THE SALTON SEA

A STUDY OF THE GEOGRAPHY, THE GEOLOGY, THE FLORISTICS, AND THE ECOLOGY OF A DESERT BASIN

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THE CAHUILLA BASIN AND DESERT OF THE COLORADO.

By William Phipps Blake.[1]

EXPLORATION.

The year 1853 was notable in the history of explorations of United States territory west of the Mississippi River. In that year, under the administration of President Pierce, with Jefferson Davis as Secretary of War, four fully equipped expeditions, authorized by Congress, were sent out to explore the almost unknown country lying between the Mississippi River and the Pacific Ocean, to look for and determine a practicable route for a railway.

Our knowledge of the country at that date may be summarized as follows: Aside from the early exploration in the northwest, Frémont, in his daring overland explorations, had made us acquainted with the obstacles and perils of a route across the Sierra Nevada; Stansbury had told us of the great Salt Lake; Sitgreaves had crossed Arizona south of the Grand Canyon, entering what is now California near the mouth of Bill Williams Fork. Emory had made a rapid military reconnaissance of the route from Fort Leavenworth, Missouri, to San Diego, in California.

To one of the expeditions of 1853 was assigned the duty of following the Sierra Nevada of California southward, to seek for any suitable pass through which a railway might be built. This survey was placed in charge of Lieut. R. S. Williamson, of the United States Topographical Engineers, with Lieut. J. G. Parke second in command, and the writer as geologist. Walker's Pass, much vaunted at the time as the best and only practicable pass in the Sierra Nevada, was the first objective point. It was most favored by Senator Gwin of California, who had personally taken the field and journeyed as far south as the Tejon, from whose summit he could see a favorable route across the Great Basin eastward. The Williamson expedition made surveys of Walker's Pass, the Taheechapah (the orthography of which has been corrupted to Tehachipi), Tejon, Cañada de Las Uvas, the passes north of Los Angeles, and the Cajon from the Mojave to San Bernardino, without finding any pass that offered an especially favorable and easy route or inviting grades.

SAN GORGONIO PASS.

Imagine, then, the enthusiasm with which the unknown great break in the mountain range between San Bernardino and San Jacinto was approached by the members of the party as we made our way eastward from the region, then practically unoccupied but now including the towns of Colton and Redlands, and found an easy grade and open country for our train of wagons to the summit, only 2,580 feet above the sea. Here, at last, was discovered the greatest break through the western Cordillera, leading from the slopes of Los Angeles and the Pacific into the interior wilderness. It had no place upon the maps and had not been traversed by surveying parties or wagons. From the summit, we could look eastward and southward into a deep and apparently interminable valley stretching off in the direction of the Gulf of California. This pass was evidently the true gateway from the interior to the Pacific Ocean. (Plate 1 A.)

[1] This paper was prepared by Professor Blake two years prior to his death in 1910 with a view to its publication in conjunction with a series of other essays upon the control of the Colorado River by the American Society of Civil Engineers. The manuscript, however, was found to be more suitable to the present volume and was secured for publication here through the kind offices of Mr. H. T. Cory. But few alterations have been made, and these consist chiefly in omissions of sections bearing upon the vegetation and other topics which are more fully treated elsewhere. The paper possesses a peculiar interest, since it is based upon observations begun by the author with his discovery of the basin-like character of the region in 1853 and extended to his last visit in May 1906.

The discovery of this practicable and easy railway route determined the construction of a southern railroad and made it necessary to acquire from Mexico the strip of country in southern Arizona since known as the "Gadsden Purchase."

We descended with eagerness into this great unknown valley, carefully reading the barometer at regular distances to ascertain the grade. Proceeding without obstacles, but with no trace of a road, and following the dry bed of a stream, now known as the Whitewater, we reached the bed of a former lake and found it to be below the level of the sea. (Plate 1 c.)

The value of this pass, as a great natural gateway through the mountains from the ocean to the interior, is emphasized by the magnificence of the mountain masses rising like sentinels, on the north and on the south. These are San Bernardino, over 11,000 feet and snow-capped for the greater part of the year; and San Jacinto, the sharp peak on the south with rugged sides, and similar elevation, which forms the northern end of the Peninsula Range.

This San Gorgonio Pass is the only great break directly through the mountains from Cape St. Lucas to the Golden Gate; and like the Golden Gate, it is a great draft channel for the inrush of ocean winds to supply the uprising heated air of the interior deserts. Topographically this valley into which we descended is the northwestern extension, prolongation, or head of the Gulf of California.

GEOLOGIC HISTORY.

That this valley was formerly occupied by sea-water is shown by the reefs of fossil oysters and other marine shells. As these fossils are now above tide-level, it is evident that there has been a considerable uplift of the whole region, and a change from marine to fresh-water conditions. Further north on the west coast of the United States we have another great longitudinal valley separating the Coast Range of California from the Sierra Nevadas. The two great valleys are similar in many respects; they both receive the drainage of the larger rivers of the interior and protect the deltas of their rivers from the direct destructive or modifying action of the sea. In the Gulf of California we find the Delta of the Colorado, and in the California valleys the deltas of the San Joaquin and of the Sacramento Rivers. The California Valley is nearly at the sea-level. The sea has been displaced by alluvium. A depression of the western coast of less than 1,000 feet would flood the valley with sea-water through the Golden Gate from the Tejon to Shasta. A similar or even less depression of the Lower California region would carry the waters of the Gulf far north of Yuma and flood the valleys for 200 miles northwest of the present head of the Gulf. A depression of 2,580 feet would connect the water of the Pacific and the Gulf at the pass of San Gorgonio, where the trains of the Southern Pacific Railway cross the divide, and would make an island of the peninsula of Lower California.

EVIDENCE OF UPLIFT.

Such, no doubt, were the conditions in Middle Tertiary times. The waves of the Gulf then washed the slope of the San Jacinto and San Bernardino, where we now find arid mountains and desert plains.

The silt of the Colorado was distributed far and wide in the interior sea, only partially cut off from the broad Pacific by a chain of islands which now form the crest of the Peninsula Mountains from San Jacinto to Cape St. Lucas. As the land gradually rose from the waves, the beds of oyster-shells and of other forms of marine life came into view and may be seen to-day, 1,000 feet above the valley on the sides of the San Jacinto Mountains. Such evidences of the former marine occupation of the valley are particularly strong and convincing along the eastern base of the Peninsula Mountains, where marine fossils of the Tertiary period are numerous, especially in the stratified formation along Carrizo Creek.

Many of these fossil shells were observed in 1853, but have since been described more in detail by other explorers, notably by Dr. E. E. Stearns of California.

Dr. Stephen Bowers, who describes many of the localities, writes of the region generally as follows:

"The water of the old Tertiary Sea, which once prevailed here, must have been extremely favorable to the propagation and growth of mollusks, especially oysters. After the vast erosion that has taken place, there are many square miles of fossil beds, especially of oyster-shells, which, in places, are 200 feet thick and may extend downward to a much greater depth. The oysters existed not only in vast numbers but in many varieties, from the small shell which is in evidence over so much of the territory, to varieties nearly a foot long and to others weighing several pounds each. One variety is nearly as round and as large as a dinner plate."

Fossil oyster-shells are perhaps most abundant in the Coyote Wells District, about 7 miles north of the international boundary line and about 375 feet above the level of the sea. Other deposits of marine shells, including shark's teeth, pectens, and univalves, are reported from one of the branches of Carrizo Creek. But the occupation of the valley by sea-water, while comparatively recent geologically, has extreme antiquity and long antedates human history, dating back to the Middle Tertiary.

The continental elevation which followed culminated in the Pleistocene, or Glacial period, when the precipitations of rain and snow are believed to have attained their maximum. At that time, the Colorado of the West had its greatest volume and transporting power. Its silt was distributed far and wide in the interior sea, then only partially cut off from the broad Pacific by a chain of islands which now form the crest of the Peninsula Mountains from San Jacinto to Cape St. Lucas. Entering the Gulf just below where the mouth of the Gila River now is, it began dropping its load of débris and silt, forming the raised delta which gradually extended westward and southerly across the upper end of the Gulf toward the Cocopah Mountains and finally to the higher ridges beyond the Pattie Basin, even to the eastern base of the Peninsula Mountains.

Aided by the gradual elevation of the land and by the tides of the Gulf, the building up of the delta proceeded rapidly. It assumed the nature of a great dam or levee stretching across the Gulf and diverting the river-water through shifting channels to one side or the other, first to the lower part leading to the Gulf and then to the upper end of the depressed area shut off from the tides. At certain seasons the tides rise to a great height at the head of the Gulf and are accompanied by dangerous bores. Such tides rushing up the mouth of the Colorado have ever been important factors in the formation of the delta. Ordinary tides are said to rise 15 feet, and in extraordinary cases to 37 feet. According to the United States Geological Survey the tidal range is from 14 to 32 feet. (See p. 17.)

LAKE CAHUILLA.

The head of the Gulf, being cut off by the Delta from the free access of the sea, became an inland lake of salt water, or at least of brackish water, with the great Colorado River at certain seasons and stages of flood flowing into it. This stream then, as now, was laden with the rich alluvial earths of its upper course, torn from the ravines and cañons of the Rocky Mountains and the Grand Cañon of Arizona. This influx of river-water, though variable in duration and quantity, must have exceeded the loss by evaporation. Consequently the level of the lake was raised until the excess overflowed to the Gulf by a lower outlet.

That such conditions continued for centuries appears certain, for the enormous accumulation of sediment within the old beach-lines tells the story of long-continued lacustrine conditions, of the displacement of the sea-water, and of the final occupation of the valley by fresh water. This is shown to us by the fresh-water shells, not only on the surface but in the blue-clay sediments, in the banks of ravines and arroyos, and in the deep borings for water, showing that the shells dropped to the bottom and were thus entombed. These fresh-water shells are so abundant in the lacustrine clay of the desert, especially at the northern end, that they accumulate in windrows before the wind. The thin pearly shells of anodonta are common in the clay about Indio. Four or five species of univalves, new to science, were collected in 1853.

The long-continued existence of such a lake is shown, not only by the fossil shells, but by the ancient shore-lines and beaches, as fresh as if recently left by retiring waters, and especially vivid and convincing north of the Delta, where they are visible for miles.

At an outlying mass of rocks at the base of the main ridges of the Peninsula or San Jacinto Mountains, a deposit of travertine marks the former height of the water by a thick incrustation, covering the granite boulders from view. The foundation rock must have been a small islet of granite projecting above the waves of Lake Cahuilla. It is now known as Travertine Point, and its base was nearly reached by the rising waters of the Salton Sea in 1907. (Plate 1 B.)

By the courteous invitation of Dr. MacDougal, I had the pleasure of revisiting this place in the month of May 1906. Crossing the valley from Mecca on the Southern Pacific Railway, we visited the then rising Salton Sea, skirting it to Travertine Point, which I again ascended half a century after its discovery and description in 1853. The old water-lines and beaches were comparatively unchanged in appearance. Concentric lines of sparse vegetation marked where the waters had stood centuries before. Looking out from the summit across the Salton Sea, it was difficult to realize that the old-traveled trail across the desert lay 15 fathoms deep under water, where before not a drop could be found.

The former lake, the shores of which are recorded on the rocks and slopes of the Cahuilla Valley north of the Delta, had an area of about 2,100 square miles. It was 100 miles long and about 35 at its widest. It was first identified and described by me in 1853, in a communication to the San Francisco *Commercial Advertiser*, edited by J. D. Whelpley, in the winter of 1853–54, and later in the reports of Exploration and Surveys for a Railroad Route from the Mississippi River to the Pacific Ocean, volume V. Its boundaries were then approximately shown and its origin explained. I have named it "Lake Cahuilla," from the name of the valley and of the Indian tribe. (See pp. 24 and 25.) The name "Salton Sea" is appropriately applied to the recent inflow and partial inundation of the valley covering the salt-beds at Salton, but the ancient lake in its entirety requires a distinctive name. If any precedent is needed for naming an ancient lake which has disappeared, it is found in the naming of the old lake in Utah by Clarence King, as Lake Bonneville. Lahontan is another example. The Great Salt Lake of Utah is the residual lake of Lake Bonneville much as the Salton Sea is the residual lake of Lake Cahuilla.

Lake Cahuilla occupied the northwestern end of the basin of the California Gulf—that portion cut off from the sea by the delta deposits. The northwestern part of the valley is also known as the Cabezon or Cahuilla Valley, so named from the Cahuilla Indians, who have inhabited the oases and tillable fringes of the Desert from time immemorial. There is a difference of opinion regarding the proper orthography of this name. It is ably discussed by Dr. David Prescott Barrows in the *Ethno-Botany of the Cahuilla Indians of Southern California*. He writes:

> "A word should be said as to the pronunciation and spelling of the tribal name, *Coahuilla*. The word is Indian, and the tribesmen's own designation for themselves, and means 'master' or 'ruling people.' There is some slight variation in its pronunciation, but the most usual is probably *kow-wee-yah*, accent on the second syllable. The spelling has been various. That used by the early writers and correct, according to the value accorded to *ll* in Spanish-American, is that adopted here—Coa-hui-lla."

The writer, in the year 1853, when passing through the "Ka-wee-yah" or Four Creel Country in California, with Lieutenant Williamson, in the endeavor to conform phonetic ally to the Indian name, wrote it "Cohuilla," and sometimes "Cahuilla." This last form seems to have been more generally accepted and is preferred to Cohuilla, Coahuilla, or any other.

DESICCATION OF LAKE CAHUILLA.

With our present knowledge of the delta deposits of the Colorado, the varying phases of the stream, the lightness and depth of its deposits of silt, its quicksands, its shifting channels, and uncontrollable ways, it is easy to realize that the inflow to Lake Cahuilla must have been extremely variable and uncertain. We can realize that under favorable conditions the whole volume of the Colorado may have been diverted alternately to the Lake and to the Gulf, and that long intervals of drought accompanied by drying up were often experienced.

Writing upon the subject in 1853, attention was directed by the writer to the traditions of the Cahuilla Indians, as follows:

"The explanation of the formation of the lake and its disappearance by evaporation which has been presented, agrees with the traditions of the Indians. Their statement that the waters retired *poco-a-poco* (little by little) is connected with the gradual subsidence due to evaporation, and the sudden floods of which they speak undoubtedly took place. It is probable that the lake was long subject to great floods produced either by overflows of the river at seasons of freshets, or by a change in its channel, or by a great freshet combined with a very high tide, so that the river became, as it were, dammed up and raised to an unusual height. The present overflows, though comparatively slight, are probably similar; and yet it is possible that the interior of the Desert might be deluged at the present day, provided no elevation of the land has taken place, and the river should remain at a great height for a long time—long enough to cause the excavation of a deep channel for New River."[1]

SALTON SEA.

This is precisely what has recently happened by the cutting of irrigating canals and by the uncontrolled flow of the Colorado water: deep and destructive channels were cut, a partial flooding of the desert followed, and the "Salton Sea" was formed. The body of water which so recently threatened the restoration of the former lake conditions, by the month of February 1907 had attained a length of 45 miles, a maximum breadth of 17 miles, and a total area of 410 square miles, with a maximum depth of 83 feet. It extended from Imperial Junction nearly to Mecca Station. It submerged railway stations and necessitated the removal of the track of the Southern Pacific for 67 miles to a higher and more northern bed. By the great and masterful exertions of the engineers in charge, seconded and supported by the Southern Pacific Railroad, the destroying deluge was stopped in the month of February 1907 and the gradual disappearance of the Salton Sea by evaporation commenced and is now in progress. In this we have immediately before us a practical exhibition of what must have happened many times before.

Evidently in the case of the ancient Lake Cahuilla, with the loss of the supply of water from the Colorado the lake disappeared by evaporation. The conditions for this were extremely favorable. Of the rate of evaporation and the time required for the complete desiccation of the valley, we have no direct evidence, but there is every reason to accept the statement of the Indians that the water retired little by little, or very slowly, and no doubt years passed before the lake dried up.

RATE OF EVAPORATION.

Experiments by me upon the rate of evaporation in the Tulare Valley, California, in 1853, indicated 0.25 inch per day, or between 7 and 8 feet yearly.[2] Dr. Buist found

[1] Report Geological Reconnoissance in California, p. 238.

[2] Report Geological Reconnoissance in California, p. 195, and Trans. Geog. Society, vol. IX, p. 39, 1849-50. See also, Trans. National Institute, Washington.

that the amount of evaporation from the surface of the water at Aden, on the Indian Ocean, was about 8 feet per annum. At the rate of 8 feet yearly, the 83 feet of water now covering the Desert, and known as the Salton Sea, will require ten and a half years for its complete evaporation.

Mr. H. T. Cory, the engineer who had charge of rediverting the Colorado River to the Gulf of California in 1906, states[1] that if there is no further inflow of the Colorado River to the Salton Basin, the sea will practically dry up by evaporation in about eighteen years, and that the actual evaporation from the Salton Sea from February 1907 to July 1912 has been almost exactly at the rate of 5 feet per annum.

From measurements of the evaporation from a tank at Calexico by Mr. Peck, of the California Development Company, the annual evaporation was shown to be about 6.73 feet, as will be seen by the following tabular report:

TABLE 1.—*Evaporation from a water surface at Calexico.*

Month.	1904.	1905.	1906.	Month.	1904.	1905.	1906.
	Inches.	*Inches.*	*Inches.*		*Inches.*	*Inches.*	*Inches.*
January......	4.39	2.72	2.57	August......	10.98	8.52	8.47
February.....	6.32	1.47	2.43	September...	8.61	7.83	6.73
March.......	8.86	4.44	5.06	October.....	8.78	6.77	5.45
April........	9.55	4.74	5.99	November...	5.40	3.23	3.61
May.........	10.91	8.38	6.84	December...	3.48	3.43	2.40
June.........	13.89	12.86	7.41	Total.....	103.64	75.00	63.66
July.........	12.47	10.43	6.76				

COLORADO DESERT.

The drying up of Lake Cahuilla left a broad region at the head of the Gulf; a depressed area below the sea-level, a trackless waste of nearly level land extending, including the Delta, for some 200 miles northwesterly beyond the present limits of tide-water in latitude 31° 30′ N., approximately 80 miles south of the mouth of the Gila River at Yuma on the Colorado. The limits of this desiccated area are approximately marked indelibly on the ground by the shore-lines and beaches of Lake Cahuilla, extending on both sides of the valley from near Yuma to Indio and beyond.

The name "Colorado Desert" was given to this region by the writer in 1853. This was before the State of Colorado received its name. It was deemed most appropriate to connect the name of the Colorado River with the region, inasmuch as the desert owes its origin to the river by the deposition of alluvions and the displacement of the sea-water.

A tendency is shown by some writers to extend the area known as the Colorado Desert so as to include the arid regions north of it, especially the mountainous region along the Colorado and the Mohave, partly known to-day as the "Mohave Desert." This was not the intention or wish of the author of the name. It was intended to apply it strictly to the typical desert area of the lacustrine clays and alluvial deposits of the Colorado where extreme characteristic desert conditions prevail, such as arid, treeless plains, old lake-beds, and sand-hills—such conditions as are found in the Sahara of Africa and in the delta regions of the Nile. The appellation may properly be confined to the regions reached by the deposition of the silt of the Colorado, whether in the form of deltas or at the bottom of ancient lakes. I should also include the bordering detrital slopes from the contiguous mountains. So restricted, the area is practically coterminous with the ancient beach-lines and terraces of the lakes which occupied the valley.

Its area is estimated at not less than 2,100 square miles; its breadth east and west opposite Carrizo Creek about 33 miles. Its height above tide ranges from 135 feet above

[1] Proceedings of American Society of Civil Engineers, November 1912.

sea-level at Yuma to an average of 42 feet following the old shore-line of Cahuilla Lake to −287 feet, now partly submerged.

FERTILITY OF THE DESERT SOILS.

The Colorado River, like the Nile, is a great fertilizer of the land which it overflows. Its alluvions are easy of tillage and are wonderfully productive. The Yuma Indians, after the subsidence of a flood, find the land ready for the seed. Walking over the newly deposited silt, a hole is made in it by the great toe, into which the seed-corn is dropped and then covered with the ball of the foot. The corn sprouts and grows with great rapidity.

The annual deposition of silt is constantly raising the level of the banks and increasing the tillable area. This process has been going on since the elevation of the land above the sea and the foundations of the Delta were laid. It is difficult to compute satisfactorily the quantity of silt brought down by the river and added to its Delta every year.

The Arizona Experiment Station made observations in 1904 indicating that the lower Colorado carries approximately 70,000 acre-feet of silt on an average annually. In the year 1904 the amount of silt in the river water varied from 84 to 3,263 parts in 100,000 parts by weight, and an acre-foot of water contained an average of 9.62 tons of silt. If it is assumed that one-half of the silt in the river water used for irrigation is held in suspension until the irrigated lands are reached, a field to which 3 acre-feet of water is applied would receive 14.43 tons of silt, which has an average value as a fertilizer of approximately $1.11 per acre-foot of water. Mr. H. T. Cory[1] gives the mean annual discharge of the Colorado River as 17,070 cubic feet per second, and the mean total discharge as 12,388,000 acre-feet.

The fertilizing sediments from the annual overflow of the Nile, which stream has much in common with the Colorado, are estimated at 6 inches of depth in a century. It is thought that the bed of the river rises 4 feet in 1,000 years. It is said that 7 feet in depth of mud have accumulated around the pedestal of the statue of Colossus, the date of which is about 1430 B. C.

The French estimated the deposit of Nile mud, from Essonan to Cairo, at 5 inches per century. The column of Rameses II is surrounded by a sediment 9.3 feet deep, fairly estimated. This monument was erected 3,215 years before, which gives a rate of 3.5 inches per century. But there are similar deposits below the depth of 30 feet, which, at the same rate of deposition, would require 13,500 years to A. D. 1854.[2]

ADAPTATION TO AGRICULTURE.

Attention was early directed to the adaptation of the desert soil to agriculture, as shown in the official report to the War Department in 1855.[3]

"The upper or gravelly plains of the Desert, especially those in the vicinity of the mouth of the Gila, are too arid and wanting in soil to be ever used for agriculture. But this is not so with a large part of the Desert—the part formed by alluvial and lacustrine clay. The whole of this clay surface may be considered as capable of supporting a luxuriant growth of vegetation provided it is supplied with water by irrigation.

"The Cahuilla Indians in the northwestern part of the Desert raise abundant crops of corn, barley, and vegetables in the vicinity of the springs at their villages. We also observed a dam at the Cahuilla villages on the northern margin of the Desert, where we stopped over night. The ground was principally clay, which by drying in the sun had become very hard, but on being cut and pulverized by the passing of the train, became dry and dusty, like dry ashes. On cutting down into it for about 12 inches it was found to be more sandy and micaceous. It appeared to be a rich soil, for wherever water reached the surface the vegetation was abundant; and a large area near the mountains was covered with a dense growth of weeds, the ground being moist.

[1] Proceedings of American Society of Civil Engineers, November 1912.
[2] Compiled from Draper's Intellectual Development of Europe, p. 87.
[3] Report Geological Reconnoissance California, Blake, and vol. v, Pacific Railway Reports, pp. 248–249.

"The vegetation around the springs was luxuriant; and wherever the soil was moistened it supported either a growth of grass or of rank weeds. The Indians had their houses in the thickly growing mesquite trees around the springs. A growth of weeds was noted over a wide area near the mountains, but not far from the cultivated field."

Samples of the soil, taken for analysis, showed the presence of all the elements necessary to fertility. It is added:

"From the preceding facts it becomes evident that the alluvial soil of the Desert is capable of sustaining a vigorous vegetation. The only apparent reason for its sterility is the absence of water; for wherever it is kept moist, vegetation springs up.

"If a supply of water could be obtained for irrigation, it is probable that the greater part of the Desert could be made to yield crops of almost any kind. During the seasons of high water, or of the overflow of the Colorado, there would be little difficulty in irrigating large areas in the vicinity of New River and the Lagoons.

"By deepening the channel of New River, or cutting a canal so low that the water of the Colorado would enter at all seasons of the year, a constant supply could be furnished to the interior portion of the Desert. It is indeed a serious question whether a canal would not cause the overflow of a vast surface and refill, to a certain extent, the dry valley of the ancient lake. This is possible and would result, provided no change of level has taken place since the water dried up." (Pages 249–250.)

GEOLOGY AND MINERALS.

The mountain ranges, which figuratively frame the valleys, rise wall-like on both sides of the Cahuilla Valley and the Desert. Those on the west are the most abrupt and rugged, and form a complete separation between the Delta region and the Pacific Ocean. These are the San Jacinto ranges of the Peninsula Mountains. San Jacinto, the highest peak, stands at the south end and on the south side of the San Gorgonio Pass, which separates it from the massive ridges of San Bernardino. Both of these mountains rise to an altitude of over 11,500 feet above the sea. The white snow-covered summit of San Bernardino is a conspicuous object for a large part of the year from the decks of vessels sailing along the coast. San Jacinto does not attract so much precipitation, but is a very sharp and picturesque peak. (Plate 7.)

Geologically, these mountains are essentially crystalline and granitic. The Peninsula ranges north of the boundary line consist chiefly of granite and syenitic rocks, in which there is an unusual amount of the mineral known as schorl, or black tourmaline. Gneiss and micaceous schists are largely developed and are sharply upraised and plicated, forming extremely rough and jagged croppings, especially on the side bounding the Desert, where there is but little soil. Owing to the desiccation of the wind from the sea, the scanty precipitation is insufficient for mountain streams of much volume. The few brooks or rivulets of the higher ridges in their descent to the valley in the rainy season are quickly absorbed or dissipated by evaporation on reaching the lower slopes.

On the seaward side of the mountain range the conditions are very different and many small and fertile valleys are found.

Amongst these, Warner's, so named for the pioneer settler, Don Juan Warner ("Juan Largo"), a tall New Englander from Lyme, Connecticut, was a great haven of rest in the early days for those who had survived the terrors of the desert in the 90 miles journey from Yuma to Carrizo Creek, without water.

These granite ridges from San Jacinto, southward, through San Diego County, have become noted for the superb gems taken from many places, more particularly for red, green, and pink colored tourmaline, obtained by patient mining. The rock generally may be said to be characterized by the abundance of the ordinary black tourmaline or schorl. Amongst the other gem-stones, the rare form of spodumene, a lithia mineral known as kunzite, is obtained here in beautiful purple or violet-colored crystals. Garnets and beryls are also obtained in these mountains. The beryls are sometimes colorless and almost as brilliant as diamonds, and are often tinted a pale rose-pink, greatly enhancing their beauty.

The mountains on the north of the great Cahuilla Valley are also granitic and form a series of sharp ridges in constant sequence, separated by gravelly slopes and valleys for a great distance up the valley of the Colorado. Some outcrops have been worked for gold in the mountain ridges a few miles north of Indio, and also at Carga Muchacha, near Yuma.

The geology south of the international boundary is but little known. At the Sierra Giganta, between Muleje and Loreto, there are precipitous cliffs of red sandstone.

VOLCANISM.

The evidences of volcanism are many and impressive in the lower Delta region of the Colorado and on the Sonora side of the head of the Gulf, where numerous craters exist and are dominated by the extinct volcano known as Pinacate. This mountain rises in a volcanic center of great extent, only about 25 miles from the shores of the Gulf. It had been recently visited by Dr. MacDougal, of the Carnegie Institution of Washington, in company with Engineer Sykes; Messrs. Hornaday, of the Zoological Park, New York; and Mr. Phillips of Pittsburgh, Pennsylvania. They found extensive pit-craters with precipitous sides and a broad region covered with lava.

Northward from this Pinacate region, volcanic outflows continue as far as Mohawk, on the railroad in Arizona, on the north side of the international boundary-line.

In close proximity to the deposits of the Colorado Delta we find the craters and outflows of the Cerro Prieto, or Black Butte, on the flanks of the Cocopah Mountains. The chief crater is in the mountain, 750 feet high, and is flanked by smaller craters, all now extinct but giving evidence of comparatively recent activity. Mud volcanoes, or salses, occur there, from which hot water and steam are escaping.

At the time of the great earthquake in San Francisco, April 18, 1906, there was an earthquake in the Imperial region of the Delta, which suggests the probable continuation of a fault-plane passing along the great interior valley of California and southward through the valley of the Gulf.

MUD VOLCANOES.

In the year 1852, Major Heintzelman, U. S. A., then commanding at Yuma, was surprised to see clouds of steam arising from the southwest portion of the desert. Visiting the place he found a great eruption of hot water and mud, with jets of steam, issuing from conical hillocks of mud. Masses of dark-colored mud were thrown to a height of 40 feet. These salses were later visited and described by Dr. John L. LeConte,[1] and by Dr. Veatch.[2]

An excellent graphic description was given by Dr. David P. Barrows in 1900.[3] He correctly observes:

> "The volcanoes are doubtless immediately due to the infiltration of water from the Colorado overflow down to the heated beds of rock not far beneath. Converted into steam, these waters burst violently upward through the deposits of silt, and around their orifices throw up encircling walls of mud."

Similar outbursts have been seen not far from the line of the railroad opposite the Salton Sea deposit, but are now covered by water.

Dr. MacDougal described the volcanic phenomena as follows:

> "Hot springs and other manifestations of volcanic energy are to be found all along the geological axis on the eastern side of the Peninsula of Baja California, but the most pronounced feature

[1] American Journal of Science and Arts, (II) XIX, May 1855.
[2] *Ibid.*, (II) XXVI, 1858.
[3] National Geographic Magazine, Sept. 1900, vol. XI, No. 9, p. 337.

of this character is to be found well out in the Delta, near Volcano Lake; here, on a saline plain, a few miles in extent, innumerable small mud cones, solfataras, and boiling pools of mud and water emit steam, smoke, and sulphurous gases, accompanied by a dull rumbling sound.

"According to the traditions of the Cocopah Indians, a member of the tribe accused of sorcery, or other serious crime, was sent back to his evil master by the simple process of dropping him into a pool of boiling mud—an obvious entrance to his abode below."[1]

SALT.

The accumulation of salt in the lowest part of the Desert was well known to the Cahuilla Indians, who resorted to it for salt for an unknown period. Being a little off the trail or road then traveled from Yuma to the settlements in California, it was not often visited or seen by the early explorers, who, after the long journey of 90 miles without water, pressed forward without delay to the shades and springs of potable water on the seaward slope of the mountains at Warner's Ranch.

Emory, 1848, mentions the salt lake as three-quarters of a mile long and a half a mile wide, and that the water had receded to a foot in depth. The salt-bed was not conspicuous in 1853, at the time of Williamson's survey. Its precise position was not ascertained. It was said that it was sometimes flooded with water, which was supposed to have reached it from the overflow of the Colorado, through the channel of New River.[2] Evidently this occasional submergence and desiccation must have caused a great difference of appearance at different times, the depression when dry being sheeted with salt, and when flooded appearing as a shallow lake of briny water. (Plate 1 c.)

This bed of salt, when not flooded, was extensively exploited by the New Liverpool Salt Company. Shipments were made from the Salton Station on the railway for many years, until the last overflow, which for a time has destroyed the industry.

In 1892 the lake was described as a salt marsh connected by a branch railway with the main track of the Southern Pacific road. At the end of this track, some 15,000 feet west of the railway, a well was bored by the Company to a depth of 300 feet. The top material largely consisted of black mud resting on a crust of salt, a mixture of the chloride of sodium and chloride of magnesium, 7 inches thick. On passing through this crust the drill dropped through 22 feet of a black ooze containing water over 50 per cent, sodium and magnesium salts, fine sand, iron oxide, and clay. It rested on hard clay, through which the drill passed for the remaining distance, 277 feet, varied only by two or three streaks of cement.[3]

The inflow of water from the Colorado River in 1891 is described as follows:

> "In the month of June 1891, a steady flow of water entered the depression (of the salt lake from the southeast and continued to the northwest uninterruptedly until an area 30 miles long an averaging 10 miles in width was covered to a depth of 6 feet, measured at the end of the Salto Salt Works' branch track. When first examined the water showed a density of 70° Beaume, whic gradually increased to 25° Beaume."

This influx of salt water gave rise to the idea that the water of the Gulf had penetrate through some underground channel, but no such channel could be found. It was fancie that the soft, briny ooze might extend under the crust beyond the marsh even to the Gul and so obtain the supply of salt water enriched by passing into and through the ooz The water, however, entered the basin through the New and the Alamo River channe which led from the lower Delta region overflowed by the unusually severe Colorado Riv flood, exactly as occurred again in 1905 and 1906.

[1] The Delta of the Rio Colorado, Bull. Amer. Geog. Soc., p. 10, 1907.
[2] Report Geol. Rec. California, p. 245.
[3] Report State Mineralogist of California, XI, p. 388.

ASPHALTUM AND PETROLEUM.

In the year 1907, according to the report by Dr. Stephen Bowers to the State Mineralogist of California, the recorder's office at San Diego showed that more than 450,000 acres of land had been located for petroleum in the Colorado Desert Mining District, in San Diego County. Expectations were great and many borings were made, but it does not since appear that any petroleum has been developed there.

Asphaltum was reported in 1891 by Dr. Bowers, from the Fish Creek District, southwest from the Mesquite Company's wells. Asphaltum occurs there and at Superstition Mountain. Dr. Bowers also reports nearly pure asphaltum from section 7, Township 11 south, Range 10 east, and at several points in the same township.[1]

SULPHUR.

Deposits of sulphur in the Cocopah Mountains have been worked in a desultory, intermittent way for many years. Common report assigns a considerable quantity to the locality on the west side of Volcano Lake, but no reliable descriptions are at hand. It is about 20 miles south of the boundary.

SODIUM CARBONATE.

Carbonate of soda occurs in quantity on the shore of the Gulf at Adair Bay, but has not been developed. The quality, as shown by samples submitted at the University of Arizona, is excellent and the crude material could no doubt be advantageously shipped to United States ports were it not for the import duties.

GOLD.

Gold-bearing quartz veins are found in the mountains north of the Desert. One was worked at Carga Muchacha, and the ore was milled at Pilot Knob for several years.

ANALOGOUS CONDITIONS ELSEWHERE.

We find in the Old World conditions analogous to those of the Gulf of California. The Red Sea, for example, also occupies a great trough or valley about 1,200 miles long, extending northwesterly and southeasterly over nearly 20 degrees of latitude, from approximately 12° to 32°, from the Indian Ocean nearly to the Mediterranean. It appears to have been cut off from a former connection with the Mediterranean by the deposits which form the Isthmus of Suez.

The Gulf of Suez, at the north end of the Red Sea, extends north-northwest for 170 miles, with an average width of 30 miles. Its shores may be regarded as a portion of the Isthmus reclaimed from the sea; the former limits of the ocean waters can be traced for several miles inland.

In each of these great continental longitudinal valleys, great geographic changes have resulted from deposits of silt-laden rivers. The Red Sea has been shortened by the deposits from the Nile, and the Red Sea of California by the deposits of the Colorado.

The phenomena of the Colorado Delta, especially changes of channels, find a close counterpart in those of the Indus Delta. This river, rising in Central Asia, in the mountains of northern India at the northeastern extension of the Himalayas, flows south and westerly and empties into the Arabian Sea about 25° north latitude. It there forms a delta 10,000 square miles in area, with a coast line of 125 miles. It exhibits a network of abandoned channels and "lost rivers," calamitous in their drying up, reducing thousands of square miles of a once fertile and inhabited country to waste and solitude. Channels once filled with flowing water are often forsaken. The flow often shifts suddenly and

[1] Reconnaissance of the Colorado Desert Mining District, by Stephen Bowers, Ph. D., Sacramento, 1901, p. 17.

many dry channels are left. Great changes in the course of the river took place in the last century. The length of the main channel abandoned was not less than 100 miles. There is evidence that shiftings of the river-bed have been going on through all ages.

An inland sea once covered the Rann of Kachh and the region is sometimes flooded during the season of the southwest monsoons.

The rate of advance of the shore-line of the Delta is rapid. It is stated that in ten years the advance of the banks at the river mouth is 3.33 geographical miles, or one-third of a mile yearly. It is estimated that the river brings down 217,000,000 cubic yards annually.

Changes very similar to the displacement of the waters of the Gulf of California by the Colorado Delta have been in progress in other parts of the world, notably at the head of the Persian Gulf, which, within a comparatively recent period, extended 250 miles farther to the northwest than the mouth of the combined stream of the Tigris and Euphrates.

In the interior valley of the upper California, which is topographically an extension of the great trough of the Gulf, there are also analogous conditions of delta and lacustrine deposits. In the valley of the Tulares there are broad regions of level lacustrine clays where evidently there were formed broad lakes of fresh water, represented to-day by the chains of shallow residual lakes from the Buena Vista to the Kern and the Tulare. These lakes, ever varying in their extent according to the water supply, owe their origin as separate sheets of water to the diversion of the San Joaquin River by its own detrital deposits from a southern and land-locked to a more northern outlet leading to the sea. The Delta deposits of this river, by extending into and across this interior valley, divided it into two parts near its center, so that the floods of the San Joaquin, which once swelled the volume of the Tulares, were finally withdrawn into the sea at the Golden Gate. All such river and lake deposits, both of the Old World and the New, are remarkable for their fertility and capacity of sustaining large populations. From this point of view the value of the Delta of the Colorado can scarcely be estimated. It fully justifies the great cost of its reclamation and control of the water supply for the benefit of this and future generations.

GEOGRAPHICAL FEATURES OF THE CAHUILLA BASIN.

By Godfrey Sykes.

GENERAL DESCRIPTION.

Although the extensive arid area of southeastern California is strikingly homogeneous in its general physical features, it has nevertheless been nominally divided, for purposes of local convenience and geographical distinction, into certain definite districts or deserts, and the Cahuilla Basin, with its associated drainage, lies almost entirely within the confines of the most southeasterly of these subdivisions—the Colorado Desert. This name was first applied to the region by the late Professor Blake, as narrated elsewhere in this volume, and it has since come into very general use.

As now defined, the Colorado Desert may be considered to include the area between the Coast Range on the west and southwest; the Colorado River on the east; the San Bernardino and Chuckawalla Mountains on the north; and to merge, without any very definite limits, into the eastern bajadas of the Peninsula Mountains to the south—some 8,000 square miles in all. (Plate 2.) It lies mainly within the United States, but its southern portion extends across the international boundary-line into the Mexican State of Baja California. It is traversed near to its northern limit, in a southeast to northwest direction, by the main line of the Southern Pacific Railroad, and within the last decade or so several subsidiary lines have been built to serve the growing needs of the prosperous communities which have sprung up upon the irrigable lands of the Imperial Valley.

Topographically the Colorado Desert is divided into two main and parallel basin areas which merge at their southeastern extremities in the alluvial plains of the Delta of the Colorado and are separated elsewhere by the Cocopah Range of mountains.

The Pattie Basin, which is the smaller and most southerly of the two, lies almost wholly within the Republic of Mexico. It has not as yet been fully examined or described, but we know that its central and lowest portion is occupied by a fluctuating lake or lagoon, fed by overflow from the lower Colorado, and it is probable that the bottom of this depression is many feet below sea-level.

The basin to the north and northeast of the Cocopahs, which constitutes the main portion of the Colorado Desert, and to which the name Cahuilla Valley was given by Professor Blake, has the general form of an acute-angled scalene triangle—the west bank of the Colorado River forming its base; the Cocopah, Superstition, and Santa Rosa mountains its southern side; and the gradually converging line of the Chocolate, Chuckawalla, and San Bernardino Mountains its northern side. The apex of the triangle lies at the summit of the San Gorgonio Pass, between the San Bernardino and San Jacinto Mountains. (Plate 7.) The extreme length of this triangle is about 185 miles and its width at the base about 75 miles.

The floor of the basin is roughly spoon-shaped, gradually dropping from its southeastern end for a distance of about 140 miles until it has attained a depth of 265 feet below sea-level, and then rising with increasing rapidity until at the summit of the San Gorgonio Pass it has risen to an elevation of some 2,500 feet above. An area of sand-hills and gravel mesas toward the northeast and a piedmont district which lies between the Superstition Mountains and the main escarpment of the Peninsula Range, complete the area under consideration.

EARLY MAPS AND EXPLORATION.

Our real knowledge of the Colorado Desert extends back but few years and is still, in many important respects, far from complete; but we know the Spaniards approached the region, if they did not actually penetrate it, within a few years after the discovery of the New World.

The first expedition to explore the head of the Gulf of California and examine the circumjacent region was the one sent out in 1540 by Don Antonio de Mendoza, the Viceroy of Mexico, under the leadership of Francisco Vasquez Coronado.

Pedro de Alarçon journeyed up to the mouth of the Colorado River by sea, and examined some parts of the Delta, and later in the year Coronado sent Melchior Diaz, with a small party, overland from Corazones, to coöperate with him. Diaz reached the river, but failing to meet Alarçon, he crossed it on rafts, and was afterwards accidentally killed while on the west side. He has, however, left an account, as recorded by Castenada,[1] of reaching a land of "hot ashes and volcanic rumblings," which no doubt refers to the mud volcanoes near Volcano Lake.

Castillo, the pilot of Alarçon's squadron, made a chart of the head of the Gulf, which appears to have been first published by Lorenzana in Mexico in 1770[2] (Plate 3), and is doubtless the earliest authentic map we have of the region. Castillo's interest, however, was chiefly that of the mariner, and he made little attempt to portray inland features.

The knowledge gained by this expedition was evidently the inspiration for the charts of all the early cartographers such as Joannes Cimerlinus,[3] Plancius,[4] Mercator,[5] Wytfliet[6] and others.

Wytfliet's map is by far the best and most interesting of these early charts, and whoever his authorities may have been, they clearly had some first-hand knowledge of the country. (Plate 4.)

The western river, which figures so prominently in nearly all of these early maps, although it appears merely as an estuary or entrance to a lagoon in Castillo's own chart, is clearly meant for the Hardy, and it is not at all improbable that in the days of these early navigators and cartographers the Hardy, the Colorado, and the comparatively insignificant channel which is now known as the Santa Clara Slough, may all have entered the Gulf by separate estuaries, and each carried a running stream, and, indeed, there is some reason for surmising that this latter channel may at that time have constituted the main mouth of the river.

Spanish interest in these distant and inhospitable lands began to wane after this early attempt at their exploration, and it was not until the memorable journey of Father Kino, in 1702, that any real addition was made to our knowledge of the region. His map, which is carefully drawn and fairly accurate, was published in various forms some years later,[7] and shows two mouths to the Colorado, but as his detail to the west of the river is obviously less complete than it is elsewhere, this omission of the estuary shown by Castillo may be regarded as inconclusive.

Father Fernando Consag was nearly contemporary with Father Kino, and a very interesting manuscript map showing the results of his work in the Gulf exists in the British Museum.[8]

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1 The Journey of Coronado, by Geo. Parker Winship, New York, 1904, p. 59.
2 Lorenzana y Buitron, Historia de Nueva Espana, 1770. British Museum, 145, d. 14.
3 British Museum, Maps 70, d. 1, 1566.
4 British Museum, Maps 920 [279], 1590.
5 A copy of Mercator's map of 1569 is to be found in the library of the American Geographical Society in New York. It is included in Jomard's Atlas, and shows the influence of Castillo's work very plainly.
6 British Museum, Maps 71, c. 7, 1598. Another excellently preserved copy of this map exists in the library of the American Geographical Society, New York.
7 A new map of North America, by Eusebius Francis Kino, London, 1786; British Museum 699, 15 (31).
8 Add. MSS. 17660 C.

His exploration was carried on by boat and extended some distance up the Colorado. Pencilled range marks upon the original map indicate that his chief observational station was upon the south end of Angel Island, and his survey was mainly a marine and coastal one.

At some time subsequent to the journeys of Fathers Kino and Consag, some other explorer or explorers must have penetrated the region, and the result of this work is to be seen embodied in the remarkable map of John Rocque.[1] (Plate 5.) This map is unique in several respects: The unusual accuracy of its detail over most of North America; the evidence that the cartographer must have had at his disposal very complete sources of information in regard to the Southwest; but chiefly, as far as the scope of this paper is concerned, from the fact that it clearly shows the combined streams of the Colorado and the Gila flowing into a lake, and having no connection with the Gulf. (Fig. 1.)

The nomenclature throughout the region shows knowledge of the work of Kino, but this very radical feature in the topography is clearly due to the work of some explorer of whose work we as yet know nothing more.

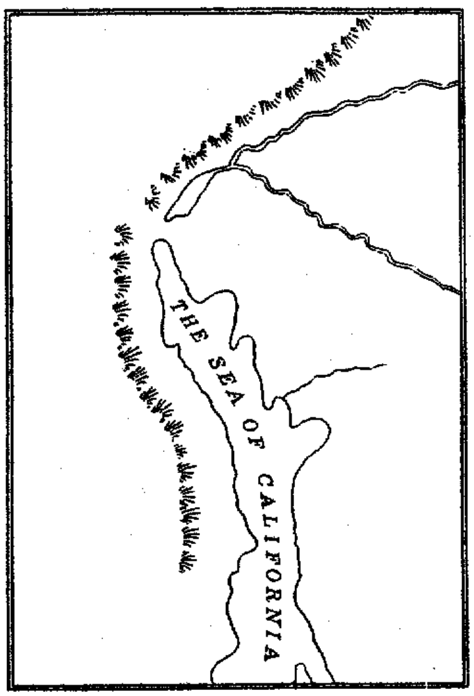

Fig. 1.—Outline map of the head of the Gulf of California and Salton Sink, according to Rocque. (Plate 5.)

A fairly comprehensive search for and examination of the early maps of the Southwest have been made in the hope of finding some conclusive evidence of former fillings of the Salton Basin within historic times, and this map at least seems to indicate that such a diversion of the river water towards the west has been known to travelers at some time between 1706 and 1760. With this clue it is probable that further search may result in giving us positive information upon the subject. A common tradition amongst the Indians of the region points to the fact that such a filling of the Basin has taken place within comparatively recent times, in which the water extended "from mountain to mountain."

Father Pedro Font traveled in and explored the region in 1776, and doubtless crossed the Colorado Desert at least twice, and also reached the shore of the Gulf on the west side of the river. His map shows a large irregular opening still farther to the west than his own approach to the Gulf, and here again we may have the western opening of the early explorers, or another interpretation of the lake of Rocque.[2] Father Font was the last of the Spanish explorers to add anything to our knowledge of the delta or desert, and his work was followed by a virtual blank of over fifty years.

MODERN EXPLORATION.

James O. Pattie was the first of more recent explorers to reach the head of the Gulf. He, with his party of trappers, journeyed down the lower Colorado to tidewater in January 1828, and during February of the same year they crossed the western part of the Delta, the Cocopah Mountains, and the basin beyond, on their way to the Spanish settlement at San Diego.[3]

[1] British Museum, K. 118.32. A divided copy of this same map also exists in the library of the American Geographical Society, New York.

[2] An excellent reproduction of Font's map is to be found in The Diary and Itinerary of Francisco Garces, by Elliott Coues. New York, 1900.

The personal narrative of James O. Pattie, of Kentucky. Edited by Timothy Flint, Cincinnati, 1833.

Lieutenant Emory marched across the basin in the latter part of 1848 and seems to have reached the shore of the Salton Lake.[1]

Major Heintzleman, commandant at Yuma, visited the mud volcanoes near Volcano Lake in 1852, and these were afterwards visited by John LeConte[2] and others.

The Williamson expedition of 1853, in which the late Professor Blake took part, is dealt with exhaustively elsewhere in this volume, and since that time our knowledge of the Colorado Desert has been gradually added to from many sources.

THE COLORADO RIVER AND ITS DELTA.

The Colorado River, carrying its heavy burden of silt toward the sea, has been the dominant factor during recent geological times in upbuilding and molding the region under consideration.

Emerging from a succession of small cañons and inclosed basins, a short distance below its junction with the Gila, it has spread its load over a vast area and in course of time has built a broad barrier across the Gulf, and so isolated the two basins which now constitute the major portion of the Colorado Desert from the sea.

The seasonal change of volume in the flow of the river is in itself favorable to the rapid upbuilding of this barrier, for the mud-laden and comparatively late spring run-off from the mountains of Wyoming and northern Colorado reaches the flat lands of the Delta at a time when the growth of annuals is well advanced, and as a consequence the overflowing water is retarded, its erosive power checked, and its load of silt evenly and quietly laid down.

So rapidly is this building going on that there is good evidence that the mouth of the river has been brought several miles farther south within the last 40 years.[3]

Such rapidity of upbuilding and the very character of the stream itself and the enormous burden of solid material which it carries yearly to the sea almost warrant us in assuming that the Colorado has been by far the most potent factor in working topographical changes in the region during recent geological times.

THE MAIN DELTA BARRIER.

From the point of the Algodones Sand Hills at the head of the Delta to the small outlier of the Cocopah Mountains known as the Cerro Prieto the distance is about 35 miles, and a line drawn between these two points represents roughly the crest of the Delta dam which separates the Salton Basin from the Gulf. This crest-line falls from about 110 feet above sea-level at the Algodones to 30 feet at the foot of the Cerro Prieto, and the present course of the Colorado River lies a little to the southeast of it.

The bed of Volcano Lake, at an elevation of about 28 feet above sea-level, no doubt represents part of the last spillway over this dam and may be taken as indicating the water-level of the Salton Lake at its last complete filling.

Gradients are so low and the growth of vegetation on the Delta so rapid that drainage channels are not very strongly marked or permanent, quickly becoming obliterated when unused, or surviving only as detached ponds or sloughs. It is fairly evident, however, that the New River and the Hardy, which together form a continuous channel across the barrier, falling in both directions from a meeting-point near the foot of the Cerro Prieto, have also formed such a spillway; and the bed of this channel at its highest point lies at practically the same level as the bed of Volcano Lake.

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[1] Notes of a military reconnoisance from Fort Leavenworth in Missouri to San Diego in California, by W. H. Emory, Washington, 1848.

[2] American Journal of Science and Arts, vol. XIX, May 1855.

[3] H. T. Cory, Irrigation and River Control in the Colorado River Delta, Transactions of American Society of Civil Engineers, vol. LXXVI, pp. 1204 to 1571. 1912.

THE PATTIE BASIN BARRIER.

The extensive alluvial region which forms the barrier between the Gulf and the Pattie Basin is in reality a continuation, past the partial obstruction offered by the Cocopah Mountains and sundry small isolated hills, of the main Delta slope until it has met and become incorporated with the shore of the peninsula. In general character the country is low and flat, cut into by numerous tidal channels from the Gulf side, and subject to much tidal and river overflow. It is probably but few feet above sea-level at any point, but as no detailed surveys or observations have as yet been made in this region, our knowledge of it is far from complete.

THE CAHUILLA VALLEY.

THE SALTON SINK.

The total area of the Cahuilla Valley is about 8,000 square miles, and out of this total an area of approximately 2,200 square miles lies below sea-level and doubtless still represents with fair accuracy the former limits of the upper extremity of the Gulf. This depressed portion of the valley floor is nearly surrounded, at a slightly higher level, by a conspicuous ancient shore-line; and as thus inclosed and defined is generally known as the Salton Sink. Its total length is about 100 miles, its greatest width 35 miles. It is roughly elliptical in form, with its major axis extending from 32° 35′ N. and 115° 20′ W., to 33° 45′ N. and 116° 15′ W. There is a break in the inclosing shore or beach-line of about 14 miles at the southeast end of the ellipse, and this space has been the entrant point for an immense prism of sedimentary material, which has almost covered the floor of the ancient gulf. A rough computation, based upon the assumption that this ancient gulf-floor was approximately level, gives the contents of this prism at about 17 cubic miles, this volume representing the amount of solid matter deposited by the Colorado within the area since its isolation from the sea, and therefore further indicating the quantity of river water which must have flowed into and been evaporated from the inclosed basin since such isolation was accomplished. (See p. 6.)

THE ANCIENT SHORE-LINE.

The tides in the head of the Gulf of California rise to a great height and are at times very violent,[1] and this energetic tidal action has been mainly instrumental in building up along the surrounding shore-line strongly marked beach-ridges, raised in exposed situations to heights of 20 or 30 feet above mean sea-level.

The extent and character of the beach-terraces surrounding the Salton Sink at once suggest their common origin with the above—the same great tidal action. With the exception of the opening mentioned above the beach-line around the Sink is nearly complete, generally conspicuous and discernible from a great distance, and about 235 miles in total length.

It should be borne in mind, however, that all this beach material must have been subjected to much washing and rearrangement by lacustrine wave-action since the cutting off of the basin from the sea, and it has probably been literally rolled and pushed up the shore slope in the exposed situations in which this action has been most vigorous and as the progressive building up of the Delta dam has raised the spillway toward its present height above sea-level. The marine shore-line in its original location has thus been obliterated. The prevailing winds in the Cahuilla Valley are from the west, and we may there-

[1] The tide tables of the United States Coast and Geodetic Survey give the ratio of range between the entrance to the Colorado River and the port of reference, San Diego, as 5.65. The extreme tidal range in San Diego is about 8.50 feet, so that under exceptional conditions a tidal range of over 50 feet may easily be exceeded at the mouth of the river. This tallies with the writer's own observation, a range of over 45 feet having been measured upon more than one occasion. (See p. 3.)

fore find that a great deal of the observed difference of level in the shore-line has been due to this same wave-action, inasmuch as there is a general discrepancy of about 15 feet between the two sides of the Sink, the northeastern, the more exposed one, being higher than the southwestern one, which has been sheltered under the lee of the mountains. The shore-line has been regular and unbroken along the northeast side of the former lake, but upon the southwestern one it has come against the mountain walls in several places, and has in general been much more irregular and diversified, the Superstition and other mountain masses having thrust forward as bold promontories. One small group of islets has existed about midway along the northeastern side of the lake, and about 6 miles off-shore when the water was at its highest level. This is the small hill-ridge to the northeast of Durmid Station on the main line of the Southern Pacific Railroad. It still bears unmistakable signs of having been subjected to the heavy assaults of surf for some considerable period.

THE DRAINAGE FROM THE COLORADO AND DELTA.

The main natural drainage lines from the Colorado to the Salton Basin, before the changes brought about by recent engineering operations, have been the Alamo and New River channels. The Alamo was the most direct, but its connection with the Colorado was in general rather obscure and liable to obstruction and obliteration by vegetation and the deposition of silt. The flow of water was intermittent and irregular and only occurred in seasons of extremely high water. The New River flow did not come directly from the Colorado, but partly from the Alamo by way of the Garza and other sloughs, and partly as overflow from the shallow catchment basin of Volcano Lake. This lake was itself filled, in seasons of normal high water, through the channels of the Paredones, the Pescadero, and other less clearly defined waterways. Normally the whole efflux from the lake went directly into the Hardy, and so into tidewater, but in seasons of exceptionally high water it would be forced also to right and left—into New River on the one hand and into the lower Pescadero on the other, and so into the lower Hardy and the Gulf. The influence of the tides is noticeable in the Hardy as far as the point of the Cocopah Mountains and has at times been instrumental in forcing a part of this Hardy and Paredones flood-water into the Pattie Basin.

The Hardy, with its associated sloughs, backwaters, and lagoons, has always occupied the position of relief channel for the flooded and surcharged Delta in times of high water, filling thus a somewhat analogous position to that of the Bahr el Zaraf in the economy of the Upper Nile.[1]

Since 1901 the flow of water in the Delta has been greatly changed, as will be detailed later, owing to the various engineering operations carried out by or on behalf of the irrigation companies and settlers in the Imperial Valley.

THE WHITEWATER DRAINAGE.

The Whitewater receives its water through various small tributaries from the south and east slopes of the San Bernardino Mountains. It is an intermittent surface stream, but undoubtedly has a large underflow, as is evidenced by the copious flow from the artesian bores in the Coachella Valley. (Plate 15.) The total length of this stream is not much over 60 miles, but its mean gradient is very steep and its occasional floods very violent. (Plate 8A.)

THE CARRIZO-SAN FELIPE DRAINAGE.

The combined drainage area of Carrizo and San Felipe Creeks is about 900 square miles, situated in the piedmont district before alluded to, to the west of the Salton Sink. San Felipe Creek rises almost immediately under the escarpment of the main, or coastal,

[1] The Physiography of the Nile and its Basin, p. 122, by Capt. H. G. Lyons, Cairo, 1906.

range, some 7 miles north of Julian. It drains the country to the south and west of the Santa Rosa Mountains and forms a junction with Carrizo Creek in about 33° 6′ N. and 115° 57′ W. Carrizo Creek itself has two forks, one coming from near the international boundary-line, and the other from the south side of the Fish Creek Mountains. The combined creek thus formed runs north to its junction with San Felipe Creek, as above mentioned, and carries on its own name down into the Salton Sink. Here, too, the water-flow is very irregular, long periods of total dryness alternating with occasional heavy floods.

THE CHUCKAWALLA WASH DRAINAGE.

The only drainage system of any importance which reaches the Salton Sink from the northeast is that known as the Chuckawalla Wash. This is a large but generally dry desert wash, which drains an area of some 250 square miles, beginning with the slopes of the Chuckawalla and Eagle Mountains. It spreads out and is virtually lost in the extensive playas which lie northeast of Durmid, but at times, during some of the heavy and violent rains to which this region is occasionally subjected, a portion of its water may pass on down into the lowest part of the Sink by way of the Salt Slough.

RECENT HISTORY.

During the summer of 1890 the water from the Colorado River filled many of the small channels and lagoons toward the southwest, and in 1891 flowed through into the Salton Sink and formed a lake several miles in length. The intervening region was comparatively little known and its drainage system hardly comprehended at that time, and the appearance of such a large body of water in close proximity to the Southern Pacific Railroad attracted much attention and gave rise to some of the wildest of rumors and hypotheses as to its origin. William Convers, followed by one or two others, succeeded in making the journey by boat from the Colorado to the lake, and so the mystery was solved.

Mr. H. T. Cory, who has a comprehensive knowledge of the conditions in the Delta of the Colorado, concludes that some flood water has found its way down the channel of New River toward the Salton every year since the inundation of 1891, and cites opinions of old settlers who allege that water came into the Salton in 1840, 1842, 1852, 1859, 1862, and 1867. The mail stage service between Yuma and San Diego was interrupted by the flood of 1862 and a flatboat was used for crossing New River for several weeks in the summer of that year. (Transactions Amer. Soc. Civil Engineers, vol. LXXVI, pp. 1204, 1571.)

In 1900, a company having been formed for the purpose, work was begun upon the task of connecting and clearing the various channels which formed the natural waterway between the river and the basin; and by the middle of 1901 water was flowing upon the irrigable lands of what has since become known as the Imperial Valley. It had been deemed advisable by the promoters of the scheme to take the water from the river in United States territory, and so the upper section of the canal was cut almost parallel to the river for several miles and with a very low gradient. This circumstance, together with the general unsuitability of the site selected for the head works, caused considerable trouble for two or three years, as more and more water was required to fulfil the demands of the growing communities in the desert; and so various openings were made between the river and the canal in order to furnish a more adequate supply.

Then in the winter of 1904–05, one of the infrequent winter floods in the Colorado, coincident with a tremendous rush of storm waters from the Gila, found before itself the unprotected head and comparatively steep downward grade of the canal, and at once began to cut and enlarge the channel. The ordinary summer flood of 1905 also poured its water through the opening, and it was soon realized that the outpour had got beyond control.

Practically the whole of the Colorado was now flowing into the Salton Basin and another flood in the following November (1905) made the task of closing the breach seem almost hopeless, although the most strenuous efforts were being made by the engineers; and it was not until February 1907 that the Colorado was finally returned into its former channel. Here again, however, the vigorous vegetation of the Delta had played its part, for the river bed had in the meantime become so choked by plant growth and the deposition of silt that the water since made repeated attempts to escape, first towards the southeast through the Santa Clara Slough, directly towards the head of the Gulf, and since—in spite of some rather hastily planned and inadequate efforts to control it in that direction—into the head of Bee River and the Pescadero and so by various ways into the Hardy, which is now, in its lower reaches, carrying virtually the whole volume of the Colorado. This surcharging of the Hardy Channel had the further effect of allowing a large quantity of water to flow over its western bank and towards the Pattie Basin, and a large lake now fills the lower part of this Sink.

During the summer of 1906, and at the time when the maximum inpour was reaching the Salton Sink, the channels of the Alamo and the New River began to cut backward from the lower end, and the soluble, loess-like soil along their courses was carried bodily into the lake, leaving the deep, precipitous-sided valleys through which the present streams flow. Much apprehension was felt at the time by the engineers lest their cutting action should reach the Colorado and so preclude all possibility of repairing the breach, but the closure was effected in time and the danger averted.

Recent observations at the eastern end of the Salton Lake (October 1912), now that the water is receding, show that there has been an enormous deposition of this or other sedimentary material subaqueously; and with further recession it will doubtless be found that this deposition has taken place far out into the lake.

Some idea of the magnitude of this displacement and redistribution of material may be obtained from a statement made by Mr. Cory,[1] that the total yardage thus moved is over 450,000,000 cubic yards, or almost twice that of the Panama Canal.

A good deal of water still passes through both the Alamo and the New River, but this is merely the overflow from the irrigation canals, and it is quite improbable that with the interests now at stake in the Imperial Valley and the close watch kept upon the river by the engineers, any further uncontrolled incursion of water will be allowed to take place.

In the region of the lower Delta, however, conditions are very different; here we have a large, wayward, and silt-laden river, thrown out of balance by a temporary diversion, and always hampered at its mouth by great and violent tides, wandering at present virtually unchecked over a large area of friable alluvium with downward grades in several directions.

All these conditions tend, as may be readily imagined, toward a condition of instability and possible geographical change; in fact, it is probable that even if the Colorado and the general drainage conditions through the Alamo and its associated channels had not been interfered with in any way by the operations of the irrigation engineers, another diversion of the river water towards the west was about due from the natural causes outlined above, and would in any case have ensued within a few years.

It is furthermore evident that as so much of the flow of the river during the growing season of the early spring is now diverted and utilized for agricultural purposes, and as the bed of the river in its lower reaches is left practically dry during the period of most rapid growth of the Delta vegetation, its obstruction and elevation will be more rapid and the stability of the irrigation and protective works menaced more and more unless adequate measures are taken for controlling and storing the flood-waters of the early summer upon the upper Colorado.

[1] Transactions of American Society of Civil Engineers, vol. LXXVI, pp. 1204, 1571.

SKETCH OF THE GEOLOGY AND SOILS OF THE CAHUILLA BASIN.

By E. E. Free.

INTRODUCTION.

The first geological examination of the region covered by this volume was made by the late Professor Blake as a part of his work for the Pacific Railway Survey and is described in the reports of that survey,[1] and more fully in the present volume. Following Professor Blake's examination, the region received only incidental notice[2] until 1909, when Mendenhall[3] published a geologic sketch of the desert in connection with a discussion of water resources. More recently Harder[4] has published some observations incidental to a study of the region just to the north.

The conclusions of the present paper are based mainly upon personal study of the region, though much use has been made of the data of Blake and Mendenhall. On various trips to the region the writer has had the advantage of accompanying the late Dr. W. J. McGee, Dr. J. M. Bell, and Professor J. C. Jones, as well as others associated with preparation of this volume, though not concerned with the geology or soils. Acknowledgments are due to all of these gentlemen for many valuable suggestions. The soil studies were made while the writer was connected with the Bureau of Soils of the United States Department of Agriculture, and were carried out with the permission and advice of Professor Milton Whitney and Dr. F. K. Cameron, of that Bureau. The writer is indebted to these gentlemen both for facilitating the course of the work and for permitting the present use of the data obtained. During these soil studies the writer was accompanied by Mr. L. D. Elliott, to whom thanks are due for most efficient assistance.

DESCRIPTIVE GEOLOGY.

The general topography of the Cahuilla Basin and its bordering mountain ranges is outlined in Mr. Sykes's paper in this volume and need not be reviewed. In its major features it differs little from the topography characteristic of nearly all desert basins of North America—rugged bordering mountains half-buried in long smooth-sloped aprons of mountain waste, which merge finally in a central salt flat, in this case covered by the Salton Sea. The main exception in the Cahuilla Basin is the openness of the southern end toward the Gulf of California. Here the mountain rim is lacking and the basin is separated from the Gulf only by the alluvial ridge of the Colorado Delta described by Mr. Sykes. Perhaps the depression as a whole is better described as a "trough" than a "basin."

The geological structure of this trough is not well known. The bordering mountain ranges have not been studied in detail and little is known of their structure, except that it is not simple. The tilted block structure, so frequent in the "basin ranges" to the north, is not discernible here. There is some reason to believe that the axis of the trough is the locus of a major fault-line continuous with the great Cajon fault to the west, and running substantially northwest by southeast. Whether or not this be the case, there has undoubtedly been much faulting in all the bordering mountains and the trough in general is certainly structural, whatever may have been its origin in detail.

[1] Pacific Railway Reports, Sen. Ex. Doc. No. 78, 33d Congress, 2d Session, vol. 5, part 2, 1856.
[2] See especially, Bailey, Saline Deposits of California, Cal. State Mining Bureau, Bulletin 24, 1902.
[3] U. S. Geological Survey, Water Supply Paper 225, 1909.
[4] U. S. Geological Survey, Bulletin 503, 1912.

Petrologically, the available information is similarly meager of detail. On the north and northeast the Chocolate, Cottonwood, San Bernardino, and San Gabriel Mountains form one range, nearly continuous from the Colorado River, until they merge with the Sierra in the highlands of Tehachapi. Where this range has been examined it is composed almost entirely of granites, gneisses, and ancient schists. From his studies in this range and to the north, Harder distinguishes two general divisions of the granitic rocks; the first is probably Pre-Cambrian and associated with gneisses and schists; the second is a later intrusive, probably Mesozoic. Overlying the early granitics, but antedating the intrusives, are fragments of slates, quartzites, and limestones of unknown age, and usually much metamorphosed and disturbed. The studies of Mendenhall[1] indicate a similar character for the Santa Rosa Mountains, Fish Creek Mountain, and other outliers of the Peninsula Range which border the basin on the southwest.

Along the basin-ward foot of the San Bernardino Range, throughout nearly its whole extent, are irregular and much eroded hills of poorly consolidated conglomerates, sandstones, and shales. In most cases these strata have been greatly disturbed and their original relations are not clearly decipherable. It seems probable, however, that they consist of three fairly well-defined members: (1) a basal conglomerate resting normally upon an eroded surface of schists and granites, such as make up the core of the range; (2) lying conformably upon this, a thick member of coarse, arkose sandstone, usually reddish in color and of quite uniform texture; (3) an upper member of very variable sandstones and clays, mostly thinly bedded and showing many probable minor unconformities. Aside from the vertical variation as thus noted it seems also that the fineness of the material in each of the main divisions increases as one recedes horizontally from the mountains. Thus the lower conglomerate decreases in thickness and its constituent pebbles become smaller, the middle arkose member shades off into a sandstone of much finer and more uniform grain, and the top member, while almost entirely of sandstones at the foot of the mountains, becomes almost entirely of clays as one approaches the basin floor. In many places these clays contain thin crusts of gypsum and in one place, about 5 miles north of the railway station of Pope, they contain an interbedded stratum of mirabilite or hydrous sodium sulphate, several feet in thickness. This series of strata will be designated the Mud Hill Series, from the Mecca Mud Hills, where it is perhaps best developed. At that locality the section corresponds to perhaps 3,000 vertical feet,[2] but it is impossible to be sure of this or to draw a general section because of the very broken character of the strata as exposed and the impossibility of determining whether observed differences in the visible fragments of the strata indicate strata of different vertical position in the section or simply variations in the same stratum at different distances from the mountains.

Beyond the southeastern end of the Santa Rosa Mountains similar sandstone and clay strata surround the granite core of Superstition Mountain and form several series of low hills which flank the outliers of the Peninsula Range much as the San Bernardino Range is flanked by the strata just described. It is scarcely possible definitely to correlate these strata with the similar series on the northeastern side of the basin, but the lithologic similarity is apparently complete and it seems very probable that both exposures belong to the same series and to the same genetic condition, whether or not they be exactly synchronous. Provisionally, all will be regarded as belonging to the Mud Hill Series.

No fossils have been found in the Mud Hill Series at the type locality at Mecca or, indeed, anywhere on the northeast side of the basin. In the valley of Carrizo Creek, however, Blake discovered strata of partially consolidated clay and sand containing oysters, pectens, and other marine shells of Miocene age. According to Mendenhall these fossiliferous beds are here the basal member of the sedimentary series. This, in connection with its general

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[1] *Loc. cit.*, pp. 10–14. [2] Mendenhall estimates 4,000 to 5,200 feet, *loc. cit.*, p. 12.

character, indicates that the Mud Hill Series is essentially late Tertiary. Very probably it includes beds of all ages from the Carrizo Creek Miocene into the early Pleistocene.

The origin of the series as a whole seems unmistakable. Its strata have every characteristic of continental beds laid down on the bordering débris slopes of desert mountains and composed of materials carried down and assorted by rain wash. Precisely similar beds are now being deposited on the flanks of hundreds of the desert mountains of North America. The prevalence of clay beds in the basin-ward part of the series suggests that these portions were deposited in a marine estuary or in the central lake of an inclosed basin which the mountains bordered, but no conclusive evidence of marine or lacustrine deposition has been discovered in this part of the series. The presence of gypsum and mirabilite, as above noted, indicates that there were at least local areas of inclosed drainage and salt accumulation. There is also the implication, strongly confirmed by the general nature of the series, that the climate under which it was deposited was arid and not essentially dissimilar from that of the present. As a whole, the series must be regarded as continental and alluvial. The marine strata of Carrizo Creek probably represent an incursion of the sea into the southern portion of the trough only.

Below the hills of the Mud Hills Series the floor of the valley is of typical alluvial outwash, similar in every respect to that of other desert basins. Nearer the mountains this is gravelly and sandy; toward the center clays and silts predominate. Always the slopes are natural and gentle, the only cuttings being the shallow channels of the "washes," always dry except for the sudden floods which follow occasional storms. This alluvial outwash covers the whole central portion of the valley and has filled it to an unknown depth. As usual, it is of interbedded sands and clays, the clay strata forming a seal for the waters of the sandy strata and producing artesian potentialities recently much developed in what is known as the Coachella Valley between Indio and Mecca. (See Plate 15.) Numerous shallow wells have been bored in this region, and several have been sunk to 1,000 feet or more. None of the wells penetrated anything but the usual alluvial succession of clays, sands, and gravels.

At present the deepest depression of the basin is occupied by the Salton Sea, the origin and character of which are fully discussed elsewhere in this volume. Before the incursion of the waters the deepest depression contained a body of crystalline salt, located south of the station of Salton, and which was utilized commercially (See Plate 1c.) It consisted of a crust of fairly pure sodium chloride under which was black mud with disseminated crystals and crystalline masses of sodium chloride and other salts, and known to extend to a depth of 25 feet below the surface. According to Bailey this was underlaid by hard clay to 300 feet. Both mud and salt were saturated with a brine, the main constituent of which was sodium chloride, but the exact composition of which is unknown.

In summary, the basin before the formation of the Salton Sea consisted of a presumably structural trough lying between mountain ranges essentially of Mesozoic or earlier granites, gneisses, and schists, and deeply filled with the erosional débris of these ranges. Bordering the ranges proper were foot-hills of Tertiary strata, apparently the broken and tilted remnants of a former alluvial apron. Below these hills the surface was entirely of recent and present alluvial fill, a typical bajada merging into a central sink of comparatively small extent and which carried a small salt body of usual type.

The extension of the Colorado Delta into this trough has already been described by Mr. Sykes, and very little need be added from the geologic point of view. The superficial layers of the Delta material, where exposed in the cuttings of the New and Alamo Rivers, consist of the usual alternating beds of fine sand and silt. No deeper sections are available and the depth of the Delta material, its relations to underlying rock or alluvium, etc., remain quite unknown. At its edges the cone of Delta material merges so imperceptibly into the rain-washed alluvium of the basin slopes that the boundary is indeterminate and the mutual relations undecipherable.

Superposed on the major features of the basin, as thus described, are several minor features which require brief notice. First is the line of "mud volcanoes," evidently decayed fumaroles, which approximately parallels the axis of the trough. These are well developed near Volcano Lake, and are now represented by several hot springs, boiling pools, etc. A former more intense activity is indicated by groups of inactive mud cones, extensive deposits of sulphur and alum, and similar evidences of fumarole action. Another group of hot springs and mud geysers was located just north of the buttes which are now islands in the Salton Sea. These were described by several early explorers and especially by Le Conte.[1] They were considerably more active than the Volcano Lake group, but not so extensive. They are now under water and their present condition is not determinable. Some 6 miles north of these, near the railway station of Lano, is another group, somewhat smaller and much more nearly extinct. Activity here is limited to a very small flow of muddy water and the escape of an occasional bubble of gas.

The buttes above mentioned as being present islands in the Salton Sea are exclusively of volcanic rocks, including pumice, glassy obsidian, and a variable volcanic tuff containing many fragments of the pumice and obsidian. No crater or other vent is visible, and the buttes are probably simply the summits of a larger mass of eruptives, probably of Tertiary age and disturbed and buried by the post-Tertiary movement and alluviation. Other small bodies of effusives and tuffs are reported by Mendenhall as interstratified with the lower members of the Mud Hill Series in the Carrizo Creek Valley. An olivine basalt, apparently effusive, was found by J. C. Jones and the writer on the summit of the Peninsula Range near Jacumba. So far as known, these are the only representatives within the Cahuilla Basin of the Tertiary volcanism so marked farther north.

Among the more recent deposits mention should be made of two areas of sand dunes, both of which are still in course of formation and change. The larger of these is the complex of "Los Algodones," in the northeastern part of the basin, as noted on Mr. Sykes's map. It is a single great dune area of usual character and offers little of interest. The second dune area is in the embayment between the Santa Rosa Mountains and Superstition Mountain and lies just south of the end of the former range. It is remarkable chiefly because the dunes are few enough and far enough apart to permit the development of the crescentic form characteristic of a freely moving dune. One of the crescentic forms is shown in Plate 6 A and B. Many others are scattered over the surrounding slope, making the only good example of these forms known in the United States and probably one of the best in the world.

Of the minor features of the basin the only additional one which needs notice is the ancient beach-line which surrounds the basin about 40 feet above sea-level and which is described by Mr. Sykes. This is well marked in almost all quarters of the basin. On the alluvial slopes it appears as a deep wave-cut terrace, as illustrated in Plate 6 C and D. On rock walls and spurs it is evidenced mainly by the crusts of travertine, described elsewhere in this volume by Professor Jones. Below this highest beach-line, wherever the topography has permitted their preservation, there appear numerous minor strands, each a few feet or inches below the next, and the series extending downward to the terrace corresponding to the high-water level of the Salton Sea. This series of ancient strands is well illustrated by Plate 29 B, where the influence of the gravel accumulations along the terrace lines has so controlled the vegetation as to mark the strands very clearly. It is difficult to regard this series of strands as anything but the record of a lake which once occupied the basin and which disappeared by evaporation as the present Salton Sea is disappearing. This was the interpretation made by the late Professor Blake, and the ancient lake has been named

[1] LeConte, Amer. Jour. Science, 1855.

"Blake Sea"[1] in his honor. (See p. 4.) The present Salton Sea has left precisely similar records. Its high-water terrace corresponds in everything but depth of cutting to the ancient high beach-line, and the present sea in its recession has left a series of semi-annual strands, illustrated in Plates 16, 21, 25, and 26, which are precisely similar in every respect to the strands of the ancient lake. Plate 6 D shows the strand system on one of the islands in the present sea. The upper two-thirds of this system belong to the strand series of the ancient lake; the lower one-third consists of the strands of the present Salton Sea. Without actual leveling it is impossible to distinguish one system from the other or to tell where the latter begins to be superposed on the former. It seems not improbable that the strands of the ancient series are semi-annual, as are their analogues in the records of the present sea.

HISTORICAL GEOLOGY.

The decipherable history of the Cahuilla Basin begins with the uplift of the San Bernardino and Santa Rosa Mountains. There is no means of dating this directly, but it seems probable on general grounds that it was associated with the uplift of the Sierra Nevada at the close of the Jurassic. It seems useless to speculate concerning the condition of the country prior to this uplift, as also concerning the cause, duration, and character of the uplift and its relation to the granitic intrusives of apparently about the same age.

Following or during the genesis of the mountains there must have been a period of considerable erosion. The earlier portions of this period are represented by no known deposits, and the material removed from the mountains either was carried entirely outside the area or is buried in the lower and unexposed portions of the alluvial fill of the trough. A little later the discharge of the products of erosion was not so free, and there were laid down on the mountain slopes the conglomerates, grits, and sandstones forming the Mud Hills Series. At the beginning of this period the sea must have occupied the southern portion of the trough, at least as far north as the locus of the Carrizo Creek Miocene. Evidently it did not fill the whole trough, since the basal member of the Mud Hills Series is well exposed at Mecca and is a true basal conglomerate of strong continental facies. It is quite possible that this period was marked by the gradual retreat of the sea from the trough, with the formation behind it of the alluvial strata characteristic of the Mud Hill Series.

The deposition of these alluvial strata was interrupted, probably in the very late Tertiary or the early Pleistocene, by the violent and general movement which broke and bent the Mud Hills strata into their present fragmentary and distorted form. While the causal displacement was perhaps relatively simple, the resultant movement of the Mud Hills Series was exceedingly complex and has not yet been unraveled in detail. This second uplift seems also to have been followed by a period of considerable erosion. The newly exposed blocks of soft clays and sands were carved into a very rugged topography. The products of this erosion doubtless went to fill the trough still further, and with time this sea of mountain waste has gradually risen until it has partially submerged the hills from which it came. At the present time each hill of the Tertiary series has its apron of alluvium, the canyons which cut it are filled with tongues of débris, and many half-buried spurs which front the major ridges indicate that we see only the top of a rugged bad-land, the larger portion of which lies submerged in its own waste. This gradual submergence of the foot-hills brings us to the present time, and the process is still at work.

Two phases of this history have not been discussed: the relations of the trough to the ocean and the Colorado, and the history of Blake Sea. The hypothesis regarding these

[1] Two other names have been suggested for this lake: Lake LeConte by Bailey (Bull. Cal. State Mining Bureau, 24 : 12 (1902), and Lake Cahuilla by Blake (Nat. Geog. Mag., 18 : 830 (Dec., 1907). Neither has taken root in the literature. The name Blake Sea is due to Mendenhall, who, however, abandoned it before publication in favor of Lake Cahuilla, as used by Blake (Mendenhall, *loc. cit.*, p. 20, footnote). In the present volume Cahuilla has been reserved for the whole basin for reasons stated elsewhere, and Blake Sea is adopted as being obviously more suitable, in the light of the history of discovery in the basin, than is the alternative name, Lake LeConte.

matters, which was advanced by Blake and is still current among geologists who have examined the basin, is that the trough was originally open to and partly filled by the ocean and was gradually cut off therefrom by the building of the Delta of the Colorado. The growth of the Delta being complete, the Colorado might flow directly into the Gulf as now, or might flow into the Cahuilla depression, fill it, and overflow into the Gulf, as it would probably have done had the engineers failed to control it after the inbreak of 1905. On topographic grounds alone Blake Sea might be regarded either as the final cut-off remnant of the arm of the sea which once occupied the trough, or as a lake produced by the incursion of the Colorado as noted. The present writer, while not venturing a vigorous dissent from this hypothesis of the exclusion of the sea by delta-building, regards it as quite unproven. The known facts of the matter are two: the strata of the Mud Hills Series are of continental origin, and Blake Sea was fresh. The former fact has already been discussed, and it has been pointed out not only that the strata in general resemble in every detail those characteristic of mountain aprons in a desert valley, but that the occurrence of gypsum and mirabilite in the series proves the existence of at least local areas from which the drainage had no seaward egress. It can not be held certain that the basin as a whole was undrained. The observed facts can be explained as well on the hypothesis of local undrained areas cut off from the main drainage line of the valley by low structural or alluvial divides. Examples of this are numerous in the present desert valleys of North America. It should be noted, however, that while the evidence does not necessarily indicate an entirely inclosed basin during the late Tertiary, it does indicate arid conditions and the absence of the sea from at least that part of the Sink which is now the lowest.

The second fact, the freshness of Blake Sea, follows from three other facts. First, shells characteristic of fresh or slightly brackish waters are scattered by millions over the desert once occupied by the ancient lake and must have been plentiful in its waters. Second, the coating of travertine deposited by the lake at its water-line, and as it underwent subsidence, is such as would be deposited from a fresh or at least a continental water. These coatings are discussed elsewhere in this volume by Professor Jones. Third, the amount of salt present in the salt-body now covered by the Salton Sea was only a small fraction of the salt which would have been deposited had Blake Sea been of ocean water. There is no possibility of the escape of any salt, and burial by alluvium seems scarcely likely when the strand-lines and terraces of Blake Sea are so excellently preserved.

We know, therefore, that the ocean did not occupy the trough just previous to the post-Tertiary uplift, and that it did not occupy the trough during the later history of Blake Sea. This leaves a long intermediate period of which we know nothing at all. During this period there may have been a marine occupation, the Delta may have been built, and the sea shut out, as generally assumed. This is quite possible, but there is no evidence directly indicating it, and it is pure speculation. It is quite as possible that the trough remained above sea-level until after the Delta dam was built, and that the depression behind the dam has never been occupied by the sea. During this doubtful period there occurred unquestionably two events: (1) the general depression of the trough relative to sea-level; and (2) the formation of the Delta dam. The varying hypotheses concerning the period vary only in the relative order in which they view these events. The current hypothesis regards the depression as prior to the building of the dam; the hypothesis suggested by the writer regards the formation of the dam as prior to the depression. Our outline of the history of Blake Sea will vary greatly according to which of these hypotheses we accept. If the former, Blake Sea will be regarded as the cut-off portion of an arm of the ocean; if the latter, it appears as a lake created by the accidental flow of the Colorado into a previously existing depression behind an alluvial divide. In either case it is certain that the formation of Blake Sea could not have been prior to the depression of the valley relative to sea-level (the Delta dam would not withstand a steeply graded overflow), and it is certain that the Colorado flowed into Blake Sea and overflowed out of it, whether or not the river stood to the Sea in a genetic relationship. If Blake Sea was originally a marine water-body, it was soon and effectually freshened by the inflow of the Colorado.

As stated, decision is now impossible between the two variant hypotheses noted. The topography of the Delta and the Delta dam strongly suggests that it was built in a water-body and at water-level, hence, that the current hypothesis is the correct one. However, an opposite implication of even greater strength is furnished by the high-level beach of Blake Sea. If Blake Sea were marine and were cut off from the ocean by the building of the Delta, this process must have required a considerable time. But the high beach-line does not indicate long-continued wave-erosion. Where the beach crosses gravels or unconsolidated strata it is deeply cut, but where it crosses rock walls there is almost no cutting, even on exposed points which would be attacked strongly by the waves. On such rock faces the ancient water-line is marked only by coatings of travertine or accumulations of loose stones. Persistent shore-lines are usually cut markedly even into the hardest rocks, and even the comparatively transient shore-lines of the Quaternary lakes of Nevada and Utah are frequently deeply graved. Absolutely nothing of the sort occurs on the high strand of Blake Sea. Any cutting which the writer has observed along it could have been done in a few score years. Indeed, some of the lower strands of the Blake Sea series, or the high-level strand of the present Salton, are sometimes cut almost as deeply as the high beach of the ancient Sea. It is difficult to reconcile this shallow cutting of its ancient beach with the long duration of Blake Sea required on the hypothesis that it was originally marine. Collateral suggestion is carried by the absence of known marine fossils from the deposits of Blake Sea, but this is far from conclusive, since such beds would belong to the earlier portion of the Sea's history and would be buried by later deposits. (See p. 46.)

In the writer's opinion, the most probable harmonization of these variant hypotheses concerning the origin of the present depression lies in a slight modification of the second hypothesis above suggested. That is, that the rise of sea-level relative to the basin has been slow and gradual and that the growth of the Delta has proceeded and kept pace with it. On this assumption the post-Tertiary Colorado is supposed flowing into the side of, and through the lower part of, a trough freely open to the sea. The sea is supposed to have advanced very slowly up this trough, the river meanwhile accommodating itself to the changing conditions by a change of grade and the resultant deposition of alluvium. It is conceivable that before the advancing sea-line reached the point where the river entered the side of the trough, the river would have built across the trough a dam sufficient to prevent further advance of the sea, especially if the displacement of sea-level were becoming less rapid—as was no doubt the truth. Further vertical displacement might produce no horizontal displacement, the deposition of alluvium by the river being rapid enough to keep the Delta dam always above the rising sea. In this way there might be formed behind the dam a dry depression such as actually exists. On this hypothesis the formation of Blake Sea would be regarded as a recent and unimportant incident due to the accidental diversion of the Colorado into the depression behind the dam. The writer regards this hypothesis as being rather more in accord with known facts than is the theory currently held. However, he has no wish to urge its acceptance. With the facts at present available, that particular period in the basin's history must be regarded as quite unknown.

With the existence of Blake Sea we leave speculation behind and return to history for which there is better evidence. Whatever its origin, Blake Sea was ultimately fresh and its disappearance was almost certainly due to evaporation following the cutting off of water supply from the Colorado. Probably this stoppage was due to a natural return of the river to its gulfward channel, though this may have been complicated by slight orographic movement or by climatic or other changes affecting the regimen of the Colorado. The fall of Blake Sea must have been by annual or semi-annual stages, much as the Salton is falling at present and as is described elsewhere in this volume by Dr. MacDougal. It has already been noted that the series of strand-lines formed by Blake Sea and by the Salton can not be distinguished from each other. Blake Sea must be included among very recent phenomena. Its strand lines and terraces are of such character as to fall a ready prey to the elements, even under desert conditions; yet they appear so fresh and undisturbed that any great antiquity is not to be thought of. It is probable that the final disappearance of Blake Sea was less than five hundred years ago, and the entire existence of the water-body can scarcely have been longer. The Indians of the region have a tradition of the previous existence and gradual disappearance of a water-body in the basin, and in spite of the notorious untrustworthiness of Indian legends it seems probable that this one has a basis of truth. Probably some direct evidence, at least of the time required for the disappearance of Blake Sea, could be obtained by a thorough study of its strand-lines, including the accurate determination of their relative elevations.

If the rise and fall of Blake Sea were due to the accidental entry of the Colorado into a previously existing basin and the later accidental diversion of the river toward the Gulf, there is no reason why this might not have happened many times nor why the basin should not have been often the home of transient lakes, such as Blake Sea seems to have been. Indeed, on *a priori* grounds such occasional repetitions of the incident would seem very probable. There is, however, absolutely no evidence that any other incursion of the river ever took place. The series of strand-lines of Blake Sea contains no member deeply enough cut to be regarded as marking more than a very transient position of the lake. Nowhere is there any evidence of rise and fall. Nowhere except below the highest level of the present Salton Sea are there any signs of a later series of strands superposed on an earlier. The strand-lines seem to record a continuous and fairly rapid fall of the water-level, and that only. It is possible, of course, that strand-lines, terraces, and similar topographic records of a lake considerably more ancient than Blake Sea might have been entirely destroyed by rain wash during an intervening period, and that earlier lakes might thus have failed to leave any record. It is difficult, however, to see how this could have happened to travertine left by these earlier lakes. If these lakes were similar to Blake Sea and to the present Salton Sea they must have deposited travertine on exposed rocks. It is not likely that such travertine coatings would be removed entirely, even by a fairly long subsequent period of erosion. The travertine of Blake Sea would have been deposited on top of these earlier travertines and the present travertine would show a superposition of different travertines, what might be called an unconformity in the travertine layer. Phenomena precisely similar to this are found in the continental lake basins of Nevada and Utah, and are especially well exhibited in the travertines or tufas of Lake Lahontan. Nothing of this sort has been observed in the Cahuilla Basin. Wherever examined the travertines are uniform in character, from the surface of the original rock to the outer layer of the coating; they show no signs of any interruption during their deposition. It is scarcely possible to be dogmatic as to the non-existence of any lakes prior to Blake Sea, but there is certainly no evidence indicating their existence. It would seem that any previous incursions of the Colorado must have been so soon checked by natural causes that the lakes produced were small and transient. A lake no larger than the present Salton Sea might fail to leave any record now legible. Indeed the occasional occurrence of such very partial fillings seems probable from the historical records cited by Mr. Sykes on page 15 of this volume. It is a little difficult to understand why the river always returned to its channel after these temporary incursions instead of continuing to fill the basins, as it seems to have done in the case of Blake Sea, and seemed about to do in the case of the present Salton Sea.

It is perhaps worth while to note the dissimilarity between the history of the Cahuilla Basin and the histories of the superficially similar undrained basins of Nevada, Utah, and eastern California. These latter also have been the home of large lakes now disappeared, and contain terraces, strand-lines, travertine deposits, and other records similar to those of Blake Sea. However, the records of these northern lakes are much more complex, and indicate a long and complicated history of rises and falls, with long periods of nearly stationary level and probably long periods of complete desiccation. These lakes were *fluctuating* lakes. Blake Sea was simply a *falling* lake. There are no records in the Cahuilla Basin of anything comparable to the fluctuations which are so marked a feature of the histories of Lake Lahontan, Lake Bonneville, and their smaller analogues. The reason is apparent. The fluctuations of the northern lakes were almost certainly climatic in origin, and due to changes of rainfall, or evaporation, or both. These changes were recorded in the fluctuations of the lakes because the basins were inclosed and varying balance of rainfall and evaporation found expression in expansions or contractions of the final evaporating surface, the lake. In the Cahuilla Basin these conditions did not exist. Whether we believe the trough to have been occupied by the sea, or whether we believe it a high and essentially a drained valley subsequently depressed, it is apparent that the rainfall would have free or nearly free egress to the sea and that variations of climate would not find so ready a record as in the permanently inclosed and high-walled basins to the north. Even if there were a period of true basin conditions following a separation from the ocean and preceding the origin of Blake Sea, it is scarcely likely that climatic fluctuations would leave a record now readable. The rainfall area tributary to the Salton Sink is not very large, and a very considerable increase of rainfall would be necessary to maintain a permanent lake in it. Records of shallow transient lakes, formed by rainfall only, may exist in the clay and salt beds of the sink bottom, but these can not now be examined, and it is doubtful if any such lake would rise high enough to leave records comparable with those of Blake Sea.

For these reasons the history of the basin offers little either for or against the theories of fluctuating climate recently advanced by Huntington and others. The evidence of climatic variations furnished so richly by the ancient lake basins to the north is altogether lacking. It is possible that the gravel-sand-clay alternations exhibited by Tertiary and Quaternary alluvium alike may be connected with climatic change, but it is just as possible that they are due to shifting of stream channels, gradual changes of grade, and the like. The decipherable events in the history of the basin seem to be connected with orographic or other changes with which climatic change had little or nothing to do. It is possible, of course, that the changes in the course of the Colorado, noted as accidental, are really related to climatic changes in the drainage basin of that river with their resulting changes in degree of overloading and in seasonal regimen, but these remain undeciphered.

THE SOILS.[1]

In origin and general character there are two types of soil represented in the basin: the desert soils of the bajada, and the river alluvium soils of the Colorado Delta. The former are mainly sandy and gravelly, though occasionally stream-action or local depressions have produced soils of silty or clayey type. The minerals composing the soil are mostly angular fragments, fresh and unweathered, and indicating in their character the shortness of the journey which they have undergone. Being derived originally from the granitic and similar rocks of the mountains, the soils are mineralogically very heterogeneous and are amply supplied with the useful soil-forming minerals. That they are very fertile when supplied with water is indicated by their very successful agricultural use in the Coachella Valley. (See Plate 15.) The alluvial soils of the Delta, being derived from the whole drainage area of the Colorado, are similarly diverse and fertile, but differ in that their mineral

[1] Considerable use has been made in this section of the reports of soil surveys in the area made by T. H. Means, J. Garnett Holmes, and others for the Bureau of Soils, U. S. Department of Agriculture, and published in the "Field Operations" of that Bureau for 1901 and 1903.

particles are somewhat weathered and are much more uniform in size. Practically all the soils of the Delta are silts or very fine sands. They are agriculturally excellent and form the very productive fields of the Imperial Valley. Aside from "alkali" (which will be discussed in a moment) their chief fault is too great heaviness and difficulty of working, due to their fine texture. True clays, however, are practically unknown.

The soils of the beaches of the Salton Sea all come within the two classes mentioned. About the northwestern two-thirds of the Sea's periphery the soils are of the desert, mountain-wash type. Nearly everywhere they are sandy and gravelly, but there are two localities where important areas of silt are found. The first, and by far the larger, is at the extreme northwestern end of the Sea and has been formed by the flood-waters of Whitewater Creek. For perhaps 5 miles along the edge of the Sea, westward from a point southeast of Mecca, the shore-line is silty and muddy. Beyond this to the west and south one encounters the sandy outwash of the Santa Rosa Mountains. The other silty area is much smaller and occurs in the valley of Carrizo Creek between the southern end of the Santa Rosa Mountains and the Superstition Mountain uplift. The soils are similar to those of the Mecca region, but are somewhat more sandy.

Over the southeastern third of the Sea's periphery the soils are of the Delta type and are very heavy and muddy. Everywhere the slopes of the beaches are very slight and the mud is usually so soft that landing from a boat is very difficult if not impossible. Toward the north, soils of this type extend along the beaches as far as the railway station of Lano, where they merge with the sandier soils derived from the outwash of the Mud Hills to the north. Indeed this merging of Delta and outwash material extends considerably to the southeast, and is noticeable perhaps as far as half-way from Lano to the mouth of the Alamo River, though the Delta material predominates through nearly all of this distance. On the southern side the Delta soils extend a lesser distance, being separated from the Carrizo Creek silty area above mentioned by about 10 miles of somewhat sandy soils produced by the outwash from Superstition Mountain. During the present submergence the area of the Delta soils has been somewhat extended along the beaches by the silt poured into the Salton Sea and distributed by it. It is probable also that the submerged soils near the mouths of the New and Alamo Rivers have received considerable vertical increments of river alluvium. (Plate 8 B.)

So far as their physical and mineral nature is concerned the soils of all the beaches are likely to be of very high fertility. Their only fault is the frequent presence of "alkali," this being the accumulation in the surface layers of excessive amounts of soluble salts, mainly chloride and sulphate of sodium. The natural accumulation of these salts is exclusively a desert phenomenon and is due to the natural movement of water, through the soil being too slight to remove the salts freed by chemical decay of the soil minerals. The water of the infrequent showers penetrates a few inches into the soil, dissolves the salts it finds there, and, when the shower is over, returns to the surface by capillary action and evaporates, leaving the salts it has brought up from below. Desert soils that are fine enough in texture to permit capillary rise of water through them are nearly always more or less "alkaline." In sandy soils, the forces of capillarity are so weak that rain-water can not reascend to the soil surface and must continue its downward journey to stream channel or underflow, taking its dissolved salts along. Sandy soils are never alkaline unless the natural drainage is for some reason insufficient. In general, on all the Salton beaches, the silty soils are more or less alkaline; the sandy soils are never so, except for some local reason, such, for instance, as the rise of underflow to the surface.

The submergence of the soils by the waters of the Salton seems to have had surprisingly little effect upon their alkali content. On the Salton beach just southwest of Imperial Junction is one of the "observation stations" described elsewhere in this volume by Dr. MacDougal, and the soils of the area have been studied by the writer since their emergence from the waters of the Sea. The soils are silts composed mainly of Delta material with perhaps a slight admixture of mountain wash from hills several miles north. Table 2 gives the average alkali content of soils submerged for different lengths of time, as well as several which were not submerged at all. It is apparent that whatever alkali was leached out by the waters of the Sea is almost immediately restored on its retreat. This is probably because of two circumstances. First, diffusion of salts through wet, silty soil is very slow, and it is probable that the submergence really produced very little leaching beyond cleaning the actual surface. Second, when the waters retreat they do so slowly and the underground water-table lags (horizontally) considerably behind the actual water-line. It follows that for some time after its emergence the soil is wet and has Salton water continually supplied to it by outward diffusion from the Sea and subsequent capillary rise. Evaporation is intense and the Salton water is brackish. These are ideal conditions for the rapid accumulation of alkali, and it is to be expected that what alkali was leached out by the Sea will be restored, or more than restored, on its retreat. Indeed, as the retreating waters become more and more saline they will leave behind them larger and larger proportions of soil alkali, probably far exceeding the alkali present in the soil before submergence. The beginnings of this process can already be detected in the fact that thin salt crusts are beginning to be visible on the soils last exposed. The soils of beaches to be exposed in future will probably have had alkali added rather

TABLE 2.—*Alkali content of soils of successive exposures, Imperial Junction beach.*

	No. of samples.	Average alkali content.
		p.ct.
Not submerged	3	1.96
Exposed in 1907	5	1.30
1908	12	1.69
1909	12	2.00
1910	15	1.59

TABLE 3.—*Mechanical analyses of soils from plantless and plant-covered zones, Imperial Junction beach.*[1]

Sample No.	Fine gravel, 2 to 1 mm.	Coarse sand, 1 to 0.5 mm.	Medium sand, 0.5 to 0.25 mm.	Fine sand, 0.25 to 0.1 mm.	Very fine sand, 0.1 to 0.05 mm.	Silt, 0.05 to 0.005 mm.	Clay, below 0.005 mm.
Plantless areas.							
	p.ct.	*p.ct.*	*p.ct.*	*p.ct.*	*p.ct.*	*p.ct.*	*p.ct.*
52	0	0	0.1	0.2	1.9	66.2	31.5
53	0	0	0	.6	5.1	65.8	28.6
55	0	0.3	.2	3.3	29.3	44.3	22.5
56	0	0	.2	2.9	34.3	35.2	27.5
57	0.2	.2	.2	4.0	40.8	30.7	24.0
58	0	.1	.7	1.6	6.3	48.5	42.7
59	0	.2	1.3	2.4	9.6	47.9	38.7
60	0	0	.2	.4	8.3	50.9	39.9
63	0	0	.2	.3	2.2	73.3	23.7
65	0	.3	.2	.4	5.4	64.8	28.8
66	0	0	.3	.3	.7	57.8	41.1
109	.3	.3	.3	.6	1.4	45.1	52.2
123	0	0	1.1	1.1	4.2	60.3	33.3
126	0	0	.1	4.8	77.4	9.5	8.2
Plant-covered areas.							
73	0	0	0.1	0.3	5.2	68.1	26.2
74	0	0	.1	5.0	72.8	10.4	11.4
79	0	0	.1	.9	13.1	40.1	39.6
80	0	0.1	0	.3	2.9	53.3	43.3
81	0	.1	.1	3.6	51.5	25.1	19.5
91	0	.2	0	1.0	13.7	50.0	34.8
113	0	.2	0	.9	10.5	52.3	35.9
114	0	0	0	0	11.0	60.2	29.0
115	0	.1	.2	9.4	55.2	23.0	12.1
116	0	0	7.7	69.5	08.4	7.0	7.2
117	0	0	0	.5	11.4	56.9	30.9
118	0	0	.2	.7	8.0	55.9	34.9

[1] Analyses are by Dr. C. C. Fletcher and others, of the Bureau of Soils, U. S. Dept. of Agriculture.

than abstracted by their submergence. In time it is to be expected that rain will restore these over-alkaline soils to substantially their condition before submergence, but the rains of the Cahuilla Basin are not only infrequent but are commonly torrential and run off so quickly that they have little action on alkali other than the washing of the soil surface. Their leaching action will be very slow.

It must be realized, of course, that all this applies only to silty soils or other soils the texture of which is fine enough to permit significant capillary rise of the soil-water. In sandy soils there is no opportunity for the shoreward seepage, capillary rise, and evaporation of the lake water, and there is therefore no tendency for the accumulation of soil alkali shoreward from the retreating water-line. Furthermore, sandy soils are so much more easily penetrated and leached by rain-water that even a very slight or very rapid rain is sufficient to remove their excess alkali.

From the viewpoint of this volume, the most important matter relating to the soils is their influence upon the distribution of the vegetation. This seems surprisingly slight. The detailed soil study of the Imperial Junction beach was undertaken especially from this point of view and led to the conclusion that no influence of the soil upon the local distribution of the vegetation was discernible. On this beach the vegetation offers two distinctive features: a repeated banding parallel to the water-line, and a thickening in and near the channels of small dry washes coming from the hills. Both of these matters are fully described in Dr. MacDougal's contribution. It was quite impossible to correlate either of these distribution features with any variation of soil or soil alkali. As a whole the soil was quite uniform both in its physical properties and its alkali-content, but such variations as did exist had absolutely no relation to the presence or absence of vegetal cover. This is shown by the data of tables 3 and 4. Table 3 gives the mechanical analyses, according to the method of the Bureau of Soils,[1] U. S. Dept. of Agriculture, of soils taken from the plant-bearing and plantless portions of the beach, respectively. It will be noted that the variations between different samples in the plantless area are greater than the difference between the soils of the two areas. Table 4 gives similar data for alkali content and leads to similar conclusions. The actual causes of the distribution of vegetation as noted relate to water supply and to the position of the shore-line, and are elsewhere fully discussed by Dr. MacDougal.

TABLE 4.—*Alkali content of soils from plantless and plant-covered zones, Imperial Junction beach.*[2]

Plantless zones.		Plant-covered zones.	
Sample No.	Alkali content.	Sample No.	Alkali content.
	p.ct.		*p.ct.*
52	1.36	73	1.61
53	.61	74	1.55
54	2.32	79	1.84
56	.69	80	.75
59	1.56	81	1.12
60	3.40	90	.86
61	2.85	91	.53
62	2.13	114	2.32
63	4.23	115	.24
64	2.32	116	.44
65	1.36	117	5.92
66	1.58	118	.63
67	.94		
77	1.66		
78	.75		
125	3.28		
127	2.03		
128	.81		
Average	1.88		1.48

[1] U. S. Dept. of Agr., Bureau of Soils, Bulletin 84, 1912.
[2] The analyses on which tables 2 to 4 were based were made by L. D. Elliott and by the Bureau of Soils.

General observations at many other points about the beaches fully confirm the results of the more intensive study of the Imperial Junction beach. The distribution of the beach vegetation seems to be quite independent of the soil. The only important influence is an indirect one, the influence of soil texture on water movement and water retention. These influences may be summarized as follows:[1]

1. Capillary power is stronger in the soils of finer texture. Water will rise higher and spread farther horizontally in such soils.

2. Rain penetrates more rapidly into the coarser soils. From a silt or clay, most of the rain will run off instead of being absorbed.

3. Drainage is more rapid and complete from the coarser soils. A fine soil will hold more interstitial (or "capillary") water than a coarse.

4. When exposed to intense evaporation a coarse soil moistened with capillary water dries out at and near the surface more rapidly than the feeble capillary powers of the soil can supply more moisture from below. A dry surface layer is thus produced, in which layer the thin water films responsible for capillary movement do not exist. This dry layer breaks the continuity of the path by which capillary water is ascending, acts as a "dry mulch" or insulator to the water below, and prevents the rise and loss of this water. On the other hand, the capillary powers of a fine soil are so much better that water is usually supplied from below as fast as removed by evaporation, with the result that all the water of the soil is lost down to the depth from which capillary rise can act. Because of this different behavior toward intense evaporation, it frequently happens that desert soils of sandy texture will retain moisture and nourish plants, when surrounding finer soils are entirely desiccated and their vegetation killed.

All four of these general principles find application to minor features of plant distribution both on the Salton beaches and on the higher slopes of the basin which the Salton waters did not reach. Many specific examples are noted in Dr. MacDougal's contribution. In all cases, however, these influences of soil texture are far subordinate to the influence of major and minor topography as directly controlling water supply. The distribution of the small dry washes which form channels for the occasional rains is far more important than the variation in soil.

It is true, of course, that the prevailing soil-alkali content of some regions, the prevailing gravelly nature of others, and similar wider soil and topographic differences between different parts of the Basin, have had considerable influence upon the content of the general flora of these "provinces." Certain species have been barred out because of their unsuitability to the general conditions of the province. In these larger ways, soil character has perhaps had an important influence on the vegetation of the basin, fully discussed elsewhere in this volume.

[1] For details the reader must consult the text-books of soil physics, *e.g.*, Mitscherlich-Bodenkunde.