113.651

Locality	Mono Lake, Cal., at 1 foot below surface.	Urmiah Lake	Owen's Lake, Cal.	Pyramid Lake,† Nev.	Sevier Lake, Utah.	Walker Lake,‡ Nev.	Winnemucca Lake, Nev.	Van Lake	Aral Sea.
Specific gravity	1.048	1.155	1.051			1.003	1.001		
Date	July 16, 1883			Aug., 1882	1872	Sept., 1882	Aug., 1882		
Analyst	T. M. Chatard	Hitchcock	O. Loew	F. W. Clarke	O. Loew	F. W. Clarke	F. W. Clarke	Chancourtois	
Reference	Bulletin No. 9, U. S. Geol. Survey, p. 26.	Lartet Geological Exploration of Dead Sea, p. 284.	Appendix JJ Ann. Rep. Chief Engineers, 1876, p. 190.	*Ante*, pp. 57 and 58.	U. S. Surv. W. 100 M., Vol. III, p. 114.	*Ante*, p. 70.	*Ante*, p. 63.	Bischof's Chemical Geology, Vol. I, p. 94.	Roth Chemical Geology, p. 465.
Sodium, Na	18.100	74.890	21.650	1.1796	28.840	.85535	1.2970	8.502§	2.4512
Potassium, K	1.111		2.751	.0733		Trace.	.0626	.246	.0584
Rubidium, Rb									.0022
Calcium, Ca	.278	.529	Trace.	.0089	.118	.02215	.0196		.4581
Magnesium, Mg	.125	2.914	Trace.	.0797	2.600	.03830	.0173	.157§	.5065
Lithium, Li			Trace.						
Iron, Fe								Trace.¶	.0008
Chlorine, Cl	11.610	119.496	13.440	1.4300	45.500	.58575	1.6934	5.693	3.8386
Bromine, Br									.0029
Carbonic acid, CO_3	14.465**		13.140	.4990**		.47445**	.3458**	5.267§	.0918
Sulphuric acid, SO_4	6.520	7.671	9.362	.1822	9.345	.52000	.1333	2.555	3.3368
Phosphoric acid, HPO_4			Trace.						.0011
Nitric acid, NO_3			Trace.						Trace.
Boracic acid, B_4O_7	.153		Trace.						
Silica, SiO_3	.268		.164	.0334		.00750	.0275	.180	.0033
Alumina, Al_2O_3			Trace.						
Hydrogen in bicarbonates, H									
Ammonium, NH_4									Trace.
Organic matter			Trace.						Trace.
	49.630	205.500	60.507	3.4861	86.403	2.50150	3.6025	22.600	10.8416

* Loss .01254 carbonic acid added to amount found: Average of two analyses. † Average from four analyses. ‡ Average of two analyses. § As sesquicarbonates. ‖ As chloride. ¶ As peroxide. ** Carbonic acid by difference.

To illustrate still further the complex character of the mineral matter impregnating spring waters, and at the same time to indicate the changes in composition to which springs are subject, we give below two analyses of the waters of the same spring collected at different seasons. The sample obtained in October was secured after a rain that followed a long dry period, and probably owes its greater richness to saline efflorescences accumulated in the interstices of the rocks during the arid season and redissolved by the percolating rain water:

Rockbridge Alum Spring No. 4, Rockbridge County, Virginia.[60] *Analyses by Prof. M. B. Hardin.*

[Reported in grains of anhydrous constituents in one U. S. gallon.]

Constituents.	Collected June 9, 1872.	Collected October 25, 1872.
Arsenic		trace.
Antimony		trace.
Lead sulphate		trace.
Copper sulphate	0. 00161	0. 10370
Iron persulphate	trace.	2. 90122
Iron protosulphate	0. 87962	
Manganese sulphate	0. 51527	1. 37352
Nickel sulphate	0. 05433	0. 22371
Colbalt sulphate	0. 03835	0. 08124
Zinc sulphate	0. 05225	0. 21748
Aluminum sulphate	18. 90905	72. 37335
Calcium sulphate	0. 35228	2. 31527
Magnesium sulphate	1. 50165	7. 36110
Potassium sulphate	0. 06278	0. 17586
Sodium sulphate	0. 00876	0. 03463
Lithium sulphate	0. 01790	0. 03241
Free sulphuric acid	2. 53866	3. 06633
Silicic acid	1. 92591	4. 38346
Sodium chloride	0. 14246	0. 14246
Calcium phosphate	trace.	0. 05174
Calcium fluoride	trace.	trace.
Ammonium nitrate	trace.	trace.
Organic matter	trace.	trace.
	27. 09088	94. 83748
Specific gravity at 60° Fahr	1. 0004	1. 00174
Cubic inches of gases in gallon of water:		
Carbon dioxide	not determined.	12. 72
Oxygen	not determined.	1. 64
Nitrogen	not determined.	4. 12

Temperature of spring 54.5° Fahr.

Springs of even more complex composition than the example given above might be presented if desired; in fact, subterranean waters are so

[60] American Chemist, 1884, p. 247.

nearly a universal solvent that all known mineral substances may be expected to occur in them. The recently discovered elements caesium and rubidium were first obtained by Bunsen in the mineral waters of Durkheim and Baden-Baden. It is to be hoped that a more minute examination of the springs of this country may lead to a similar increase in our knowledge of the constituents of the earth.

OCEAN WATERS.

Rivers with their loads of mineral matter in solution, derived both from surface and subterranean drainage, commonly flow into the ocean and are evaporated. The water rising in invisible vapor from the ocean's surface is again condensed, and much of it falls on the land as snow, rain, and hail, thus completing the cycle of changes. The mineral matter contributed to the ocean in solution, together with the substances dissolved directly from the bottom and sides of the oceanic basins, remains when the waters evaporate, and tends to increase the salinity of the sea. The precipitation of mineral matter from the waters of the ocean or its assimilation during the growth of plants and animals need not be considered at this time.

The results of chemical investigations, particularly those of Forchhammer and the chemists of the Challenger Expedition, have shown that the composition of the total solids dissolved in sea water from all portions of the ocean—excepting in the immediate vicinity of the land or near the mouths of large rivers—and for all depths, is remarkably constant. Disregarding the presence of the rarer substances, Dittmar gives the average composition of the solids dissolved in sea water as follows:[61]

Chloride of sodium	77.758
Chloride of magnesium	10.878
Sulphate of magnesia	4.737
Sulphate of lime	3.600
Sulphate of potash	2.465
Bromide of magnesium	0.217
Carbonate of lime	0.345
Total salts	100.000

A table giving the composition of the waters of the ocean at many localities, as determined by Professor Forchhammer,[62] is introduced here for

[61] The Voyage of H. M. S. Challenger, Physics and Chemistry, Vol. I, p. 204.
[62] Philosophical Transactions of the Royal Society of London, Vol. CLV, p. 257.

comparison. It shows not only the average composition of the great bulk of the waters of the globe, but illustrates one of the most important stages in the history of natural waters.

Comparison of the means of all regions of the ocean (German Ocean, Kattegat, Baltic, Mediterranean, and Black Sea excepted).

[Expressed in parts per thousand.]

Region.	Chlorine.	Sulphuric acid.	Lime.	Magnesia.	All salts.
The Atlantic between the equator and N. lat. 30°	20.034	2.348	0.595	2.220	36.253
The Atlantic between N. lat. 30° and a line from the north point of Scotland to Newfoundland	19.828	2.389	0.607	2.201	35.932
The northernmost part of the Atlantic	19.518	2.310	0.528	2.160	35.391
The East Greenland current	19.458	2.329	......	......	35.278
Davis Straits and Baffin's Bay	18.379	2.208	0.510	2.064	33.281
The Atlantic between the equator and S. lat. 30°	20.150	2.419	0.586	2.203	36.553
The Atlantic between S. lat. 30° and a line from Cape Horn to the Cape of Good Hope.	19.376	2.313	0.556	2.160	35.038
The ocean between Africa, Borneo, and Malacca	18.670	2.247	0.557	2.055	33.868
The ocean between the southeast coast of Asia, the East Indian and Aleutic islands	18.462	2.207	0.563	2.027	33.506
The ocean between the Aleutic and the Society islands	19.495	2.276	0.571	2.156	35.219
The Patagonian cold-water current	18.804	2.215	0.541	2.076	33.966
The South Polar Sea	15.748	1.834	0.498	1.731	28.565
Mean	18.999	2.258	0.556	2.096	34.404

It is evidently difficult, if not impossible, to obtain an accurate average of the composition of the ocean in all latitudes and at all depths, but a convenient approximation to the truth may be reached The mean of 34.404 parts per thousand, given in the above table, is the result of a very large number of analyses, but includes regions of high northern and high southern latitude, where the sea must be somewhat affected by the melting of the great glaciers of these regions. It seems questionable, therefore, whether the mean given above is high enough to be taken as the average salinity of the ocean. Leaving out the analyses of the waters of Davis Strait and of the South Polar Seas, we obtain a general average of 35.101. From 134 analyses of waters from various parts of the open ocean, given in Roth's Chemical Geology, the general average of 34.957 parts per thousand was obtained. Dittmar states[63] that of 160 analyses of sea water collected by the Challenger Expedition—

	Parts per thousand.
The lowest (from the southern part of the Indian Ocean, south of 66° S. lat.) contained	33.01
The greatest (from the middle of the North Atlantic, at about 23° N. lat.) contained	37.37
Average	35.19

In general, therefore, we may assume 3.5 per cent. as the average of total solids in sea water.

Besides chlorine, sulphuric acid, calcium, magnesium, and sodium, which make up $\frac{99}{100}$ of the total salts dissolved in the ocean, the investigations of Forchhammer and others have demonstrated the presence of 26 elements in solution, including bromine, iodine, flourine, phosphorus, silicon, boron, silver, gold, copper, lead, zinc, cobalt, nickel, iron, manganese, aluminium, magnesium, strontium and barium. Many of these are present in extremely small quantities, and have only been detected by the aid of the spectroscope; while the presence of others has been determined by indirect analysis. As methods of research become more refined, and larger bodies of water are dealt with, it is to be presumed that more of the elements entering into the composition of the earth will be found dissolved in the waters of the ocean.

The following comparison of the composition of ocean and river waters is from Roth's Chemical Geology; the figures represent the mean of a large number of analyses, and give percentages of total solids:

Constituents.	Ocean water.	River water.	River water in regard to *a*, *b*, and *c* only.
a. Carbonates	0.21	60.1	80
b. Sulphates	10.34	9.9	13
c. Chlorides	89.45	5.2	7
d. Other matter	....	24.8	....

This comparison indicates the result of a very complicated series of changes, dependent upon both biological and chemical reactions, which occur when river waters are subjected to the process of concentration that

[63] Voyage of H. M. S. Challenger, Chemistry and Physics, Vol. I, p. 201.

takes place in the ocean. As shown in the table, the carbonates mostly disappear, the sulphates increase slightly in percentage, while chlorides (mostly common salt) become the characteristic ingredient.

WATERS OF INLAND SEAS.

When rivers empty into a basin that has no outlet, their waters are evaporated in the same manner as in the ocean, and both their mechanical and chemical impurities are left as additions to the filling of the depression. Examples of such areas of interior drainage are well known in various parts of the world. In southern Asia, the Caspian, Aral, Dead Sea, and many other saline lakes, are the evaporating basins for independent hydrographic areas. The region of the Sahara in northern Africa is also shut off from the general oceanic circulation, but, owing to the high mean temperature there prevalent, the surface waters are mostly dissipated before lakes are formed. In South America another basin situated in the elevated tablelands of Peru and Bolivia is without drainage to the ocean. In North America there are small areas of a similar nature in Mexico; but the typical example on this continent is furnished by the Great Basin. Many of the lakes and seas situated in these various interior basins are without outlet, and are highly charged with saline matter. In some instances the percentages of the most abundant salts have reached their points of saturation and precipitation is taking place. The greater density of many inclosed lakes as compared with the ocean is due to the fact that concentration has been greatest in the restricted basins The paucity of animal and plant life in most inclosed lakes has also some slight bearing on the problem.

To facilitate the comparison of the inclosed lakes of this country with similar waters elsewhere, we introduce a somewhat extended table of analyses of this class of lakes, embracing all within the United States the composition of which is known. This table includes the densest of natural waters and exhibits the extreme of a series that commenced with the nearly pure water formed by the condensation of atmospheric vapor.

When inclosed lakes were first studied it was quite naturally supposed that their usual saline condition could only be accounted for by assuming that they were isolated bodies of sea-water which had been shut off from the general area by an elevation of the land. This hypothesis has been mostly abandoned, however, as one lake after another has been studied, until at the present time it is difficult, if not impossible, to point to a single lake, excepting perhaps the Caspian, having such a history. The origin of the salt lagoons found on so many shores is not here included, as their mode of formation is too obvious to admit of their being confounded with inland seas.

SUCCESSION OF SALTS DEPOSITED UPON EVAPORATION.

As already seen, inclosed lakes are constantly receiving additions from streams, springs, and rain, but do not overflow, their influx being counterbalanced by evaporation. This assures us that their percentage of saline matter must increase. This process continuing, a point is eventually reached when the waters are saturated with one or more of the more abundant salts and precipitation commences. Very simple experiments suffice to prove that waters of complex composition, when subject to slow evaporation, do not deposit their salts in a homogeneous mass, but in successive layers or strata of varying composition. As the order in which different salts are deposited varies with the composition of the waters, it is safe to say that in no two lakes is the succession of saline deposits formed on evaporation apt to be identical. Disregarding for the present the reactions of the various salts upon each other, it is evident that in the evaporation of natural brines the order in which the contained salts will be deposited is inversely as the order of their solubility. For example, a salt that requires a large amount of water for its solution, or, in other words, is sparingly soluble, will reach its point of saturation and commence to crystallize out, as evaporation progresses, previous to the deposition of a more soluble salt. To illustrate, it has been found that calcium carbonate requires about 10,000 times its weight of water, saturated with carbon dioxide, for its solution, while calcium chloride is very deliquescent and dissolves in nearly its own weight of water. In inclosed lakes to which streams are contributing these salts in equal quantities, and in which evaporation equals or exceeds the supply of fresh water, it is evident that the calcium carbonate would reach its point of saturation and commence to separate long before the waters had become rich in calcium chloride. In fact, owing to its deliquescent nature, natural evaporation seldom proceeds far enough to cause the precipitation of the chloride. The early deposition of calcium carbonate when natural waters are evaporated is rendered the more certain for the reason that it is by far the most abundant salt found in surface waters.

The fact that various salts are deposited in a regular succession when mineral waters are evaporated, is of great service in securing certain ones in a pure state by the method of fractional crystallization. In evaporating the brines of Syracuse the precipitation of ferric oxide and calcium sulphate is first secured by moderate concentration; the water is then conducted to lower vats and evaporation is continued until the sodium chloride has mostly crystallized. The mother liquor, rich in magnesium and calcium, is then allowed to go to waste. In the Soda lakes near Ragtown, Nevada, sodium and calcium carbonates crystallize out as the mineral gaylussite, by the natural concentration of the waters; when evaporation is continued, the deposition of sodium sulphate and carbonate takes place previous to the crystallization of common salt.

On concentrating sea water it has been found that calcium carbonate is usually the first constituent to be precipitated. This salt is not always found when the waters of the ocean are analyzed, but may usually be detected when the sample examined is taken near shore. The quantity delivered to the ocean by the drainage of the land, seems to be almost exactly counterbalanced by its secretion in the tissues of animals and plants.

The separation of sodium sulphate, potassium chloride, and common salt from the mother liquor derived from the concentration of sea water, by alternate evaporation and cooling, is the principle of Balard's well-known process so largely used in the south of Europe. In Merel's modification of this process a low temperature is obtained artificially. When sea water is concentrated until its specific gravity is 1.24 (28°B.) it deposits about four-fifths of the common salt it originally contained; after adding 10 per cent. of fresh water to the mother liquor remaining, it is passed through a refrigerating machine and its temperature lowered to—18° C. The low temperature causes double decomposition to take place between the magnesium sulphate and the sodium chloride; sodium sulphate being deposited and the magnesium chloride remaining in solution. The mother liquor still retains some common salt together with potassium chloride. The first of these is obtained by evaporating until the specific gravity of 1.33 (36°B.) is reached, which causes the deposition of nearly all the common salt; the remaining liquor is then conducted to shallow vats and allowed to cool; this causes the precipitation of the whole of the potassium as the double chloride of potassium and magnesium.[64]

The succession of chemical precipitates formed when sea water is evaporated has been succinctly described by M. Dieulafait, in the Popular Science Monthly,[65] from which we quote the following:

> First a very weak precipitation occurs of carbonate of lime with a trace of strontium, and of hydrated sesquioxide of iron, mingled with a slight proportion of manganese. The water then continues to evaporate, but remains perfectly limpid, without forming any other deposit than the one I have mentioned, till it has lost 80 per cent. of its original volume. It then begins to leave an abundant precipitate of perfectly crystallized sulphate of lime with two equivalents of water, or gypsum, identical in geometrical form and chemical composition with that of the gypsum-beds. This deposit continues until the water has lost 8 per cent. more of its original volume; then all precipitation ceases till 2 per cent. more of the original quantity of water has evaporated away. Then a new deposit begins, not of gypsum, but of chloride of sodium, or sea-salt. * * * The deposition of pure or commercial salt continues till the volume of the water has been again reduced by one-half, when a precipitation of sulphate of magnesia begins to take place with it. This continues, the two salts being deposited in equal quantities, till only 3 per cent. of the original quantity of water is left. Finally, when the water has been concentrated to 2 per cent., carnallite, or the double chloride of potassium and magnesium is deposited. Spontaneous evaporation cannot go much further. The residual mother-water will not dry up at the ordinary temperature even in the hottest regions of the globe; its chief constituent is chloride of magnesium. A body of sea-water, evaporated naturally, will then leave a series of deposits in which we will find, as we dig down, the following minerals in order: deliquescent salts, including chiefly chloride of magnesium; carnallite, or the double chloride of potassium and magnesium; mixed salts, including chloride of sodium and sulphate of magnesia; sea-salt, mixed with sulphate of magnesia; pure sea-salt; pure gypsum; weak deposits of carbonate of lime with sesquioxide of iron, etc.

The correspondence between the succession of salts formed by the evaporation of sea-water, and the succession found in many saline deposits now worked for rock salt, is of great interest, and no doubt explains the genesis of some saline deposits. It is not always necessary, however, in the explanation of the presence of salts in lenticular basins to assume that the deposits commenced with isolated portions of sea-water. On the contrary the study of inclosed basins indicates that deposits of this nature sometimes result from the long continued concentration of ordinary river-waters. The presence of salt or fresh water mollusks associated with saline

[64] Report of Juries: International Exhibition, 1862, Class II, pp. 48–54.

[65] October, 1882.

deposits, in some instances, gives evidence as to whether the beds in which they occur were precipitated from ocean or inland waters.

The precipitation of salts in inclosed lakes is still farther illustrated by Great Salt Lake, Utah, the composition of which in the years 1850, 1869, and 1873, is given in Table C. At the present time the lake is lower than in 1873, when the last analysis was made, but there is no reason to suppose that there has been any change in the salts with which the waters are charged. As in all inclosed lakes, the percentage of total salts in a given quantity of the brine changes as the waters rise and fall. To illustrate, the amount of saline matter contributed to Great Salt Lake during a single year, for example, is so small in comparison with the quantity which the lake holds in solution, and varies so little from year to year, that the composition of the residue obtained by evaporating a sample of the lake brine would remain practically constant for a long period, provided precipitation did not take place. The amount of water reaching the lake varies with the seasons, and also undergoes secular fluctuations, dependent on climatic changes, extending over a term of years. The brine is thus diluted when the lake is unusually full, and greatly concentrated when the lake is reduced abnormally by evaporation.

Owing to the large amount of sodium sulphate dissolved in the waters of Great Salt Lake, and since it is much more soluble in warm than in cold water, its precipitation takes place during cold weather. When the temperature rises it is redissolved. If the waters of the lake are cooled artificially to about 20° Fahrenheit, an abundant precipitation of flocculent sodium sulphate takes place. Each year, on the approach of cold weather, the waters of the lake lose their transparency and become cloudy and opalescent, owing to the precipitation of sodium sulphate in a state of minute subdivision. In the depth of winter the temperature of the atmosphere about the lake sometimes falls as low as —20° F. On these occasions sodium sulphate is precipitated in immense quantities and collects along the shores in thousands of tons. Nature has here anticipated Balard's process for obtaining sodium sulphate, and is carrying on the operation on a grand scale.

From the analyses of the tributary streams we know that large quantities of calcium carbonate are contributed to Great Salt Lake in solution; but the chemist fails to find this salt in the brine itself. The extreme scarcity of animal and plant life in the waters shows that it could not be removed by organic agencies; it must, therefore, either be precipitated or perhaps in part decomposed and changed to the chloride. The very small percentage of calcium in the lake, however, is sufficient proof that this element must have been precipitated, probably as the carbonate, when the river and lake waters were mingled The presence of large quantities of oolitic sand along the shores of the lake, which is apparently still in process of formation, is strong evidence in support of this hypothesis. This lake furnishes a typical instance of the concentration of ordinary meteoric waters by evaporation. We may conclude, therefore, from this and other instances which might be enumerated, that in inclosed lakes, as in the ocean, calcium carbonate will be the first salt precipitated as evaporation progresses.

Great Salt Lake is now so concentrated that the crystallization of common salt is taking place in certain portions where the water is shallow. Over hundreds of acres along its southwest border the bottom is covered with a continuous crust of salt crystals, forming a pavement sufficiently strong to support a horse and rider. This condition was observed during the arid season; whether the salt is redissolved during the rainy season or not, has not been determined. From the observations recorded above we learn that precipitation is now taking place in three separate ways in the waters of a single lake; (*a*) calcium carbonate is thrown down, probably throughout the year, as the tributary streams mingle with the brine of the lake; (*b*) sodium sulphate is precipitated in all portions of the lake when its temperature falls below 20° F.; (*c*) sodium chloride crystallizes in the very shallow portions during the arid season. An example of this nature teaches that a stratified saline deposit might form in an inclosed basin as a result of fractional crystallization dependent upon changes of temperature. The deposits found in the smaller of the Soda Lakes at Ragtown, Nevada (see page 79), apparently illustrate such an occurrence.

DEPOSITION OF CALCIUM CARBONATE.

In considering the natural methods by which calcium carbonate is precipitated from solution, we have, as preliminary data, that this salt is more abundant than any other in ordinary surface waters, constituting, usually, nearly one-half of the total of solids in solution in average rivers; that it is the first to be precipitated when such waters are evaporated; and that calcium ordinarily exists in solution as the bicarbonate, $CaO\ CO_2$, the presence of free carbon dioxide (carbonic acid) being essential for its solution.

Under the conditions prevalent in nature it is evident, from the elementary laws of chemistry, that the precipitation of calcium carbonate may take place in at least three ways: (*a*) By evaporation, concentration being carried beyond the point of saturation. (*b*) By the loss of the carbon dioxide necessary to hold the salt in solution. This gas escapes when pressure is removed or temperature increased; it passes off gradually when carbonated waters are exposed to the air, especially if agitated, as in the spray of water-falls and in breaking waves. (*c*) By chemical reaction, as when an alkaline carbonate is added to water holding calcium chloride in solution. Of these three methods we need to consider at this time only the results of concentration and loss of carbon dioxide; as dissolved gases are driven off during evaporation, these two methods act together. So far as the chemistry of inclosed lakes is concerned it is evident that the precipitation of calcium carbonate must depend almost entirely on concentration by evaporation; chemical reaction may in certain cases play an important part, as when a spring holding $CaO\ CO_2$ rises in an alkaline lake; but, in general, the conditions under which a number of salts may exist in a solution is too little known to warrant one in ascribing a reaction to this cause when it may be more simply explained as a result of evaporation.

With this elementary sketch of the chemistry of natural waters we will proceed with our study of the history of Lake Lahontan.

Section 2.—CHEMICAL DEPOSITS OF LAKE LAHONTAN.

In commencing the study of the chemical precipitates of Lake Lahontan, we have for our guidance the fact that the rivers now entering the basin flow through the same channels that they occupied during the Quaternary, and that many of the springs which rose in the bottom of the former lake are still active. The salts contributed to the former lake were, therefore, of essentially the same nature as those now being carried into the basin. From these data and a knowledge of the composition of the present lakes of the basin, it is evident that at least the general chemistry of the waters of the former lake may be inferred. Providing that no salts were deposited in the basin during an antecedent period of desiccation, it is evident from the character of the inflowing waters, that during its first rise Lake Lahontan was a fresh-water lake, with about the normal percentage of calcium carbonate but richer in sodium salts than is common with ordinary lakes in regions where stratified rocks abound. We need to qualify this statement, perhaps, for the reason that the lake rose slowly, owing to a gradual change from arid to more humid conditions, and became somewhat concentrated during its gradual increase. At the time of its first maximum it must have been somewhat more highly charged with mineral matter than is usually present in lakes with outlet. Should a climatic change take place which would allow Pyramid Lake to expand at such a rate that at the end of a hundred years, for example, it would be 900 feet deep, *i. e.*, refill the Lahontan basin, it would form a fresh-water lake in which the chemist could detect a somewhat greater percentage of saline matter than occurs in the Laurentian lakes; but to the taste it would appear as fresh as ordinary river waters. Such, we conceive, was the nature of Lake Lahontan at its first rise.

From our knowledge of the chemistry of natural waters we should expect that calcium carbonate would be the first precipitate formed as the waters of Lake Lahontan were concentrated, and should evaporation and precipitation balance each other for a considerable time, an immense deposit of this salt would be accumulated. If loss and supply were balanced

for a long period, or if evaporation were to exceed supply, we should expect that other salts would be deposited in a definite succession. The probable composition of the waters of Lake Lahontan, if a single evaporation is considered, indicates that, as concentration took place, the dissolved salts would be deposited, with some intermixture it is true, but mainly in the following order: (1) Calcium carbonate; (2) calcium sulphate; (3) sodium sulphate; (4) sodium carbonate; (5) sodium chloride, followed by the precipitation of the more deliquescent salts In nature, however, this order would be altered by fluctuations of temperature, variations in density, and other disturbing conditions. Should the desiccation be incomplete the remaining waters would form a dense mother-liquor, rich in magnesia, potash, and soda, and containing some of the less common substances, as lithium, boracic acid, etc.

On entering the Lahontan basin—which, as we know, never overflowed—with this theoretical history before us, we are surprised to find that, with the exception of immense deposits of calcium carbonate, there are no accumulations of saline precipitates to be seen. Moreover, the water-bodies now occupying the lowest depressions in the bed of the former lake, are not dense mother-liquors, but, on the contrary, contain even less than half of one per cent. of total solids in solution. It is evident, therefore, that the history we are endeavoring to trace is an exception to the rule sketched above, which seemed self evident when considered in a theoretical way. As we proceed we hope to explain this apparent anomaly, at least in part.

CALCAREOUS TUFA.

The deposits of calcium carbonate occurring in the Lahontan basin are most abundant in the valleys where the former lake was deepest, and are usually inconspicuous or, perhaps, entirely wanting in places where the waters were shallow. The best localities for the study of these chemically formed rocks are on the borders of the Carson Desert and about the shores of Pyramid and Winnemucca lakes. The steep rocky sides of these secondary basins, and the isolated buttes occurring in them, seem to have been especially favorable for the deposition and preservation of calcareous deposits. The tufa frequently forms a sheathing 50 or 60 feet thick upon the older rocks; at other times it assumes the form of domes and castellated masses that in some cases rise a hundred feet above the nuclei about which crystallization first took place. Of all such localities in the basin the most remarkable are the Marble Buttes at the southern, and the Needles at the northern end of Pyramid Lake; Anaho and Pyramid islands are also loaded with immense accumulations of tufa, and are points of special attraction to the student of chemical geology.

Early in the examination of these deposits it was found that they occur in definite layers, and form a well-defined sequence in which three main divisions, together with many minor variations, may be easily traced Classifying the major divisions according to the structure of the rock, beginning with the first formed, we have: (1) Lithoid tufa; (2) Thinolitic tufa; (3) Dendritic tufa.

LITHOID TUFA.

We have applied this name to the first of the three main deposits of calcium carbonate precipitated from the waters of Lake Lahontan. It is compact and stony in structure, light yellowish gray in color, and weathers into forms of extreme ruggedness. It frequently shows a concentric and sometimes a well-marked tubular structure when seen in cross-section, but when forming a coating to rock surfaces it is usually composed of thin, superimposed layers. In well-exposed sections of lithoid tufa the banded structure of the deposit is often distinctly marked, and at times, particularly near the base of the deposit, or near the center of the dome-shaped masses occurring in isolated positions, the layers of tufa having a compact stony structure are separated by others of dendritic tufa, the character of which will be described a few pages farther on. Viewed externally, the coatings of this variety of tufa on cliffs and buttes appear to be formed of comb-like masses, imbricated in such a manner as to resemble a massive thatch. This appearance can only be seen to advantage above the limit of the more recent tufas; it is especially well displayed on the upper portions of Anaho Island and the Marble Buttes. Much of the gravel forming the prelacustral alluvial slopes of the Lahontan basin, as well as that composing the earlier-formed terraces and embankments, is cemented by it into a compact conglomerate.

Lithoid tufa is found nearly everywhere throughout the valleys formerly occupied by Lake Lahontan, where the conditions for its deposition and preservation were favorable. In vertical range it occurs from the lowest part of the basin now open to inspection, up to a horizon about thirty feet below the highest of the ancient beaches. The broad wave-cut shelf, which, so far as can be determined, is the upper limit of this variety, we have called the Lithoid terrace (see page101). At its upper limit this tufa is seldom more than eight or ten inches in thickness, as it remains to-day after a long period of weathering; but lower in the basin it attains a thickness of ten or twelve feet; what its maximum development may be is difficult to determine, as its base is nearly always concealed by lacustral deposits or later formed tufas.

The surface of the lithoid tufa when exposed by the removal of the sheathing of thinolite crystals that usually covers it below the horizon of

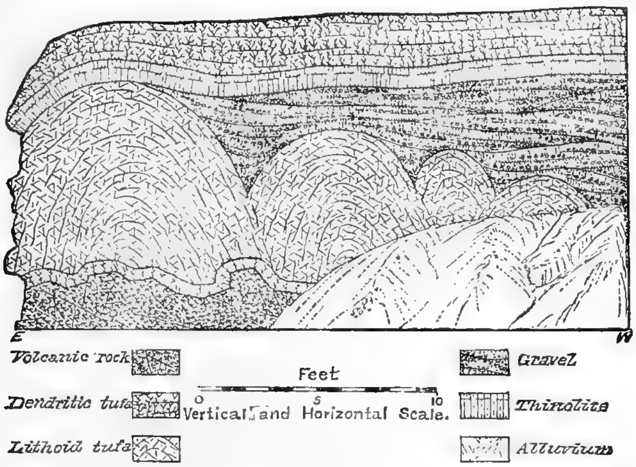


FIG. 27.—Section showing current-bedded gravels between lithoid and thinolite tufa.

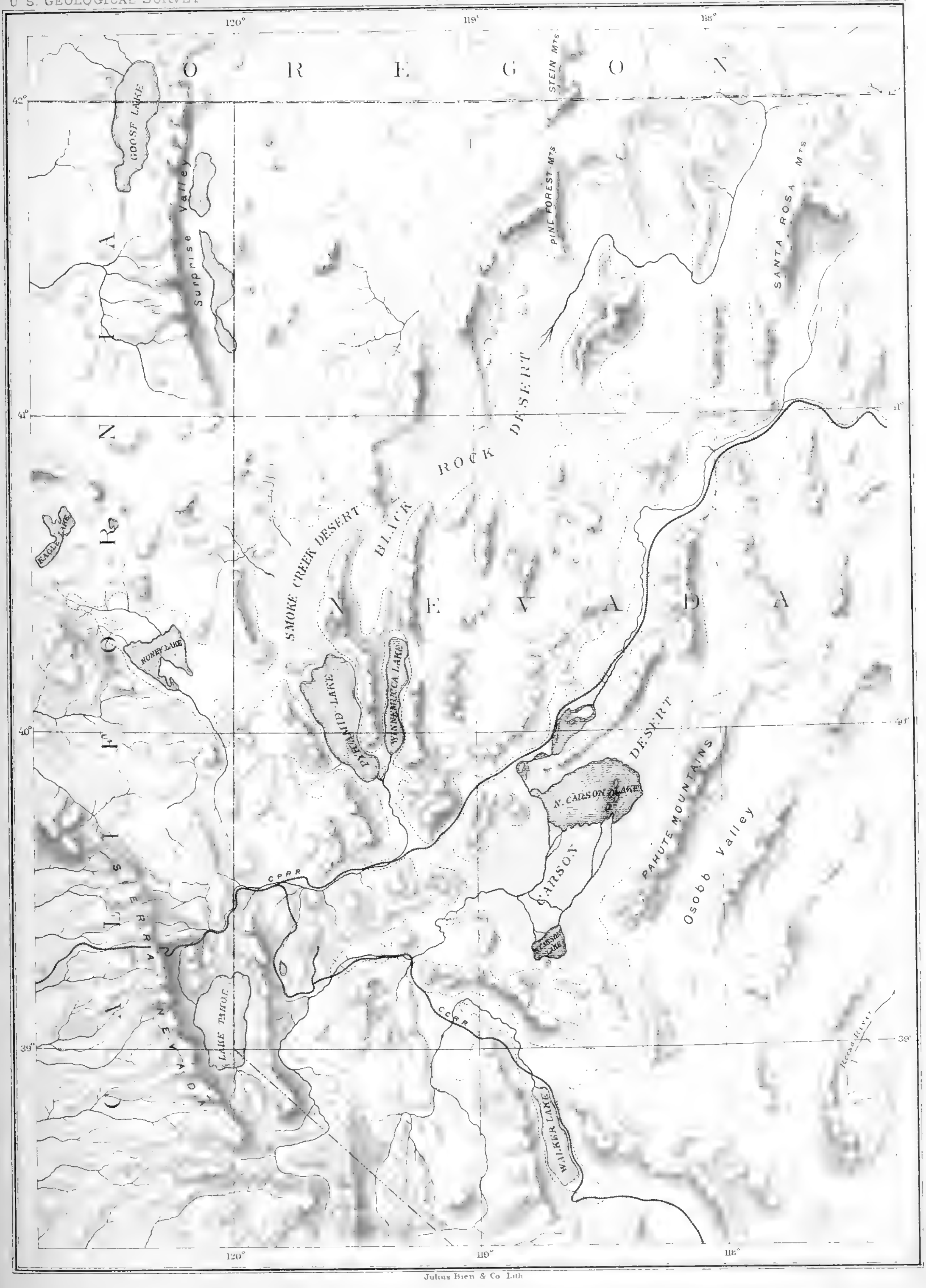
the thinolite terrace, sometimes shows the effect of weathering which took place previous to the deposition of the second formed variety. In places the two layers are separated by a deposit of pebbles two or three feet in thickness, united by a calcareous cement, or by current-bedded gravels, as shown in the following drawing of a section exposed at the eastern base of the Marble Buttes. In some instances stones and pebbles were carried upwards by the action of sub-lacustral springs about which tufa was being deposited, and became inclosed in the calcium carbonate as it was precipitated; this occurrence is not to be mistaken, however, for the partings of current-bedded gravel described above, which must have been deposited by waves and currents in shallow water. The weathering of the lithoid tufa is not always apparent, but has been observed in a number of instances, and can only be interpreted on the suppostion that the first-formed tufa was exposed to subaërial erosion by a lowering of the lake previous to the deposition of the thinolite crystals. The surface of the lithoid tufa above the upper limit of thinolite is weathered to a much greater extent than below that horizon, indicating that its erosion continued throughout the low-water stage during which thinolite was forming.

The lithoid tufa of the Lahontan basin is identical in structure and general appearance with the greater part of the tufa deposited in Lake Bonneville, and has essentially the same chemical composition. It is also represented on a limited scale in a number of the minor Quaternary lake basins of Utah and Nevada. Similar deposits are now forming in Pyramid, Walker, and Winnemucca lakes, as described in Chapter III. It is evident that this variety of tufa corresponds in all respects with the first calcareous deposit precipitated when ordinary meteoric waters are evaporated.

THINOLITIC TUFA.

Succeeding the lithoid tufa in order of deposition, and forming another coating on the sides of the Lahontan basin, is a deposit of interlaced crystals of calcium carbonate, which were called "Thinolite" by Mr. King.[66] In the reports of the U. S. Geological Exploration of the Fortieth Parallel, however, this term is used to designate any of the calcareous deposits of the ancient lake, whether crystallized or not. In the present report we restrict the name to the variety of tufa exhibiting a definite crystalline structure, presently to be described. We may remark, in passing, that no crystals having a resemblance to thinolite have been found in the Bonneville basin; nearly all the calcium carbonate there deposited is of the character of lithoid tufa, as

[66] U. S. Geological Exploration of the Fortieth Parallel. Washington, 1878, Vol. I, p. 517.



Julius Bien & Co. Lith

WATER SURFACE ON LAKE LAHONTAN AT THE THINOLITE STAGE.

Scale 29 miles = 1 inch

stated in the preceding paragraph. In a few instances, however, a dendritic structure may be detected; as is the case, also, in the lithoid deposits of the lake we are now studying.

In the Lahontan basin thinolite crystals are only found in the lowest depressions, as, for example, about the shores of Pyramid and Winnemucca lakes and on the borders of the Carson Desert. Its geographical extent, as shown on the accompanying map, embraces the Carson Desert, the valleys of Pyramid and Winnemucca lakes, together with the Black Rock and Smoke Creek deserts. The divide between Carson Desert and the valley in which Pyramid Lake is situated, is higher than the upper limit of the thinolite tufa; we must conclude, therefore, that when Lake Lahontan evaporated away sufficiently to admit of the formation of thinolite—or of the crystals after which it is a pseudomorph—the water-surface was below the level of the pass to the eastward of Wadsworth, and the lake consequently, divided into at least two water-bodies. On the preliminary map of Lake Lahontan, published by the writer in the Third Annual Report of the U. S. Geological Survey, the lake at its thinolite stage is represented as extending through from the Carson Desert to Pyramid Lake; this error has been corrected on the accompanying map. It was also indicated on the previous map, that Smoke Creek and Black Rock deserts were without thinolite deposits; later observations have shown that they do occur in large masses at certain localities on the borders of these basins, with the same general relations to the other tufa deposits that they have in the most typical localities.

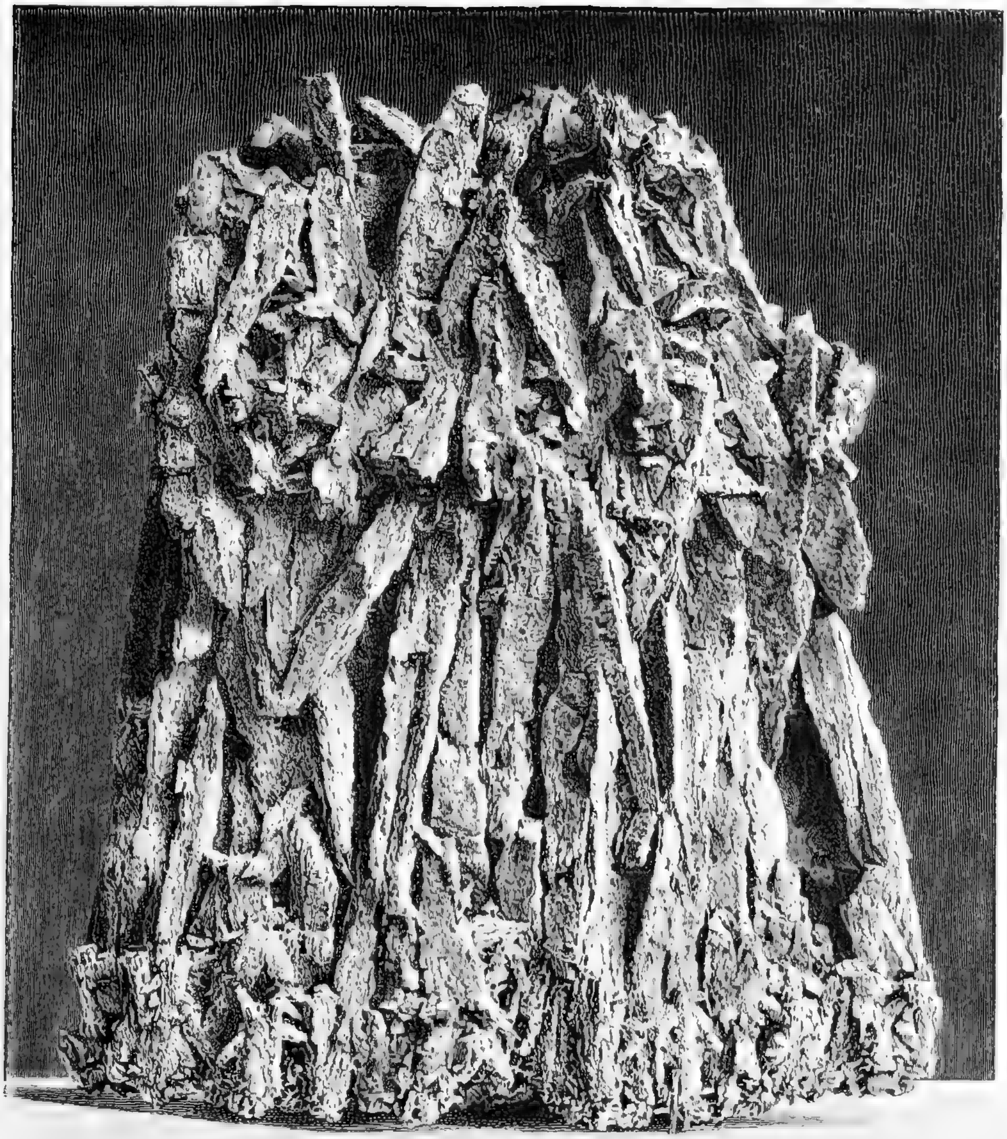
The valley of Walker Lake must also have formed an independent water-body during the thinolite stage of Lake Lahontan, but no crystals belonging to this period of the lake's history have been found in that basin. As will be described later, there are masses of thinolite about Walker Lake corresponding to quite recent deposits of the same mineral in the Black Rock Desert.

In its vertical range the thinolite is limited by the broad shelf, named the thinolite terrace, which occurs at an elevation of 110 feet above the 1882 level of Pyramid Lake. In only a single instance has the thinolite been observed to extend above this horizon. On Anaho Island the terrace is strongly carved and forms a conspicuous feature in the contour of the island when seen from a distance; on the northern side of the island the thinolite tufa extends about 15 feet above the water-line of the terrace and forms a thin wedge of interlaced crystals included between the lithoid tufa and the heavy deposit of dendritic tufa. The upper limit of the thinolite probably varies in the several basins in which it occurs, but no accurate measurements of differences of level have been made.

The sheathing of thinolite extends from the lithoid terrace down to the lowest point in the bottom of the basin now open to inspection. Near its upper limit it is from 6 to 8 feet thick, but increases to 10 or 12 feet near the surface of Pyramid Lake. Like the lithoid tufa it was deposited in successive layers, as is shown by its banded structure. Throughout the mass we find definite layers or zones of small and large crystals alternating with each other. Near its outer limit the bands of crystals are divided by narrow layers of sheets of dendritic tufa; indicating that the condition of crystallization were alternately favorable for the production of the crystalline or the dendritic structure. The circumstances favorable for the formation of the latter finally prevailed, and only dendritic tufa was deposited.

PROFESSOR DANA'S CRYSTALLOGRAPHIC STUDY OF THINOLITE.

While carrying on the field study of Lake Lahontan, large quantities of the different varieties of tufa were collected, and special attention given to securing as many specimens as could well be desired for illustrating the structure and mode of occurrence of thinolite. A representative portion of this collection, together with similar material from the Mono Lake basin, was placed in the hands of Profs. G. J. Brush and E. S. Dana for the purpose of obtaining an authoritative statement of the mineralogical relations of thinolite. This study was finally undertaken by Professor Dana, whose report forms Bulletin No. 12 of the publications of this Survey. To the student of Lahontan history this report is especially welcome as it clears away the previous hypothesis, advanced by King, to the effect that thinolite is a pseudomorph after gaylussite. The following description of thinolite is quoted with slight verbal alterations from Professor Dana's bulle-



A CHARACTERISTIC SPECIMEN OF THINOLITE.

tin[67] to which the reader should refer for a more complete elucidation of the subject.

In general it may be said that the thinolite collected from different localities, both in the basin of Lake Lahontan and of Mono Lake, while varying widely in external aspect, is yet remarkably uniform in all essential characters. It is thus established beyond question that the original mineral deposited was throughout the same, although, in consequence of the varied conditions to which it has been subjected, the forms resulting from its alteration are very diverse. Thus, in some specimens there is only a delicate skeleton remaining, the whole consisting of thin plates, held togther in their parallel position by a slight central frame-work, while in others the whole is as firm and compact as a crystalline limestone, and between the two extremes many interesting varieties occur. The most important condition upon which this difference depends is the varying extent to which a deposition of calcium carbonate has taken place subsequent to the first alteration of the original mineral.

As has already been stated, the thinolite is most characteristically developed about Pyramid Lake. The writer has had in hand specimens from the Marble Buttes, from the Needles, from Anaho Island, and from the Domes, and, as they illustrate well the different varieties, it will be convenient to refer to them by localities, although no special significance is probably to be attached to the particular spot from which the individual specimens were collected.

The delicate, open, porous variety of thinolite is best shown in the specimens from the Marble Buttes, of which illustrations are given in Plates XXXII and in Fig. 1 of Plate XXXIII. The external form of the crystals is roughly that of a rectangular prism, with projecting edges and generally tapering toward the extremities. The color is gray to brown. These crystals are commonly from a quarter of an inch to an inch in diameter and up to 8 or 10 inches or more in length. They are generally grouped in a more or less closely parallel position, often compactly, with only very little interlacing. In other cases, especially when the forms are

[67] Page 15, et seq.—The numbers referring to Plates in this quotation have been changed so as to denote their position in the present volume.

smaller, they have widely divergent positions, interpenetrating each other, and giving a large mass an open, reticulated appearance. In addition to the elongated crystals, numerous smaller ones, half an inch or an inch in length, make up parts of these masses, projecting from the sides of the larger crystals and forming divergent groups among themselves. The small crystals have generally the form of an acute pyramid, and are sometimes square in outline, sometimes rhombic; the sides are usually concave, and the edges project sharply. The exterior surface of the larger crystals is rough and open, often with a delicate mossy covering, and the whole crystal is porous throughout, as if eaten out so as to leave only a skeleton behind. Upon a superficial examination no regularity in the structure is evident, but on looking more closely it is seen that the apparently rough and irregular surface is made up of portions of thin plates, each set parallel to the sides of the crystal and uniformly converging in one direction. Thus when one of the groups of nearly parallel crystals is viewed end on, from one extremity or the other, it is seen that the edges of the plates, irregular as they are in outline, are all presented to view at once, as if each crystal, though prismatic in general outline, were made up of a series of acute skeleton pyramids, hopper-like in form, placed one within another. Still further, when the section produced by the cross-fracture of one of these elongated crystals is examined, there is seen, more or less distinctly, a series of apparently rectangular ribs forming concentric squares or rectangles, with diagonal ribs joining the opposite angles.

The specimens in hand from the Needles, Pyramid Lake, correspond closely with those which have been described, though hardly showing the structure so clearly. This is also true of some of those from Anaho Island. The majority from the latter locality, however, are much more firm and compact. Here, too, the crystals are usually elongated, and in a single specimen grouped in nearly parallel position. The edges of the plates are also commonly distinct on the sides, and show the same convergence toward one extremity. The masses, however, instead of being open and porous, and consequently light in the hand, are close, compact, and heavy. Instead of the delicate, open skeleton, with fretted surface, seen in the cross-fracture, the section is nearly solid, and sparkles with the reflection from the cleavage

Explanation of Plate XXXIII.

Fig. 1. Group of thinolite crystals from Marble Buttes, Pyramid Lake (reduced one-half); open porous variety.

Figs. 2 and 3. Transverse sections, natural size; Fig. 2, open skeleton form; Fig. 3, partially filled up with amorphous $CaCO_3$. These sections show the system of rectangular (square) and diagonal ribs, which consist of granular crystalline $CaCO_3$.

Fig. 4. External appearance (reduced one-half) of a single crystal, with part of a second, the internal structure of which shows that it has but a single termination; the comparatively smooth surface is due to the secondary deposition of $CaCO_3$.

Fig. 5. Longitudinal section of open variety (reduced one-half), showing the two systems of plates converging upward at an angle of about 35°.

Fig. 6. Complete crystal (reduced one-half) which yielded the section in Fig. 2; the line in which the section was made is indicated.

Fig. 7. Acute pyramidal crystal (reduced one-half) which yielded at its base the section given in Fig. 3.

Fig. 8. Square pyramidal crystal (reduced one-half) which gave, at the point indicated, the section in Fig. 13; the surface has been made smooth by subsequent deposition of $CaCO_3$.

Figs. 9 and 10. Skeleton crystals (natural size) showing cap-in-cap structure, and thus revealing the true square pyramidal form of the original mineral.

Fig. 11. Crystals (natural size) from the Domes, Pyramid Lake; the surface smoothed over by subsequent depositions of $CaCO_3$, with sproutings from the edges and extremities.

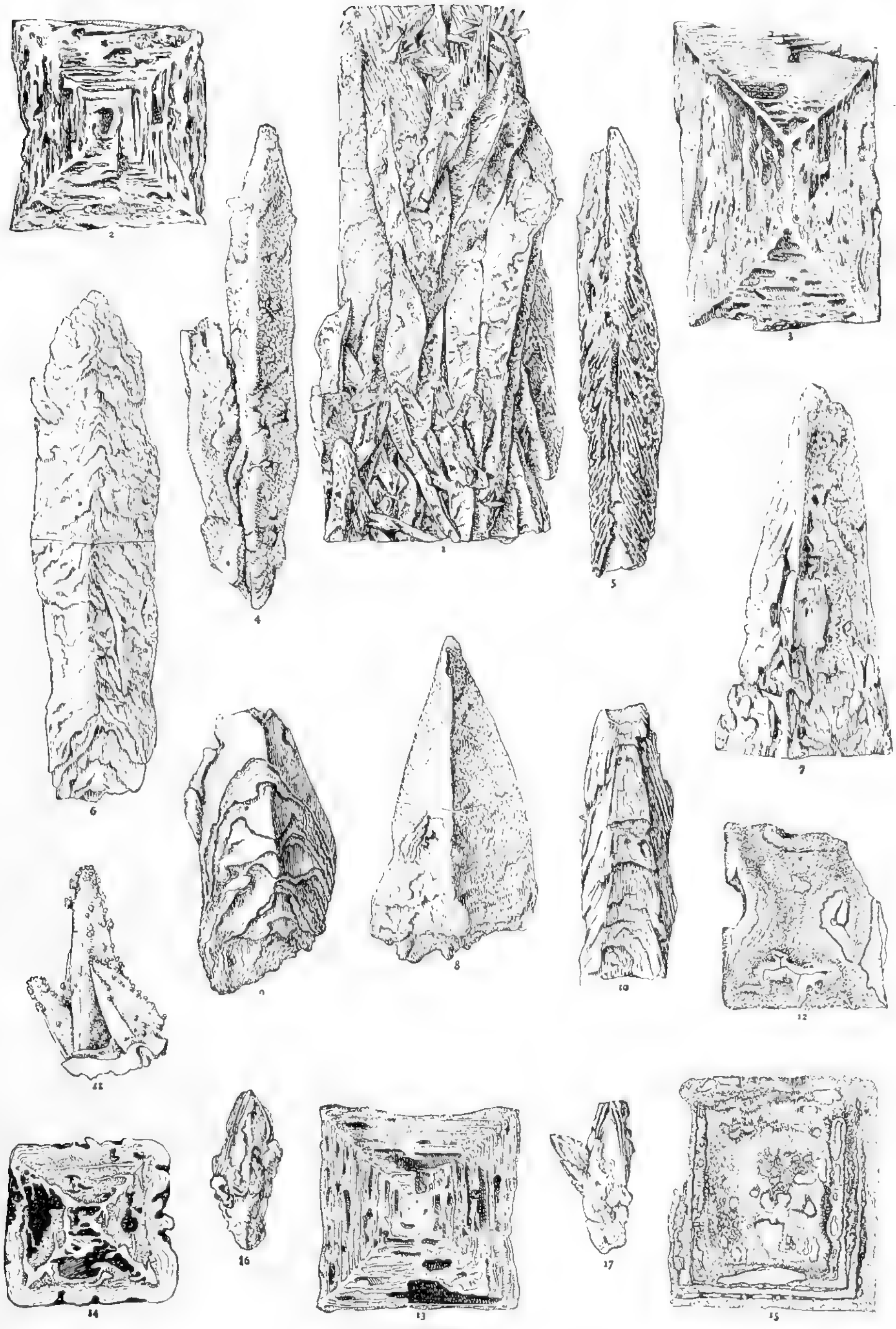
Fig. 12. Section (magnified 8 times) of a crystal from the Domes, like that in Fig. 11, showing a diagonal and rectangular frame-work, partly crystalline, granular, partly amorphous, with layers of secondary carbonate opal-like in structure.

Fig. 13. Section (natural size) of the crystal shown in Fig. 8, cut transversely at point indicated; it shows the same frame-work of granular crystalline carbonate, partially filled in with secondary $CaCO_3$.

Fig. 14. Section (natural size) showing the usual frame-work, partially filled in with secondary $CaCO_3$, and with successive layers also around the outside.

Fig. 15. Section of a crystal from the Marble Buttes, magnified 8 times, and showing the structure lines of crystallized carbonate, and also in the cavities the acicular crystals of aragonite. (?)

Figs. 16 and 17. Small pyramidal crystals (natural size), showing by dissection the cap-in-cap structure, and thus, like Figs. 9 and 10, revealing the true pyramidal form of the original mineral.



ILLUSTRATIONS OF THE STRUCTURE OF THINOLITE

surfaces of the calcite grains. In other cases the outer surfaces are smooth and rounded, and the unaided eye sees little of the structure except on a cross-fracture; in these instances, as will be more fully explained immediately, a deposition of calcium carbonate has filled up the skeleton form and incrusted and smoothed over the surface.

The specimens from the Domes represent still another type of the thinolyte. The crystals here have uniformly an acute pyramidal form, and are grouped in irregular, divergent positions. Their surfaces are brownish yellow in color and show little of the edges of the parallel plates conspicuous in the variety from the Marble Buttes They are, on the contrary, nearly smooth, except when covered with watery excrescences, which in some cases are thickly clustered about the edges and extremities. One of these crystals (natural size) is shown in Fig. 11, Pl. XXXIII. On the fracture this variety is found to be nearly as firm and compact as a fine-grained crystalline limestone; in fact, the unaided eye would regard the whole as crystalline throughout. The color on the fracture is slightly yellowish white.

Examination of sections of crystals.—In order to get at the true structure of the crystals which have been described, it is necessary to resort to sections cut transversely and longitudinally; these reveal the form most clearly and satisfactorily. A cross-section of a crystal like those first described—the open, porous variety from Marble Buttes—is shown in Fig. 2 (natural size). As seen in the figure it is made up of lines in position parallel to the sides of a square prism, and in addition there are two sets of distinct diagonal lines intersecting at right angles to each other; between these ribs are open spaces. A closer examination of the specimen represented in Fig. 2 shows that the material consists of rhombohedral calcium carbonate, or calcite, of a distinctly granular crystalline structure throughout. The whole presents an open tessellated appearance. The external form of the crystal which yielded Fig. 2 is shown reduced one-half in Fig. 6. The point at which it was divided is indicated by a black line. The form is roughly that of a square prism tapering slightly in both directions, but the external form does not conform, in this respect, to the internal structure except at the upper extremity. The irregular edges of the upwardly converging plates are clearly shown in this figure.

A longitudinal section of another crystal (one-half natural size) is shown in Fig. 5. It presents also an open skeleton appearance analogous to that of Fig. 2. As seen in the figure the plates converge upwards on either side of the longitudinal axis, meeting at an angle of approximately 35°. Like the previous case, it consists entirely of purely granular crystallized calcite with only a little mossy covering on the surfaces of the plates. It is to be noticed here that the plates all converge upwards from one extremity of the crystal to the other, and this, as will be remarked later, is almost universally true even in the case of crystals, the external form of which tapers off at both ends.

Another transverse section (natural size) is shown in Fig 3. It is like Fig. 2 in most respects, except that the square is elongated in one direction and the diagonals meet in a central rib. Moreover while the skeleton frame-work consists as before of crystallized calcite (left white in the drawing), the intermediate spaces are partially filled up with a secondary deposit of calcium carbonate, which is apparently amorphous, and has been deposited in granular form and, too, in lines parallel to the crystalline plates. This subsequent deposition, however, has not gone far, and the general appearance is nearly as open as the one first described. The outline of the crystal which yielded this section is shown in Fig. 7 (reduced one-half). As seen here it tapers gradually to the terminal edge, forming a sharp extremity. The external form approximates to the true crystalline form of the original crystal, but is somewhat more acute, as shown by the edges of the plates exposed on the surfaces, and by the angle at which the plates within converge

In Fig 13 another section is given (natural size). This shows much the same tessellated appearance, the structure being essentially the same as in the others described, but the secondary deposition of amorphous calcium carbonate has gone still further, so that as a whole it is more compact. The skeleton ribs parallel to the sides and the diagonals are, however, still very distinct and entirely crystalline. The form of the crystal which gave this section is shown in Fig. 8 (one-half natural size). As seen here it is an acute square pyramid, approximately conforming in outward form to the internal structure. The surface is here no longer open and fretted,

Explanation of Plate XXXIV.

Fig. 18. Thinolite from Black Rock Desert (reduced one-half), the individual crystals running off into a compact stony tufa, so that the mass from above has a cauliflower-like form.

Figs. 19 and 20. Thinolite from Mono Lake, California (natural size), showing the grouping of the composite crystals.

Fig. 21. Thinolite from Mono Lake (natural size), fragment of a large composite crystal, made up of small acicular crystals in parallel position.

Fig. 22. Transverse section of the crystal represented in Fig. 21, showing the same skeleton structure distinct in crystals from Pyramid Lake (Figs. 2, 3, etc.).

Figs. 23 and 24. Group of thinolite crystals from Mono Lake (natural size), showing the acicular form, and also the way in which the crystals are coated over with secondary carbonate.

Fig. 25. Group of small crystals (magnified 4 times) from Mono Lake, showing the same method of grouping common in the Sangerhausen pseudomorphs, as shown in Fig. 26.

Fig. 26. Group of Sangerhausen pseudomorphs (natural size); compare Fig. 25.

Figs. 27 and 28. Isolated thinolite crystals (magnified twice), showing resemblance in form and surface marking to Sangerhausen crystals; compare Figs. 31 and 32.

Fig. 29. Thinolite crystal (natural size), showing cap-in-cap pyramidal structure, similar to Figs. 16 and 17, Plate II.

Fig. 30. Thinolite crystal (magnified 4 times), showing resemblance in form to the Sangerhausen pseudomorphs; compare with Figs. 31, 32, and 38.

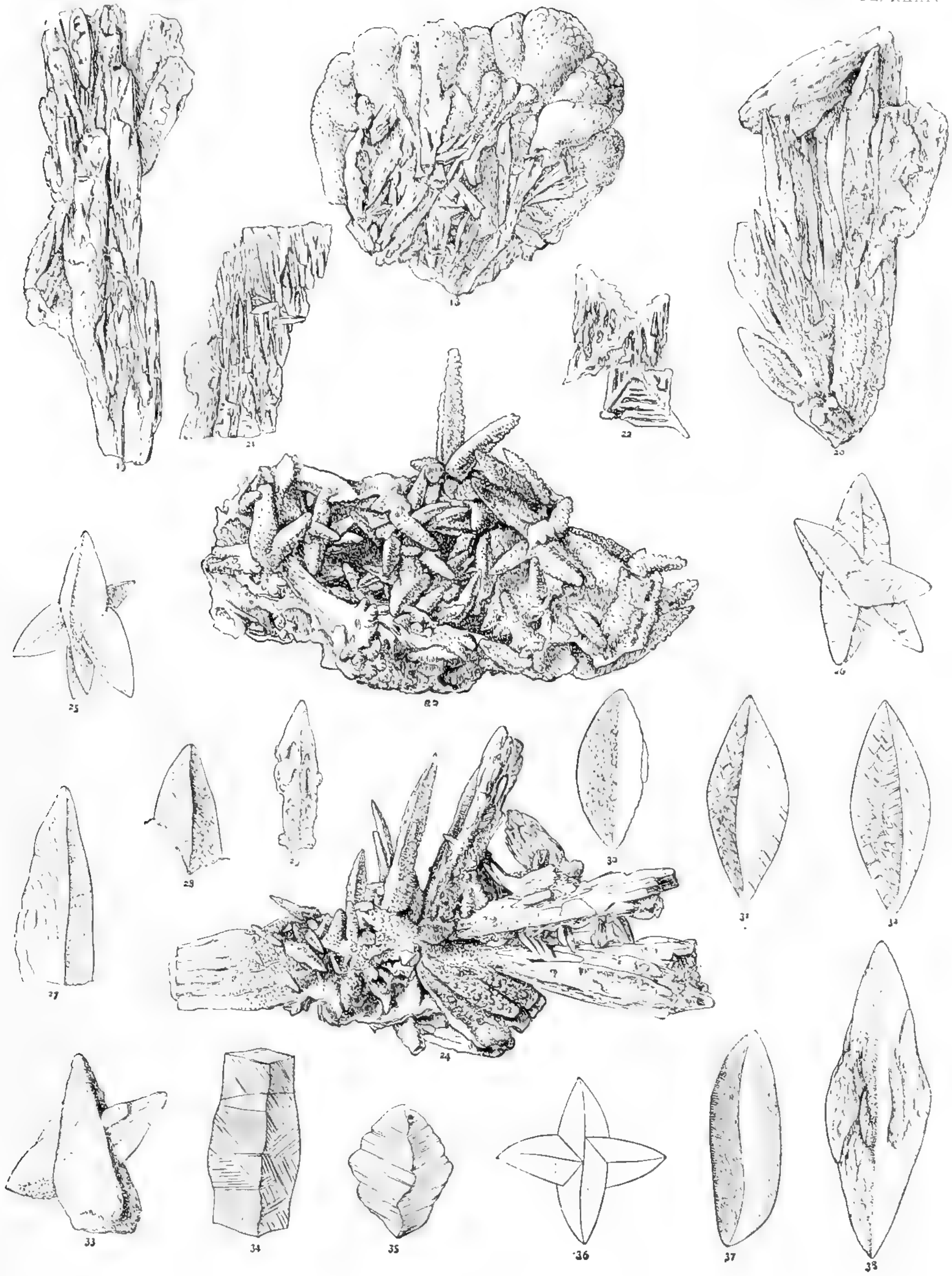
Figs. 31 and 32. Single Sangerhausen crystals, showing form and external markings; Fig. 31, natural size; Fig. 32, magnified twice.

Fig. 33. Group of small thinolite crystals (magnified 4 times); compare with Fig. 26.

Figs. 34 and 35. Pseudomorphous crystals, consisting of granular calcite from Astoria, Oregon; copied (reduced one-half) from figures by J. D. Dana in the Geology of U. S. Exploring Expedition, p. 656.

Figs. 36 and 37. Pseudomorphous crystals, consisting of granular calcite, from New South Wales; copied (reduced one-half) from figures by J. D. Dana in the Geology of the U. S. Exploring Expedition, p. 481.

Fig. 38. Pseudomorphous crystal (natural size) from Kating, Silesia.



ILLUSTRATIONS OF THE STRUCTURE OF THINOLITE

as in the others, but nearly smooth, except as it is covered with small wart-like prominences. The color is a dark brown. The line in which the section was cut is shown in the figure.

Still another section is shown in Fig. 14 (natural size), and one which marks a further degree of deposition of secondary calcium carbonate. The crystal from which it was taken had a square form tapering slowly upward, and the surface was covered with small mammillary prominences. The skeleton of crystalline calcium carbonate is here nearly concealed by the added amorphous material, and the outer portion consists of concentric layers of the same substance.

The exterior appearance of another crystal is shown in Fig. 4 (one-half of natural size). As seen, it tapers slightly toward both extremities, and it was cut longitudinally, in the idea that it might be a doubly terminated crystal, but the structure lines all converged toward one end, showing that, like most of the others, the growth was only in one direction. As the surface indicates, the crystalline skeleton has been nearly filled up with amorphous calcium carbonate.

In addition to the sections given and others like them of large crystals, numerous thin sections were also cut transverse and longitudinal to smaller crystals. They revealed under the microscope the same points which the microscopic examination of the larger sections showed—that is, the presence of the same skeleton of crystallized calcium carbonate with the concretionary depositions added to it. The calcite grains are large, each one having a distinct rounded or elliptical outline, and they are packed closely together, with a little brownish amorphous matter between them. Many of them show the rhombohedral cleavage; others show a crystalline nucleus which has apparently grown by the addition of further crystalline matter. The secondary calcium carbonate has generally a concentric or banded structure resembling some kinds of opal.

These sections also show another point of interest; namely, the presence of groups of acicular crystals in parallel position filling more or less completely the cavities in the skeleton structure, and sometimes projecting into the cavities. These are seen in many cases, and are the general rule, though sometimes absent; they are indicated magnified eight times in Fig.

15. These acicular crystals show uniformly extinction parallel to their prismatic direction, and hence it seems clear that they must belong to an orthometric system. It seems probable that they are aragonite. A chemical examination of an uncovered slide gave results in accordance with this suggestion.

A section of one of the crystals from the Domes is shown in Fig. 12 magnified eight times. To the eye the broken crystal appeared to be crystalline throughout; in the section, however, as examined under the microscope, there is seen to be a crystalline frame-work made up of calcite grains, filled in with amorphous matter, and in addition outer layers of banded opal-like carbonate, so that it conforms in general to cases like those before represented. The diagonal lines are here clearly developed, and there are also rectangular lines more or less distinctly indicated. These are illustrated somewhat obscurely in the figures. Other sections showed essentially the same relations.

Structure in dissected crystals.—As has been stated, the external form of the thinolite crystals seldom gives the true crystalline form. The process of dissection, however, which has laid bare the skeleton-like ribs which have been described, sometimes results in showing the true pyramidal form of the original mineral. In such cases we may have a series of skeleton crystals, each a hollow pyramid as a cap to the one preceding. This is shown in Fig. 9, which will explain itself, and again in Fig. 10 (both natural size). In another case a mass of the calcareous tufa, showing little structure, has its surface partially covered with pyramidal crystals an inch in length. Each one was a skeleton crystal inclosing a pyramidal crystal, and sometimes several crystals after the fashion of a nest of pill-boxes. The outer surface of the crystals was incrusted with a moss-like covering, often entirely hiding the form. Two of these are represented in Figs. 16 and 17 (natural size), and another in Fig. 29, Plate XXXIV.

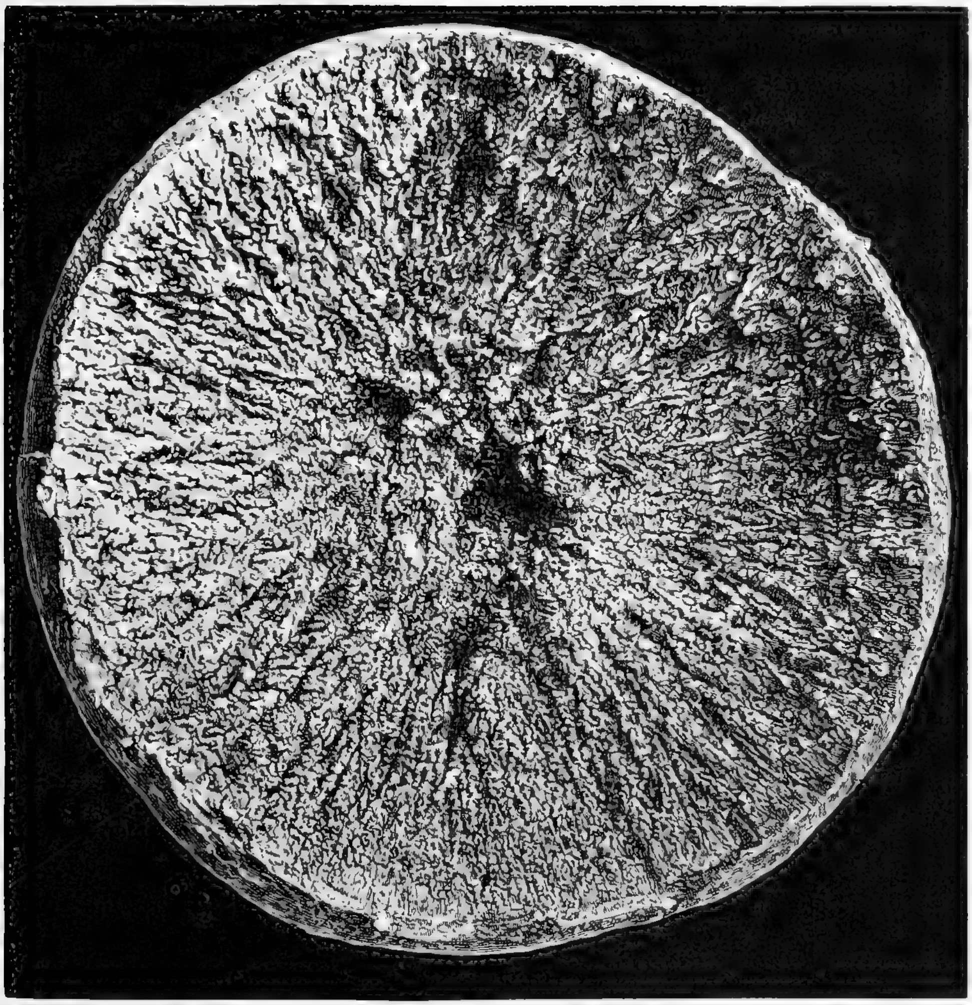
Before passing to the description of the next succeeding tufa deposit, we may note that the external surface of the thinolite does not exhibit evidence of having been weathered previous to the deposition of the dendritic variety. This may be taken as conclusive evidence that the lake surface did not fall below the horizon of the thinolite terrace subsequent to the deposition of thinolite until after the dendritic tufa was formed.

DENDRITIC TUFA.

A change in the chemical nature of Lake Lahontan, which terminated the crystallization of thinolite, is recorded by a third calcareous deposit, which, from its resemblance in structure to arborescent forms, we have called dendritic tufa. The conditions that brought about this change in the character of the calcium carbonate precipitated appears to have been a dilution of the waters in which the thinolite was deposited. This is evident from the fact that the dendritic tufa reaches a higher level than the layer of thinolite. This third variety is by far the most abundant of all the chemical deposits of Lake Lahontan, and occurs from the bottom of the basin up to an elevation of 320 feet above the level of Pyramid Lake in 1882. In many places it is not less than 50 or 60 feet in thickness and may at times exceed this amount. The principal precipitation took place at an elevation of between 200 and 300 feet above Pyramid Lake. The abundance of the accumulation at this horizon is so great that it gives a convex outline to the cliffs on which it was deposited, as may be seen at the Marble Buttes and on the islands in Pyramid Lake. It is frequently suspended from cliffs in pendent, comb-like masses, which sometimes suggest the appearance of Cyclopean tile-work, and present surfaces of extreme ruggedness. The aspect of cliffs when loaded down with tufa is well shown on Plate XXIV, Vol. I, of the reports of the United States Geological Exploration of the Fortieth Parallel, and is also represented on Plate XXXVI of the present volume. Like the lithoid and thinolitic tufas already described, the dendritic variety is yellowish gray in color and weathers into similar rough and angular forms. It is distinguishable at a glance, however, from the earlier varieties by its peculiar dendritic structure. In typical specimens, the sprays of tufa branch and expand from central nuclei, in such a manner as to appear not unlike twigs of cedar changed to stone. This arborescent or dendritic structure is shown on Plate XXXV, which is a reproduction of a photograph of a section of a small dome or loaf-like mass, the top of which has been removed by weathering.

As the lake stood about 220 feet above the thinolite terrace when the highest deposit of dendritic tufa was formed, the geographical distribution of this variety is of broader extent than that of the thinolitic; but it is not so widely spread as the lithoid tufa.

It not only occurs in far greater abundance than either of the other varieties, but is found in various relations to the lacustral sediments, etc., which the other tufas have not been observed to present. In many localities on the deserts where nuclei of gravel, shells, etc., were present, the surface is frequently covered here and there with tufa-growths having a striking resemblance to mushrooms or tuberous roots, which are frequently spoken of as "fossil mushrooms," "fossil turnips," etc. A few characteristic examples of the pseudo-vegetable forms are represented on Plate XXXVII. Fig. A shows a growth about four inches high springing from a water-worn pebble; Fig. B, of one-third natural size, is a deposition of tufa on a rocky crag that projected an inch or two above the lake bottom; in Fig. C the deposition commenced about grains of sand; Figs. D and E show the tops of mushroom-shaped growths. At some localities the "mushrooms" occur of large size and form a continuous pavement over the surface of the former lake bottom, as may be seen along the road between Wadsworth and Pyramid Lake, and again in the Carson Cañon, north of Churchill Valley. At these localities the symmetrical outline of the tufa-forms has frequently been modified by the contact of one with another during their formation, so that now they are polygonal instead of circular in horizontal section. These masses are frequently hexagonal when seen from above and have rounded dome-shaped tops, which are sometimes hollowed out by the weathering of their summits and cellular interior in such a manner as to form irregular vases. In many instances the separate mushroom-like masses springing from independent nuclei are 10 or 15 feet in diameter and weigh many tons. In the walls of the cañons carved by the Humboldt and Truckee rivers through the sediments of Lake Lahontan sections are exposed of continuous layers of dendritic tufa, interstratified with marls and



A CHARACTERISTIC SPECIMEN OF DENDRITIC TU[illegible]

clays. The occurrence of evenly stratified lacustral beds, containing the shells of fresh-water mollusks, above the layer of dendritic tufa, is evidence that the lake rose after the precipitation of the tufa and was essentially fresh.

As in the earlier formed varieties, a section of the sheathing of dendritic tufa exhibits many alternating bands, showing that the deposition took place from without and was subject to many variations.

CHEMICAL COMPOSITION OF THE TUFA DEPOSITS.

Carefully collected samples of each of the varieties of tufa described above were submitted to Prof. O. D. Allen, of Yale College, for analysis, who reports their composition as follows:

Constituents.	Lithoid tufa.	Thinolitic tufa.	Dendritic tufa.
Insoluble residue	1.70	3.88	5.06
Lime (CaO)	50.48	50.45	49.14
Magnesia (MgO)	2.88	1.37	1.99
Oxide of iron and alumina	.25	.71	1.29
Carbonic acid (CO_2)	41.85	40.90	40.31
Water (H_2O)	2.07	1.50	2.01
Phosphoric acid (PO_5)	.30	trace.	trace.
Chlorine and sulphuric acid	trace.	trace.	trace.
Total	99.53	98.81	99.80

It will be seen from this report that the composition of the tufas gives no hint as to differences in the conditions under which they were deposited. With the exception of the insoluble residue, which may be considered in a measure as accidental—being in part foreign matter imprisoned during the precipitation of the tufa, and in part carried into the insterstices of the rock as atmospheric dust after the desiccation of the basin—the various specimens have essentially the same composition. Special tests have been made in the case of thinolite to determine if in some instances it might not contain notable quantities of calcium chloride or other similar salt, but the results were negative. In common with all the tufa deposited in the Quaternary lake basins of the Far West, the several Lahontan varieties, as found at the present day, are simply impure calcium carbonate.

SUCCESSION OF TUFA DEPOSITS.

The relation of the three varieties of tufa to each other, and the manner of their occurrence on the interior of the Lahontan basin, are indicated in the following ideal section of the lake shore:

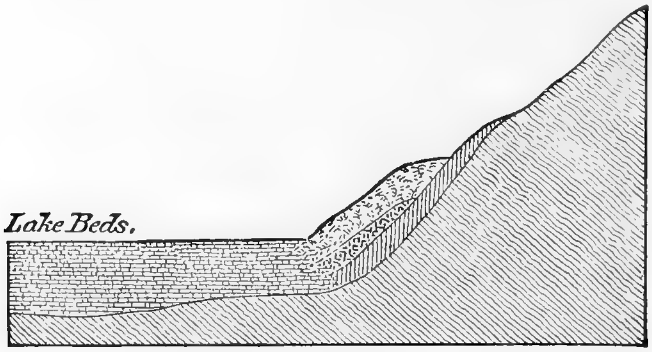


FIG. 28.—Diagram showing succession of tufa deposits.

The first formed deposit, lithoid tufa, extends upward about 500 feet above the horizontal lake-beds occupying the bottom of the basin. The second deposit, thinolitic tufa, finds its upper limit about 100 feet above the present level of Pyramid Lake. The third and last, dendritic tufa, extends upwards to within approximately 200 feet of the highest shore-line. The lower limits of the tufas cannot be determined with accuracy, as they are concealed by lacustral sediments.

Considering these deposits by themselves, we learn that Lake Lahontan rose to about the level of the lithoid terrace, and then evaporated away to a horizon certainly somewhat lower than the present level of Pyramid Lake. During this evaporation the lithoid tufa was deposited, and evidently owes its precipitation directly to the concentration of the lake waters. The lake was then refilled to the level of the thinolite terrace, where it must have maintained a nearly constant horizon for a long time. Concentration by evaporation continued and the deposition of the crystals after which thinolite is a pseudomorph, took place. From this horizon the lake surface was carried upwards about 220 feet, with many oscillations, and for a long period deposited dendritic tufa. Subsequently the basin was more completely filled, as is shown by the lacustral beds that occur above

DENDRITIC TUFA DEPOSITED ON A CLIFF

the dendritic tufa in the Humboldt and Truckee cañons. During this last rise the water surface reached a horizon about 30 feet above the lithoid terrace, and carved the Lahontan beach—the highest water-line in the basin. From this level the lake evaporated away until the basin reached at least its present condition, and probably a much greater degree of desiccation. We should expect that other deposits of tufa would have been formed during this final evaporation. Thus far, however, there are but few observations to sustain this hypothesis. Smoke Creek Desert and the valley of Pyramid Lake are separated by a low divide, which at a certain stage in the lowering of the lake must have parted the waters in the two valleys. The basin now floored by the desert underwent complete desiccation, and on its surface we find the mineral matter precipitated from the waters as they evaporated. The desert where not concealed beneath recent playa deposits, is covered with an abundance of thinolite crystals, mostly scattered and broken, which, from their position, must have been deposited during the last recession of the waters. The highest point at which this tufa was found may be taken at about 50 feet above the surface of the desert, or a little below the level of the divide at the southern end of the basin. The crystals scattered over the surface of the desert are somewhat different in appearance from the thinolite found in such abundance about Pyramid Lake; and, at their upper limit, pass into a dense, compact, and usually botryoidal mass which closely resembles gray stone-ware. See Fig. 18, Plate XXXIV. As is common with tufa deposits, these crystals are usually grouped about solid nuclei, and frequently form rosette-shaped masses 4 or 5 inches in diameter.

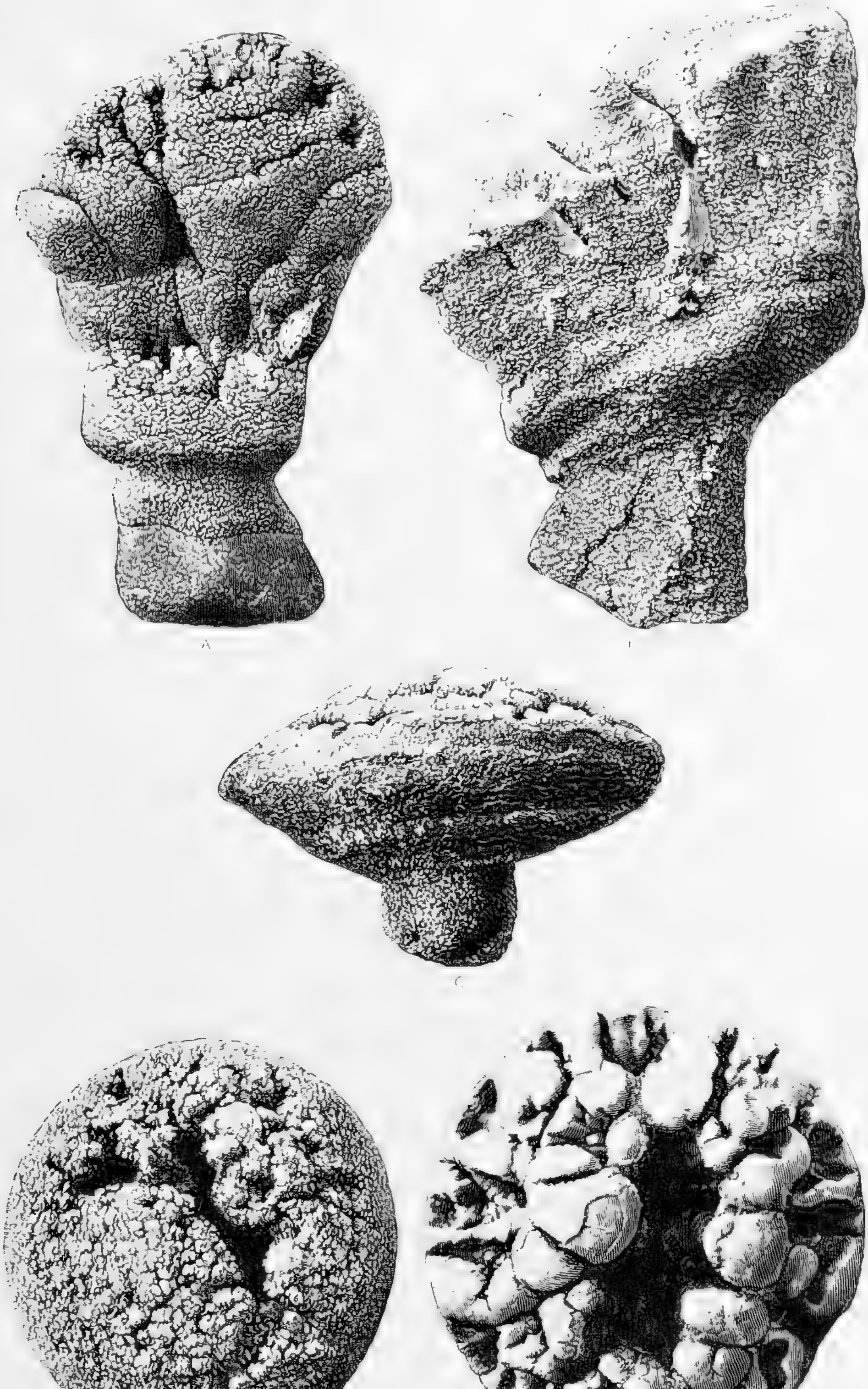
Direct superposition of this variety of tufa upon the dendritic has not been observed; but the sediments on which it rests are probably of the same date as those covering the dendritic tufa in the Truckee and Humboldt cañons. Thinolite crystals of the same character as those scattered over the surface of the Smoke Creek Desert, have been observed at the southern end of Winnemucca Lake, and on the shore of Walker Lake; at the time of their formation, each of these basins must have contained an independent water-body.

In the valley of the Humboldt, near Humboldt Lake, a thin deposit of yellowish, coral-like tufa has been observed coating domes of the dendritic variety, which is quite different from any of the lower tufas occurring in the basin.

From their position at the top of the series we refer both of the varieties of tufa described above to the last evaporation of Lake Lahontan. The coral-like form was deposited when the lake filled its basin up to within 80 or 100 feet of the Lahontan beach; and the thinolite was crystallized when evaporation had lowered its surface so greatly that it became divided into separate basins, one of which, the Smoke Creek Desert, was completely desiccated.

About Pyramid Lake, where the records of Lahontan history are most complete, these evidences of the last recession of the waters have not been satisfactorily observed. The absence of the second deposit of thinolite in this basin is possibly due to the depth of the waters that occupied it, which did not reach a sufficient degree of concentration to admit of the formation of thinolite crystals, at least not in that portion of the basin now open to inspection. Observation has thus far been unable to show conclusively that coral-like tufa similar to that formed at a recent date in the Humboldt Valley, occurs at other localities, but an outer coating on many of the domes about Pyramid Lake is very similar and is probably of the same date. Its general absence may perhaps be accounted for in many localities by assuming that it would be the first of the tufas to be removed by erosion, after the evaporation of the waters in which it was deposited. Our information regarding the later-formed varieties of tufa is but fragmentary, and does not afford as complete a record of the post-dendritic oscillations of the lake as could be desired.

Carrying our study of tufa deposits one step nearer the present, we find that the rocks and tufa-crags about Pyramid Lake are coated with a thin deposit of calcium carbonate, in the form of compact gray tufa, up to the height of about 12 feet above the level of the lake in 1882. This sheathing also descends beneath the lake surface and, judging from its freshness, it is evident that it is still in process of formation. The similarity between the tufa now forming and the variety first deposited from the waters of Lake Lahontan,



indicates that the concentration of the waters of Pyramid Lake at present must approximate that of the ancient lake during its first rise. In sheltered bays among the Needles, where springs with a temperature of about 100° F. rise in shallow water, there are beaches of creamy-white oölitic sand, which, like the calcareous coating on the rocks, is still in process of formation.[68] The calcium composing the oölitic sand is probably derived from the warm springs near at hand, which are also depositing a light-colored, porous tufa on the lake bottom. In a number of instances, tubular and mushroom-shaped growths occur about the orifices of the submerged springs. Some of these irregular tubes rise 5 or 6 feet above the bottom of the lake, and afford passages for the warm waters that stream through them. It is evident that the precipitation of calcium carbonate commences at this locality at the instant that the warm spring-water comes in contact with the cooler and denser water in which it rises. No chemical examination of these spring waters has been made, but judging from their taste they are practically fresh. The tubular forms produced are high in comparison to their diameter and form miniature towers and domes, which in deep, still water might grow to be of large size. A few of them are represented in Fig. 6, page 61. They assist one in understanding the origin of certain Lahontan tufas, which we shall next consider.

TUFA DEPOSITS IN THE FORM OF TOWERS, DOMES, CASTLES, CRAGS, ETC.

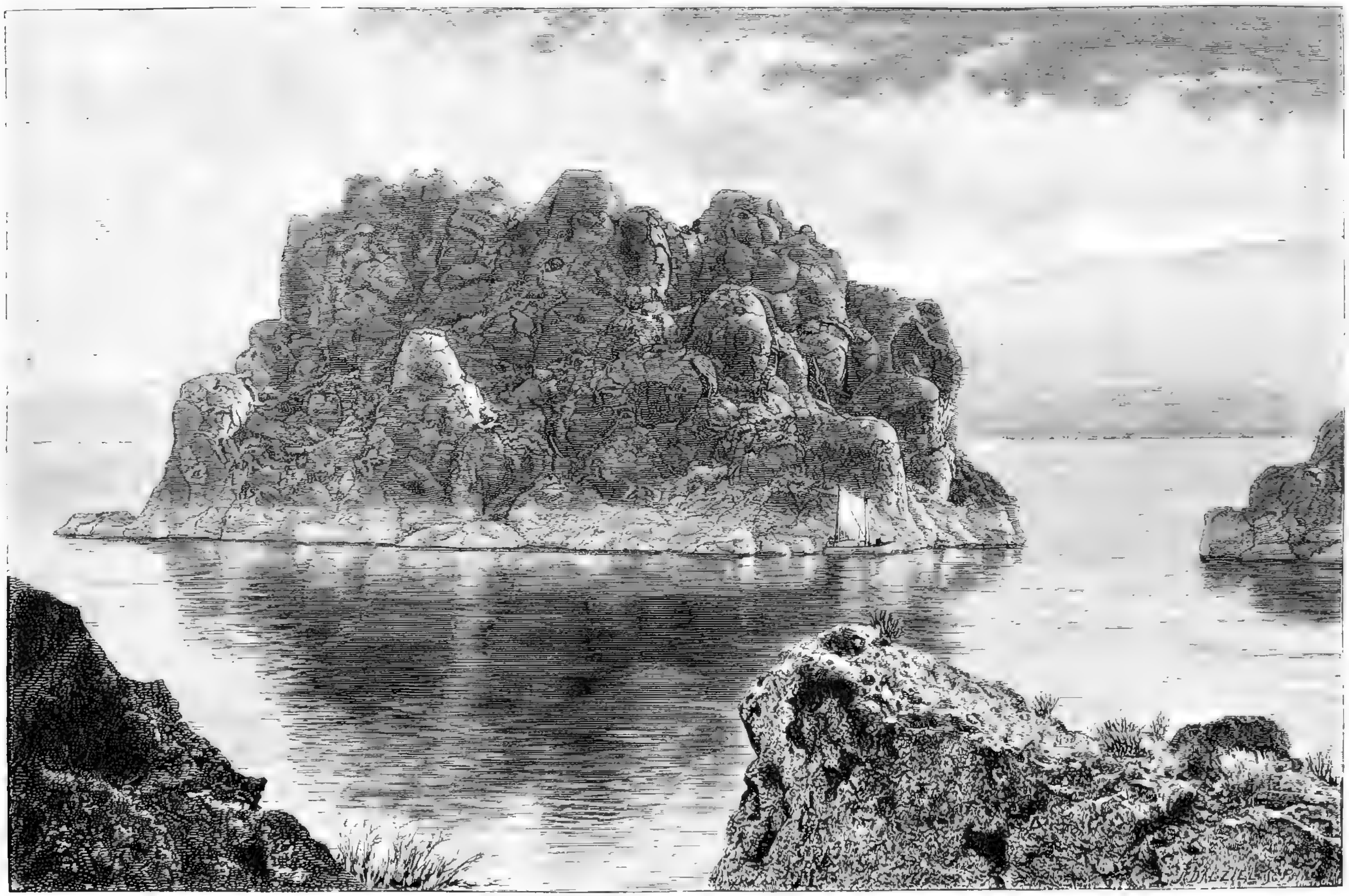
In the foregoing descriptions our attention has been directed to the layers of tufa sheathing the interior of the Lahontan basin. We now turn to other deposits of the same nature occurring in isolated positions at various distances from the borders of the valleys, which we shall call tufa domes, towers, castles, etc., as their forms may suggest. Some of these masses are now wholly or in part submerged beneath the waters of the existing lakes, while others are scattered throughout the desert valleys which were formerly flooded, and frequently resemble isolated watch-towers or crumbling ruins, the origin of which must be a puzzle to one not familiar

[68] The general features of this locality have been noticed in describing Pyramid Lake, page 60.

with the mode of their formation These tufa-forms occur of all sizes, from mushroom-shaped cakes a few inches high, up to castellated masses rising over a hundred feet above the desert, and frequently contain many thousands of tons of calcium carbonate. Isolated tufa-masses may be studied to advantage about the shores of Pyramid and Winnemucca lakes, and at a few localities on the borders of the Carson Desert. The rugged promontory known as the Needles is surrounded by a number of peculiarly shaped islands which rise from 15 or 20 feet of water to a height of 40 or 50 feet above the lake's surface. The Needles and all the associated islands are composed of tufa, which takes the form of towers and domes of the most rugged and picturesque description. The highest of the Needles rises like a cathedral spire to the height of 300 feet, and is apparently composed of tufa throughout. At the top only lithoid tufa is found; at the base of the spire, where the rock swells out and forms a dome, there is a great thickness of the dendritic variety; at the base, where the rock has been weathered and broken, a heavy deposit of thinolite crystals is exposed, interstratified between the lithoid and the dendritic. The precipitation of calcium carbonate has been so abundant at this locality that the rocky nucleus about which the crystallization commenced can only be seen in a few places.

In some instances tufa domes and towers are grouped in clusters and unite with one another in such a manner as to form castle-like masses of great size, which call to mind the ruins of mediæval strongholds. The appearance of one of these water-built structures standing on the western shore of Pyramid Lake is shown on Plate XL; like all the tufa deposits in the basin that are not submerged, this ancient castle is fast crumbling into decay and ruin.

Isolated towers and shafts of tufa are sometimes seen standing on the desert in independent masses that are frequently 50 or 60 feet high, and furnish most instructive examples of deposits of this nature. These structures are frequently weathered and broken in such a manner as to expose every desirable section of their interiors, and afford abundant opportunity for the study of their anatomy. The inspection of some of these broken shafts shows at a glance that they have a concentric structure, and are composed of three varieties of tufa, as in the case of the deposits sheathing the



interior of the basin. A cross-section of one of these columns is shown in the following diagram. The central portion (*a*) is of compact lithoid tufa, which usually exhibits a concentric or tubular structure, and is very frequently from 6 to 10 feet in diameter; surrounding this core is a layer of thinolite crystals, forming the concentric band (*b*), which is commonly from 2 to 6 feet thick; outside of this layer is a coating of dendritic tufa (*c*), of somewhat greater thickness than the thinolite layer, which sheathes the outside of the tower and arches over the low dome forming its summit.

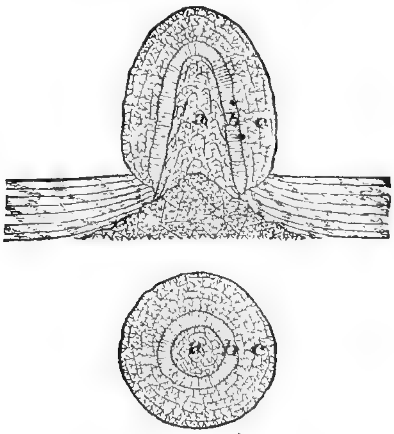


FIG. 29.—Vertical and horizontal sections of a tufa tower.

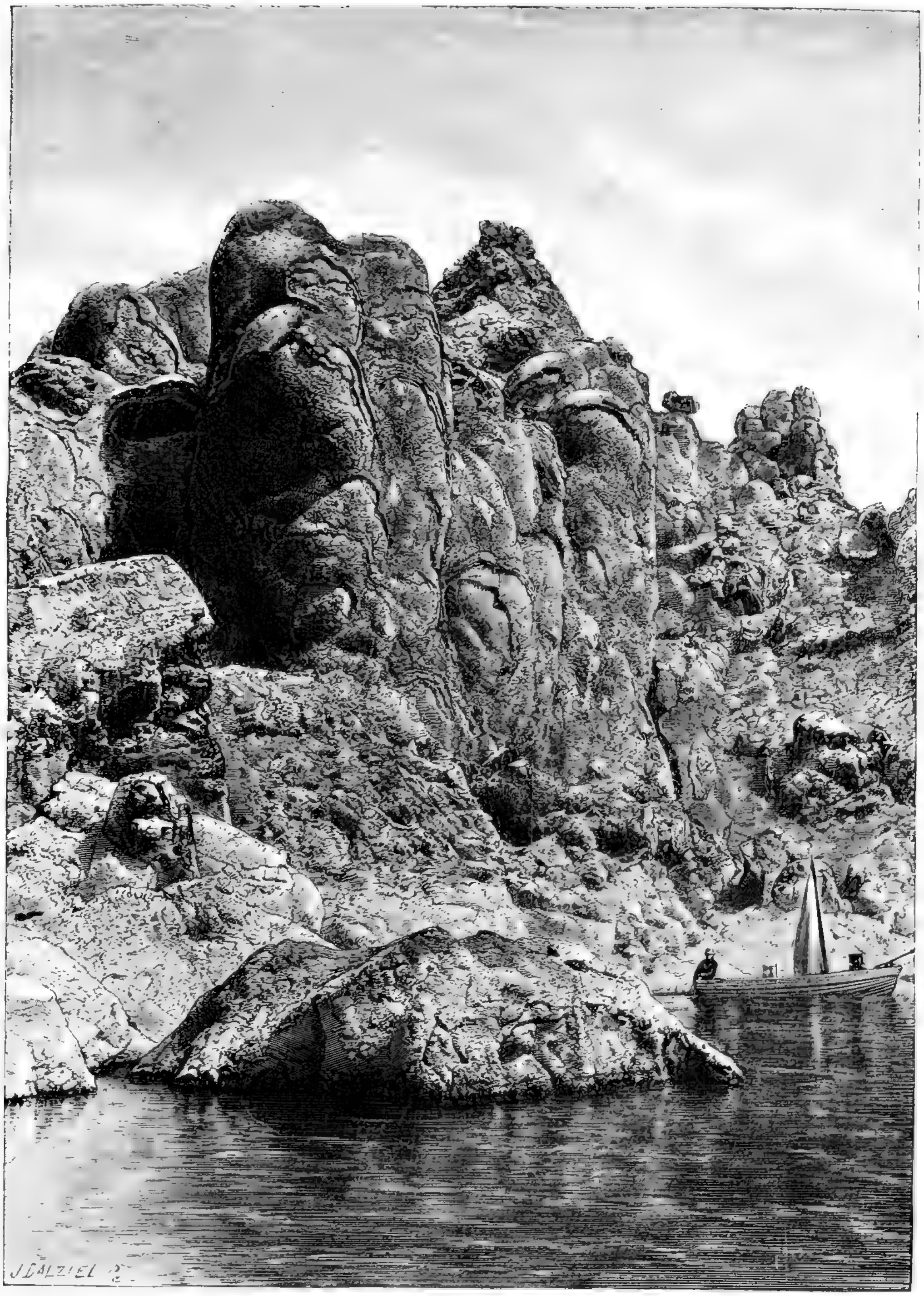
ot only are these isolated towers composed of distinct layers of the three varieties of tufa we have mentioned, but each of these main divisions is itself banded. The cross-section of some of the tufa towers shows that the inner core of lithoid tufa is composed of as many as fifteen or twenty distinct envelopes; at the center and near the outer margin, some of these bands have a dendritic structure. Sections of the middle or thinolite member reveal that it also is composed of a large number of concentric bands, some formed of large, and some of small crystals; near the outer portion of this deposit thin layers of thinolite alternate with narrow bands of dendritic tufa. The outer sheathing of dendritic tufa is also composed of many layers. Each of these concentric circles seen in the cross-section of a tufa tower, like the annual rings of an exogenous tree, is a section of a cylinder that has been formed about the previous one. It is evident that each concentric band records a change of greater or less importance in the character of the solution from which the calcium carbonate was crystallized. The lithoid and dendritic varieties having a much closer resemblance to each other than either has to the middle or thinolite member; it is apparent that the chemical conditions which favored their deposition, although not identical, were not widely divergent. As the first and third members of the series were deposited when the lake was deep and of broad extent, we may conclude that they were precipitated from comparatively dilute solutions; the thinolite, on the other hand, is only found low in the basin, and must consequently have crystallized from waters that were more concentrated

The structure of the isolated domes, towers, castles, etc., corresponds, even in minute detail, with the structure of the tufa layers sheathing the sides of the basin; thus adding strength, if additional evidence were needed, to the conclusion that they were deposited during three well-defined stages in the history of the former lake.

CONDITIONS FAVORING THE DEPOSITION OF TUFA.

From the facts already gathered concerning the history of Lake Lahontan, it is evident that the principal condition which favored the precipitation of the calcium carbonate dissolved in its waters, was concentration by evaporation; the tributary streams at the same time continuing to supply fresh quantities of calcium carbonate. We do not forget, however, that chemical reactions must have taken place among the various salts as the lake became concentrated, which would affect the nature of the precipitates. The conditions under which a mixture of saline substances exists in solution are too little known, however, to enable one to determine what changes may have taken place

The conditions favoring the formation of lithoid tufa seem simple in their nature and not difficult to determine. This variety is apparently identical with that precipitated in neighboring Quaternary lakes, and is very similar to the deposits now forming about many springs, or being precipitated from the spray of water-falls, and from the waters of lakes in which evaporation equals or exceeds supply. The deposits now forming owe their deposition to the loss of carbon dioxide, and to evaporation; and are so similar to the first-formed Lahontan tufa, that there seems no doubt but that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the ancient tufa was deposited in a similar manner and was a direct precipitate from lake waters. It is evidently not a pseudomorph, and since its deposition has undergone but slight change.

We have already noted that the dendritic tufa is much more closely related in its structure to the lithoid than it is to the thinolitic variety. The alternation of lithoid and dendritic tufa in narrow bands indicates that the conditions under which they were deposited were very similar. At the time each of these varieties was precipitated the lake was of broader extent and had a much greater depth than when the crystallization of the thinolite took place. From these facts we conclude that the dendritic tufa, like the lithoid, was precipitated when the lake waters were moderately concentrated. At the time of its formation, however, they must have been more highly charged with chloride of sodium, alkaline carbonates, etc., than during the early part of its history. The presence of these salts may account for the peculiar forms assumed by the calcium carbonate upon crystallizing. This variety of tufa, like the lithoid, has remained practically unchanged since it was deposited, and cannot be considered a pseudomorph after any other mineral.

From the relative height of the various tufa deposits on the sides of the Lahontan basin we know that the lake was much lower during the thinolitic stage than when the other varieties of tufa were formed. It was, therefore, presumably a more concentrated chemical solution. This statement requires qualification, however, when we consider that between the lithoid and thinolitic stages the lake sank far below the thinolitic terrace and may have undergone complete desiccation. If the lake was evaporated to dryness at that time, one of three results might have ensued: (a) The precipitated salts might have been buried beneath playa deposits, in which case the lake formed when the basin was partially refilled might have been essentially fresh. (b) The lake might have been partially refilled before any of the precipitated salts were buried, in which case it would be an alkaline and saline solution of the same character as during the low stages previous to desiccation. (c) Lastly, a partial precipitation and burial of the saline content might have occurred; in this case the less soluble salts would have been removed, leaving the waters in the condition of a mother-liquor, characterized by the presence of the more deliquescent salts. Let us consider the probable effect of each of these conditions on the character of the calcium carbonate subsequently deposited.

If the first case, we should expect that there would be but a slight, if any, deposition of tufa in the rising lake. If precipitation of calcium carbonate did take place, however, it would be expected to have the same characteristics as the tufa formed during the first high-water period, but as the thinolite is markedly different from the lithoid tufa we may disregard this postulate.

If the second were true, and all the precipitated salts were redissolved, the previous condition of the lake would be practically re-established, and the ensuing deposits of tufa could not be expected to differ from that previously precipitated.

If the third were true, a change in the nature of the lake when the basin was partially refilled would result. The first salts to be deposited from a brine obtained by the concentration of waters like those found in the rivers of the Lahontan basin would be calcium carbonate, calcium sulphate, and sodium chloride. As calcium carbonate had already been deposited in immense quantities, and the per cent. of calcium sulphate was probably small, the principal salt that would be precipitated upon a partial crystallization of the substances dissolved in the concentrated lake water would be sodium chloride. If the precipitation and burial of the mineral substances in solution had been stopped at this stage and the basin partially refilled, the resulting lake would have been characterized by the presence of more soluble salts among which the alkaline carbonates would have predominated. The calcium carbonate subsequently contributed by streams and springs as the lake rose would have been precipitated under different conditions than had previously obtained, and this might have caused it to assume a different crystalline form. Thus the postulate of a partial desiccation of the basin agrees best with the facts observed.

As a qualification of the second hypothesis, we might assume, that during the time intervening between the formation of the lithoid and thinolitic tufas concentration was continued for a long period without the depo-

TUFA CASTLE, WEST SHORE OF PYRAMID LAKE, NEVADA

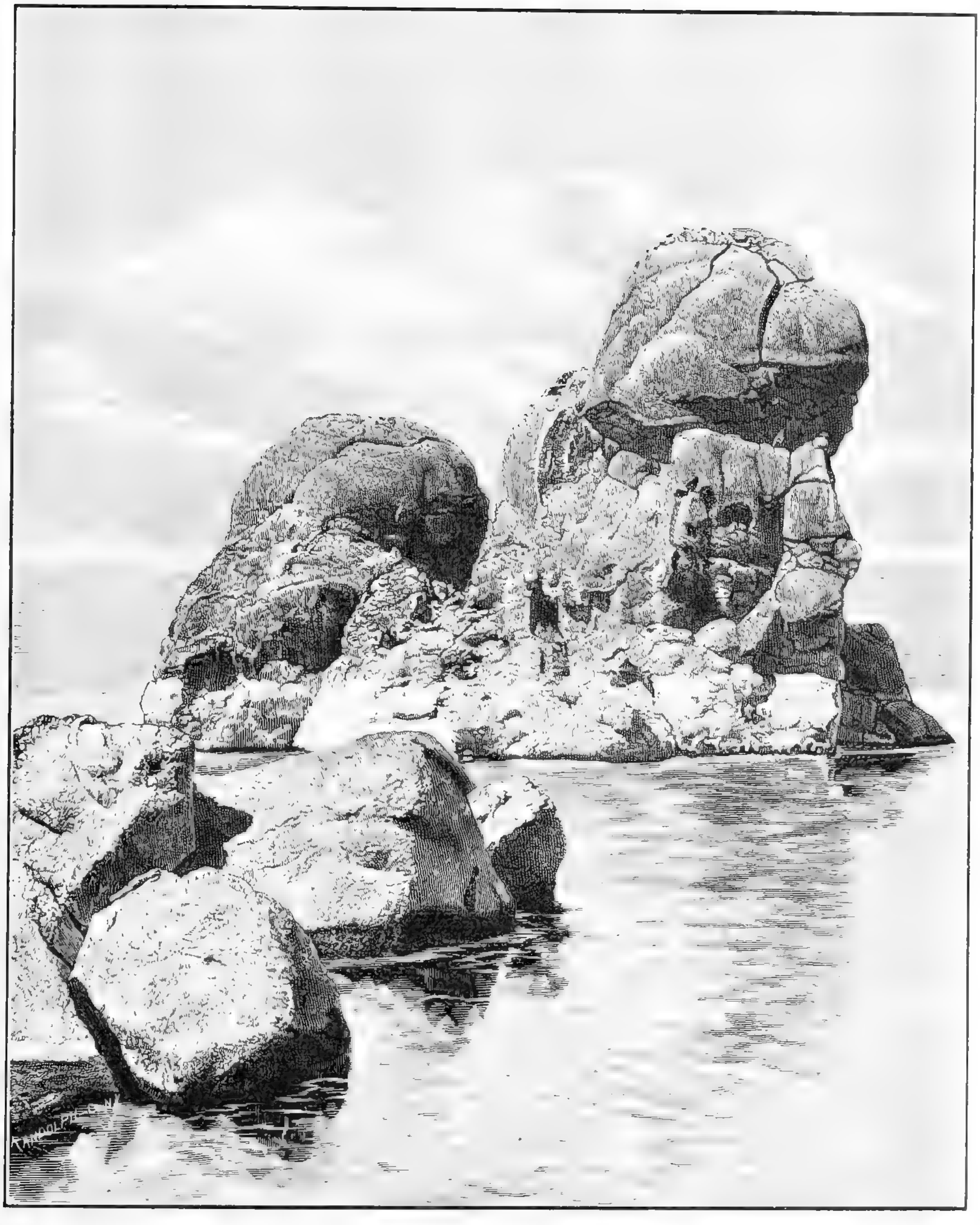
sition of any of the contained salts. The water would thus be more highly charged with saline matter when the lake rose to the level of the thinolite terrace than when it previously stood at that horizon. Under these conditions the composition of total salts would remain practically constant, but their percentage in a given quantity of water would be increased. Our ignorance of the influence that the presence of various salts exerts on the character of the calcium carbonate precipitated from saline waters renders it impossible for us to predict that it would differ in crystalline form when deposited in strong or weak brines. A partial desiccation would cause a more marked change in the chemistry of the lake than continued concentration. We are inclined, therefore, to the belief that the former is the more probable hypothesis of the two.

The positive element in the problem is that a marked change did take place in the character of the calcium carbonate precipitated, which is proof of an alteration in the chemistry of the lake waters, unless the question of temperature be considered as of weight in the problem. The assumption that this change was an increase in the percentage of alkaline carbonates in the waters is strengthened by the fact that thinolite has only been found in this country in basins characterized by the presence of these salts, viz, in the Lahontan and Mono basins. In the Bonneville basin, tufa was deposited on quite an extensive scale, but it did not assume the form of thinolite. Since that basin last overflowed its waters have been concentrated until they are strong brines, without producing the conditions necessary for the formation of thinolite. It is evident, therefore, that some element in the chemistry of the lakes on the western border of the Great Basin, in which they differed from their sister lakes to the eastward, determined the crystalline form of the calcium carbonate precipitated from them. This difference was most probably the greater richness of the western lakes in alkaline carbonates.

It has already been pointed out that lithoid and dendritic tufa must have been deposited from the same solution under slightly varying conditions, for the reason that narrow bands of these varieties alternate with one another. A similar alternation of thinolite and dendritic tufa has been observed in many places, which seems evidence that these varieties were deposited from the same waters under somewhat diverse conditions. A characteristic feature of inclosed lakes is their inconstancy of level. It seems evident that the banded character of the tufa deposits may be correlated with fluctuations of the lakes in which they were formed. In the case under consideration, we may reasonably assume that when the waters were concentrated, thinolite was crystallized; when they became somewhat dilute, the tufa assumed the dendritic form. Finally the lake rose and remained for a long time above the thinolitic limit and only the dendritic variety was deposited. Our observations lead to the conclusion that the changes from conditions favoring the crystallization of thinolite to those admitting of the formation of dendritic tufa or *vice versa*, during certain stages of the lake, were very slight. It appears quite probable that the alternation of thin layers of these varieties of tufa may record alternate arid and humid periods. That they are not annual growths, thinolite being formed during the summer and dendritic tufa during the winter, is evident from the fact that the quantity of calcium in even the thinner layers is too great to have been contributed to the basin within a single year.

Professor Dana's studies have shown that thinolite is a pseudomorph, but what the antecedent mineral may have been still remains an enigma. Geological observations when considered by themselves tend to the hypothesis that the waters in which thinolite was formed were charged with sodium carbonate, and that the crystals now represented by the thinolite were a compound of soda and lime, presumably as the double carbonate. Professor Dana has shown, however, that this postulated mineral could not have been gaylussite (as supposed by King) and, in fact, was not any natural or artificial crystal that has been recognized. It appears as if the unknown mineral must have been produced by a delicate adjustment of the chemical conditions of lake waters—in which the influence of the mass and of temperature perhaps played an important part—which has not been observed in nature or reproduced in the laboratory. In reference to the chemical nature of the original mineral Professor Dana says:

"The description of the original crystalline form of the thinolite, so far as it can be made out, is sufficiently complete to give an emphatic neg-



[illegible]

ative answer to the question as to the nature of the original mineral. It was *not* gaylussite, nor gypsum, nor anhydrite, nor celestite, nor glauberite, nor, in fact, any one of the minerals which might suggest itself as a solution of the problem. The crystalline form is totally irreconcilable with any of these. This is so clear, from what has gone before, that the question admits of no argument at all. But more can be said: the original mineral was one which does not appear thus far to have been observed in its natural condition, although, as will be shown later, it probably has occurred abundantly at numerous other localities. Furthermore, a review of all the artificial salts of calcium, sodium, and magnesium has failed to bring to light any one which would satisfy the conditions required.

"It seems, therefore, that any explanation of the original condition of the thinolite beds of Lake Lahontan must at present rest on hypothetical grounds, and much as a definite solution of the problem is to be desired, it is not now attainable. A few suggestions may not be out of place here, ... The open skeleton forms, consisting now of crystallized calcium carbonate, make it seem very probable that the original mineral was a double salt, and that a salt containing calcium carbonate as one of its members. Only on such a supposition is it easy to understand the removal of so large a part of the original material and the leaving behind of these plates of calcium carbonate, marking the original crystalline structure. Whether the original crystals were or were not solid throughout, at the time of their formation, it is not possible to say now with certainty; very probably they varied much at different points in this respect. From the analogy of soluble salt deposited rapidly from aqueous solutions, it seems likely that open, cavernous forms were common, perhaps the rule. But even supposing this to be true, no one can inspect such groups of skeleton crystals as those from the Marble Buttes without seeing that what now remains is only a part of what originally crystallized out of the saline waters of Lake Lahontan. This fact, coupled with the other just mentioned, that the remaining skeleton consists of crystallized calcite in granular form, gives, a very important hint as to the changes which these crystalline beds have undergone. The successive steps may have been as follows: (1) The deposition of crystals as the lake waters evaporated; (2) a change of conditions, *e. g.*, an addition of fresh water to the lake (as supposed by King), leading to the solution of a part of the substance of the crystals and the simultaneous recrystallization of the remaining calcium carbonate; (3) the subsequent and independent deposition of the carbonate, solidifying and coating over the skeleton forms.[69] The conclusion reached by Mr. King, that the original mineral was gaylussite, satisfies the requirements tolerably well, for it is then necessary only to explain the removal of the sodium carbonate, and the calcium carbonate remains behind. Unfortunately for this hypothesis, it is impossible to reconcile forms which now remain, showing how the original mineral crystallized with the monoclinic forms of gaylussite.[70] Furthermore, Mr. Russell finds several other grounds, independent of this crystallographic proof, for the belief that the supposed enormous deposit of gaylussite could not have taken place. But if not gaylussite, what was the original mineral?

"It is hardly profitable to go beyond the above suggestion, that it may have been a double salt, containing $CaCO_3$, unless the hypothesis can be based upon some observed facts; but fortunately some facts can be pointed to which lead to a possible explanation of the enigma, and which are in any case very suggestive

"The only crystalline forms bearing any close resemblance to the acute tetragonal pyramids of the thinolite, of which the writer has any knowledge, are those of the *pseudomorphs of lead carbonate after phosgenite*, first described by Krug von Nidda,[71] from the zinc mines in Upper Silesia. This similarity in habit and angle is the more striking, as the thinolite form is an

[69] U. S, Geological Exploration of the Fortieth Parallel, Vol. I, p. 517.

[70] At the time when Mr. King had this subject under investigation he submitted several specimens to the writer for inspection, and he then gave a qualified assent to the conclusion Mr. King had reached in regard to them. One of these specimens, as Mr. King had noted, showed some crystals which bore a remarkably close resemblance to the well-known Sangerhausen pseudomorphs, then generally referred to gaylussite. This similarity suggested identity of origin—a conclusion which (after a further study of the same specimen) the present investigation has confirmed, as noted below—and thus gave apparent support to the gaylussite hypothesis. The other specimens then in hand were somewhat like Fig. 1, on Plate XXXIII, and upon the inspection given them—no opportunity was had for careful study—they gave negative results; a certain outward similarity to the elongated crystals of gaylussite from South America (called *clavos*, nails) was noted, but nothing more definite.

[71] Krug von Nidda: Ueber das Vorkommen des Hornbleierzes und des Weissbleierzes in den Krystallformen des ersteren in Oberschlesien, Zeitsch. geol. Gesellsch., II, 126, 1850. See also Blum, Pseudomorphosen, Zweiter Nachtrag, 68.

unusual one. A number of these pseudomorphs are in the Blum collection, which became the property of the Yale Mineralogical Museum in 1872. They correspond to the description given by Krug von Nidda. They have the form of a square prism, sometimes terminated by a pyramid having an angle over the extremity of about 36°, and occasionally show traces of an octagonal pyramid; other forms show only a very acute square octahedron, with a summit angle of about 13° in one case and 26° in another. One specimen shows these forms imbedded in a white clay. They are now completely altered to compact, fine-granular lead carbonate, except for the presence of an occasional minute nucleus of the original mineral.

"The hypothesis to which this resemblance leads is this: that *the original mineral may have been chloro-carbonate of calcium isomorphous with phosgenite;* that is, a mineral having the composition $CaCO_3+CaCl_2$ isomorphous with $PbCO_3+PbCl_2$, and now altered to $CaCO_3$, as in the phosgenite to $PbCO_3$. The hypothesis, as far as the crystallographic relations are concerned, is a most natural one. The difficulty arises when we consider the peculiar nature of calcium chloride, and hence question whether an anhydrous molecular compound of calcium carbonate and calcium chloride could have been deposited from the waters of Lake Lahontan. Obviously this is a subject for synthetic experiment, and whatever the nature of the original mineral, it ought to be possible to approximate to the conditions under which it was made and so to reproduce it. It is to be hoped that the work now being carried forward by the chemists of the Geological Survey may lead to some decisive results in this direction.

"In the meantime it is interesting to note the only case in which, so far as the writer can ascertain, a chloro-carbonate of calcium has been formed. The experiments are described by Fritzsche in the Bulletin of the St. Petersburg Academy for 1861, and reprinted in the Journal für praktische Chemie.[72] He states that on evaporating the solution of crystallized calcium chloride, prepared in large quantities for technical purposes, there remained a small amount of a sandy powder, which kept a yellowish aspect so long as the calcium chloride solution was concentrated, but in a dilute

[72] J. Fritzsche: Ueber ein Doppelsalz aus kohlensaurem Kalk und chlorocalcium. Jour. prakt. Chem., LXXXIII, 216, 1861.

solution became finally white. When some of the crystals were placed on a glass slide under the microscope, and then water poured upon them, it was observed that they for a moment were completely transparent and underwent no change; soon, however, the surface became clouded, and then a granular separation took place gradually. As the $CaCl_2$ was dissolved they entirely lost their transparency, and finally there remained *only a skeleton of calcium carbonate corresponding in form and size to the original crystal.* These fell to pieces when touched, and there resulted minute spherical masses of probably amorphous carbonate. This salt was found to have the composition $2CaCO_3+CaCl_2+6H_2O$. The crystals were shown by v. Kokscharof to belong either to the orthorhombic or monoclinic system. It is not to be supposed that this salt of Fritzsche is in any way an explanation of the thinolite enigma, and yet his observations are of great interest in this connection. In order to complete the subject the fact may be noted that Berthier speaks of forming a compound of calcium-carbonate and chloride by fusion.

"Another hypothesis may be offered as to the composition of the original mineral, viz: that it was a double salt of calcium and sodium, perhaps conforming to the formula $CaCO_3+NaCl$, or better $CaCO_3+2NaCl$, which, it is possible, might also be isomorphous with phosgenite. This is so purely hypothetical that very little weight can be given to it; still it may not be entirely useless to throw out the suggestion, although various serious objections at once come up to mind. In any case it must be borne in mind that carbonates and chlorides were the salts most likely to be precipitated from the lake water, and calcium and sodium were the prominent basic elements at hand."

The crystals deposited on such an enormous scale in Lake Lahontan are considered by Professor Dana as being of the same nature as the well known Sangerhausen pseudomorphs Similar crystals have also been found at other localities, but for the discussion of these mineralogical relations we must refer the reader to Professor Dana's report, where these matters are considered at some length.

Throughout the Lahontan basin the various deposits of tufa are most abundant on steep rocky slopes and on isolated buttes which were formerly submerged. Its exceptional abundance at these localities is due principally to the fact that the rocky surface afforded stable support for the precipitates deposited upon them; and its preservation is insured because precipitous shores are in general only slightly modified by wave action, and are not favorable to sedimentation. The dash of the waves against sea cliffs may also promote precipitation for the reason that the waters are aerated, thus facilitating the escape of carbon dioxide, the presence of which is necessary to the solution of calcium carbonate. Wherever tufa occurs on the surface of lake beds a solid nucleus may nearly always be found about which the calcium carbonate was deposited. Pebbles and shells lying on the bottom, or rocky points projecting above the mud, were favorable nuclei around which crystallization took place. About such centers mushroom-shaped growths were formed like those shown on Plate XXXVII, or domes and castles of great size were slowly built up. Solid nuclei seem essential for the commencement of these imitative structures, and appear to play the same role as the nuclei in the familiar experiments of crystallizing alum and rock candy. Some of the towers and castles in the Lahontan basin, which contain hundreds and even thousands of tons of tufa, are known to spring from small centers of accretion. When crystallization was once initiated, precipitation appears to have been accelerated and may possibly have been continued in waters that were below the point of saturation. When the crystallization began about a small nucleus at the bottom of the lake the tendency was to build upwards. Owing to this tendency the tufa deposited in isolated localities assumed the form of domes and towers instead of spreading out laterally and forming sheets or thin flat-topped masses.

The fact that calcium carbonate cannot remain in solution in concentrated lake waters, but is precipitated as soon as delivered by tributary streams, indicates that tufa is a deposit of moderately saline waters. In Great Salt Lake little more than a trace of calcium is found, and this probably exists as the sulphate. In Mono Lake about six hundredths of one per cent. has been found by analyses. The dense alkaline waters of the Soda Lakes near Ragtown, and of Abert Lake, Oregon, are free from calcium; yet all of these lakes are fed by waters that hold about the normal amount (0.0088 per cent.) of calcium carbonate found in river waters. When streams and springs enter these highly concentrated lakes, the calcium carbonate they hold in solution is at once precipitated, either in an amorphous or a crystalline condition, and accumulates at the bottom in the form of marl or, in some instances, as oolitic sand. In order that tufa may be deposited about the borders of a large lake it is evident that the calcium carbonate must remain in solution for a considerable time so that it may be carried to distant parts of the lake; hence the lake waters cannot be highly concentrated or else the calcium would be precipitated before reaching points situated at a distance from the mouths of the inflowing streams. From observation we learn that compact lithoid tufa is now being deposited in Pyramid and Walker lakes, which contain about three-tenths of one per cent. of total solids in solution. In the more highly concentrated lakes mentioned in this paragraph, no deposits of tufa have been observed in process of formation. This evidently indicates that a lake in which heavy deposits of calcium carbonate were accumulated could not have been a concentrated solution during the tufa-forming stages. The deposition of marl in lakes of concentrated water has not been observed, but it appears probable that the highly calcareous beds found in the sediments of some of the Quaternary lakes of the Great Basin were precipitated from saline waters. The precise chemical conditions which determine whether the calcium carbonate precipitated from lake waters shall be incoherent and form marl, or whether it shall crystallize on coming in contact with foreign bodies or previously formed crystals has not been determined. Questions of this character are in a great measure beyond laboratory experiment for the reason that large bodies must be dealt with in order to reproduce the conditions of nature.

That the shells of mollusks occur in thousands in both the lithoid and the dendritic tufa, is also proof that the waters of Lake Lahontan were only moderately concentrated at the time these deposits were formed. No traces of fossils have been found in the thinolite crystals.

When springs rise in the bottom of a lake a new element is introduced into its chemical history. Sublacustral springs, charged with carbon dioxide and calcium carbonate, upon mingling with the waters of a lake may part with their dissolved gases and deposit calcareous tufa. Again, the waters of a lake may be such a strong brine that calcium carbonate cannot be retained in solution, as is the case with Great Salt Lake at the present time. In such an instance the calcium carbonate contributed by springs would be precipitated when their waters mingled with those of the lake. Phenomena of this nature have been observed at the Needles, as described on page 61, and may be studied at a number of localities in Mono Lake. This lake, as shown by the analyses given on table C, is a strong solution of the carbonate and the sulphate of soda, chloride of sodium, etc., while many of the springs that rise in it are quite remarkable for their purity, but yet contain a small percentage of calcium carbonate which is deposited about their points of discharge. These accumulations frequently form domes of large size that are porous and tubular in structure, and in many respects resemble those standing in the deserts of the Lahontan basin. In numerous instances the deposits from the springs in Mono Lake form irregular tubes that are clustered together and frequently branch and expand as they grow upwards, thus forming columnar and vase-shaped structures. A most instructive exhibit of this nature is to be seen in the western portion of Mono Lake, near the mouth of Mill Creek. At this locality, a part of which is shown in Plate XLIII, there are as many as fifty or sixty tufa domes standing in from twelve to fifteen feet of water, many of which rise from ten to twelve feet above the surface of the lake. The tops of some of these structures are occupied by basin-shaped depressions, which in a few instances, are filled with water that rises through the irregular tubes and open spaces in the column beneath. The water in these basins is cool and fresh, and overflowing, fountain-like, down the sides of the vases, mingles with the waters of the lake. These structures are still growing by the gradual precipitation of calcium carbonate, which is taking place, however, only above the lake surface. They are nearly always considerably smaller at the lake surface than at the top, and in general form are not unlike the sponges known as Neptune's cups, found in southern seas They are not only striking examples of chemically formed rocks that are of interest to the geologist, but they are fountains of sweet water in the midst of a lake that is utterly unfit for drinking. In some instances tufa towers ten or twelve feet in diameter, perhaps occurring in clusters, rise twenty or thirty feet above the bottom where soundings show the water to be forty feet deep. From a boat these structures may be clearly seen when sailing over their submerged summits. At times springs rush upward from openings in the tops with such force that their presence is distinctly marked at the surface by a low dome of water.

The formation of tufa finds many illustrations in the Mono basin which will be described more completely in a future report. Only a few examples are mentioned here as supplementing those observed in the Lahontan basin. On the southern shore of Mono Lake, near the Mono Craters, there is an area several acres in extent, bordering the lake, that is covered with thousands of slender tubular columns of tufa from a few inches to three or four feet in height. These are porous and tubular in structure, and must have been built up by the deposition of calcium carbonate from the waters that once rose through them. When the orifice at the top of a column became closed other openings were formed at the side, thus causing the structure to become irregular and sometimes branching. This strange forest of contorted tufa trunks was formed by springs beneath the surface of the lake when it stood at a higher level than at present, and has been left exposed by a recession of the waters.

The similarity in structure between the tufa deposits formed about sublacustral springs in Mono Lake, and the inner core of lithoid tufa in many of the tufa towers now standing in the desiccated basin of Lake Lahontan, is sufficient indication that many of the latter were deposited in a like manner. This explanation, however, cannot be extended to the coatings of thinolite and dendritic tufa enveloping the cores of lithoid. From our present knowledge we may conclude that there are at least two ways in which tufa towers may originate. First, by the direct precipitation of calcareous tufa about nuclei. Second, from the precipitation of the same material from springs rising in lakes that are highly charged with mineral matter in solution.

TUFA DOMES IN MONO LAKE, CALIFORNIA

SECTION 3.—DESICCATION PRODUCTS.

During the centuries that witnessed the deposition of the vast amount of calcareous tufa now found in the Lahontan basin, other salts were contributed to the lake in varying proportions. Upon the evaporation of the waters these more soluble salts were eventually deposited, and, as the lake never overflowed, they must still be retained in the basin.

Instances of the deposition of salts by the evaporation of inclosed lakes are common, and may be illustrated by many examples in the Great Basin. The salt fields in Osobb Valley; the saline deposits left by the evaporation of the Middle Lake in Surprise Valley, California, in 1872; and by the broad salt field now covering the desiccated basin of Sevier Lake in Utah, are all cases in point.

In the Lahontan basin, deposits of this character, which have resulted directly from the evaporation of the former lake are nowhere to be found. The accumulations of common salt, sulphate of soda, etc., occurring in considerable quantities at certain localities, have in all cases been deposited since the evaporation of the former lake. In some instances these accumulations are due to the leaching of saline clays, and the evaporation of the resultant brine in restricted areas, as in the case of the salt fields in Alkali Valley; at other times saline deposits of considerable thickness have resulted from the evaporation of spring waters. Over very large areas the Lahontan beds are frequently whitened with a saline efflorescence, which also owes its accumulation to secondary causes, as will be described a few pages in advance.

Wherever the Lahontan sediments have been examined they have been found more or less highly charged with salts of the same character as those that were most common in the waters of the former lake. The total quantity of saline matter thus imprisoned is certainly very great, and is assumed to represent the more soluble substances contributed to Lake Lahontan.

THE FRESHENING OF LAKES BY DESICCATION.

The apparently anomalous phenomena of the desiccation of a great lake without leaving a surface deposit of salt, seems explicable in only one way. Adopting the suggestion advanced by Mr. Gilbert in explanation of some portion of the history of Lake Bonneville, the absence of saline deposits is accounted for by the hypothesis that they were buried and absorbed by lacustral clays and playa deposits during periods of desiccation.

The freshening of a lake by desiccation may be illustrated in all its stages in the various basins that have been examined in the Far West. A lake after a long period of concentration becomes strongly saline, and finally evaporates to dryness, leaving a deposit of various salts over its bed. During the rainy season the bottom of the basin is converted into a shallow lake of brine which deposits a layer of sediment; on evaporating to dryness, during the succeeding arid season, a stratum of salt is deposited which is, in its turn, covered by sediment during the succeeding rainy season. This process taking place year after year results in the formation of a stratified deposit consisting of salts and saline clays in alternating layers. The saline deposits may thus become more and more earthy until the entire annual accumulation consists of clays. The site of the former lake then becomes a playa. A return of humid conditions would refill a basin of this character, and might form a fresh-water lake, the bottom of which would be the level surface of the submerged playa.

The larger lakes of the Lahontan basin, as well as a number of less importance in eastern Nevada and southern Oregon, are without outlet. They occur in basins that in almost all cases were occupied by much larger water-bodies during the Quaternary, which, like their modern representatives, never overflowed. From the long period of evaporation that has taken place, one would expect the existing lakes to be dense mother-liquors. The fact is, however, that they are but slightly charged with saline matter, and in some instances are sweet to the taste and sufficiently fresh for all culinary purposes. In many localities the lacustral beds surrounding and underlying the present lakes are highly charged with soda salts, which rise to the surface during the dry season as efflorescences.

As these lake basins were never filled to overflowing, we are forced to conclude that influx was counterbalanced solely by evaporation, and that during periods of extreme desiccation the saline deposits became buried and absorbed by the marls and clays which accumulated in the valleys.

Having analyses of the waters of an inclosed lake, and knowing also the composition of its tributaries, we can determine, at least approximately, the length of time it has been in existence, provided no salts previously deposited were dissolved when the basin commenced to fill. For the purpose of making a computation of this nature in the case of the lakes now occurring in the Lahontan basin, the following table has been compiled from analyses given in chapter III.

TABLE D.—*Composition of the principal lakes and rivers of the Lahontan basin.*

LAKES.

In 1,000 parts of water.	Pyramid (average of 4 analyses).	Walker (average of 2 analyses).	Winnemucca.	Average.	Probable combination in average composition.	
Silica (SiO_2)	0.0334	0.0075	0.0275	0.02280	Silica (SiO_2)	0.02517
Calcium (Ca)	0.0089	0.02215	0.0196	0.01688	Calcium carbonate ($CaCO_3$)	0.03221
Magnesium (Mg)	0.0797	0.0383	0.0173	0.0451	Magnesium carbonate ($MgCO_3$)	0.20483
Potassium (K)	0.0733	trace	0.0686	0.04730	Sodium carbonate ($NaCO_3$)	0.48327
Sodium (Na)	1.1796	0.85535	1.2970	1.11065	Potassium chloride (KCl)	0.09894
Sulphuric acid (SO_4)	0.1822	0.5200	0.1333	0.2785	Sodium chloride (NaCl)	1.94244
Chlorine (Cl)	1.4300	0.58375	1.6934	1.23488	Sodium sulphate (Na_2SO_4)	0.40195
Carbonic acid (CO_3) by difference	0.4990	0.47445	0.3458	0.43975		
Total	3.4861	2.50150	3.6025	3.19586	Total (99.00 per cent. accounted for)	3.18881

RIVERS.

In 1,000 parts of water.	Humboldt.	Truckee.	Walker.	Average.	Probable combination in average composition.	
Silica (SiO_2)	0.0326	0.0137	0.0225	0.0229	Silica (SiO_2)	0.0219
Alumina (Al_2O_3)	0.0013			0.0004	Alumina (Al_2O_3)	0.0004
Calcium (Ca)	0.0489	0.0093	0.0228	0.0270	Calcium carbonate ($CaCO_3$)	0.0675
Magnesium (Mg)	0.0124	0.0030	0.0038	0.0064	Magnesium carbonate ($MgCO_3$)	0.0224
Potassium (K)	0.0100	0.0033	trace	0.0044	Sodium carbonate ($NaCO_3$)	0.0294
Sodium (Na)	0.0467	0.0073	0.0318	0.0286	Potassium carbonate (KCO_3)	0.0015
Sulphuric acid (SO_4)	0.0477	0.0054	0.0284	0.0271	Potassium chloride (KCl)	0.0064
Chlorine (Cl)	0.0075	0.0023	0.0131	0.0076	Sodium chloride (NaCl)	0.0076
Carbonic acid (CO_3) by difference	0.1544	0.0287	0.0576	0.0802	Sodium sulphate (Na_2SO_4)	0.0393
Total	0.3615	0.0730	0.1800	0.2046	Potassium sulphate (K_2SO_4)	0.0011
					Total (99.98 per cent. accounted for)	0.1975

Commencing with the simplest instance, we have in the case of Walker Lake an inclosed water-body which receives its entire supply from the Walker River. The total quantity of saline matter contained in the lake water is 13.89 times as great as in an equal volume of river water. It follows, therefore, that nearly fourteen times the present volume of Walker Lake has been evaporated in order to bring the waters to their present degree of salinity. If we know the average annual influx, we can determine the length of time required to bring the lake to its present density. From the very few measurements available, we have assumed 200 cubic feet per second, or 700,000,000 cubic yards per annum, as the average discharge of the Walker River at the present time (see page 44). The volume of the lake, as determined from the data given on Plate XV, is 13,159,000,000 cubic yards. It would therefore require between eighteen and nineteen years for the river to supply water enough to fill the lake basin to its present extent. As the total saline content of the lake amounts to about fourteen times what would be contained in an equal bulk of river water, it would require 260 years for the river, with its present volume, to supply the amount of saline matter now dissolved in the lake, provided there had been no loss of the salts contributed. Observations have shown, however, that calcium carbonate is being deposited from the waters of the lake. A comparison of the analyses of the lake and river waters given on pages 46 and 70, shows that there is even less of this salt in the lake than in an equal volume of the river water. All of the calcium now contributed is apparently at once precipitated. The remaining salts occurring in the lake are more soluble than calcium carbonate, and we have no reason to suppose that any of them are being precipitated. Dropping calcium carbonate from the analyses, and considering the remaining salts only, we learn that in these the lake is 19.66 times as rich as the river waters. Making the computation as before, but using the last mentioned value for the relative salinity of the lake and river, we find that it would require 343 years for the river to supply the amount of salt now contained in the lake.

Approaching the question in another manner, it is evident that we may determine the annual inflow, providing the annual evaporation is known, for the reason that the inflow and the evaporation now counterbalance each other. There are no observations on the rate of evaporation in this region, but in a similar calculation relating to Great Salt Lake, Mr. Gilbert, after considering all the data available, has assumed 6 feet per annum as the loss by evaporation. In the comparatively fresh waters of Walker Lake the rate of evaporation under the same atmospheric conditions must be considerably greater than in the nearly saturated brine of the Utah Lake. In order not to overestimate, however, we will assume the same rate of evaporation in Walker Lake that has been adopted in the case of Great Salt Lake, viz., 6 feet per annum. The area of the lake is 118 square miles, or 365,516,800 square yards; an annual loss of 6 feet by evaporation gives 731,000,000 cubic yards as the total annual evaporation. This estimate was made independently of the former, but the data in each case are necessarily indefinite, and the close approximation in results is not an indication of accuracy.

The average depth of Walker Lake is 118 feet, and as the waters are 19.66 times as saline as those of the river, omitting calcium carbonate from each, it would evidently require the evaporation of a lake of fresh water of the present size and 2,320 feet deep to produce the amount of saline matter now held in the lake. Evaporation taking place at the rate of 6 feet per year, it would require 370 years to reduce this hypothetical lake to the present volume of Walker Lake. Before drawing any conclusions as to the length of time that the present lakes of the Lahontan basin have existed, we may make a more general calculation of the same nature as the above.

Let us suppose the three principal lakes of the Lahontan basin united, and supplied by the three rivers of which we have analyses, viz., the Humboldt, the Truckee, and the Walker. We should have a lake 1,300 square miles in area, with an average depth of 117 feet, and containing 26.71 times the percentage of salt held by the average of the tributary streams, not including $CaCO_3$. To obtain a water-body of this degree of salinity from the concentration of the river-waters would require the evaporation of a lake of the area of the assumed one and 3,125 feet deep. Evaporation taking place at the rate of six feet per year, it would require 521 years for the waters to be condensed to the degree represented by the present lakes. This estimate has been made without considering the amount of saline matter brought into the lakes by springs; and assumes that no salts remained in the basin when the process began. We know, however, that very large quantities of various salts are contributed to the lakes of the Lahontan basin from subterranean sources. Any conclusion derived from the above considerations must be weighted by the fact that the analysis of the rivers were in all cases of samples collected outside the old lake basin, and therefore not affected by the substances derived from the richly saline clays and marls of Lahontan date, through which they carved channels sometimes a hundred miles in length before reaching the lakes into which they empty. The present lakes also derive large quantities of foreign matter from the temporary rills that are formed after the infrequent storms and are charged with the salts derived from the efflorescences formed on the surrounding desert surfaces during the arid season. It is true that the data we have used for computing the flow of the rivers as well as for obtaining the average annual evaporation are based upon very incomplete observations, but we feel confident that future study will show these estimates to be below rather than above the reality. With all these considerations in view, it seems evident from the calculations we have made, that the lakes of the Lahontan basin could not have existed under the present conditions for more than a few centuries at the most without being far more saline and alkaline than we now find them. From the hypothesis of the freshening of lakes by desiccation we conclude that the basin of Lake Lahontan was completely desiccated for a period, ending, we will say, about three hundred years ago, which was sufficiently long to allow of the burial of any saline deposits that may have been left from the evaporation of previous water-bodies in the same basin. By complete desiccation we mean that the various secondary basins formerly flooded by Lake Lahontan became sufficiently dry during successive years, or at intervals of a number of years, to admit of the formation of playa-lakes and playas, and the burial and absorption of saline matter beneath playa deposits. That this was the actual condition of the various valleys composing the Lahontan basin at no distant date is rendered still more probable by the fact that the bottoms of all the lakes of the region are level-floored, and have the same general contour as many neighboring valleys which are occupied by playas.[73]

Applying this line of argument to all the inclosed lakes of the Great Basin, we find, with the exception of Great Salt and Sevier Lakes—the Soda lakes near Ragtown, Nevada, and Mono Lake, not being considered, as they are of an exceptional character—that there is not a lake among the number that could have undergone the present rate of concentration for more than a very few centuries without being far more saline than we now find it. By consulting Table C, it will be seen that with the exceptions we have mentioned there is not a lake in the arid region of the West that contains more than one-fiftieth of the quantity of the more common salts necessary for saturation. This appears to be *prima facie* evidence that these lakes have undergone some process by which their salts have been eliminated within very recent times. In the case of Great Salt Lake we find an exception not only in the amount of saline matter it holds in solution, but also in its environment. With this exception, all the lakes of the Great Basin occupy narrow valleys in which a lake on evaporating would deposit its salts in a comparatively restricted area, thus favoring their burial by playa deposits. The basin of Great Salt Lake, on the other hand, is not only of broad extent, but receives its entire water supply from one side, and is thus unfavorable in its topographical relations for the burial of products of desiccation beneath playa deposits. The present density of this lake may therefore be due to the fact that its salts were not buried during a time of desiccation which admitted of this result in smaller basins; consequently, when the valleys were reflooded, the lakes in the smaller basins were fresh, while in the larger one the unburied saline deposits left by the evaporation of the former lake were redissolved.

The order in which a number of inclosed lakes in an arid region like the Great Basin, will become dry during a time of more than usual desiccation, depends on many conditions; one of the most important of which is the ratio of evaporating surface to elevated catchment basin A lake whose hydrographic basin is low will be extremely sensitive to climatic

[73]A comparison of the lake basins of the Lahontan region with the depressions holding the Laurentian lakes, shows that the bottoms of the former are more nearly horizontal and far more regular than those of the latter.

oscillations; while one receiving the drainage from a lofty mountain range may be but slightly lowered by a climatic change that would produce desiccation in a neighboring valley. From this and other allied reasons, Great Salt Lake may not have been evaporated to dryness during the time that the lakes of western Nevada completely disappeared.

The only analysis we have of the waters of Sevier Lake gives 8.64 per cent. as the total of saline matter in solution. The sample analyzed was collected in 1872; ten years later the lake was almost completely desiccated, and its site converted into a field of salt. We have classed this as a playa lake, and do not consider it of importance in the present discussion, as it not only varies greatly in salinity, owing to variations in volume, but is also so situated that it receives the drainage of a broad desert and must receive large quantities of saline matter from the efflorescences formed each year on the neighboring land surface.

A comparison of the molluscan life of Pyramid and Walker lakes with Lahontan fossils indicates that a marked change has taken place in the fauna of the basin since the last high-water stage of the old lake. This question is considered in the chapter devoted to the life history of Lake Lahontan.

Section 4.—EFFLORESCENCES.

In the preceding pages we have had occasion to speak of the saline incrustations, or efflorescences, to be seen over large areas in the Lahontan basin. It is now our purpose to describe these accumulations more fully. They originate in the saline lacustral clays which floor all the valleys once occupied by the ancient lake, and usually occur in greatest abundance on the borders of the larger deserts, where they not uncommonly whiten the surface over many square miles. In tracing their distribution it is noticeable that they occur most abundantly in those portions of the valleys that are underlaid by the clays deposited directly from suspension in the ancient lake, but are not found on the surfaces of many of the more modern playas which occupy the lowest depressions in the various basins, thus showing that the recently formed playa-beds are in many instances less saline than the true lacustral clays.

The genesis of the efflorescent salts that appear on desert surfaces is not difficult to explain. During the rainy season the clays become saturated with moisture, but on the advance of summer they dry at the surface at the same time that moisture rises from below through the action of capillary attraction. The waters saturating the beds are rendered saline by the salts they dissolve from the clays, and on evaporating at the surface deposit all foreign matter as a surface incrustation. The incrustations thus formed are frequently five or six inches in thickness. They frequently dissolve and disappear during the winter, only to reappear when the heat of summer dissipates every drop of moisture from the surface of the deserts.

From the manner in which saline efflorescences are formed, it is evident that they give a very fair indication of the character of the more soluble salts impregnating the lacustral beds which floor the valleys. The analyses inserted below are of representative samples gathered on the surface of the deserts at widely separated points in the Lahontan basin, and may be taken as indicating approximately the relative abundance of the more soluble salts in the sediments of the ancient lake. Local variations occur, but in general they consist mainly of the more common salts of soda, as has been shown by qualitative tests of a large number of samples in addition to the quantitative analyses here introduced,[74] which were made by Dr. T. M. Chatard. Sample No. 1 is from the surface of the desert, a few miles north of the northern end of Walker Lake. No. 2 is from near Black Rock Point in the Black Rock Desert. Efflorescent incrustations are nearly always mingled with portions of the sand and clay on which they rest, but in the following analyses only the portion soluble in water is considered:

Constituents.	No. 1.	No. 2.
	Per cent.	*Per cent.*
Silica (Si_2O)	1.96	2.18
Potassium chloride (KCl)	1.18	1.39
Sodium chloride (NaCl)	2.53	59.32
Sodium borate ($Na_2B_4O_7$)	4.15	1.00
Sodium sulphate (Na_2SO_4)	17.49	27.05
Sodium carbonate ($NaCO_3$)	72.69	9 06
	100.00	100.00

[74] See also Reports of U. S. Geological Exploration of the Fortieth Parallel, Vol. I, Table of chemical analyses, No. V.

The total quantity of saline matter occurring as an efflorescence on the deserts of the Lahontan basin would be found very great could it be reckoned in tons. At many places it is of economic importance for the common salt, sodium carbonate, boracic acid, etc., that it contains. The industries arising from the commercial value of these deposits, although limited at the present time, may be increased, at least so far as the gathering of common salt is concerned, almost without limit, the supply in many localities being far beyond any demands that are likely to be made upon them.

A good illustration of the nature of the salts impregnating the Lahontan sediments is furnished by an examination of the various salt-works located within the lake basin.

BUFFALO SPRINGS SALT WORKS.

At the Buffalo Springs Salt Works, situated on the west side of Smoky Creek Desert, the brine from beneath the desert is allowed to collect in wells, and is then pumped into vats at the surface and left to evaporate. The crust of salt that remains is then gathered and is found sufficiently pure for all domestic uses. About 250 tons are annually collected, the total amount produced since the works were started being not far from 1,500 tons. When fresh water is caused to flow over the surface of lake-beds in the vicinity it soon becomes strongly saline, and when it gathers in hollows and evaporates it leaves a crust of salt that is sometimes several inches in thickness. This method is employed, to some extent, for obtaining the less pure grades used principally for chloridizing silver ores

Two miles east of the works there are level, pond-like areas on the surface of the desert that are usually covered with a white efflorescence some inches in thickness. Other depressions are soft and completely saturated with bitter brine. In some, there are deposits of sulphate of soda at least several feet in thickness, but never probed to the bottom. When examined by the writer, these sulphate beds were covered to the depth of several inches with mother-liquor or soft mud that rendered the surface unsafe to walk upon. The whole desert region, on the edge of which the

Buffalo Salt Works are situated, is one vast stretch of yellowish mud, without vegetation, impassable except during the dry season, and locally known as the "mud lakes." The salt obtained from the wells of the salt works and the sulphate of soda, and other minerals found on the surface near at hand, are all derived from the salts impregnating the Lahontan Lake beds.

The brine from the wells has been analyzed by Mr. F. W. Taylor, of the National Museum, with the following result:

Specific gravity, 1.1330.

Silica in solution	trace
Calcium sulphate	0.1467
Magnesium sulphate	.8833
Potassium sulphate	.3111
Sodium sulphate	.5306
Sodium chloride	14.8383
Water	83.2900
	100.0000

EAGLE SALT WORKS.

Another locality favorable for the study of the desiccation products of Lake Lahontan is at the Eagle Salt Works, situated near the Central Pacific Railroad, about 18 miles east of Wadsworth. The long valley in which they lie was a strait during the higher stage of Lake Lahontan. When the water fell about 100 feet the region where the salt is now found became a bay, connected with the Carson division of the lake through the Ragtown Pass. The country about the works is a desert mud plain, much of which is covered during the summer by a white saline efflorescence. The method here employed for obtaining the salt is to dissolve the crust that is formed on the surface of the desert and allow the saturated water to gather in shallow vats and evaporate. The water from springs on the eastern edge of the plain is conducted over the surface of the lake-beds, and made to flood small areas inclosed by low dams or ridges of clay. From the flooded areas it soaks through the clay ridges and enters shallow vats dug in the lake-beds on either side, where it evaporates and deposits its salts. The areas inclosed by clay ridges and flooded by the fresh water are called "reservoirs" by the workmen, and the long troughs between them, where the brine evaporates, are known as "vats." These are arranged alternately and may be multiplied to any extent. A profile through a reservoir and the vats on either hand is shown in the diagram.

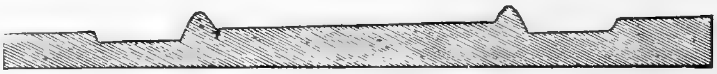


FIG. 30.—Section of reservoir and vats at Eagle Salt Works, Nevada.

The lake deposit here is a fine greenish mud or clay, and is so completely saturated with brine that a thick crust is formed on the surface by efflorescence every dry season. The salt, being supplied from the beds below the surface, is renewed every summer, thus allowing a series of crops to be gathered from the same ground.

A sample of brine from a vat in which the salt had begun to crystallize was analyzed by Mr. Taylor, with the following result:

Specific gravity, 1.2115.

Silica (insoluble)	.0028
Iron and alumina (insoluble)	.0004
Calcium sulphate	.2897
Calcium chloride	.3578
Magnesium chloride	.3787
Potassium chloride	.0023
Sodium chloride	25.3793
Water	73.5890
	100.0000

The annual yield of salt during the past ten years is reported to have been about 2,500 tons. The production has been determined solely by the demand. The amount that could be collected by the simple process of leaching the saline lake-beds and evaporating the saturated waters is practically without limit.

SAND SPRING SALT WORKS.

The most instructive salt field in the Lahontan basin is situated at the eastern end of a long, barren valley, joined to the Carson desert on the southeast by a narrow pass, and known as Alkali Valley. The floor of this valley, when left dry by the evaporation of Lake Lahontan, had the same general level as the Carson desert, and the lake-beds may be traced through the pass from one desert to the other. In riding from the Carson desert eastward into Alkali Valley, one comes to a line crossing Alkali Valley from north to south, beyond which the surface of the desert has a gentle inclination eastward. The surface of the lake-beds when first deposited was horizontal, and the present inclination is due to a fault crossing the valley with a north and south strike, and to the tilting of the orographic block on which the eastern portion of the valley is situated. The tilting of the floor of the valley resulted in the establishment of a drainage to the eastward for the surface waters, and the formation of a small lake at the eastern end of the valley near Sand Springs. During the winter the water collects there, forming a sheet of brine of variable size, sometimes covering 10 or 15 square miles of surface, but with a depth of only a few inches. In the summer the water evaporates and adds to the layers of salt previously deposited.

The deposit of salt thus accumulated is from 3 to 5 inches thick near the margins, and is said to have a depth in the central portion of the basin of not less than 3 feet. It is gathered by simply shoveling it into barrows and wheeling it out on to firm ground, where it is piled in huge heaps ready for transportation.

The surface of the inclined lake-beds draining to the salt fields is absolutely destitute of vegetation, and usually exhibits no saline efflorescence, since this is dissolved away to supply the salt field. The soil, like that beneath the accumulated salt, is a fine, greenish, saline clay, and may be readily examined in the sides of drainage channels, which score the sloping surface to the depth of 3 or 4 feet.

The method here arranged by nature for dissolving the efflorescent salts from the surface of the lake-beds and evaporating the saline waters in the restricted basin is practically the same as that employed by man on a smaller scale at the Eagle and Desert Crystal Works.

Associated with the salt obtained at the various salt works are greater or less quantities of the borate of soda and the borate of lime, and in some cases, as at the borax works in Alkali Valley, they attain such importance as to afford a considerable quantity of borax. There are many other localities in the Lahontan Basin where the chloride, the borate, the sulphate, and the carbonate of soda exist, sometimes in large quantities, in the incrustations that form on the deserts, but at present the demand is not sufficient to warrant the working of these deposits for economic purposes.

RÉSUMÉ OF CHEMICAL HISTORY.

The fluctuations of Lake Lahontan, so far as we have been able to determine from the study of its chemical records, may be briefly summarized as follows:

The waters first formed a fresh-water lake having approximately the outline represented on the accompanying map[75]—which indicates the extent of the lake at the highest stage of all—and then evaporated away with many minor oscillations, until a greater degree of desiccation of the basin than the present was attained. During this oscillation the waters were saturated with calcium carbonate and deposited vast quantities of lithoid tufa.

Whether the lake evaporated to dryness or not during the time intervening between the formation of the lithoid and thinolitic tufa remains undetermined. The contrast in the character of the tufa formed before and after this event is thought to indicate a partial evaporation, or perhaps complete desiccation, with the burial of the less soluble salts This is the inter-Lahontan period of desiccation.

The waters next rose to about the level of the thinolite terrace, with many fluctuations, and formed at least two and probably three independent water-bodies, which were more highly charged with saline matter than during the first expansion. From this solution, which was probably nearly identical in the various basins, the mineral after which the thinolite is a pseudomorph was crystallized.

The thinolitic stage was closed by a rise of the lake. The waters were diluted, but probably still contained a larger per cent. of saline matter than during the lithoid stage, and the third or dendritic variety of tufa was deposited on an immense scale, but did not attain as great an elevation on the sides of the basin as the first formed tufa.

During these three major oscillations there were many minor fluctuations of level, as is proven by the large number of variations in the tufas formed.

After the precipitation of the dendritic tufa the lake rose higher than ever before, the evidence being furnished by gravel embankments, terraces,

[75] In pocket at end of volume.

and sedimentary deposits (see Chap. IV), and then evaporated away probably to complete desiccation.

During this last subsidence a thin coating of coral-like tufa was formed, followed by the crystallization of a comparatively limited quantity of thinolite.

When the lake approached complete desiccation after the post-dendritic rise, it became divided into a number of independent areas, as during the inter-Lahontan subsidence. It is presumed that all these basins became completely desiccated, probably for a long term of years, and that the salts precipitated were buried beneath playa deposits so completely that when some of the basins were partially refilled, the salts were not redissolved. This period of desiccation—as determined by calculating the time that would be required for the existing lakes to attain their present degree of salinity—is thought to have terminated not more than three hundred years since.

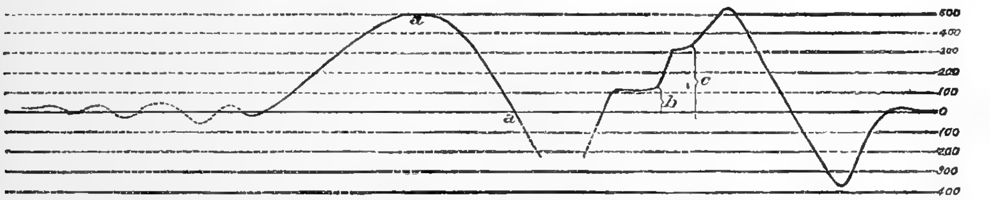


Fig. 31.—Curve exhibiting the rise and fall of Lake Lahontan: *a a*, deposition of lithoid tufa; *b*, deposition of thinolitic tufa; *c*, deposition of dendritic tufa. The figures indicate, in feet, the fluctuations of the ancient lake above and below the 1882 level of Pyramid Lake.

If we project the fluctuations of Lake Lahontan in a curve (Fig. 31), the ordinates representing depths of the lake at various stages, and the abscissas succession in time, we find there are two maxima and two minima. We know that the first of the two high-water periods was the longer continued, for the terraces the waves then cut in the rocks are broader and more strongly marked than the terraces recording the second rise. The second high-water period was of shorter duration, but the lake rose to a higher level than at the first filling.

The salts impregnating the Lahontan sediments, which are now carried to the surface as efflorescences, are believed to have been absorbed from the waters of the ancient lake by the clays and marls forming its bottom, when the lake was greatly concentrated by evaporation.

CHAPTER VI.

LIFE HISTORY OF LAKE LAHONTAN.

The fossils obtained from the sediments and tufa deposits of Lake Lahontan consist of the bones of mammals and fishes; the shells of fresh-water mollusks and of ostracoid crustaceans; the larval cases of a caddis fly; a single chipped implement of human workmanship; and vegetable vestiges of a doubtful nature.

Mammalian bones were obtained at a number of localities in the sides of the Humboldt and Walker River cañons, and, with the exception of a single vertebra found in the medial gravels, they were all derived from the upper lacustral beds. These fossils were submitted to Prof. O. C. Marsh for determination, but only a partial report as to their character has been rendered. So far as determined they include a proboscidian (elephant or mastodon), a horse, an ox, and a camel. The fossils were usually detached and scattered through the sediments, more than one or two bones of the same individual being seldom found at a single locality, except in the case of the elephant or mastodon bones obtained in the Humboldt Cañon near Rye Patch, where nearly an entire skeleton must have been entombed; many of the bones had been removed, however, before the locality was visited by the writer. The failure to obtain mammalian remains from the lower lacustral deposits is of but little weight as negative evidence, for the reason that the beds are imperfectly exposed; a more critical search would, perhaps, reveal an abundance of fossils.[76]

[76] I would suggest in this connection that the disappearance of a number of large mammals from the fauna of this continent since the deposition of the upper Lahontan sediments may have been caused by the extreme aridity which followed the last recession of the lake. An intensely arid climate

The remains of fishes were found at a few localities in the upper lacus tral clays exposed in the Truckee Cañon. No determination of these fossils has been made, farther than the fact that they belonged to *Teleost* fishes of considerable size. They probably indicate that the ancient lake was not strongly alkaline or saline, but, on the other hand, they are not proof that it was fresh; as a number of the brackish lakes of the Great Basin at the present time are abundantly stocked with fish. Little weight can be attached to these fossils, however, in determining the character of the former lake, for the reason that they might have been contributed by inflowing streams even though the water of the lake was a strong brine. Dead fish are sometimes found floating in Great Salt Lake, Utah, which must have come from the inflowing streams. These are preserved for a long time by the brine of the lake but must eventually become buried in the sediments now forming at the bottom of the basin, and, when fossilized, will, in a certain sense, form a false entry in the geological records.

During our examination of the Lahontan basin, fossil shells were obtained at a large number of localities, and in many instances were found in great abundance. Both the fossil and recent mollusks collected, together with the similar material previously obtained by Mr. Gilbert from the Bonneville basin, were studied by Mr. R. Ellsworth Call, who also paid a brief visit to each of the ancient lake basins during the summer of 1883, for the purpose of increasing the collections and making himself personally familiar with the peculiarities of the region. The results of Mr. Call's investigations have been published as Bulletin No. 11 of the Reports of this Survey, to which the reader is referred for detailed information in reference to the fossil shells mentioned in the present volume. Besides the shells inclosed in tufas and lacustral sediments there are others, termed semi-fossil, which

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certainly followed the disappearance of the Quaternary lakes of the Far West, and, so far as that region is concerned, this would furnish a sufficient cause for the extinction of the large mammals which were formerly abundant. This hypothesis is open to objections, however. Evidence that an arid climate succeeded the Glacial epoch in the eastern portion of this continent has not been recognized. Even if it could be shown that a period of extreme aridity preceded the present climate, it is difficult to understand why certain mammals, as the elephant, mastodon, horse, camel, megalonyx, etc., should have become extinct, while others no more capable of withstanding great changes of environment should have survived. The recent extinction of a number of mammals is an enigma the solution of which would reflect much light on the mutations of faunas during the older and still more obscure portions of geological history.

frequently occur in abundance on the surfaces of the deserts at a distance from existing streams and lakes Some of these unquestionably lived in the former lake during its last recession and were left strewn over its bottom when desiccation took place; in many cases, however, the surface shells are true fossils that have been separated from their matrix of clay and marl and accumulated in certain areas by the action of the wind. Other "dead shells," of which *Pyrgula Nevadensis* is an example, have only been obtained about the shores of the existing lakes and are probably still living in their waters; these are also termed semi-fossil.

The thousands of shells obtained are all of fresh-water forms, and include 27 species, grouped under 20 genera and 7 families. The genera and species, together with the horizon from which they were obtained, are indicated in the following table:

Table of shells found in the Lahontan basin.

	Lower Lahontan.	Middle Lahontan.	Upper Lahontan.	Semi-fossil.
Margaritana margaritifera, Linn	......	......	+	+
Anodonta Nuttalliana, Lea	......	+	+	+
Sphærium dentatum, Hald	......	......	+	+
striatinum, Lam	......	......	+	+
Pisidium ultramontanum, Prm	......	......	+	+
compressum, Prm	......	......	+	+
Helisoma trivolvis, Say	......	......	+	+
ammon, Gould	......	......	......	+
Gyraulus parvus, Say	......	+	+	+
vermicularis, Gould	......	......	......	+
Menetus opercularis, Gould	......	......	+	+
Limnæa stagnalis, Linn	......	......	......	+
Limnophysa palustris, Mull	......	+	+	+
bulimoides, Lea	......	......	+	+
Limnophysa sumassi, Bd	......	......	+	+
humilis, Say	......	......	+	+
Physa humerosa, Gould	......	......	+	+
Pompholyx effusa, Lea	+	+	+	+
Carinifex Newberryi, Lea	......	......	+	+
Ancylus Newberryi, Lea	......	......	+	+
Amnicola longinqua, Gould	......	......	+	+
Pyrgula Nevadensis, Stearns	......	......	......	+
Fluminicola fusca, Hald	......	......	+	+
Valvata virens, Tryon	......	......	+	+
Vallonia pulchella, Mull	......	......	+	+
Succinea stretchiana, Bd	......	......	+	+
Pupilla muscorum, Linn	......	......	+	+
	1	4	23	27

In arranging the fossils according to their geological horizons we have considered the lower lacustral beds as, at least in part, contemporaneous with the lithoid tufa; the medial gravels have been correlated in time with the thinolitic tufa; and the upper lacustral clays with the dendritic tufa.

As indicated in the list, only a single species (*Pompholyx effusa*) has thus far been derived from the lower lacustral clays. This was found in great abundance in the lithoid tufa on Anaho Island, and was equally common in other localities at a corresponding geological horizon. This is the most abundant and characteristic fossil of the Lahontan sediments; it occurs from the base of the oldest of the tufa deposits all the way through the series, and is one of three species of mollusks found living in Pyramid Lake at the present day.

All the fossil shells obtained are of recent species, and the majority have been found living in the Great Basin. A comparison of the living and fossil forms has shown that the fossils are depauperate, and exhibit greater variations in the size, thickness and sculpture of their shells than occur in living examples of the various genera and species when obtained from regions where they find a congenial environment. In this connection Mr. Call says:

"The wide range of *Pompholyx* in Lahontan beds makes possible a valuable comparison of the same species from localities representing stages of the lake widely separated in point of time. . . . . . . Specimens taken from the lithoid tufa on Anaho Island, in Pyramid Lake, when compared with those from horizons correlated with the dendritic period present the widest range among individuals. The shells from both localities are higher than Pyramid Lake form, are much thinner, and the coiling of the whorls is much looser. The lithoid tufa specimens present a large proportion of costate forms, the ratio being as 1 to 2, while in recent specimens the ratio is as 1 to 32. The recent species approximate *P. effusa*, var. *solida* Dall, while in sculpture and elevation the earlier forms of the lithoid tufa approach nearest to the typical *P. effusa*, Lea."

Comparative measurements of *Pompholyx effusa* from deposits of lower and upper Lahontan beds, and of specimens found living in Pyramid Lake, show that the average size of the fossils from the older horizon is below that of the Pyramid Lake specimens; while those from the upper Lahontan sediments are larger than the living examples. On comparing the size of the Pyramid Lake specimens with the average of the same species from fresh water localities in the same region, it was found that the shells from fresh water were larger than those obtained from Pyramid Lake, which, it will be remembered, is somewhat saline and alkaline (see analyses, pages 57 and 58). A large number of measurements of fossil and living forms, shows that the

Lahontan fossils are smaller and exhibit greater variation than the same species when living under normal conditions. On comparing the size of *Pompholyx* from Anaho Island (lower Lahontan), "white terrace" (upper Lahontan), and White Pine, Nevada, (living), the ratio of 63: 88: 100 was obtained.[77]

The investigations of conchologists have proven that there are at least three variations of environment which may cause depauperation in fresh water mollusks, viz., salinity, low temperature, and scarcity of food.

As regards salinity, it has been shown that a sudden change from fresh to saline water, i. e., to water resembling that of the ocean, is fatal to fresh-water mollusks. When the change is gradual the life of the species may be maintained until a considerable degree of salinity is reached, but the limit has not been determined, and is known to vary widely with different species. To make the experiments in this direction definite and comparable with the gradual changes which take place in the waters of inclosed lakes, would require a much greater length of time than has yet been devoted to the subject. Enough has been determined, however, to show that a gradual increase in the salinity of a lake would be accompanied with the depauperation and decrease of its molluscan life; should the salinity continue to increase until a condition approximating that of the ocean was reached, the molluscan life would become nearly if not completely extinct. We may reasonably conclude, therefore, that the waters of Lake Lahontan were not strongly alkaline or saline during the time the sediments and tufas so richly charged with fossil shells were deposited. It is perhaps well to mention in this connection that there is no reason to doubt that the mollusks whose shells are found in such abundance actually inhabited the ancient lake. They could not have been contributed by inflowing streams and are not found in exceptional abundance where springs entered the lake. The degree of salinity attained by the ancient lake cannot be determined, but, as we have seen, must have been low, at least during the high-water stages. This conclusion is most definite in the case of the upper lacustral marls which are frequently charged with the shells of *Anodonta*, a genus which, at the present time, is confined to waters of exceptional purity.

[77] These measurements refer to the length of the shells.

In the experiments that have been made in reference to the influence of saline waters on the life and growth of fresh water mollusks, the effect of common salt (sodium chloride) has principally been considered. The lakes of Nevada, however, are characterized by the presence of alkaline carbonates, which it is believed have a more decidedly deleterious effect on the life and growth of fresh water mollusks than common salt. This consideration lends still greater weight to the conclusion that the waters of the former lake were not highly charged with mineral matter during the time the fossil-bearing sediments and tufas were formed.

The condition of several of the enclosed lakes of the Great Basin at the present time, however, indicates that a very moderate degree of salinity and alkalinity is perhaps favorable to the growth of fresh water mollusks. Franklin, Ruby and Humboldt lakes are all more highly charged with salts than is the case with ordinary lakes and streams (the total of solids in solution, however, not exceeding a small fraction of 1 per cent.) but have an abundant molluscan fauna. The inference is that a decided although indefinite degree of salinity is requisite to produce depauperation. In the more strongly saline and alkaline lakes, of which Mono, Abert and Great Salt Lake are examples, careful search has been made for living mollusks but none have been found. These lakes are believed to be entirely destitute of both molluscan and piscine life.

As Lake Lahontan never overflowed, it is safe to conclude that its waters at all times must have been less pure than those of ordinary lakes with outlet. The depauperation of its fossils and their variation in size at various horizons, are thus correlated with known saline and alkaline conditions, which also varied with fluctuations of lake level. We conclude, therefore, that at least one cause of the depauperation of the mollusks now found fossil was the chemical composition of the waters they inhabited.

In reference to the evidence furnished by the Lahontan fossils as to the climate of the Quaternary, a conclusion seems impossible at this stage of the investigation, for the reason that a sufficient cause for the observed variation and depauperation of the shells has been found in the chemical character of the waters in which they lived. If we postulate a cold Quaternary climate, the logical sequence would be a depauperation of the fresh-water mollusks; but since a similar change would result from the necessary chemical condition of the waters of an inclosed lake in which concentration had been long continued, no definite conclusion as to the effect of the low temperature seems possible. On the other hand, a warm Quaternary climate would presumably be favorable to the growth of mollusks, but even if the climatic conditions were favorable, a more potent element in their environment caused the shells to become depauperate.

Mr. Call's studies have shown that the molluscan fauna of Lake Lahontan was characterized by the predominance of the *Limnæidæ*. This family of mollusks at the present time is of world-wide distribution, but is found most abundantly in cold-temperate and subarctic regions. During the Quaternary it may be presumed to have had a similar isothermal distribution. Thus in a very general way it might be inferred that the Quaternary climate in the region of Lake Lahontan was colder than at present. The wide distribution of the *Limnæidæ*, however, and their known powers of enduring marked changes of environment, render this conclusion of doubtful value. The majority of the molluscan species that inhabited Lake Lahontan are still living in the Great Basin, and so far as this branch of the palæontological evidence bears witness, we see no reason for concluding that the former climatic conditions differed materially from the present. The only safe inference seems to be that the climate of the Great Basin during the life of the mollusks we are considering was not characterized in mean temperature by *extremes* of either heat or cold.

As regards the scarcity of food in Lake Lahontan, in reference to the depauperation of its molluscan fauna, we know that the mollusks now found fossil, like their living representatives, must have subsisted mainly on convervoid growths. This form of vegetable life flourishes not only in fresh, but also in brackish and alkaline waters, as may be seen in the various lakes of the Great Basin at the present time. There is therefore no reason to conclude from the probable composition of the waters of Lake Lahontan that food of the character required by mollusks was not abundant. The profusion of fos il shells in the sediments and tufas leads to the same conclusion, for without sufficient food molluscan life could not have been so prolific.

The fossils that might be expected to throw the most light on the climatic problem are the mammalian remains, but, unfortunately, up to the present time these have been found in such limited numbers that but little evidence as to the nature of former climatic changes can be derived from them.

Throughout Lahontan history *Pompholyx effusa* was the most abundant species in the molluscan fauna, but only a very few individuals of this genus have been found living in the present lakes of the basin. Moreover, the dead shells of *Pyrgula Nevadensis* occur in profusion on the shores of Pyramid and Walker lakes, but have not been discovered among Lahontan fossils. This species is probably now living in the lakes of the region, as is indicated by the fresh appearance of the shells, in some of which the soft parts of the mollusks are still adhering.

The occurrence of *Pompholyx* throughout the Lahontan series and its rarity in the existing lakes of the basin, as well as the absence of *Pyrgula* from Lahontan fossils, and its abundance in a semi-fossil condition, are believed to indicate that there was an *interregnum* between the time of Lake Lahontan and the beginning of the present lakes of the basin. If our reading of the records is correct, this time of change was a period of extreme desiccation during which the lakes of the region evaporated to dryness, their salts becoming buried beneath playa deposits, and their molluscan life nearly if not completely exterminated.

The absence of *Pyrgula* in Lahontan sediments, and its abundance in a semi-fossil condition about the shores of the present lakes, in which it is now rare, seems explicable on the assumption that it was introduced into the basin at a recent date and found a congenial habitat in the mildly saline waters of Pyramid and Walker lakes. Subsequently these lakes became too saline and alkaline for its existence, and it was nearly if not completely exterminated, so far as they are concerned. The present chemical composition of the lakes in question is believed to indicate about the limit of salinity or alkalinity that fresh-water mollusks can sustain.

The cases of a minute crustacean of the genus Cypris occur throughout the Lahontan series, and at times are so abundant that they form the principal portion of strata for several feet in thickness, as may be seen in the walls of the Truckee Cañon. At the base of the layer of dendritic tufa exposed along the Humboldt and Truckee rivers this fossil occurs in profusion, frequently intermingled with the shells of *Pompholyx*. On the borders of the Carson Desert the cases of Cypris have been accumulated by the wind in such quantities as to form small drifts resembling sand dunes. What specific name this fossil may bear has not been determined, but species with which it is evidently closely related are known to live in both fresh and salt water. Its value, therefore, as indicating the nature of its environment in Lake Lahontan is indefinite.

FIG. 32.—Larval cases of a caddis fly encased in lithoid tufa.

At a single locality, the larval cases of a caddis fly were obtained, which were coated over and partially imbedded in lithoid tufa (Fig. 32). This fossil is very similar to the larval cases of the caddis fly now found abundantly in streams and lakes, and, so far as the evidence goes, indicates that the waters in which the fossils were formed were not intensely alkaline or saline.

The worm-like larval cases of a fly occur in the tufa about the Soda Lakes near Ragtown, but these are evidently of quite recent date and cannot be considered as Lahontan fossils.

The fossil from the Lahontan basin that will probably be considered by both geologists and archæologists as of the greatest interest, is a spear-head of human workmanship. This was obtained by Mr. McGee, from the upper lacustral clays exposed in the walls of Walker River Cañon, and was associated in such a manner with the bones of an elephant, or mastodon, as to leave no doubt as to their having been buried at approximately the same time. Both are genuine fossils of the upper Lahontan period. The spear-head is of chipped obsidian and is in all respects similar to many other implements of the same nature found, commonly on the surface, throughout the Far West. It was discovered projecting point outwards from a vertical scarp of lacustral clays 25 feet below the top of the section, at a locality where there were no signs of recent disturbance. This fossil, which is the only evidence at present known of the existence of man on the shores of the Quaternary lakes of the Great Basin, is represented natural size in the following figure.

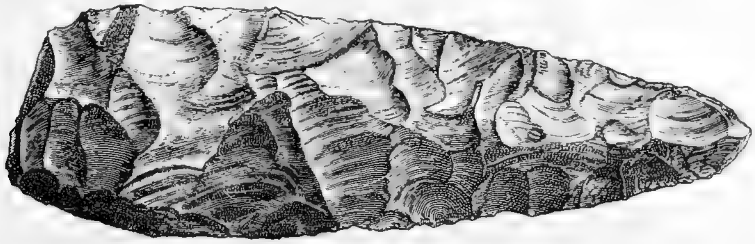

FIG. 33.—Spear-head of obsidian from Lahontan sediments.

The only fossils of a vegetable nature thus far referred to Lake Lahontan are certain problematic, stemlike tubes, from one to two inches in length, and approximately the thirtieth of an inch in diameter, which occur in great profusion at the base of the lithoid tufa on Anaho Island. In some places the lower two or three feet of the tufa is very largely composed of these remains. Our reference of these fossils to the vegetable kingdom is only provisional, however, as they have been examined by several skilled palæontologists without having their relations definitely determined. It has been suggested that they are the casts of grass-like stems, but their uniform diameter and the absence of joints seems to preclude this determination. In describing the variations presented by *Pompholyx* from Anaho Island, Mr. W. H. Dall has spoken of these fossils as the casts of the leaves or needles of the pine;[78] it is possible that this may be the true explanation of the enigma.

[78] Science, Vol. I, 1883, p. 202.

No leaves or vegetable stems of any kind, excepting the fossils mentioned in the last paragraph, have been found among the records of the old lake, and no drift timbers seem to have been deposited in the bars and embankments that have been examined. The absence of such fossils apparently indicates that the shores of the former lake were not heavily wooded. The borders of our Northern lakes at the present day are thickly clothed with forests and their shores encumbered with stranded logs and stumps in such quantities as to have considerable influence on the character of the shore phenomena resulting from wave action. Had the shores of Lake Lahontan been as densely wooded as are those of Lake Michigan, for example, it seems impossible that abundant records of the fact should not have been discovered during our sojourn in the basin.

A superficial microscopical examination of the sediments of the ancient lake has shown that they are richly charged with the silicious skeletons of infusoria, and sometimes abound in sponge spiculæ. A detailed study of these fossils was not practicable, and, as these forms of life are so widely distributed and live under such diverse conditions, it seems doubtful in the present instance, if a more critical examination would greatly assist in solving the chemical and climatic problems with which the student of the Quaternary geology of the Great Basin is principally concerned.

No fossils have been found in the thinolitic tufa, although careful search has been made at many localities. At times shells may be seen in the open spaces between the crystals, but these are believed in all cases to have been accidentally introduced at a recent date. The absence of all life records in this deposit strengthens the hypothesis that the thinolite was crystallized from waters highly charged with mineral matter.

In correlating the various Lahontan deposits we have considered the thinolite as stratigraphically intermediate between the lower and upper lacustral clays, and, at least in part, contemporaneous with the medial gravels. The fossils obtained from the medial gravels are of fresh-water species, but were collected near the borders of the basin and at a greater elevation than the upper limit of the thinolite. The fossils may thus represent a stage in the recession or in the refilling of the lake when its waters were not so dense as when the thinolite was crystallized. In the Humboldt

Cañon where fossils were found in the medial gravels, it is probable that the strata are in part a flood plain deposit, accumulated when the lake was below that horizon.

SUMMARY.

The evidence derived from organic remains indicates that Lake Lahontan throughout its higher stages was never a strong saline and alkaline solution. Even during the abundant precipitation of dendritic tufa the lake was inhabited by mollusks in great numbers, and was probably also the home of *Teleost* fishes of large size. During the thinolitic stage, when its waters were greatly concentrated by evaporation, the absence of fossils indicates that it was uninhabited by either fishes or mollusks.

The life history of the lake, as we know it at present, cannot be considered as affording definite information in reference to the character of the climate during the Quaternary. The reason is that any change in the molluscan life that might be due to climatic oscillations, is complicated and masked by the effects produced by variations in the chemical composition of the waters.

When other basins in the same region are explored, especially those which found outlet, the character of their mollusean fossils may lead to positive conclusions in this direction, for in such instances the influence of an abnormal chemical condition of the waters on the growth of mollusks would be eliminated.

CHAPTER VII.

RÉSUMÉ OF THE HISTORY OF LAKE LAHONTAN.

The history of the fluctuations of the Quaternary lake of northwestern Nevada is recorded in various ways, as has been described in the last three chapters, which treat it from the physical, chemical, and biological standpoints; in the present chapter it is our purpose to present briefly the conclusions based upon these various lines of evidence. The phenomena observed have great diversity of character, but when interpreted in terms of geological history, they support and supplement each other in such a way that the conclusions drawn are believed to be well sustained. Moreover, the facts observed in the Bonneville basin and in more than a score of desert valleys throughout the northern half of the Great Basin which contained contemporary water-bodies, harmonize with the interpretation of the Lahontan record here presented.

The fact that all the minor basins in the arid regions of the Far West are filled to a depth of many hundreds of feet with alluvium and lacustral sediments, together with the occurrence of the beach lines of the Quaternary lakes on the surface of the vast alluvial cones, leads to the conclusion that all these basins were barren deserts before the rise of the Quaternary lakes. The pre-Lahontan condition of northwestern Nevada must have closely resembled its present character, but at times it was probably completely desiccated.

The change of climate admitting of the existence and gradual expansion of lakes in the various valleys throughout the Great Basin caused a number of those situated in northwestern Nevada to rise sufficiently to unite and form a single irregular water-body 8,922 square miles in area. This was the first rise of Lake Lahontan. Like all inclosed lakes it must have fluctuated in depth and extent with the alternation of arid and humid seasons, and risen and subsided also in response to more general climatic oscillations, which extended through years and perhaps embraced centuries. Finally the climatic conditions which favored lake expansion ceased, and a time of aridity, like that which preceded the first rise, was initiated. The lake slowly contracted until its basin reached a greater degree of desiccation than that now prevailing. This was the inter-Lahontan period of desiccation.

During the first rise lacustral marls and clays were deposited throughout the basin; the depth of these is unknown, but they certainly exceed 150 feet in thickness. The waters were saturated with calcium carbonate and the precipitation of great quantities of compact stony tufa took place. Deposits of tufa were formed on rocky slopes throughout the basin, and are not especially abundant at the mouths of streams. This is thought to indicate that although the waters were saturated with calcium carbonate, they were not highly charged with other chemical substances. This conclusion is sustained by observation of conditions under which a similar tufa is being deposited in existing lakes, and also by the presence of gasteropod shells in the lithoid tufa in great abundance.

The time of low water, and perhaps of complete desiccation, that succeeded the first rise of Lake Lahontan, is recorded by stream channels carved in the lacustral beds and by current-bedded gravels and sands superimposed upon previously formed strata. Sections of inter-Lahontan gravel deposits have been observed wherever the material filling the lake basin is well exposed, and furnish indisputable evidence that the lake was greatly lowered before the gravels were deposited. These gravels were in turn covered by a second lacustral deposit, thus forming a tripartite series, a counterpart of which exists in the Bonneville basin. The first formed tufa deposit was exposed to subaërial erosion during the inter-Lahontan period of low water and became broken and defaced.

The character of the next succeeding tufa deposit indicates that a change had taken place in the chemical conditions of the waters of the lake when the basin was again partially flooded. This alteration in the composition of the salts dissolved in the lake is thought to have been brought about by a partial deposition of the saline matter accumulated during the first high-water stage, at the time of the inter-Lahontan period of desiccation. The tufa superimposed upon the lithoid variety is known as thinolite; it is composed of well-defined crystals and is without fossils. It was evidently precipitated from a more highly concentrated chemical solution than that from which the lithoid variety was deposited. That this was the case is rendered evident, since the crystalline variety occurs only low down in the basin, while the lithoid tufa may be found within 30 feet of the highest terrace carved by the waters of the ancient lake.

After the crystallization of thinolite had been carried on for an indefinite period, the lake rose to within 180 feet of its first maximum, and the heaviest deposit of calcium carbonate found in the basin was precipitated. During this stage the lake was not strongly saline, as is shown by the abundance of gasteropod shells obtained from the sediments and tufas accumulated during this portion of its history.

After the precipitation of the dendritic tufa, the lake continued to rise and at last reached a horizon 30 feet higher than the first maximum. During this expansion the waters lingered but a comparatively brief time at the highest level and then slowly subsided. The increase in depth after the deposition of dendritic tufa is shown by the presence of lacustral sediments upon that deposit. The structure of the higher bars and embankments about the border of the old lake basin, proves conclusively that the greatest lake expansion was during the second rise.

With the last recession of the lake all portions of its basin were brought within the reach of wave action, and the tufa deposits sheathing its interior were broken, and the fragments swept away by currents, and built into embankments and terraces. The waters continued to fall until the basin was completely dry. All the salts not previously precipitated were deposited as desiccation advanced, and became buried and absorbed by playa clays. The proof of the occurrence of this time of desiccation is furnished by the comparatively fresh condition of the existing lakes of the basin, and by the change in the molluscan fauna which took place since the last high-water period. The duration of this post-Lahontan arid period is unknown, but it was finally terminated—probably less than 300 years since—by an increase in humidity. The present lakes then commenced their existence.

Throughout its history, Lake Lahontan has been subject to a multitude of minor oscillations, as is indicated by the banded and stratified character of the tufa deposits lining the interior of its basin.

The character of the climatic changes which brought about both the great expansions and contractions of Lake Lahontan, as well as the minor fluctuations to which it was subject, will be indicated, so far as the writer has been able to interpret the records, in the following chapter.

CHAPTER VIII.

QUATERNARY CLIMATE.

In preceding chapters we have considered the physical, chemical, and biological histories of Lake Lahontan, as determined from facts gleaned here and there in its now empty basin. In each of these chapters reference has been made to the climatic conditions on which these various elements of history depended. In the present chapter it will be our aim to review the evidence afforded by the records of the ancient lake which have a bearing on the determination of the climatic conditions that permitted of its existence.

The investigations of naturalists have shown that the fauna and flora of a region are expressions of its climatic condition. To the geologist, the physiography of a country reflects, with nearly equal clearness, the effects of that resultant of a plexus of independent meteoric forces, designated by the term climate. Each year, as the seasons succeed each other, the geological changes, that are ever active, although so slowly and so silently that many times they escape observation, may be correlated with the elements of climate on which they are most closely dependent. Of the atmospheric forces at work, on every hand, in remodeling the earth's surface, those dependent upon humidity and temperature are the most obvious. These vary in intensity with the seasons, and at times their independent workings may be observed. Throughout the geological ages these same invisible agents of the air have never ceased to work changes on the earth, at times surrounding it with warmth, beauty, and life, and again, as the æons passed on, blotting out the fair picture themselves had drawn, and replacing it with cold, desolation, and death.

The general effects of climate are so well known that one may predict the results produced by its various elements on the aspect of a given region.

The geologist is enabled to reverse this process, with greater or less success, and, from the records in the rocks, determine the prevailing climatic conditions of bygone ages. The interpretation of the Lahontan records in terms of climate is at the same time the most interesting and the most difficult of the problems that their study has suggested. The character of the Quaternary climate of the Great Basin has been treated in a comprehensive manner by Mr. Gilbert in a monograph on Lake Bonneville, which, it is expected, will soon be published. We are thus, not unwillingly, constrained to confine our studies to the evidence afforded by the records of Lake Lahontan. Our attention will necessarily be mainly directed to the questions of humidity and of temperature.

Among the topographic characteristics of arid regions are angular mountain tops, cañons with precipitous walls, and alluvial cones where streams from the mountains lose their grade upon reaching the valleys. The last of these features is perhaps as striking as any of the others, and is of special interest in the present discussion. Many times the bases of mountains are completely encircled by a sloping pediment of unassorted *débris*, either angular or rounded, which is the most abundant at the mouths of cañons. Such accumulations form alluvial slopes, and when the *débris* occurs in more or less conical or fan-shaped piles it forms alluvial cones. These deposits have been studied especially by Drew[79] and Gilbert;[80] by the former in the arid regions of Southern Asia, by the latter in the Great Basin. As described by Gilbert, "The sculpture of a mountain by rain is a twofold process—on the one hand destructive, on the other constructive. The upper parts are eaten away in gorges and amphitheaters until the intervening remnants are reduced to sharp-edged spurs and crests, and all the detritus thus produced is swept outward and downward by the flowing waters and deposited beyond the mouths of the mountain gorges. A large share of it remains at the foot of the mountain mass, being built into a smooth sloping pediment. If the outward flow of water were equal in all directions this pediment would be uniform upon all sides, but there is a principle of concentration involved, whereby rill joins with rill, creek with

[79] Journal Geological Society of London, Vol. XXIX, 1873, pp. 441–471.
[80] Second Annual Report U. S. Geological Survey, p. 183 *et seq.*

creek, and gorge with gorge, so that then when the water leaves the margin of the rocky mass it is always united into a comparatively small number of streams, and it is by these that the entire volume of detritus is discharged. About the mouth of each gorge a symmetric heap of alluvium is produced, a conical mass, of low slope, descending equally in all directions from the point of issue, and the base of each mountain exhibits a series of such alluvial cones, each with its apex at the mouth of a gorge, and with its broad base resting upon the adjacent plain or valley. Rarely these cones stand so far apart as to be completely individual and distinct, but usually the parent gorges are so thickly set along the mountain front that the cones are more or less united, and give to the contours of the mountain base a scalloped outline."

In the Lahontan basin alluvial cones are to be seen everywhere about the bases of the mountains, and were evidently a conspicuous feature in the pre-Lahontan topography, as is abundantly illustrated by the fact that the shore lines of the former lake are traceable for hundreds of miles on alluvial slopes of great magnitude. This is particularly noticeable in the northern portion of the basin where the lake was generally shallow, and may be observed especially in the Humboldt and Quinn River valleys and about the bases of the Slumbering Hills. The same phenomenon is also conspicuous about the borders of the Carson Desert and in Buffalo Spring, Alkali and Mason valleys, as well as at many places on the borders of Walker Lake Valley. These alluvial slopes streaming down from the mountains to a horizon far below the old beach lines, bear evidence that the valleys were deeply filled with alluvium before they were occupied by the Quaternary lake. Since many of these basins never overflowed, it is evident that the alluvial slopes were formed during a time of desiccation when evaporation equaled or exceeded precipitation. If this had not been the case, it is manifest that lakes would have been formed and the *débris* filling their basins arranged in stratified beds or built into bars and embankments. A large number of valleys in the northern part of the Great Basin which held inclosed Quaternary lakes have been explored, and in each instance the same relation of shore terraces to previously formed alluvial slopes has been observed. It is therefore considered as proven that an arid climate prevailed for a long time previous to the existence of the Quaternary lakes, the records of which are now observable. The rate at which alluvial cones are formed is irregular and depends on a number of variable factors, as, for example, the amount of precipitation, the grade of the cañons, character of the rock forming the mountain, etc. As the geological and topographical conditions at a definite locality may be considered constant, so far as the present discussion is concerned, it is evident that alluvial cones are in some manner a record of rainfall. Many observations have shown that they are usually formed in arid regions, and result from sudden storms which flush the cañons and sweep out the accumulated *débris* with violence. This is observable not only during the occasional "cloud bursts," as the sudden storms of the Far West are called, but may also be inferred from the occurrence of angular rocks, weighing many tons, on the surfaces of the alluvial cones. During the intervals between the storms, disintegration takes place in the uplands, and the smaller tributaries deposit their loads in the larger cañons, which thus become charged with *débris*. The rapid deposition of alluvium about the mouths of cañons is largely influenced by the fact that what was entirely a surface stream during its cañon course, sinks below the surface on passing to the alluvial slope and deposits its load. These considerations might be extended and the action of perennial streams contrasted with the results produced by infrequent storms, but perhaps enough has already been written to show that alluvial cones are not only characteristic of arid climates but that the precipitation which produced them is commonly paroxysmal. There is manifestly no uniform rate at which subaërial alluviation takes place and no definite measure of the time necessary for the accumulation of *débris* of this character, but the comparative size of the deposits made during distinct periods furnishes at least a general indication of the relative length of time required for their accumulation

Assuming that the conditions of alluviation were equally favorable during the pre-Lahontan and recent arid periods, we may determine from the magnitude of the subaërial deposits in each instance the relative duration of the two periods. The Lahontan terraces carved on the slopes of ancient alluvial cones are but delicate inscriptions which, in a geological sense, are extremely ephemeral, yet they are clearly legible at the present day, thus indicating the recency of their origin. The time that the terraces have been exposed to subaërial erosion must evidently be extremely brief in comparison to the ages required for the accumulation of the vast *débris* piles on which they were made.

Another, although less definite proof of the aridity of the time preceding the rise of Lake Lahontan is furnished by the cañons of the streams that enter the basin. In many instances these were excavated to their present depth before the existence of the lake, which subsequently occupied their channels for many miles. An illustration of this phenomenon is furnished by the cañons of Smoke and Buffalo creeks, which were eroded to the depth of 250 or 300 feet through compact basalt before the rise of Lake Lahontan. When the lake had its greatest extension it occupied the lower portions of these gorges and filled them deeply with marly-clays and delta deposits, at the same time that their walls became loaded with tufa. When the lake retired the streams reclaimed their ancient channels and commenced the removal of the lacustral strata. The creeks are now flowing over their ancient beds of basalt, but the recent corrasion of the volcanic rock is scarcely perceptible. The amount by which the cañons have been deepened during the present arid period, as compared with the work accomplished in pre-Lahontan times, is certainly in the proportion of one to many thousand. Parallel illustrations of the same phenomena are furnished by the rivers which enter the basin from the west, all of which flow in channels of pre-Lahontan date, and became partially filled with lacustrine strata and subsequently re-excavated as in the previous instances. Each of these streams now flows through a cañon within a cañon, in the manner illustrated by the diagram on page 44.

It might be said that when these cañons were formed, the basin to which they are now tributary had a free drainage to the sea. It is impossible to prove or disprove this hypothesis, but in general, cañons of the character of those in question may be considered as characteristic of arid regions. Besides, we know, from the great depth of marl and gravel in many of the valleys of the Great Basin, that they have been regions of accumulation for long periods. The weight of evidence is such, in our judgment, as to confirm the hypothesis that an arid period of long duration preceded the first rise of Lake Lahontan of which we have definite knowledge.

The variations and fluctuations of the pre-Lahontan arid period are unknown, but, from the general teachings of meteorology, we may reasonably conclude that, like the present climate of the Great Basin, it was marked by many fluctuations in precipitation and evaporation, which at times gave origin to lakes of greater or less extent. As the arid period drew to a close and more humid conditions prevailed, it is most reasonable to suppose that the change was gradual. The phenomena do not call for a sudden break in the processes of nature.

Humidity of the Lahontan period.—Inclosed lakes may be considered as representing the net balance between precipitation and evaporation. As the relations of these two climatic elements are complex and independent, their resultant will be inconstant and variable; their mutual neutralization, so far as the lakes of a region are concerned, must, therefore, be a matter of delicate adjustment. It follows from this that the difference in climate between a time of expanded lakes and a time of desiccation might be comparatively moderate.

In a given area, like the Great Basin, we may safely say that a lowering of the mean annual temperature will increase precipitation and decrease evaporation, thus affording the climatic conditions favorable to the expansion of the lakes. On the other hand, a rise in the mean annual temperature would increase evaporation and decrease precipitation, thus favoring the contraction and extinction of inclosed lakes. The existence of a large number of lakes in the Great Basin during the Quaternary is seemingly good evidence that the climate of the region during the time of their greater expansion was more humid than at present; unless it can be shown that there was a very great decrease of evaporation without a corresponding increase of precipitation, a phenomenon only to be observed at the present time in the arctic latitudes.

That many of the lakes did not overflow is equally positive evidence that precipitation within their hydrographic basins could not have been excessive. Had the rainfall been even moderately copious, it seems self-evident that the entire Great Basin must have become tributary to the ocean. Inclosed lakes of the present time are located in arid regions. The lakes of humid regions invariably overflow. In arid countries the water surfaces of the lakes are small in comparison to the areas that they drain; in humid regions the reverse is the rule. Lake Lahontan, as previously stated, was 8,422 square miles in area, and drained a region over 40,000 square miles in extent; the water surface of the basin at the present time is approximately 1,500 square miles. The Quaternary lake during its maximum, occupied approximately one-fifth of its hydographic basin; at the present time only about one-twenty-sixth of the same area is covered by water. From these data alone it will be seen that the present is a time of desiccation in comparison to certain portions of the Quaternary.

Comparing Lake Lahontan with existing lakes in humid regions, we find that its water surface was small in reference to its drainage area. In the case of Lake Superior, for example, the area of the lake is to the area of its hydrographic basin as 1 to 1.72. The combined areas of the Laurentian lakes is to their combined drainage areas as 1 to 3.19.[81] Could the Laurentian lakes be inclosed, so that the only escape for their waters would be by evaporation, it is evident that they would expand and occupy a vastly larger part of their drainage areas than at present. In fact, the mean annual evaporation in this region is much less than the mean annual rainfall, so that an inclosed lake would be an impossibility.[82]

[81] In obtaining the data given above, the following table was compiled, which we insert for convenience of reference.

Areas of lakes and of their hydrographic basins.

Lakes.	Water areas.	Hydrographic areas.	Ratio of water area to hydrographic area.
	Square miles.	*Square miles.*	
Superior	30,829	84,961	1 to 1.72
Michigan (including Green Bay)	21,729		
Huron (including Northwest Passage 1,556, and Georgian Bay 5,626)	22,322		
Saint Clair	396		
Erie	9,633		
Ontario	7,104		
Combined areas	93,733	299,919	1 to 3.19
Bonneville	19,750	52,000	1 to 2.63

[82] Ann. Rep. Chief of Engineers, U. S. A., 1869, pp. 645-648.

Considerations of this character might be multiplied, but it is presumed that enough has already been written to show that the climatic change which gave origin to Lake Lahontan but did not permit it to overflow, must have been one of moderate precipitation in comparison, for example, with the present rainfall of the region of the Laurentian lakes, even if we consider the rate of evaporation in the Great Basin to have been the same during the Quaternary as now. An increase in the annual rainfall of a region may safely be considered as causing a decrease in the mean evaporation, thus indicating that the rainfall in the region of Lake Lahontan during the Quaternary, could not have been greatly in excess of the present mean annual precipitation in the same area. It will be seen from this that the history of Lake Lahontan is decidedly in opposition to the hypothesis that the climate of the Glacial epoch was characterized by a marked increase in precipitation.

A safe conclusion seems to be that the change from arid to more humid conditions which produced the Quaternary lakes of the Great Basin was not sudden or excessive, but consisted in gradual climatic oscillations of *moderate range.*

Considering the question of humidity alone, we venture to correlate periods of lake expansion with an increase in mean annual precipitation; and periods of contraction and desiccation with decrease of rainfall We therefore use the diagram representing the fluctuations of Lake Lahontan, as an expression of the humidity element in the climate of the region during the Quaternary. Interpreting the curve representing the oscillations of the lake in terms of humidity we have:

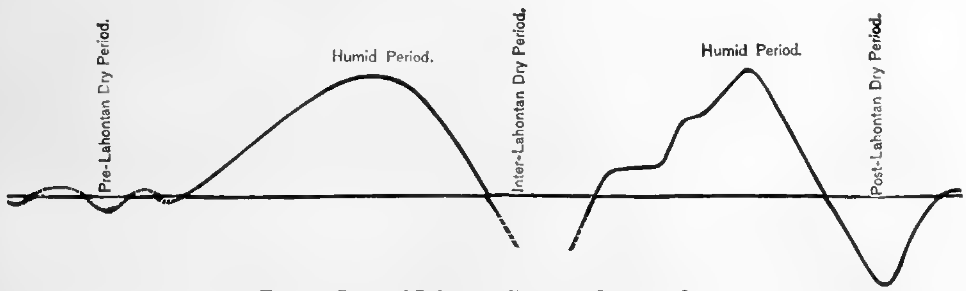

FIG. 34.—Curve of Lahontan climate. Wet *versus* dry.

Temperature of the Lahontan Period.—Considering temperature as the controlling climatic element—in reference to a restricted region, as in the preceding discussion—and knowing that a high temperature promotes evaporation and hence tends to decrease the volume of lakes, and that a low temperature produces a contrary result, we should apparently be justified in concluding that as the Quaternary lakes of the Great Basin were larger than the present water-bodies of the same region, the former climate must have been colder than the present. It may be said, however, that had the cold been intense and produced arctic conditions, precipitation would have been retarded. This postulate, however, is not applicable to the area in question, where the climatic oscillations were of moderate intensity even in comparison with the present prevailing arid conditions, thus indicating that if the periods of desiccation were times of arctic cold, the lake periods must have been at least sub-arctic. On this assumption the Great Basin to-day should have a climate resembling that of circumpolar lands. The absence of "ice walls" about the smaller of the Quaternary lakes of the Far West is negative evidence, perhaps of some value, in opposition to the above hypothesis. Moreover, the character of the abundant molluscan fauna of the Lahontan basin precludes the hypothesis of an arctic climate.

If we postulate sub-tropical or tropical conditions of the Lahontan basin during the Quaternary, we must, from the analogy of tropical countries in general, conclude that the region would probably have been humid as well as warm, and consequently productive of abundant faunas and floras. The absence of fossils indicative of such conditions is sufficient evidence that they did not prevail. In the chapter devoted to the life history of the former lake it has been shown that its shores must have been at least as desolate and lifeless as the borders of the existing lakes of the same region.

The alternation of humid and arid conditions during the Quaternary finds, perhaps, its best analogue in the present annual climatic changes of the same region. The seasons in the Great Basin are two, an arid and a humid, the former being of the greater length. In the winter precipitation is abundant in comparison with the summer; in fact nearly the entire rainfall of the year takes place between December and March. During these months the skies are clouded, and rain and snow are not infrequent; the rivers rise, and many channels that are completely dry during the summer become flooded; the inclosed lakes increase in area and many new ones are formed in basins that are parched deserts during the summer months. The winter season is, therefore, the humid period, during which evaporation is decreased, and is in every way favorable to the existence of lakes. Could these conditions be continued for a sufficient length of time each year it is evident that the Quaternary lake basin would be refilled.

On the other hand, throughout the arid season the rain ceases almost entirely, the skies are clear and cloudless for days and perhaps weeks at a time; the heat in the desert valleys becomes intense, and evaporation is greatly accelerated. The result is a decrease and failure of the streams and the shrinkage and disappearance of the lakes. These annual changes illustrate the character of the secular oscillations that took place during the Quaternary.

The former great extension of the lakes of the Great Basin is, therefore, considered as evidence that the mean annual temperature was then lower than at present. Interpreting the curve given on page 237, which indicates the fluctuations of the Lake Lahontan, in terms of temperature we have the following as a generalized diagram of this element in the climate of the Quaternary:

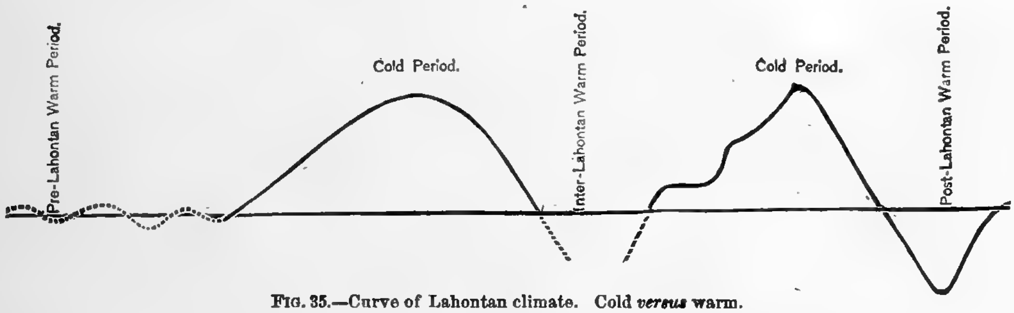

FIG. 35.—Curve of Lahontan climate. Cold *versus* warm.

In the last few pages of this attempt to decipher the prevailing characteristics of the climate of the Quaternary in the region of Lake Lahontan, the questions of humidity and temperature have been considered in reference to a *restricted area*. In treating of such a complicated and far-reaching question, however, it is evident that we should not be confined by geographical limits, but must count the changes of climate in broad and perhaps far-distant regions. In fact, a study of the climate of a given region, to be complete, must contemplate the atmospheric phenomena of the world. Neither can we postulate an alteration of a single element in the climatic environment of a region without altering the relations of all the remaining elements. Hence the interpretation of geological records in terms of climate become more and more difficult.

Our conclusions, therefore, in reference to the climate of the Quaternary are at the best somewhat arbitrary and are open to controversy. The weight of evidence and the impressions which one receives from the study the phenomena in question are such as to lead to at least a well-grounded opinion, even if some of the facts observed might be interpreted differently by different observers.

The present arid climate of the Great Basin cannot be explained by saying that the temperature is high and consequently the water that is precipitated is rapidly evaporated. On the contrary, evaporation is rapid, probably for the reason that precipitation is moderate, or, perhaps more accurately, because the mean annual humidity of the atmosphere is low. In explanation of the present aridity some writers have attempted to show that as the prevailing winds blow from the Pacific, and consequently are obliged to cross the Sierra Nevada before reaching the Great Basin, the mountains condense their moisture, and hence they reach the region to the eastward as drying winds. In this explanation it is forgotten that the Sierra Nevada is scarcely, if at all, more humid than the Wasatch or some of the higher of the basin ranges, and that much of the Pacific slope is also an arid country, although situated between the ocean and the mountains that are supposed to rob the winds of their moisture. Other explanations of the aridity of much of the region west of the Rocky Mountains have been advanced, but it remained for Captain Dutton to present the view that apparently has the strongest foundation.[83] This writer explains the aridity by peculiarities of the currents of the Pacific. In brief, this theory assumes that the currents from the north which follow the western border of the continent cool the air that is carried over them towards the land, this being the prevailing direction of the air currents of the region; consequently, on reaching the

[83] American Journal of Science, Vol. XXII, 1881, pp. 247-250.

land, the air has its temperature increased, and thus becomes a dry wind. If this explanation of the present climatic condition of the Great Basin be accepted, it is evident that past fluctuations in the climate of the same region could be accounted for by assuming changes of direction in the currents of the Pacific.

Testimony of the Glaciers.—Thus far our discussion has been confined to the evidence afforded by the records of the ancient lakes. It is manifest that the glaciers which existed on the neighboring mountains during the time the lakes were flooded should furnish additional evidence bearing on the same question.

The climatic conditions favoring the origin and growth of glaciers has recently been a subject of controversy. Some writers have claimed that the Glacial epoch was a warm period, in comparison with the present, and that the extension of the glaciers was due to an increase of precipitation caused by a greater evaporation over distant oceanic surfaces, the increased evaporation being caused by a general rise of the mean annual temperature. This hypothesis, we believe, was first suggested by Tyndall and Frankland, and has been extended by Professor Whitney in his work on "Climatic Changes in Later Geological Times." A number of articles in various scientific journals have also been published in extension and support of the same assumption.

It is beyond the scope of the present volume to enter into the theoretical discussion thus opened, nor is it necessary, as the arguments brought forward by the writers cited above have been controverted by Newberry, Dutton, Gilbert, and others, who adhere to what may be called the orthodox belief—having been held by the majority of writers on geological climate—that glaciers are an index of cold, and that their great increase during the Quaternary was due to a decrease in mean annual temperature. In other words, the winters during the Glacial epoch were longer or more severe than at present, and their snows not completely melted during the short summers. The conclusions reached by these writers is so entirely in accordance with all that has come under our own observation in reference to the existence of glaciers, that we do not hesitate in considering their determinations as final. The fact that the winter season in the Far West, for example, is the one that favors the accumulation of snow and the growth of glaciers, while during the summer these conditions are reversed, seems enough in itself to show that an extension of the winter conditions, from whatever cause, for a greater portion of the year would favor the extension of the present glaciers and the formation of new ones, as well as the increase of the existing lakes and the flooding of valleys that are now arid throughout the year. Prolonging the winter conditions in temperate latitudes would therefore initiate a glacial epoch. This is the more evident as the climatic change necessary to cause an extension of the existing glaciers of the Sierra Nevada so as to approximate to their former magnitude, or the growth of the existing lakes of the Great Basin until they equaled the extent of the Quaternary water surface of the same region, need not be considered as a climatic change of great intensity.

There are no records of the former existence of glaciers within the basin of Lake Lahontan, but the western border of its hydrographic basin was once buried beneath a vast accumulation of snow and ice that covered all the higher portions of the Sierra Nevada. The East Humboldt range, which forms a portion of the eastern border of the same drainage area, was also glacier-crowned. In the central portion of the basin, the Shoshone, Star Peak, and Granite ranges rise to an elevation of about 10,000 feet, and are reported by the geologists of the Fortieth Parallel Exploration to bear evidence of former glaciation about their summits.

The former presence of extensive glaciers on the Sierra Nevada and Wasatch mountains, and of ice fields of less extent on some of the intermediate ranges, is sufficient to prove that during that time all the mountains of the region must have been snow-covered for at least a large portion of each year. This in itself—unless the temperature throughout the year was below freezing—would necessitate the formation of lakes in the inclosed basins between the ranges. In three instances in the Bonneville basin, and at four localities near Mono Lake, the glacial and lake records of Quaternary date overlap. The moraines at the western base of the Wasatch mountains which descend below the level of the Bonneville beach have been described by Mr. Gilbert;[84] in this instance, however, the relative age of the moraines and lake terraces is indefinite. In the Mono basin a number of

[84] Second Ann. Rep. U. S. Geol. Survey, p. 189.

glaciers of large size formerly flowed down from the High Sierra, which forms its western border, and deposited moraines of great magnitude, on which the terraces of the Quaternary lake, that formerly filled the basin to the depth of nearly 900 feet, are distinctly traced. The moraines at Mono Lake were carried out into the valley as parallel ridges, or morainal embankments as we have found it convenient to call them, which in several instances are prolonged for a considerable distance below the highest of the ancient beaches, and have terraces traced not only on their outer slopes but on the inner sides of the *couches* formerly occupied by glacial ice. In some instances deltas have been formed between the extremities of the morainal embankments. The proof is therefore conclusive that the greatest extension of the glaciers preceded the maximum rise of the lake. How far the glaciers had retreated up the cañons before the lake occupied their former beds it is impossible to determine. It has also been found that the glaciers of the Mono basin had two or more periods of maximum extension, separated by times when the ice withdrew far up the cañons through which it flowed. There were at least two well-marked glacial epochs in the Sierra Nevada. The lacustral records of the Mono basin indicate two periods of high water, corresponding, it is presumed, to the two main periods of glacial extension. All the facts known to us are in harmony with the conclusion that the two humid periods recorded in the Bonneville and Lahontan basins were practically synchronous with the two periods of maximum extension of the Sierra Nevada glaciers. The fact that the greatest rise of the Quaternary lake occupying Mono Valley occurred after the greatest expansion of the glaciers does not militate against this determination, but indicates that the melting of the snow and ice on the mountains contributed an unusual supply of water to the lake, which then received its greatest flood. When mountains bordering an inclosed basin are loaded with snow and ice, it is evident that a rise of temperature will cause a flooding of the valleys. The analogy between the glacial climate of the Great Basin and the winter climate of the same region at the present time, thus finds another parallel.

The evidence leading to the correlation of the two high-water stages of Lake Lahontan with the two Glacial epochs of the northern hemisphere has already been indicated. Should this conclusion be sustained, it follows that both series of phenomena resulted from a common climatic change. In the case of Lake Lahontan we have attempted to demonstrate that the change which caused the expansion of the lake was a lowering in the mean annual temperature, and that the periods of desiccation indicate a relative rise of temperature. This interpretation is in harmony with the verdict of the great majority of writers in reference to the prevailing elements in the climate of the Glacial epoch. In former times, as at present, the climate of various regions in the same latitude differed widely in reference to humidity. The more humid regions were the areas of greatest glaciation.

The discussion of the ultimate cause of the cold of the Glacial epoch is beyond the scope of the present report.

A summary of the writer's conclusions in reference to the climatic oscillations indicated by the fluctuations of Lake Lahontan is embodied in the following schedule:

1. Pre-Lahontan arid period	Probable climatic conditions	A time of aridity; precipitation small; evaporation rapid; temperature high.
	Results	Lakes small, at times desiccated; mountains free from glaciers.
2. First rise of Lake Lahontan	Probable climatic conditions	Precipitation moderate; evaporation decreased; temperature low.
	Results	Large lakes in the valleys and glaciers in the mountains.
3. Inter-Lahontan arid period	Probable climatic conditions	Decreased precipitation; evaporation rapid; temperature high.
	Results	Lakes smaller than at present, and at times possibly desiccated; glaciers contracted and possibly completely melted.
4. Second rise of Lake Lahontan	Probable climatic conditions	Precipitation moderate, but probably more copious than during the first rise; evaporation decreased; temperature low.
	Results	Broad lakes and large glaciers.
5. Post-Lahontan arid period	Probable climatic conditions	A time of great aridity; precipitation small; mean temperature higher than at present.
	Results	Lakes desiccated and glaciers melted.
6. Present time	Climatic conditions	Precipitation small; evaporation rapid; mean temperature about 50° Fahr.
	Results	Country arid; rivers small and fluctuating; lakes and glaciers small.

CHAPTER IX.

GEOLOGICAL AGE OF LAKE LAHONTAN.

A review of the facts bearing on the age of Lake Lahontan necessitates some repetition, but seems desirable in order to present the evidence in a connected form.

The reader is already aware that Bonneville and Lahontan were the largest of an extensive series of lakes which formerly occupied the valleys of the Great Basin. That the lakes here indicated—represented for convenience of reference on Plate I—were contemporaneous seems too positive to be questioned. The records in the various basins are identical, consisting of terraces, gravel embankments, sedimentary deposits, fossils, etc., in which no difference of age can be detected. Moreover, the existence of lakes in inclosed basins is dependent on climatic changes too broad in their effect to have been felt in a single valley without producing similar results in others near at hand That the lakes now under discussion, not only existed at the same time, but were also of a very recent date, is considered as abundantly proven by the fact that they left the very latest of all the completed geological records to be observed in the Great Basin.

The fossil shells obtained from the sediments and tufas of Bonneville and Lahontan, and a few of the smaller sister lakes, all belong to living species. The mammalian remains discovered in the sediments of Lake Lahontan are the same as occur elsewhere in Tertiary and Quaternary strata. The spear head of chipped obsidian obtained in the upper Lahontan sediments is considered good evidence—although as yet unsustained by other finds of a similar character—that man inhabited this continent during the last great rise of the former lake.

The greatest expansion of the waters of the Mono basin, occurred subsequent to the last extension of the Sierra Nevada glaciers. Although this is the only instance known where the relation of the former lakes and glaciers of the Great Basin is clearly determinable, yet it seems a necessary inference that the other lakes of the same region attained their maximum at the same time. As the formation of glaciers and the extension of lakes in inclosed basins necessarily result from similar climatic changes, we correlate the two flood periods of Lake Lahontan with the two periods of maximum extension of the Sierra Nevada glaciers. Again, from similarity of phenomena, the two periods of glaciation on the mountains of the Far West, are correlated in time with the two glacial epochs of northeastern America, as recognized by certain geologists. If this determination is correct, it follows that the last great expansion of the lakes of the Great Basin occurred during the close of the Glacial period, and may be considered as contemporaneous with the Champlain epoch of the eastern States.

That the valleys of the Great Basin held lakes, at least at intervals, throughout the Quaternary, is not only probable, *a priori*, but is indicated by the great thickness of marls, clays and gravels that fill these depressions. In the Bonneville basin these deposits have been penetrated to a depth of over 1,500 feet without reaching the underlying rock. That the lower portion of the material filling these depressions may be of Tertiary age, is certainly possible, but the records of the passage of the Tertiary into the Quaternary are so obscure and so little known that it is at present impossible, at least in the lake-beds of the Far West, to say where the former ends and the latter begins. When Lake Lahontan began its existence will probably never be known, except in a general way; but that it reached its greatest extension in late Quaternary times and was approximately synchronous in its fluctuations with the advance and retreat of the Sierra Nevada glaciers during the Glacial epoch is a fair deduction from the evidence recorded in the present volume.

In regard to the time, as measured in years, that has elapsed since the events described in this report took place, we have but shadowy evidence to offer. It has been estimated by James Croll,[85] from astronomical data, that

[85] Climate and Time, New York, 1875. Chap. XIX.

the last Glacial epoch terminated about 80,000 years ago. Other investigators have approached the problem in different ways and reached widely discordant results. At present even an approximate measurement in years of the time that has elapsed since the last great retreat of the glaciers of the northern hemisphere seems impossible. Considering that Lake Lahontan fluctuated synchronously with the advance and retreat of the glaciers during the Glacial epoch, we must conclude that its last evaporation followed the last great retreat of the glaciers. Our studies in the Far West have shown that there is no reason for supposing that the retreat of the Sierra Nevada glaciers was a sudden event, partaking of the nature of a catastrophe, or that the evaporation of the lakes which were supplied by the melting ice, was a matter of a few years. On the contrary, the glaciers are believed to have retreated slowly; with many pauses, and the evaporation of the lakes to have extended through centuries. Even if the Glacial epoch can be proven to have terminated 80,000 years ago, there is no reason for considering that desiccation of the lakes followed that event within many thousand years. As stated at the beginning of this paragraph, we have no definite evidence to show that the Quaternary lakes were flooded a certain number of years since; but one familiar with the shore phenomena displayed in the valleys of the Far West cannot fail to be impressed with the perfection with which these structures have been preserved. In many instances the embankments of gravel are as perfect in contour and as regular in slope as if constructed but a few years ago. Subaërial erosion is reduced to a minimum in such instances, however, for the reason that the structures are porous and absorb nearly all the rain that falls upon them, allowing it to percolate quietly through their interstices. Changes of temperature have but little power to alter their forms, owing to the large size of the interspaces and the readiness with which moisture is removed. The only elements of subaërial erosion to which gravel embankments seem open to attack are the wind and the beating of rain During the lapse of centuries even these slow processes must effect appreciable changes, but as yet this is scarcely apparent in the embankments built in Lake Lahontan. It is evident that gravel embankments in arid regions, so situated that they are not within the reach of stream erosion, may be considered among the most permanent of topographic forms; more constant, in fact, than the rocky mountain tops. It is not surprising, therefore, that the gravel structures fail to give evidence as to their age.

We might consult the cañons carved through Lahontan sediments since the recession of the lake for a time measure; but the amount of erosion here apparent could have been performed by the existing streams in a few years, owing to the unconsolidated character of the strata and the high grade of the streams caused by the lowering of their base level upon the withdrawal of the lake waters. Moreover the streams have meandered but little within their cañons, thus indicating that these trenches have not been long finished. On the whole the cañons indicate that but a brief period has elapsed since their excavation began.

The tufa deposits of the basin have been exposed to erosion since the withdrawal of the lake waters, and might be expected to present some indication of the time they had been subjected to subaërial erosion. These deposits are porous and open in structure and favor the absorption and retention of moisture. They are thus especially liable to the destructive effects incident to the freezing of water in the interspaces of rocks, especially as the rains and frosts of the Great Basin occur together. We may, therefore, expect that the subaërial erosion of the tufa deposits would be rapid, and that if they had been exposed for a long period they would exhibit marked evidence of waste and decay. The fact is, on the contrary, that these deposits are remarkably well preserved. The greater amount of fracture and displacement that has been observed has evidently resulted from the weight of the deposits when left unsupported by the waters in which they were formed. The only conclusion to be drawn from the tufa deposits in reference to the date of the last desiccation of Lake Lahontan is that their time of exposure has been short.

Again, in reference to the shells strewn over many portions of the deserts which, in many cases, must have been left by the evaporation of the former lake, we find that these fossils, or semi-fossils, as they have been termed, are bleached white and have lost their epidermis, but are otherwise frequently as perfect as when inhabited by the mollusk to which they belonged. That these fragile bodies have been drifting about at the caprice of the winds for thousands of years without being destroyed is improbable, to say the least.

Other facts bearing on the determination of the length of time that has elapsed since the close of the Glacial epoch may be observed in the cañons of the High Sierra, and have been described in part in a previous essay.[86] We need not consult the moraines left by the ancient glaciers, as these, like the gravel embankments mentioned above, are comparatively stable structures; but in the glaciated cañons there are numerous bosses and domes of granite and quartzite that have been exposed to the sky since the glacial ice was melted from above them. The ice-polish on these ledges is still conspicuous, and causes them to glisten in the sunlight as brilliantly as do similar surfaces adjacent to the existing glaciers of the High Sierra and of Switzerland. These smooth surfaces are still scored with fine hair-like lines, and the eye fails to detect more than a trace of disintegration that has taken place since the surfaces received their polish and striations. Here again we meet with the difficulty of applying quantitative measurements; but as there is a limit to the time that rock surfaces may retain their polish it seems reasonable to conclude that in a severe climate like that of the High Sierra it could not remain unimpaired for more than a few centuries at most.

The cumulative weight of these various lines of inquiry is such as to lead to the *opinion* that the last desiccation of the Quaternary lakes of the Great Basin certainly occurred centuries but probably not many thousands of years ago. On the other hand, it might be argued that the presence of the bones of the mastodon, camel, and horse in the lacustral clays, deposited during the last great rise of the lake, is abundant evidence of the antiquity of that event. The date of the various fluctuations of Lake Lahontan, as measured by the standard used in human history, thus remains an open question.

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[86] Existing Glaciers of the United States, Fifth Annual Report U. S. Geological Survey.

CHAPTER X.

POST-LAHONTAN OROGRAPHIC MOVEMENTS.

In our sketch of the origin of the Lahontan basin (*ante*, page 24), a brief account of the pre-Quaternary faults of the region was given. As there stated, the area we are studying has been broken by profound fractures, which resulted in the division of the rocks into a great number of orographic blocks. The unequal displacement of these gave origin to the various valleys that were occupied by the Quaternary lake. In the present chapter we wish to direct attention to similar movements of the earth's crust which have taken place since the evaporation of Lake Lahontan.

The traveler in the Great Basin frequently sees low escarpments in lacustral beds and alluvial slopes, which form irregular lines along the bases of the mountains, and at times cross the valleys. In profile, these scarps present various appearances, as illustrated by the following sections. Where they cross alluvial slopes they usually exhibit a profile similar to that shown at *a*. In the open valleys they form a small cliff or steep ascent, joining a

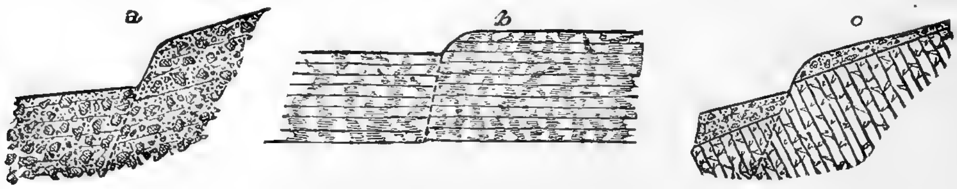
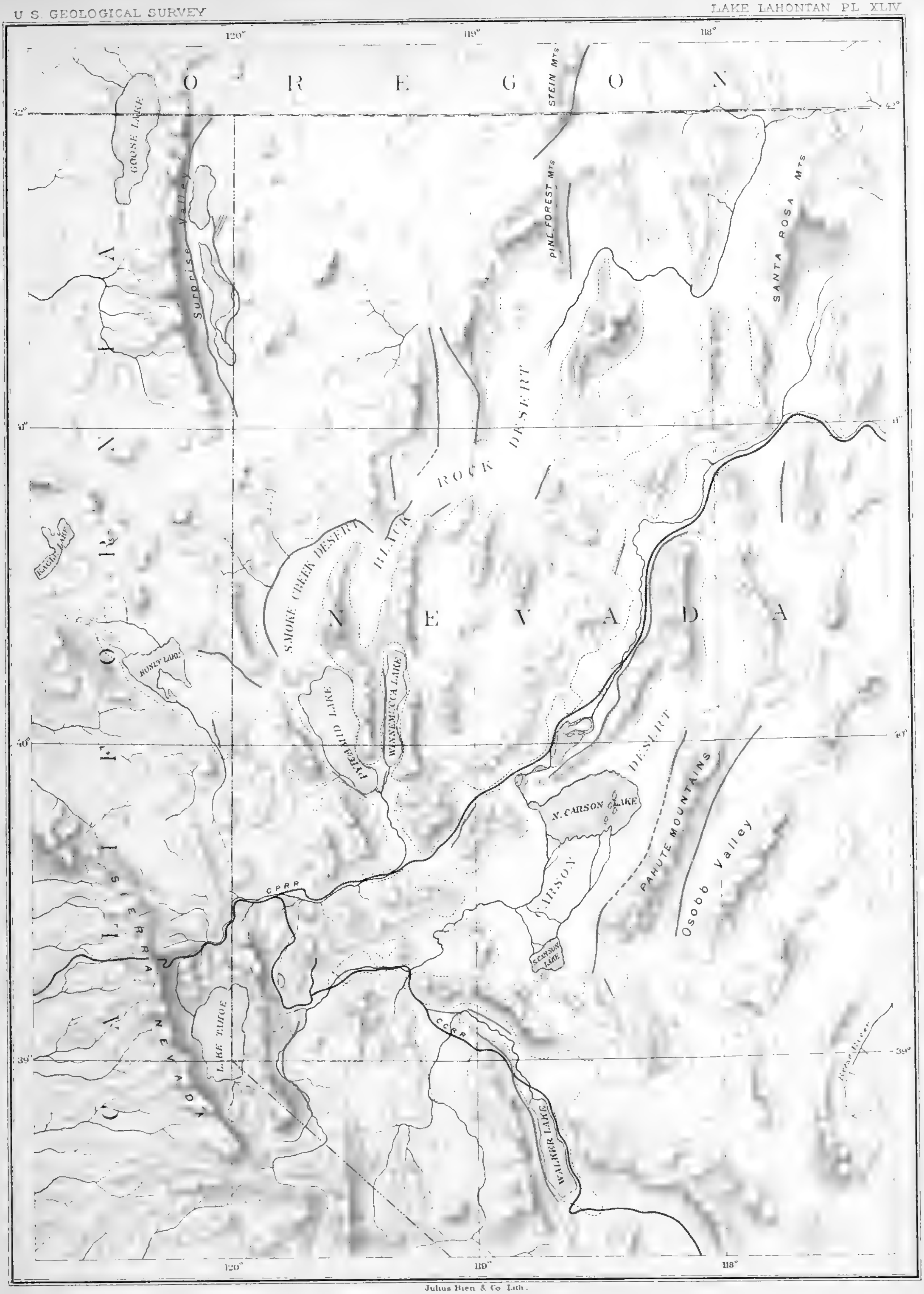


FIG. 36.—Ideal cross-profiles of faulted beds.

horizontal plain below with a similar plain above, as indicated in section at *b*. On a mountain side the scarp is usually partially in rock and partially in alluvium, as represented at *c*. The course of the scarps is always irregular, and sometimes forms zigzag lines that may be followed for many miles.



Julius Bien & Co. Lith.

POST-QUATERNARY FAULT LINES.

Scale 29 miles = 1 inch

The scarps differ from the steep slopes bounding water-built terraces and embankments—that neither their upper or lower limits are horizontal for any considerable distance; they are characterized by irregularity, and do not define the boundaries between deposits of different character. They occur both above and below the highest beaches of the Quaternary lakes of the region where they are found, and exist in valleys that have a free drainage as well as in those that are inclosed and once held lakes. It is, therefore, evident that their origin is totally independent of the action of waves and currents, and it is equally clear that they cannot be the result of erosion.

Scarps of this nature were first observed in the Great Basin by Mr. Gilbert, while examining the western base of the Wasatch Mountains, and were recognized as the result of recent orographic movements.[87] In other words, they are fault scarps of very late origin. Their recency is shown by the fact that they commonly occur in Quaternary lacustral sediments and recent alluvial slopes, and form steep slopes of earth and gravel that are but little modified by erosion, and in many instances are bare of vegetation.

In many cases, it is evident that they could not have existed in their present condition for more than a few years. Sometimes they are more than a hundred miles in length, and vary from a few feet to more than a hundred feet in height.

Recent faults of this nature have been observed along the western base of the Wasatch Mountains, at the eastern base of the Sierra Nevada, and on the foot-slopes of many of the intermediate Basin ranges. In the Lahontan area recent fault scarps are a common feature in the topography of the valleys, and furnish one of the many interesting problems in the physical geology of the region.

All of the lines of post-Lahontan displacement that are actually known to exist in the Lahontan basin are sketched on Plate XLIV, with as much accuracy as the topography of the map admits. It is evident that our knowledge of this phenomenon is incomplete, as only the more recent displacements are apt to attract attention, for the reason that when erosion has modified the scarps it is frequently impossible to determine whether post-

[87] Second Annual Report U. S. Geological Survey, p. 192.

Quaternary movement has taken place or not. Could the full extent of the recent fault lines be indicated on the map, it is probable that they would form a complicated series of intersecting lines that would embrace nearly the entire area.

The first feature of general interest that presents itself upon commencing the study of these recent faults, is that they frequently, if not always, follow the courses of ancient displacements that are usually of great magnitude. They are recent movements of ancient faults.

The intimate association of thermal springs with recent faults is to be noticed not only in the basin of Lake Lahontan, but throughout the entire area of interior drainage thus far explored. It is also to be noticed that the hottest springs almost invariably occur on the lines of displacement that have suffered the most recent movement. So nearly constant is this correlation, that wherever thermal springs occur, other evidences of recent orographic movement are almost always at hand. The suggestion has been advanced in this connection[88] that the high temperature of the springs is due to the friction of the rocks along the sides of the fault plane. It is the conversion of motion into heat. As, however, the faults result from a profound fracturing of the earth's crust, it is evident that any water which finds its way into a fault may descend to great depths and consequently reach regions of high temperature; it is more than probable, therefore, that the springs derive at least a portion of their heat from the internal heat of the earth. It is impossible at present to determine how much of the heat affecting springs is caused by friction and how much is due to the prevailing high temperature of the earth at great depths. Probably both causes conspire to produce the results observed.

The intimate association of the thermal springs of the Lahontan basin with recent displacements may be illustrated by comparing Plates VIII and XLIV, which will show that but a very few thermal springs occur in this area that are not closely associated with recent faults.

The various lines of recent displacement in the Lahontan basin have so many features in common that it is unnecessary to enter into a detailed description of each. All that are represented on Plate XLIV, within the

[88] Third Annual Report U. S. Geological Survey, p. 232.

POST-QUATERNARY FAULT ON THE SOUTH SHORE OF HUMBOLDT LAKE

borders of the ancient lake, exhibit scarps in lacustral beds and gravel deposits, and are therefore more recent than the last rise of the lake.

The appearance of the fault at the western base of the West Humboldt range is shown on Plate XLV; the point of view being near the southern end of Humboldt Lake. The precipitous mountain face shown in the picture is in reality an ancient fault scarp of grand proportions, which was somewhat eroded before the existence of Lake Lahontan. During the time the lake occupied Humboldt Valley its waves carved a number of terraces along the base of the mountains, which are represented in the sketch, and are familiar to many who have traveled over the Central Pacific Railroad. Between the highest terrace and the shore of the present lake there is an irregular line of cliffs—in part obscured by talus slopes—which has been produced by recent orographic movement. This fault scarp is composed principally of cemented gravels of Lahontan age, but in places the rock forming the mountains may be seen beneath the clastic beds. The character of the section exposed at many localities along this fault is represented in diagram *c*, Fig. 36. This fault scarp may be traced continuously from the Mopung Hills northward, along the bases of the West Humboldt and Star Peak ranges, to the neighborhood of Winnemucca, a distance of over a hundred miles; its full extent, however, remains to be determined. Throughout the greater part of its course it crosses alluvial slopes, with a fresh scarp from ten to twenty feet, or more, in height, its greatest magnitude being near its southern end. Along the eastern shore of Humboldt Lake it forms a nearly vertical escarpment, fully fifty feet high. At the Mopung Hills it divides into several branches, which may be traced to the border of the Carson Desert, and then become obscured.

In describing the shore phenomena on the Niter Buttes, a spur of the main range, at the southern end of Humboldt Lake (see *ante*, page 112), some account was given of sloping terraces, which indicate that orographic movement must have taken place during inter-Lahontan time. We have evidence, therefore, that the fault along the west base of the West Humboldt range attained a great magnitude previous to the existence of Lake Lahontan, that it underwent some disturbance during inter-Lahontan time, and has increased its displacement fully fifty feet since the evaporation of the Quaternary lake.

The hot springs at Hot Springs Station, on the Central Pacific Railroad, occur on a line of recent displacement, which may be followed for a few miles, both north and south, from the present site of the springs. Deposits of extinct springs may be seen for a mile or more north of the present point of outflow, indicating that former openings, through which the springs rose, have been filled by calcareous deposits, thus compelling the waters to find other points of egress along the line of fracture.

The recent fault on the east side of the Carson Desert is marked by a low scarp in alluvium, and a change in the drainage where the displacement crosses Alkali Valley. East of Borax Springs, situated in Alkali Valley on the line of fracture, the slope of the desert surface is eastward, and conducts the drainage to the end of the valley where a lake of brine is formed, which on evaporating leaves a deposit of salt of economic importance. Alkali Valley is bordered on all sides by precipitous mountains, excepting where it opens into the Carson Desert, and formed a deep bay during the existence of Lake Lahontan. In passing from the Carson Desert into Alkali Valley no change in the nearly level desert surface is noticeable until the line of faulting is reached; the plain then inclines gently eastward as we have described. It is evident that this inclination of the desert surface has taken place in post-Lahontan times, and is due to a slight tilting of the orographic block on which Alkali Valley is located.

The course of the fault indicated on Plate XLIV, as crossing the northern border of Mason Valley, is rendered conspicuous in the topography of the valley bottom by a scarp from ten to twenty feet high in lacustral marls and clays, and by numerous thermal springs. This is probably a continuation or a branch of a displacement in Walker River Valley which presents a section of Lahontan sediments fully 150 feet high. In common with the majority of the recent displacement of northern Nevada, both ends of this fault are obscure and indeterminable.

What is probably a continuation of the series of disturbances observed in Mason Valley is indicated by a recent scarp along the east base of the Wassuck or Walker Lake range. The influence of this displacement on the contour of the lake bottom is indicated to some extent by the soundings given on the map forming Plate XV. The lake is deepest in the immediate vicinity of the fault line.

It is probable that the direction taken by Walker River on leaving Mason Valley was determined by orographic movement, as it does not follow what appears to have been its natural course, but the character of this change is difficult to describe. The former outlet of Mason Valley was through a narrow gorge leading to the Carson River which it entered at a point opposite the site of Camp Churchill. This would probably have been the course taken by the stream when the waters of Lake Lahontan were withdrawn for the last time, had not orographic movement caused a slight change in the slope of the valley and thus deflected the river to the right. This phenomenon will be better understood on consulting the accompanying pocket map, where the ancient channel leading from Mason Valley to the Carson River is indicated.

That portion of the great Sierra Nevada fault which defines the western border of Carson and Eagle valleys has undergone a recent displacement of from ten to thirty feet, as is shown by fresh scarps in earth and gravel, and also by the outflow of heated waters at several localities. The recent scarp in this instance has been followed all the way from near Carson City to beyond Genoa; the full extent of the movement, however, far surpasses these limits.

The basin of Lake Tahoe is an orographic valley of the Great Basin type, but is situated at a high altitude in the Sierra Nevada on the border of the interior drainage area. With the exception of the hot springs at the northern end of the lake, no evidence is known to the writer tending to show that there has been recent orographic movement in its immediate vicinity.

The faults along the eastern base of the Pine Forest Mountains; on the western margin of the Black Rock range, from Black Rock point northward, and at the northern base of the Harlequin Hills are all marked in the topography of the country by recent scarps that seldom exceed twenty feet in height. At numerous points along these lines of displacement thermal springs come to the surface.

The large group of hot springs near Ward's ranch, on the western border of the Black Rock Desert, and the group at the east end of Granite Mountain, are both on lines of recent displacement.

The fault that crosses the western border of Smoke Creek Desert differs from most others in the Lahontan basin in the fact that it traverses the valley at a considerable distance from the mountains. Its course is marked by numerous thermal springs, and by a low scarp which at times becomes too indistinct to be easily traced. There is but little question that this line of displacement is a continuation of the fault to be seen at Granite Mountain, which apparently comes to view again along the borders of the Black Rock Desert farther northward. The connection between these various fragmental fault lines has not been traced, and we have represented on Plate XLIV only such portions as have actually been observed. The course of this fault across the southern portion of Smoke Creek Desert is indicated by a low and somewhat rounded scarp with a nearly east and west strike. The springs along the fracture irrigate the desert sufficiently to admit of the growth of grasses and desert shrubs which mark its course by a line of verdure through the absolute waste. Farther northward, in the neighborhood of Sheep Head Spring, the fault changes its course and becomes nearly north and south in its trend; farther northward, still, it bends more to the eastward, and, finally, near Round Hole Spring it has an approximately east and west strike. Its course is thus nearly crescent-shaped, but it has many more irregularities than we are able to represent on the accompanying map. On the line of this fault near Buffalo Springs there are a number of tufa piles rising abruptly from the desert to a height of thirty or forty feet, which exhibit the three varieties of tufa that are characteristic of the Lahontan calcareous precipitates. It is evident that the nuclei of these deposits were formed by subaqueous springs, as described in a previous chapter, thus showing that the fracture along which they are situated must have existed during the time the desert was occupied by the ancient lake. In a few instances the tufa piles situated immediately above the line of fracture have been split from base to summit by a recent orographic movement, and are now parted by vertical fissures two or three feet wide, into which a person can descend a number of feet lower than the surface of the desert.

The fault described in the last paragraph is at such a distance from the highlands to the westward that no alluviation has taken place in its neighborhood. There has, therefore, been no transfer of load from one side of the displacement to the other. The thrown side of the fault underlies the broad desert and was lightened previous to the last fault-movement by the removal of 500 feet of water from its entire surface. It is quite evident, therefore, from the nature of the facts, that the unequal loading of contiguous orographic blocks, which has been assumed as an explanation of fault movements in certain instances, cannot be considered an element in the present example.

A fault along the northern side of Honey Lake Valley shows about as great an amount of post-Lahontan movement as any in the basin. In this instance the trend of the fault is irregular, but in general its course is northwest and southeast; its hade is nearly perpendicular, and the recent displacement at times exceeds a hundred feet. The thrown block underlies Honey Lake Valley. From the position of the present lake and the direction of drainage in the valley, it seems evident that the mountains between Smoke Creek Desert and Honey Lake Valley must have been upheaved to produce this fault. A similar but more gentle movement of the same mountain mass would account for the recent scarp described above which crosses the Smoke Creek Desert.

The faults represented on Plate XLIV, to the north of the Lahontan drainage area, are of the same character as those already described, and will require but a word of explanation at this time.

The recent displacement on the west side of Surprise Valley, California, has a throw varying from 20 to 50 feet, and may be traced for nearly a hundred miles across alluvial slopes and gravel embankments of Quaternary age. As in numerous other instances, its course is marked by thermal springs, some of which are of high temperature and afford a large volume of water. The fault along the eastern base of the Stein Mountains, Oregon, falls in this same category, and together with other similar displacements in the same region will be found described briefly in the Fourth Annual Report of the U. S. Geological Survey.[89]

From the studies of the recent displacements of the Lahontan basin which we have been enabled to make, it seems safe to conclude that these orographic movements are but the continuation of a series which had its beginning long previous to the Quaternary. These movements were in progress during the existence of Lake Lahontan, as indicated by sloping terraces, and no less plainly by tufa deposits along lines of fracture. As shown above, the evidence that these movements have been in progress in very recent times is abundant. The character of the phenomena is such that it is impossible to resist the conclusion that the forces which produced the results described are still in action.

Whether the faults have been formed gradually without any marked disturbance, or whether they have been paroxysmal, is not definitely known. That earthquakes are felt from time to time in various parts of the Great Basin, and the results produced by the Owen's Valley earthquake of 1872, tend to the conclusion that the orographic movements have been paroxysmal in their nature.

The Owen's Valley earthquake, it will be remembered, resulted in the formation of a false scarp of the same character as those we have been describing, which may be traced for a number of miles As reported by Mr. Gilbert, who recently visited Owen's Valley, the main scarp produced in 1872 varies from 10 to 20 feet in height, hades eastward at a high angle, and agrees in all its features with the similar scarps observed throughout the Great Basin. This is apparently the latest slip in the great Sierra Nevada displacement.

In the case of all the recent faults of the Great Basin thus far examined, the movement has been nearly vertical, and but slight crumpling or contortion of the adjacent strata has taken place.

A general view of the phenomena presented suggests that in the majority of instances the blocks now forming the mountains have been raised vertically, while those beneath the valleys remained nearly undisturbed. This hypothesis cannot be sustained by direct proof, however,

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[89] Pages 442–454.

and meets with apparent opposition in the case of the fault along the western border of Walker Lake. In this instance a depression of the thrown block is indicated by the deepening of the waters of the lake as one approaches the line of displacement. As pointed out by Mr. Gilbert, Great Salt Lake has probably been shifted to the eastward of its normal position by orographic movement, which we may consider, at least in part, as the result of a movement of the great Wasatch fault; thus indicating that the thrown side of the displacement was depressed.

By way of a summary of this chapter we may state that the recent faults of the Great Basin have the following characteristics:

They are irregular and angular in their course, in reference to both vertical and horizontal planes.

They occur most commonly on the steeper side of the basin ranges, and, so far as known, invariably hade toward the valley, *i. e.*, the valleys occupy the thrown sides of the displacements.

Their scarps occur in alluvium and in lacustral beds, and cut the embankments and terraces of Quaternary lakes; many times they present fresh slopes of earth and gravel that are unclothed by vegetation, and but little affected by erosion. Occasionally they cross stream-beds and cause rapids; as is the case where the Wasatch fault crosses American Fork, Utah.

At hundreds of localities thermal springs come to the surface along the lines of fracture.

In the majority of instances the recent movement has taken place along ancient lines of displacement; the post-Quaternary fault in such cases is but a small fraction of the entire disturbance.

INDEX.

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