Plate 1

The White Sands, Otero Basin, New Mexico. The view is southwest toward the San Andreas Mountains. In foreground are parallel dunes with characteristic vegetation. (Reprinted from Publication No. 6.)

BOTANICAL FEATURES

OF

NORTH AMERICAN DESERTS

BY

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Botanical Features of North American Deserts.

INTRODUCTION.

Botanical science in its technical and applied branches has reached a stage of development in which it has become plainly evident that adequate progress in research in physiology, in comprehensions of life-histories, and in formulating the general principles governing the origin, environic relations and distributional movements of plants may be expected only by experimental methods in the field or in actual contact with the types of plants under consideration under normal environmental conditions.

In no part of the subject is this so imperative as in the study of the xerophytic and highly specialized forms characteristic of the desert regions of the world, which comprise a total area equal to that of a large continent. The aridity, widely ranging temperatures of soil and air, physical and chemical properties of the soils, conditions of insolation and radio-activity, together with the special forces modifying distribution, furnish a set of conditions not easily duplicated by the regulation of the artificial climates of glass-houses and not adequately represented by preserved material in herbaria and other collections. A European botanist of ability scarcely lays down his work at the end of a life of zeal and industry devoted to the study of the cacti under cultivation in a climate entirely foreign to them, when an examination of these peculiar forms in their native habitats reveals the necessity for a complete repetition of the entire investigation.

When the Carnegie Institution of Washington was established, Mr. Frederick V. Coville determined to present to it a plan for a Desert Botanical Laboratory. This long-cherished project was an outcome of his work in the Death Valley Expedition, in 1891. A plan was accordingly drawn up by him and presented to the Institution's Advisory Committee in Botany. This committee considered and approved it because it promised results concerning the fundamental processes of protoplasm as important as any in the whole realm of botany. The Board of Trustees of the Institution also gave their approval to it, and appropriated $8,000 for the establishment of such a laboratory and its maintenance for one year. Messrs. Coville and MacDougal were appointed by the Institution as an Advisory Board in relation to the matter. This Board decided to place the Laboratory under the immediate charge of a resident investigator, who should carry on researches under its guidance, and should be responsible to it in his relations to the Institution. It was planned to begin a few inquiries of wide scope and important bearing to be carried on by the resident investigator until decisive results were obtained.

THE LABORATORY LOCATION TRIP.

Each member of the Advisory Board had visited, during the preceding twelve years, most of the more marked desert areas of the country. Nevertheless, it was deemed profitable to make, together, a systematic tour of these deserts, in order to gain a better comparative knowledge of the aspects of their vegetation and to select a locality offering the greatest advantages and facilities for the proposed work. Accordingly, between January 25 and February 28, 1903, they made a reconnaissance of the region along the Mexican boundary. As the outcome a site was selected on Tumamoc Mountain near Tucson, Arizona, and the erection of a laboratory building, according to plans approved by them, was begun. The organization of the laboratory was carried a step further by the appointment of Dr. W. A. Cannon as resident investigator.

In the absence of any publication dealing with the general features of American deserts, it seemed desirable to present the general results of observations made during the trip and include with them some of the information gained during previous work in deserts, illustrating the text with reproductions of landscapes showing characteristic vegetation. The paper embodying these features was brought out as publication No. 6 of the Institution in November, 1903.

The establishment of the Desert Laboratory and the continuance of the examination of the arid regions has made available a much greater amount of general information concerning the extent and character of the vegetation of such areas. The newer contributions concern the sagebrush deserts of the Great Basin, in Nevada and in Utah, the tropical deserts in southern Mexico, the arid depressed basins of the delta of the Colorado River, the Sonoran Desert, the Cucopa Mountains, and the desert of San Felipe de Jesus, in Baja California. The results of the explorations of Hedin, Pumpelly, Willis, MacMahon, and Huntington in Asia, and of other workers in Australia and Africa, together with the fuller data noted above, permit some more satisfactory generalizations than had been hitherto possible.

The edition of publication No. 6 (being the only attempt yet made to furnish a sketch of some of the characters of American deserts) having been exhausted, it has been thought advisable to include such portion of it within the present volume as might be necessary for completeness. This interpolation is made without special indication of the repetition, except in the plates. The character of the investigations taken up in connection with the main subject is fairly indicated by the work described in the next section.

EARLIER INVESTIGATIONS AND DEVELOPMENT OF DEPARTMENT OF BOTANICAL RESEARCH.

Upon taking up his duties at the Desert Laboratory in September, 1903, Dr. W. A. Cannon began the investigation of certain problems involving study of the relation of plants to atmospheric moisture, in which some notable improvements in methods and some important results were obtained in the next two years, as indicated by the titles published in the Year Books of the Institution. Incidentally, attention was also paid by him to the morphology and physiology of phanerogamic parasites, which are found in some abundance in the desert, and to other specializations in root-structure for water-storage and in chlorophyl distribution in shoots.

Prof. V. M. Spalding was granted the privileges of the Laboratory late in 1903, and also carried on some work upon the relations of shoots to atmospheric moisture. Later he began a systematic study of the distribution of desert plants, and in accordance with a comprehensive plan was given a series of grants to extend his work, in which notable progress has been accomplished in some of the major problems presented. Mrs. E. S. Spalding was also given the privileges of the Laboratory in 1903, and has taken up an investigation of certain features of water-storage by cacti and succulents of the region contiguous to the Laboratory.

Dr. B. E. Livingston was given a grant in 1904 for carrying out an investigation of the relation of plants to soil moisture, and spent the summer of that year in residence at the Laboratory. The results obtained are embodied in publication No. 50.

Prof. Francis E. Lloyd, Teachers' College, Columbia University, was given the privileges of the Laboratory in 1904 for the purpose of carrying out an investigation upon the physiology of stomata, which had been subsidized by the Botanical Society of America. In the following year this work was continued under a grant from the Institution, and has now been brought to completion and the results published as publication No. 82.

Mr. Frederick V. Coville, of the U. S. Department of Agriculture, continued an investigation of the drink plants of the North American Indians, which had been begun during the Laboratory location trip, and the results of his work were published by the Smithsonian Institution.

Dr. D. T. MacDougal, of the New York Botanical Garden, carried out various pieces of explorational work, paying attention to observations on distribution, ecology, and desert topography in Texas, in the vicinity of the Colorado River, from The Needles to the Gulf of California, around the mud volcanoes of this region, in the Cucopa Mountains, and in the Salton and Pattie basins, the results of which have been brought out in various publications. In much of this field-work Mr.

Godfrey Sykes, of Flagstaff, Arizona, participated, and an authentic map of the delta and contiguous regions was prepared, which was published in 1905, the principal features of which are reproduced in plate 34.

Workers in several branches of science have visited Tucson for limited periods and used the facilities of the Laboratory for securing desired information concerning their special researches.

It was deemed desirable to correlate the work being carried on at the Desert Laboratory with the other botanical investigations of the Institution, and by act of the Trustees on December 18, 1905, the Department of Botanical Research was created, with Dr. D. T. MacDougal as director. The staff of the station was constituted of Dr. W. A. Cannon, Dr. B. E. Livingston, Prof. V. M. Spalding, and Mr. Godfrey Sykes; and Prof. F. E. Lloyd was appointed for one year to complete his work upon stomata.

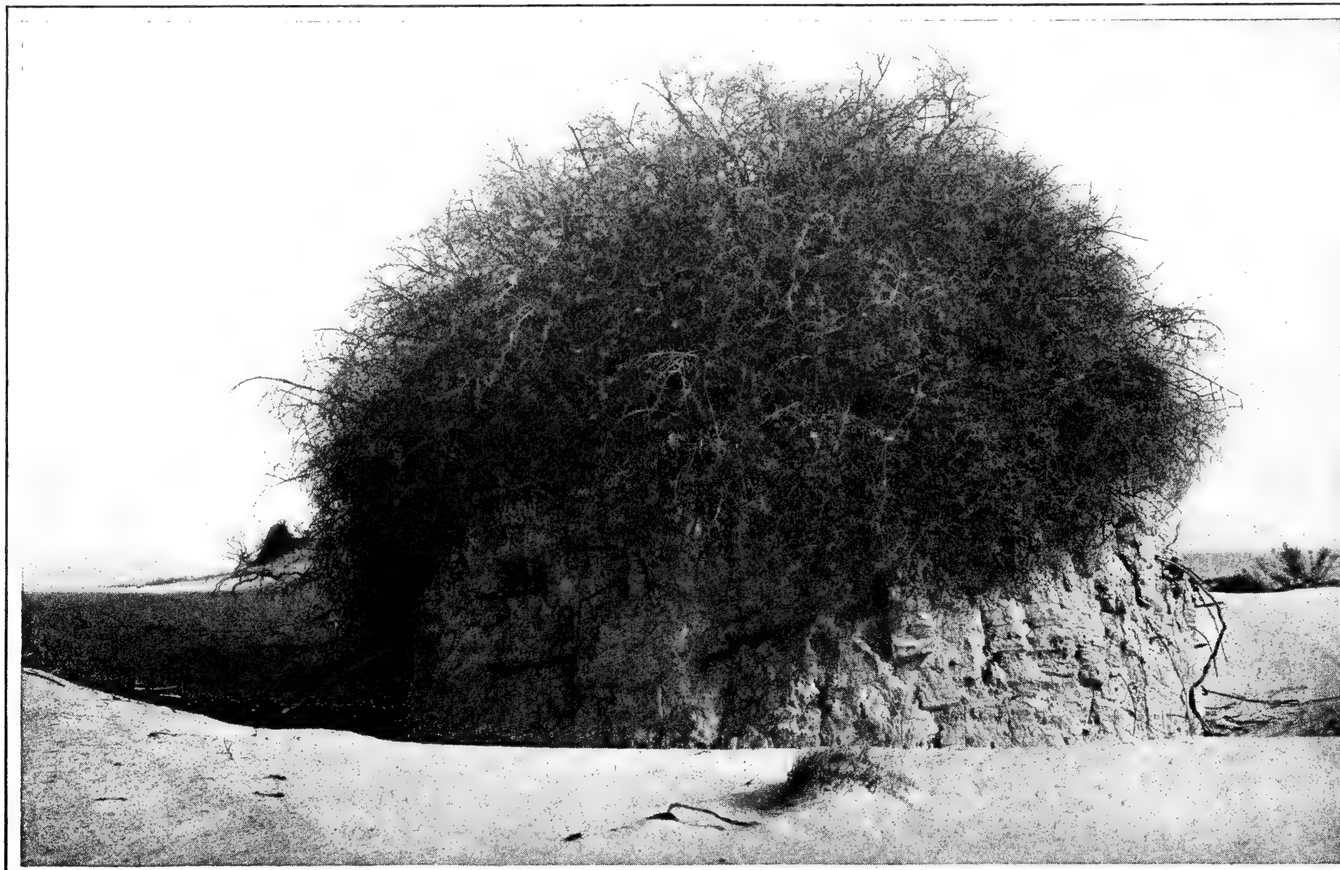
In accordance with the newly formed plans, the Desert Laboratory, at first established to carry on certain special investigations, was made the headquarters of the department and, so far as possible, the efforts of the members of the staff not resident at Tucson were brought into correlation with the activities of the Laboratory.

The reorganized staff assembled early in 1906 and operations were begun at once by which the capacity of the Laboratory was doubled, a greenhouse was erected, a new pumping-plant and reservoir for well-water and rain-water constructed, and a wire fence was thrown around the principal tract of the domain of the Laboratory. By the acquisition of controlling titles, the tract of land originally given to the Institution for the use of the Laboratory in 1903 was increased to 860 acres, including nearly the whole of Tumamoc Hill and a large area of mesa-like slope to the westward.

In addition to the individual researches undertaken by the various members of the staff, other questions arise in the activity of a laboratory of this kind which require the combined and organized effort of the entire staff for a term of years. Work of such character demands the utmost exactness and fullness of records, in which the observations and experimental results are interpreted in the broadest general manner. Furthermore, it is important that such work should be begun by adequate methods, and that it cover possible developments in advanced stages of the work, if the results obtained are to be commensurate with the total effort expended.

A group of problems of this character was offered by the depressed basins which form a part of the delta of the Colorado River and which have an exceedingly arid climate.

Much of the more pronounced desert of North America has been in submersion during comparatively recent geological periods, and consequently the origin and distribution of the highly specialized flora which inhabits such regions have resulted from forces which may now be studied



Column in White Sands. Shade and mechanical action of roots of three-leaved sumac have prevented a section of a dune from being moved by action of the sun and wind, and it remains in columnar form.

Area left bare by dune which has moved to the right, and out of the view. Advancing dunes on left. Grama grass (*Bouteloua*) on level space in foreground.

Water-hole in the White Sands, Otero Basin, New Mexico. The water is locally known as "gyp" water. A group of cottonwoods (*Populus*) are shown in background on the right. (Reprinted from Publication No. 6.)

Tree yucca (*Yucca radiosa*) in Otero basin, New Mexico. The large plant still bears emptied pods of previous season, and the bases of dead and weathered leaves on the lower part of the stem. The two smaller plants are specimens of the same species. (Reprinted from Publication No. 6.)

in action in the Salton and Pattie basins, which are filled with water at long and irregular intervals.

The Salton Basin is an irregular oblong depression with an area of 2,000 square miles, having its long axis lying northwest and southeast, extending from the angle formed by the San Jacinto Mountains and San Bernardino foothills, in California, to a point across the international boundary line between the United States and Mexico, being cut off from the Gulf of California by the alluvial deposits in the delta of the Colorado River. The lowest part of this depression is 287 feet below sea-level, and the presence of an old beach-line several feet above sea-level shows that comparatively recently it has been the site of a lake which emptied southwardly into the Gulf of California. Within historic times, however, the basin has been empty, and this great bowl is one of the marked features of the Colorado Desert. The rainfall is exceedingly scanty and the soil is highly charged with salts of various kinds; consequently the vegetation is of a pronounced spinose or halophytic type.

Several times within the last century the flood-waters of the Rio Colorado have been diverted to such an extent as to flow into the basin and form a small lake, and the presence of several minor beach-lines on the slopes of the basin suggests that such inflows have taken place repeatedly within the last few thousand years, and also that the level of the ancient lake was not lowered uniformly.

During the last three years faulty engineering operations opened a channel leading into the basin, and the result was that the main flow of the Colorado River ran into the depression and a lake with an area of 500 square miles was formed, accompanied, of course, by the entire destruction of the desert vegetation on this area. The commercial interests imperiled, together with the history of the previous inflows, leads to the belief that we may soon have available the spectacle of the drying up of this lake and the advance of the desert vegetation to reoccupy the areas left bare by the recession of the water. As a fortunate prelude or beginning of this study, Dr. D. T. MacDougal and Mr. Frederick V. Coville visited the basin in 1903 and made some observations upon the vegetation, together with some photographs of the manner of occurrence and habit of several of the more important native forms. The evaporation and seepage in the region are such that at least ten or twelve years will be necessary to empty the basin or reduce it to a minimum, which will thus afford experimental conditions on a large scale of the revegetation of a submerged area by xerophytic plants.

The Pattie Basin, which is connected with the lower portion of the delta around the southern end of the Cucopa Mountains, also received some of the flood, and the body of water formed, the Laguna Maquata, has had a more nearly continuous existence, being entirely dried up only occasionally. It is, in fact, repeating the earlier history of the lake in the Salton Basin, and the study of the conditions in the two localities contemporaneously may confidently be expected to yield results of great value.

An examination of the effect of the advancing shore-line upon desert vegetation was made in May, 1906, and a more serious expedition was made to both basins in February, 1907, in which areas were selected and surveyed for detailed investigation as to the conditions of soil moisture, salt content, and physical factors of the soil, together with the movements and development of plant societies.

Another general problem requiring the focused effort of the Laboratory is comprised in the influence of altitude and climatic factors upon vegetation with respect to the direct reactions by which individual adaptation is accomplished and to possible alterations in the transmission of hereditary qualities.

As a result of various horticultural and agricultural activities and of the constant interchange of living material which has taken place among botanical gardens and other collections of living plants, assembled for observational purposes, a large number of species have been transferred from one country to another, and some observations as to alterations in habit and form resulting from such removals are recorded. A few experimental tests have been made in the cultivation of species through a range of altitude and some of the morphological changes induced have been described. It is known that the color, time of bloom, habit, structure of the root and shoot, general aspect of plants, and economic value may be greatly altered by cultures at various altitudes, but no systematic tests have been made to determine to what factors in the climate these differences are due. The solutions of the problems involved would settle some of the most important problems in general physiology and would also go far in enabling us to account for the structure and form of the species of which the vegetation of the earth is composed.

It is by means of experimental observations of this kind that it also may be hoped to obtain evidence as to the inheritance of somatic variations, a question which has been a much vexed one for many years. No adequate tests have yet been made to ascertain whether or not the marked changes induced in plants by cultivations at altitudes higher or lower than the normal are fully transmissible to succeeding generations grown under other conditions.

The practical problems of acclimatization offer some highly peculiar conditions. Thus, two separated localities may offer meteorological conditions apparently similar, so far as ordinary methods of weather records show, yet the exchange of plants between the two places will be attended with but indifferent success, even when differences in composition of the soil are accounted for. It seems unnecessary to point out that when the factors in climate have been accurately analyzed as to their effect upon vegetation a much more rational basis will be afforded for efforts at acclimatization.

A small plantation has been established in the grounds of the Laboratory in the alluvial valley of the Santa Cruz River at an elevation of 2,100 feet, with a rainfall averaging 12 inches; and a second on the slopes of the Santa Catalina Mountains, in an arid locality at an elevation of about 5,400 feet. A third series of experimental cultures has been installed in Marshall Gulch, on the southern slopes of Mount Lemon, the culminating peak of the range, at an elevation of about 8,000 feet. The rainfall in the last-named locality is such that the vegetation is of a distinctly mesophytic character. Steps are taken to obtain thermometric and other data which will allow an analysis of the climate in all of the localities named. Several years will be necessary before any definite conclusions may be drawn from the results of these cultures, which, however, already present some new and striking facts.

DESERT REGIONS OF NORTH AMERICA.

TRANSITION FROM THE HUMID REGIONS TO THE CHIHUAHUA DESERT, IN WESTERN TEXAS.

An analysis of the conditions to be met in this vast region, based upon an actual survey, has recently been made by Professor Bray (Vegetation of the Sotol Country, Bulletin of the University of Texas, Scientific Series No. 6, 1905), and the general results are set forth in the following paragraphs, collated from his paper on the subject:

Eastern Texas has the characteristic humid and warm-temperate flora of the Gulf region, with the long-leaf pine (*Pinus palustris*), the cane (*Arundinaria*), bald cypress (*Taxodium distichum*), and associated species, with a rainfall of over 50 inches annually. Passing westward from the Sabine River, by well-marked steps, a pronounced xerophytic aspect of the vegetation is encountered west of San Antonio, 300 miles from the starting-point, and the desert character of the flora becomes very marked in the sotol country, 200 miles farther west, and takes on increased aridity in the region of El Paso, in the Chihuahuan Desert, with a rainfall of about 10 inches yearly.

Orange, on the Sabine River, has an elevation of only 12 feet above the sea-level and an annual rainfall of about 50 inches. The region comprises a flat coastal plain, with low sandy ridges, river bottoms, and bayous. The vegetation includes cane (*Arundinaria*) and reed swamps; humid subtropical bottom-land forests, with magnolias, bay, pecan, hollies, oaks, gums; dense cypress and tupelo swamp forest, thickets of palmetto (*Sabal glabra*); heavy forests of long-leaf pine and of loblolly pine.

Houston, 60 miles to the westward of Orange, rises but 40 feet above sea-level and shows a slightly smaller amount of rainfall, the annual precipitation being 45 inches. The country may be considered as an extension of the Coastal Plain, with sand ridges higher than at Orange and with well-defined drainage channels. The western border of the Atlantic type of continuous forest is to be found in this region; also of the southern pine. Coastal prairie areas are included, bearing wet-soil grasses, rushes, sedges, and many prairie annuals. Marshes are found in which occur the spider lily and *Daubentia longifolia.*

Luling, 260 miles west of Orange, is 416 feet above sea-level and has an annual precipitation of about 33 inches. The region has a rolling surface, the soils being sandy loam, gravelly clay, and rich alluvial bottom-lands, and shows many wide expanses of grass-land with an abundance of prairie annuals.

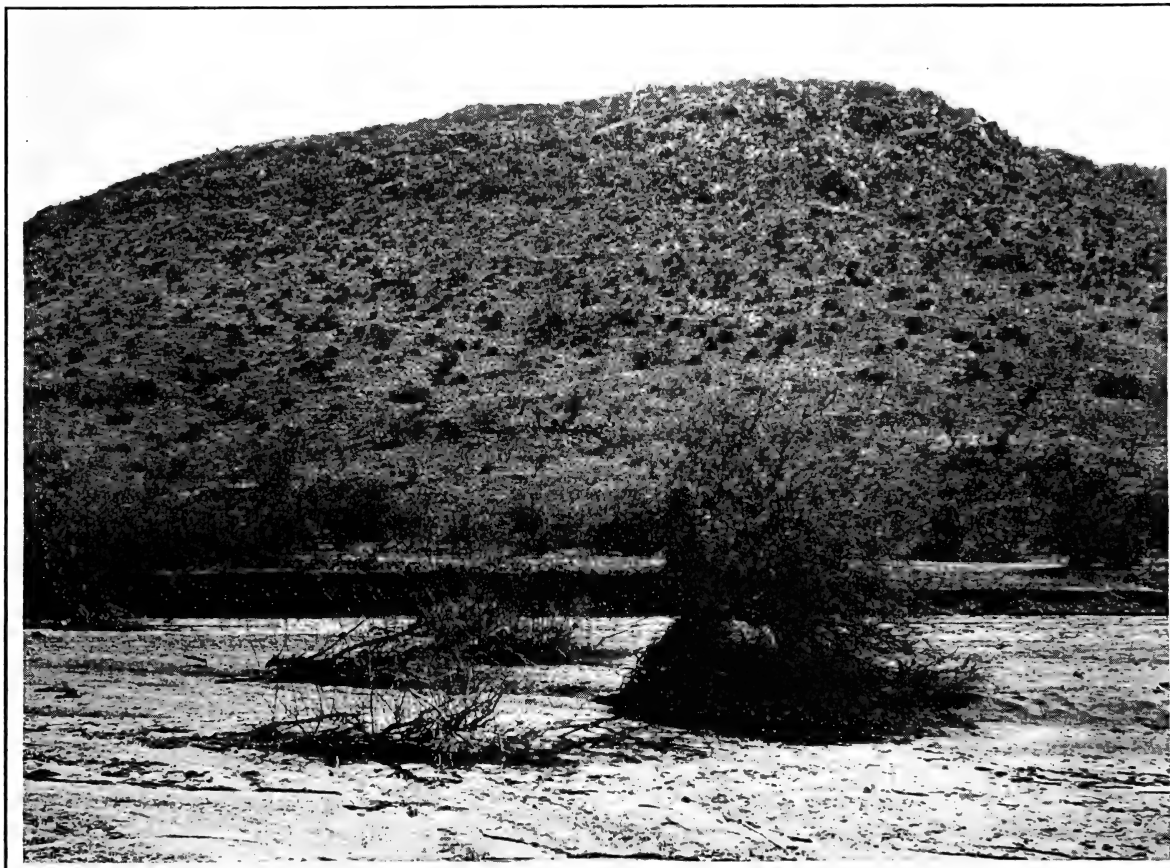
Numerous sandy and gravelly soil species are found, among which are *Indigofera leptosepala, Crusea allococca, Callirhoe involucrata, Meriolix serrulata, Aphanostephus arkansanus, Sida lindheimeri, Allionia nyctaginea, Berlandiera lyrata,* and several species of cacti; e. g., *Opuntia lindheimeri, O. leptocaulis, Echinocereus cæspitosus,* and *Cactus heyderi.*

San Antonio is 316 miles west of Orange, at an elevation of 686 feet, and has an annual precipitation of about 29 inches. This place marks with fair distinctness the inner border of the Rio Grande plain, with slightly rolling surface and deep porous soils, and the southern margin of the Great Plains area, with the roughly eroded escarpment of the Edwards Plateau limestone.

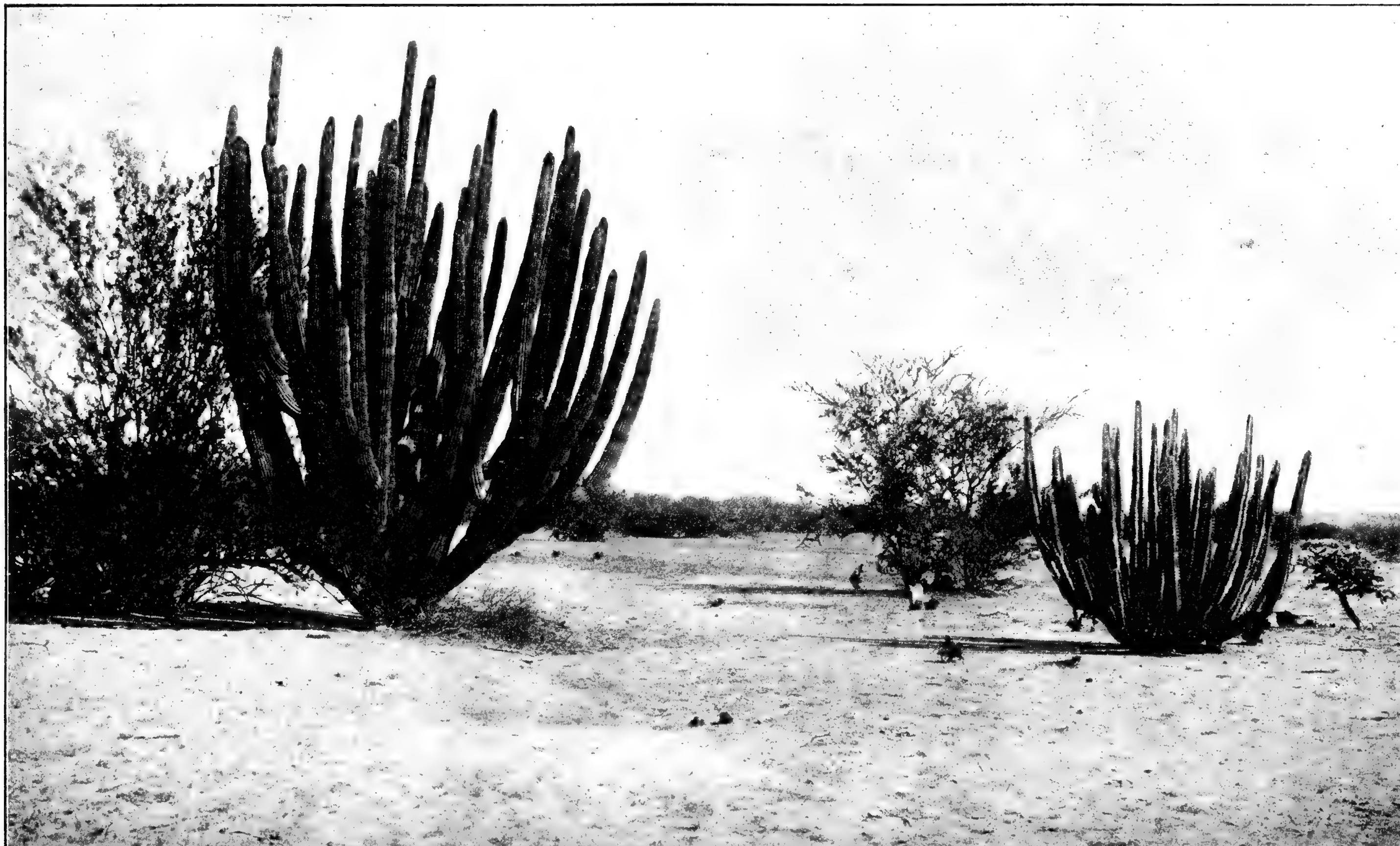
On the one hand, Gulfward, the Rio Grande plain contains a thoroughly lower Sonoran flora, of which woody species are the most obvious, constituting the widely known chaparral, which here, however, is scarcely typical, being of too luxuriant growth; e. g., the mesquite, which is most abundant, being a tree 15 to 20 feet tall. The Mimosæ begin to dominate here, notably mesquite, *Acacia farnesiana, A. wrightii, A. amentacea*; brasil, *Zizyphus;* much *Opuntia engelmanni* and *O. leptocaulis, Lippia* (*Aloysia*) *ligustrina,* all of which become more abundant west of the Sabinal; grasses of the western plains and more of the northern plains annuals; *Yucca rupicola* and *treculeana.* On the other hand are the limestone hills, marking the dissected margin of the Great Plains region in a xerophytic timber vegetation with extensive cedar brakes (*Juniperus sabinoides*), mountain forms of live-oak and hackberry, shin-oak (*Quercus breviloba*), cedar-elm (*Ulmus crassifolia*), *Ungnadia speciosa, Brayodendron texanum,* etc., being notably a timber vegetation with modified Atlantic forest species mixed with typical lower (and sometimes upper) Sonoran species; e. g., madroña (*Arbutus xalapensis*).

Spofford (Fort Clark) is 449 miles west of Orange, at an elevation of 1,015 feet and with an annual precipitation of 24 inches. This is also on the northern border of the Rio Grande plain, and is characterized by rolling gravelly ridges and intervening flats with finer soils.

Yucca radiosa which has elongated its stem sufficiently to keep its crown above a moving gypsum dune, the crest of which has passed it a few feet. The excavation has laid bare a trunk twice the ordinary length. White Sands, New Mexico. (Reprinted from Publication No. 6.)



Steep slope of granite foothill in the Sierritas, covered with sotol. A flood has recently descended the streamway, uprooted the palo verde and mesquite, and cut into the alluvial deposit on the farther bank.



Vegetation of the Sonora desert near Torres, Mexico. The cactus on the left is the pitahaya (*Cereus thurberi*), about 20 feet high; the one on the right is *Cereus schottii*. (Reprinted from Publication No. 6.)

Yaqui Indian family and dwelling at El Rancho, west of Torres, Mexico. At the right stands a Papago Indian guide. At the left is the Yaqui family, father, mother and two daughters. Two palo fierro trees (*Olneya tesota*) are in background. (Reprinted from Publication No. 6.)

The more xerophytic chaparral species are in evidence here; e. g., *Leucophyllum texanum*, *Microrhamnus ericoides*, *Karwinskia humboldtiana*, *Celtis pallida*, *Kœberlinia spinosa*, *Acacia constricta*, *A. berlandieri* (the huajilla), *Leucæna retusa* (also, of course, the mesquite), *Acacia amentacea* and *wrightii*, and *Mimosa fragrans* (of farther east); occasional specimens of Mexican greasewood (*Covillea tridentata*), *Krameria canescens* and *ramosissima*, *Yucca treculeana*, etc.

Del Rio is 486 miles west of Orange, at an elevation of 956 feet, and although but a short distance from Spofford has a rainfall markedly less, the annual amount being on an average but 20 inches. This place lies in the alluvial valley of the Rio Grande and near the rough margin of the Edwards Plateau. Ridges with coarse limestone fragments and flats with calcareous clay and alluvial soils are included. Near here begins the arid, rocky, débris-covered country, to be included in the Chihuahuan Desert, which becomes emphasized a short distance to the westward, between Devil's River and the Pecos, where sotol, ocotillo, lechuguilla, and cacti begin to predominate.

The region shows areas of short open chaparral, with broken stretches of grass-land, or rather areas bearing bunchy grasses, while huajilla, *Leucophyllum*, *Parkinsonia texana*, and various species of *Opuntia* are abundant.

Langtry is 550 miles west of Orange, at an elevation of 1,321 feet, and has an annual precipitation of but 15 inches. It lies near the canyon of the Rio Grande, the surrounding country including many of its branches, as well as high, gracefully sloping hills, wide draws, and broad divides, with coarse and fine débris of limestone everywhere. This is the typical sotol region, and the sotol (*Dasylirion texanum*) abounds on the broad divides, while the lechuguilla (*Agave lechuguilla*) occurs in abundance on the hilltops and slopes. Dwarf chaparral shrubs, *Covillea*, *Flourensia cernua*, *Microrhamnus ericoides*, *Parosela formosa*, *Ephedra antisyphilitica*, *Jatropha spathulata*, *Acacia constricta* and *A. greggii*, *Krameria*, *Lycium*, *Mortonia*, *Fouquieria splendens*, and the following cacti are found: *Echinocereus cæspitosus*, *E. dasyacanthus*, *E. paucispinus*, *E. longispinus*, *Opuntia arborescens*, *O. arenaria*, *O. engelmanni*, *O. leptocaulis*, *Ariocarpus fissuratus*, *Echinocactus brevihamatus*, *E. horizontalonius*, *E. longihamatus*, *E. setispinus*, *E. texensis*, *Lophophora williamsii*, *Cactus conimamma*, *C. heyderi*, *C. micromeris*, *C. pectinatus*, *C. pusillus*, *C. scolymoides*, *C. viviparus*, *C. dubius*, and *Cereus greggii*.

Haymond is 668 miles west from Orange, at an elevation of 3,883 feet, and has an annual precipitation of about 15 inches. The region here is a high, gently rolling plateau, bearing isolated mountains. The soil is fine, deep, and the surface of the ground is windswept. This marks the western border of the sotol region and the edge of a grass-covered area, the cylindrical opuntias being abundant.

Marfa is 743 miles west from Orange, at an elevation of 4,692 feet, with a rainfall of about 19 inches yearly. This lies on a level plateau with fine loose soil and with isolated mountain masses, and is a typical "short-grass" country. Prairie annuals are numerous and abundant and *Kœberlinia* and *Yucca radiosa* are found. Among the annuals are *Asclepias latifolia*, *A. tuberosa*, *Astragalus mollissimus* and *A. caryocarpus*, *Psoralea linearifolia* and *P. digitata*, *Hoffmanseggia jamesii*, and *Meriolix intermedia*.

El Paso is 939 miles west from Orange, at an elevation of 3,718 feet, and receives an annual precipitation of about 10 inches.

The region here includes the valley of the Rio Grande, with its numerous forms adapted to the dry air and rooting in the alluvium, and *Covillea*, *Sarcobatus*, *Fouquieria*, *Croton*, many cacti, shrubby composites, scattered grasses, and other xerophilous forms on the mesas.

Of the various separable regions in the transition from the humid to the arid areas of the West, that bearing the sotol bears a vegetation of marked xerophytic type and is true desert. Since the sotol region is one in which the physiographic factor is a determinative one, it is possible to delimit it with some accuracy.

In Texas the main body of the sotol country is embraced in the rough limestone region lying between the breaks of the Devil's River and the front ranges of the Cordilleras near Marathon, over 150 miles west, extending thence southwestward over the region of the great bend of the Rio Grande. Northward, tongues of the sotol formation reach out along the divides of the drainage area of the Devil's River into the Edwards Plateau, and of the Pecos River into the Stockton Plateau, and farther westward the formation follows the foothills and eastern front of the mountains into southern New Mexico. Westward to the Rio Grande at Presidio and El Paso the sotol formation occurs wherever the physiographic features with which it is identified are repeated, viz., débris-covered mountain slopes and rolling or hilly areas representing the progress of dissection of the plateaus.

The lechuguilla is almost as widely abundant as the sotol in this region, and has been estimated to cover more or less densely an area of 20,000 square miles. The distance across this sotol-lechuguilla belt where it is crossed by the Southern Pacific Railway from east to west is about 150 miles.

THE SAND-DUNES OF CHIHUAHUA.

South of El Paso and crossed by the old traders' trail from the settlement of Santa Fé to the city of Chihuahua is a long stretch of sand-dunes known locally as Los Medanos (supposedly a modification of Los Meganos). Necessarily these were known to the earlier travelers, as evinced by the following apt description by J. R. Bartlett, "Personal Narrative," etc., 1854).

He says:

The *Medanos*, or Sandhills, are a peculiar feature in this country, stretching in a line from northwest to southeast for some twenty miles, as far as I could judge. Nearly destitute of vegetation, their light yellow or whitish appearance presents a strong contrast to the deep brown of the adjacent mountains, which form the background of the landscape. The sand is very light and fine and forms deep ridges resembling the large waves of the ocean. When the wind blows, this sand is set in motion, filling up the former valleys and forming new drifts or hills. The road is then entirely obliterated, not a footprint or a wagon-rut being left to show the direction. Two miles brought us to the spring known as Samalayuca (Ojo de Samalayuca). It is a complete oasis in the desert, and consists of a small pool of water, in and around which are bushes and trees. It seems to be placed here by nature for the weary and thirsty traveler, by whom the route would else be impassable. On the west there is not usually any water nearer than the Salado, thirty miles distant, which is also the distance of El Paso, the nearest point to the north. Eastward is San Elizario, twenty miles.

Since these dunes seemed to be unfamiliar to botanists of to-day, a brief visit was made to them by Messrs. Coville and MacDougal, and to the region between Samalayuca and a point 6 miles to the southward.

The dunes, where the railroad crosses them, are about 40 feet high, with scant winter vegetation consisting of a few woody plants, principally a labiate bush (*Poliomintha incana*), an *Artemisia*, a *Chrysothamnus*, *Yucca radiosa*), and a suffrutescent *Senecio*. Two perennial grasses, an *Andropogon* and a *Sporobolus* with a spike-like panicle (*Sporobolus crysptandrus*), are of frequent occurrence, as are the remnants of many annual plants. The *Yucca* takes an important part in binding the sands; roots were seen extending in a nearly horizontal direction 40 feet from the plant.

From the dunes toward Samalayuca the valley bottom has vegetation of mesquite mixed with *Zizyphus*, *Kœberlinia spinosa*, and *Atriplex canescens*. An annual *Croton* forms a thick, spindle-shaped tumbleweed adapted for rolling along one axis.

The highest part of the dunes is not crossed by the railroad, but lies east and southeast from Samalayuca about 5 miles and apparently rises 200 feet from the plain.

About 9 pounds of the material of which the dunes were composed was collected by removing a thin surface layer and then placing it in a cloth waterproof bag. This material was forwarded to Dr. W. J. Gies, consulting chemist to the New York Botanical Garden, with the request for an analysis. The results obtained by him are found on pages 16 and 17 of this paper.

THE OTERO BASIN.

Extending northward for nearly 100 miles from El Paso is the noted Jornada del Muerto (Journey of Death), which has a width of 30 to 40 miles. It formed a portion of the route connecting the earliest settlements along the Rio Grande, and here the traveler was compelled to leave the stream far to the westward, in its deeply cut, inaccessible canyon, and toil for two or three days in the burning heat without water, except such as might be carried. It was for three centuries one of the most menacing and hazardous overland journeys to be encountered in the American Desert. Recent investigations, however, have shown that the region traversed is in reality a basin, and that water is to be found, as in many other deserts, within a reasonable distance of the surface.

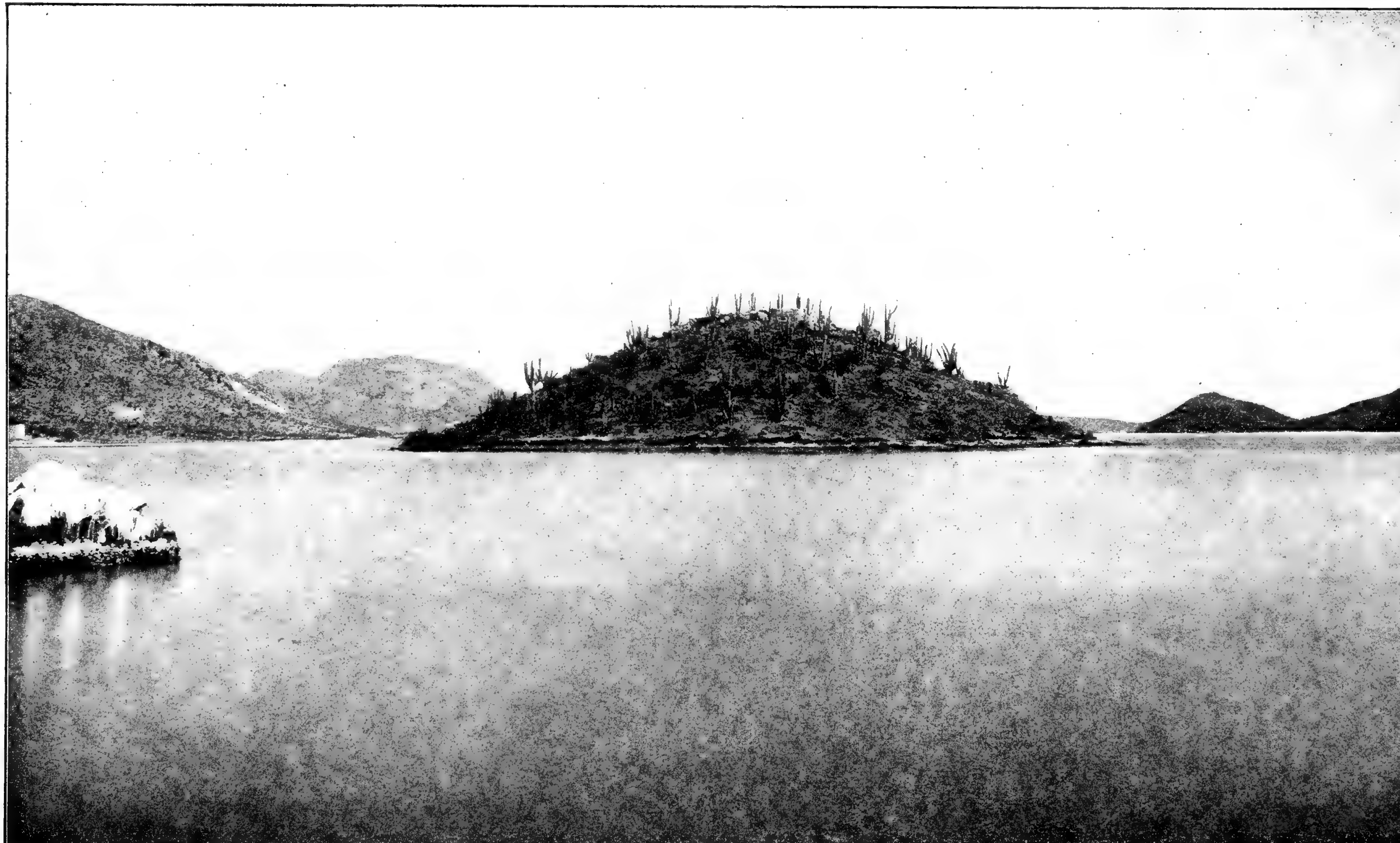
The San Andreas Mountains form part of the eastern boundary of this basin, and beyond lies an equally remarkable desert, that of the Otero basin. This basin lies with its longer axis in a north and south direction, bounded on the east by the White and Sacramento Mountains and on the west by the San Andreas and Oscuro Mountains. Once the bed of an ancient lake, it has had a complicated geological history. A lava-flow extends without interruption for 50 miles east of the Oscuro Mountains, and this or other causes must have interrupted the great stream which may have flowed southward through the basin, expanding into a lake with varying dimensions as the conditions varied from humid to arid in the alternation of climate, which has finally brought it to a condition at the present time in which the rainfall is scarcely a dozen inches. The ancient Lake Otero probably began its existence in the Tertiary times and must have occupied an area of nearly 2,000 square miles, and a vertical section by means of well-bores shows a very heavy sedimentary deposit.

The oscillation of this body of water carried its dissolved salts through various stages of concentration even to complete precipitation, and the beds of material thus laid down were covered by later deposits of sediment. The fact that different salts are precipitated at different degrees of saturation accounts for the deposition of the various saline compounds separately. More modern erosion cuts these deposits in places and lays them bare in others. Thus the intermittent streams which come down from the mountain canyons cut into and bring down in solution some of the ancient deposits, which are carried out toward the center of the basin and laid down again by evaporation in the level floor-like playas. In some places the drainage water percolates down through an inclined deposit and comes to the surface as a salt spring which builds up a cone-shaped deposit around its vent. (C. L. Herrick, Lake Otero, an ancient salt lake basin in southeastern New Mexico, Amer. Geol. vol. 34, p. 174, 1904).

As a result of the interplay of a complex series of geological factors, the central portion of this basin to-day shows some highly characteristic desert features, among which are to be reckoned the great salt and soda flat in the western portion, the salt lake southwest from Alamogordo, and most striking of all, the "White Sands," an area of about 300 square miles covered with dunes of gypsum sand rising to a maximum height of 60 feet.

Guarequi (*Ibervillea sonoræ*) under a clump of large opuntias. The large expanded stem-base, which serves as a storage organ, lies almost entirely above the surface of the ground. (Reprinted from Publication No. 6.)

Water jars (ollas) at a Yaqui dwelling, west of Torres, Mexico. One of them is on a stump of palo verde. Under it are three shoots of Indian corn, irrigated by the drippings. (Reprinted from Publication No. 6.)



Desert island in Guaymas bay, Mexico. The large cactus is *Cereus pringlei*. There is a fringe of mangrove (*Avicennia* and *Rhizophora*) along the beach. (Reprinted from Publication No. 6.)

The surface of the dunes is sparkling white, due to the dry condition of the gypsum powder, but a few inches beneath it is of a yellowish or buff color and is distinctly moist and cool to the touch, even when the air is extremely hot. The smallest particles may be crumbled in the fingers, and as a consequence the dunes are solidly packed except on newly forming steep slopes (plate 1).

The most characteristic plant of the dunes is the three-leaf sumac (*Rhus trilobata*), which occurs in the form of single hemispherical bushes 4 to 8 feet high, the lower branches hugging the sand. The plant grows vigorously, the trunk at or beneath the surface often reaching a diameter of 3 inches. The binding and protecting effect of this bush is often shown in a striking manner when in the cutting down of an older dune by the wind a column of sand may be left protected above from the sun by the close covering of the branches and leaves, and the sand in the column itself bound together by the long penetrating roots. An incrustation, apparently of gypsum, is often found on dead roots. One of these columns was about 15 feet high from its base to the summit of the protecting bush and about 8 feet in diameter at the base (plate 2). A curious fact brought out in the denudation of the underground trunks of this plant by the shifting of the dunes is the abundant exudation of a pale amber gum with the characteristic aroma of the crushed twigs. This, mixing with the sand, forms hard, honeycombed masses sometimes 3 inches in diameter.

Other characteristic woody plants of the dunes are *Atriplex canescens*, two species of *Chrysothamnus*, and *Yucca radiosa*. The underground trunks of the *Atriplex* often attain a diameter of 4 inches, those of the *Yucca* 6 inches. A marked peculiarity of the White Sands is that a cottonwood is occasionally found in the lower dunes, reaching a foot in diameter, but seldom more than 15 feet in height; yet at the same time not a mesquite was seen. The mesquite is a tree requiring less moisture than the cottonwood. Apparently the presence of an excess of gypsum is prejudicial to the growth of the mesquite.

The bottoms among the dunes have a dense vegetation as compared with that of the dunes themselves. It is characterized especially by the presence of a grama grass (*Bouteloua*), forming almost a turf, and by frequent clumps of *Ephedra* of a grayish purple color at this season and with 3-scaled nodes (plate 3). These bottoms usually show no sign of moisture, but in two places we found water-holes, the water so alkaline that the horses would not drink it at the end of their first day's drive. About both holes occurred the salt-grass (*Distichlis spicata*) and wire-grass (*Juncus balticus*), both of them characteristic of moist alkaline soils (plate 4).

The relation of *Yucca radiosa* to the sand dunes is unusually interesting. A group of four small yucca shoots standing about 3 feet high to the tip of the highest leaf was found upon the summit ridge of a 30-

foot dune. We dug the trunk out to a depth of 14 feet. All four plants were from branches of the same trunk, the lowest branch arising about 16 feet from the base of the dune; the main trunk and the branches bore marks of rosettes of leaves at intervals all the way to the lowest point reached. The trunk was thicker here, about 4 inches, than at any point above. The strata in the cut showed that the yucca once stood on the front slope of the dune. The trunk sloped in the direction in which the dune was moving. In the plain in front of the dunes were occasional low plants of the same species of yucca. Considering all the evidence, the conclusion is irresistible that the yucca originally grew on the plain, was engulfed by the sand, and gradually grew through each successive layer of sand that drifted over it until the summit of the dune was reached. In the vicinity, at the rear of the dune, were other long trunks partly denuded by the passing of the dune (plates 5 and 6).

The greatest flow of air over the dunes is from the southwest, yet other winds are strong enough to complicate the movements of the dunes. The major motion appears to be in an easterly or northeasterly direction, and places are found where the eastern margin of the white sands have advanced a mile within 20 years, although it is not to be taken for granted that the entire mass has such absolute annual rate of movement. The occupancy of a portion of the soil by a dune changes its physical qualities and leaves behind it such infiltrated material that when left bare a different series of plants finds a foothold, as was found by numerous observations.

Analyses of Sands.—The following report on the gypsum sand from the White Sands of the Otero Basin and on sand from the Chihuahuan Desert has been made by Dr. William J. Gies:

I present herewith the results of my chemical analyses of the two samples of sand expressed by you to me from Tucson, Arizona, on February 16 and received by me on February 24:

SAMPLE I. LOCALITY: OTERO BASIN, NEW MEXICO.

General Description.—Color white to delicate cream, with occasional very minute black particles. There were also a few reddish and yellowish-red grains. Now and then red specks could be detected in the white grains. Glassy grains of silica were present. Nearly all the grains were very small, about the size of those in ordinary sea sand. A few larger masses were made up of many of the small grains cemented or fused together. These masses were more cream-colored than the small grains; some contained a dark nucleus. They varied in size from such as were only three or four times the bulk of the uniformly small grains to a few which were nearly as large as a pea. No special crystalline qualities were observed in any sample of the sand. The grains were angular or rounded by erosion. Fragments of elytra of beetles were detected and occasional pieces of hair and small splinters were also seen.

Before subjecting the sand to anaylsis it was passed through a copper sieve the meshes of which were just large enough to permit the passage of the typical and uniformly sized grains. Only a few grams of material, consisting of the larger fused particles, elytra of beetles, hair, etc., were separated in this way from four kilos of the sand as received. All of this material was regarded as extraneous matter, and only the main bulk of the sand was analyzed quantitatively.

Qualitative Data.—The sand dissolved readily in water and in dilute acids, leaving only a slight residue of silicious matter. The black particles in the sand seemed to be entirely insoluble in these media. The aqueous solution was neutral to litmus. The hydrochloric acid solution was slightly yellowish in color, due doubtless to the presence of iron. On diluting the hot concentrated sulphuric acid solution, crystals of calcium sulphate quickly separated. On igniting the sand it immediately blanched, and abundance of water was evolved, but the sand did not fuse, even in platinum, over a blowpipe. Extraction of the ignited sand in water gave a solution slightly alkaline in reaction. Only a minute trace of carbonic acid gas could be produced from the sand on ignition, a fact showing that practically no organic matter is contained in it. Such organic matter as was actually present in the few particles separated from the sand consists, as already stated, of the fragments of insects, excreta of animals, etc., and is too slight in quantity to have much significance as nutrient material for plants.

On drying a sample of the sand in an air-bath at 100° C. it soon became translucent and finally snow white. The grains retained their original shape. Water of crystallization was eliminated in abundance. The sand contains traces of sodium phosphate and chloride. The larger particles removed with the sieve contained a more decided quantity of chlorine, 0.7 to 0.9 per cent.

Quantitative Analysis.—Preliminary Data.

A. Sand dried in an air bath at 30° to 35° C.:

(*a*) On drying a constant weight in an air-bath at 110° to 120° C. the quantity of water eliminated was 19.9 per cent.

(*b*) On drying to constant weight in an air-bath at 50° to 60° C. the weight of the substance remained the same.

(*c*) On continuous percolation at room temperature of small quantities of distilled water at a time over the sand, until about 100 parts water to 1 of sand was used, 79.9 per cent of the sand was dissolved and only 20.1 per cent of it remained as residue. The latter was still dissolving when the experiment was discontinued and further percolation would have reduced the amount of residue (see under *B*, (*b*) 4 below).

(*d*) On continuous percolation, as above, with distilled water at 30° C. the dissolved matter amounted to 87.1 per cent and the residue to only 12.9 per cent. Further percolation would have decreased the weight of the residue (see under *B*, (*b*) 3 below).

B. Sand dried in an air-bath at 110° to 120° C.:

(*a*) On ignition in a platinum crucible over a blowpipe the loss of weight was 1.1 per cent.

(*b*) On treatment for three hours with about 1 liter of hot acids, hot water, or cold water per gram of substance the following data were obtained:

	Solvent.	Substance dissolved.	Residue.
		P. ct.	*P. ct.*
1	One part NCl and three parts H_2O..	97.4	2.6
2	Two parts HNO_3 and two parts H_2O	97.8	2.2
3	Boiling H_2O....................	94.3*	5.7
4	Cold H_2O (15° C.)................	96.4	3.6

*Calcium sulphate is more soluble in cold than in hot water.

Some General Deductions.—The analytic results set forth in the above table and in the one given below show that the sand is mainly composed of grains of calcium sulphate derived from crystalline gypsum. Silica and also silicate of iron and aluminum are present in small amounts. Insignificant quantities of soluble substances such as chloride (probably of calcium) may also be detected.

The sand is free from nitrogenous matter, except such minute amounts of animal débris and excreta as have already been referred to.

Percentage Composition. (Sand dried at 30° to 35° C. and at 110° to 120° C.)

	I.	II.	Average.	Average.
	P. ct.	*P. ct.*	*P. ct.*	*P. ct.*
CaO	30.4	31.2	30.8	38.5
SO_3	44.5	43.9	44.2	55.1
SiO_2	2.8	2.6	2.7	3.4
Al_2O_3 } Fe_2O_3 }	0.4	0.4	0.4	0.5
H_2O	....	20.8	20.8	1.1
Traces: O, Cl, Na, PO_4 (by difference)	....	....	1.1	1.4
Calcium sulphate, $CaSO_4.2H_2O$	....	....	95.8	....
Calcium sulphate, anhydrous	....	....	75.0	93.6

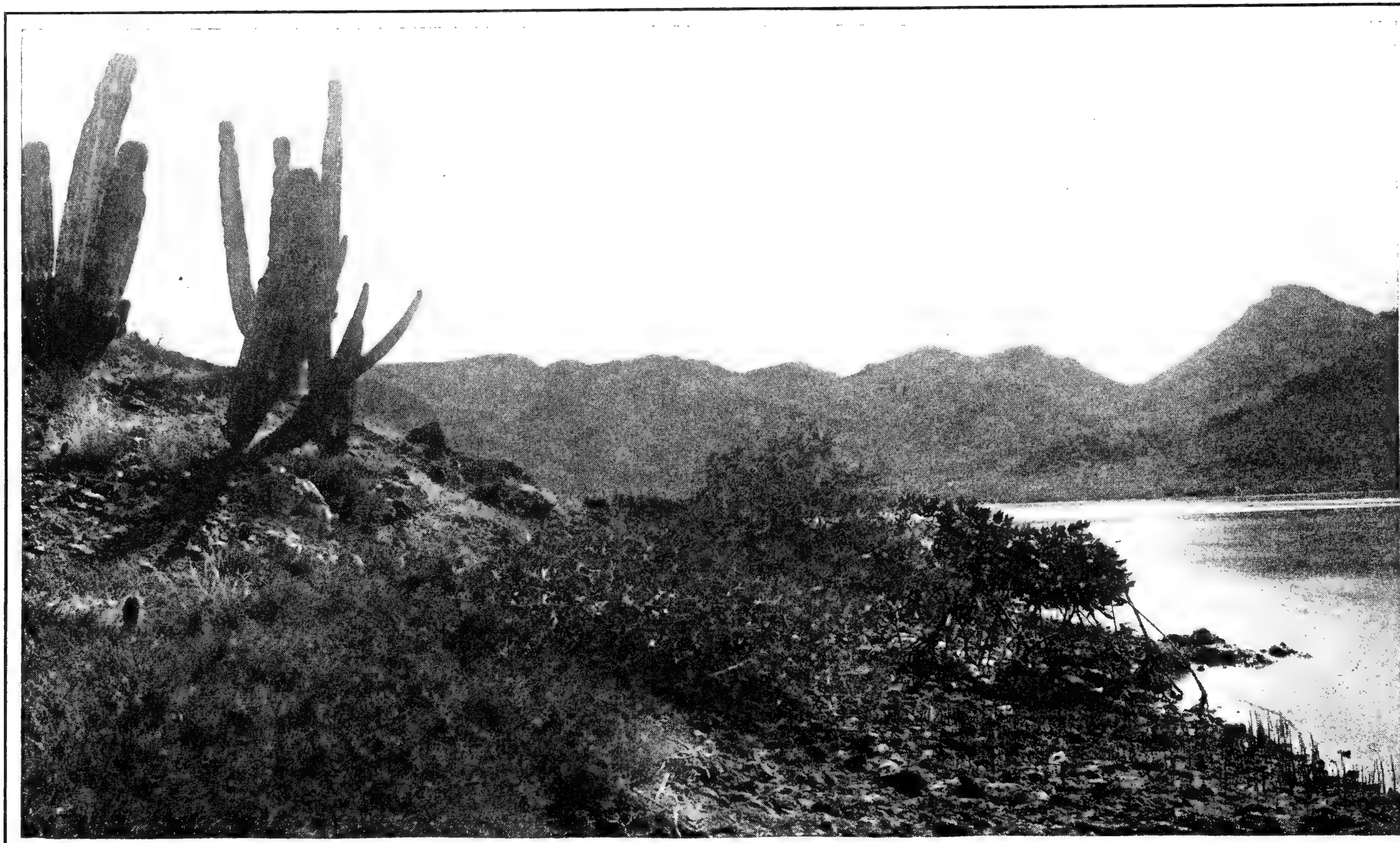
It is very evident that the sand readily dissolves in water. Every rain, no doubt, dissolves some of it and the waters in the district from which the sand was obtained must be heavily charged, probably to the saturation-point, with gypsum. On the evaporation of such water, in the sand or in pools, calcium sulphate is again rapidly deposited.

Sample II. Locality: Samalayuca, Chihuahua, Mexico.

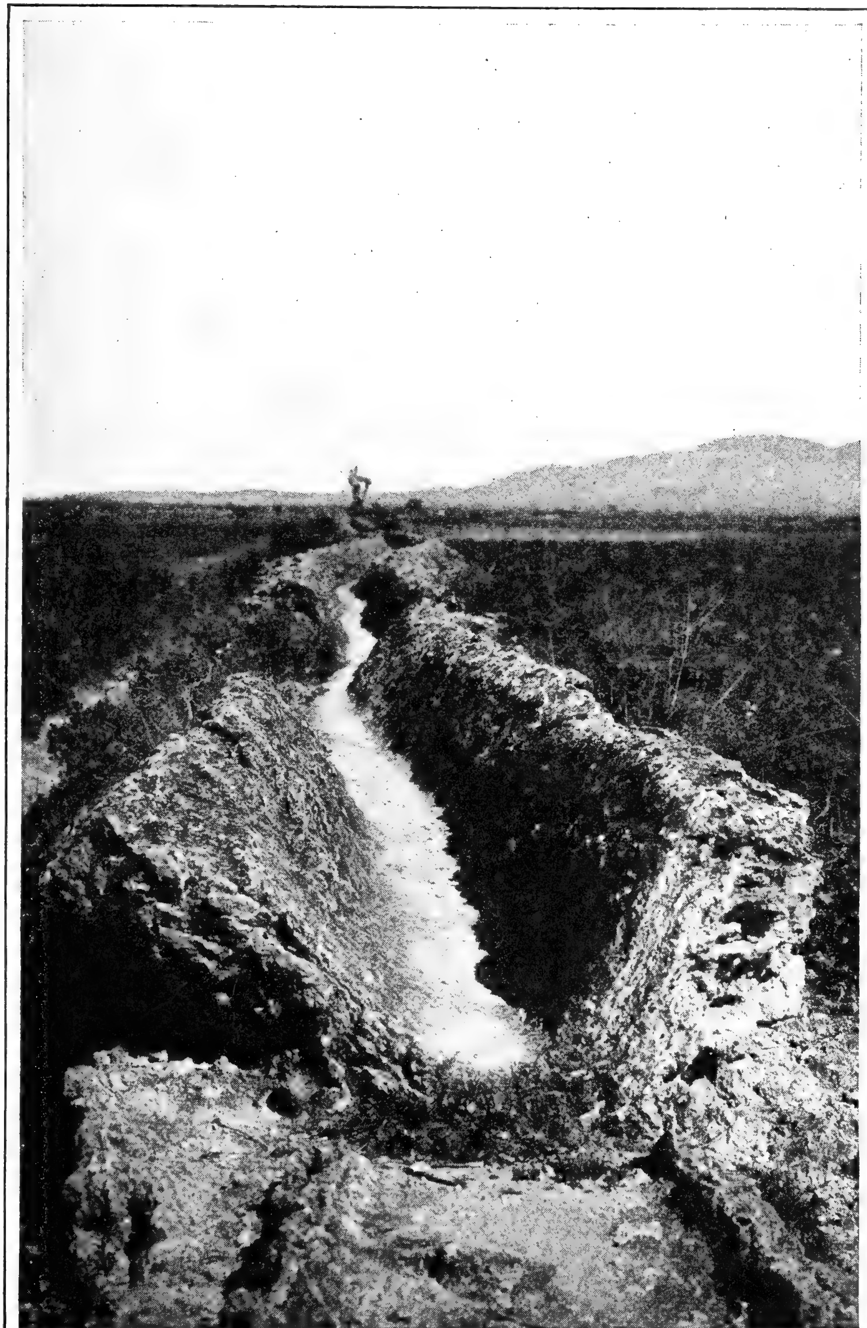
General Description.—A composite sand, yellowish to light-brown in general appearance. No crystals were detectable in it. The grains were of irregular shape, but of fairly uniform size. None were any larger than the small, uniformly sized ones of Sample I. The grains were angular, with the edges showing the effects of erosion. Glassy and brownish grains predominated. Others with the following colors were to be seen: Amethyst, dull white, dirty yellow, purple, black, and red.

All of this sand passed readily through the sieve used on Sample I. No extraneous matter was found in it.

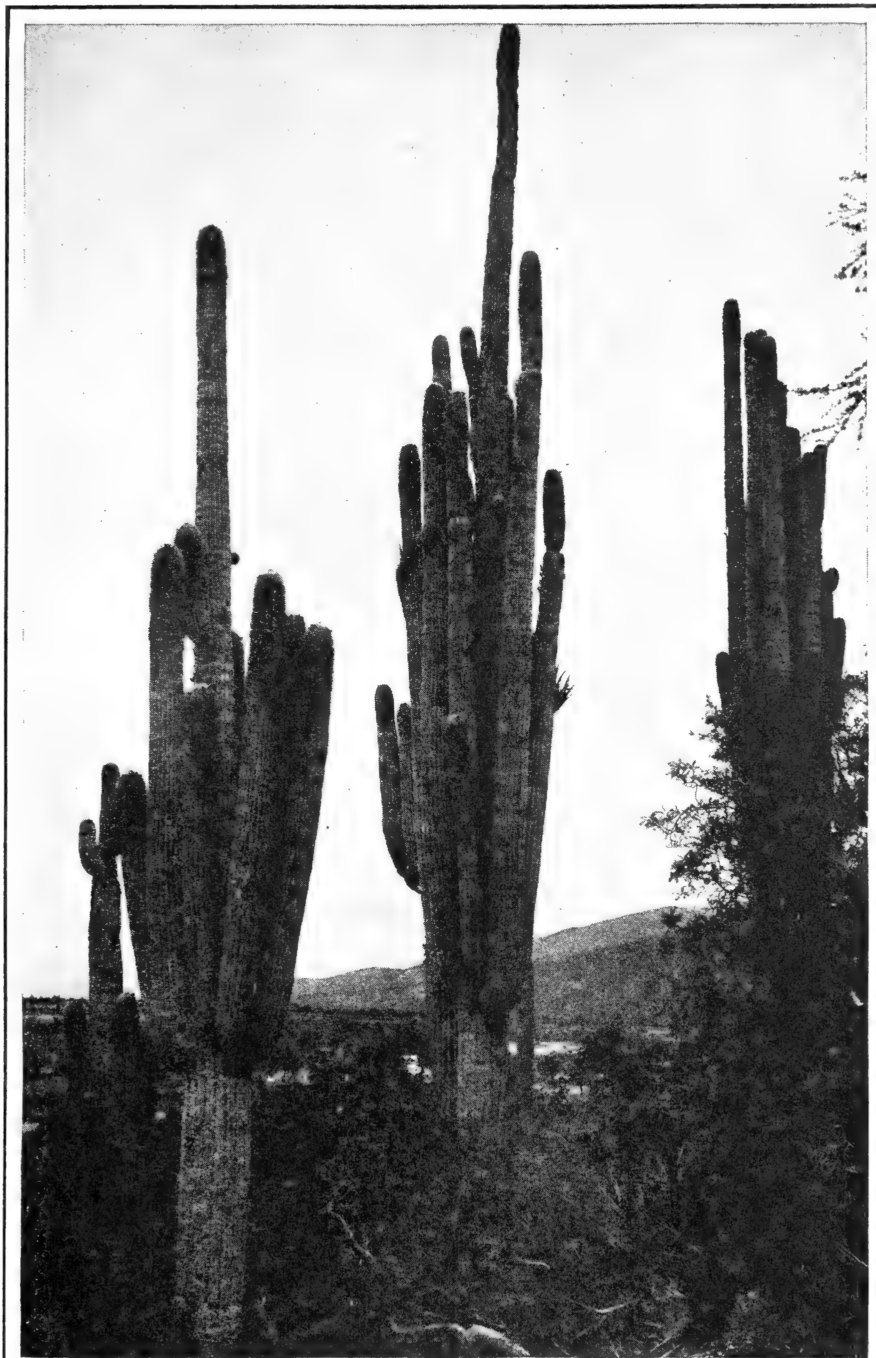
Qualitative Data.—The sand was very resistant to the solvent action of water, alkalies, and acids, scarcely anything dissolving in these fluids, hot or cold. The colored grains were somewhat reduced in number after treatment with acid, the solution in hydrochloric acid having a yellowish tinge. The sand fused with sodium carbonate with great difficulty. The fused mass was bluish-gray in color. On ignition the sand lost only a slight amount of water. It became pink and yellowish-red in places, but did not fuse, even in platinum over a blowpipe. Carbonic acid gas could not be obtained from it on ignition, so that the sand is obviously entirely



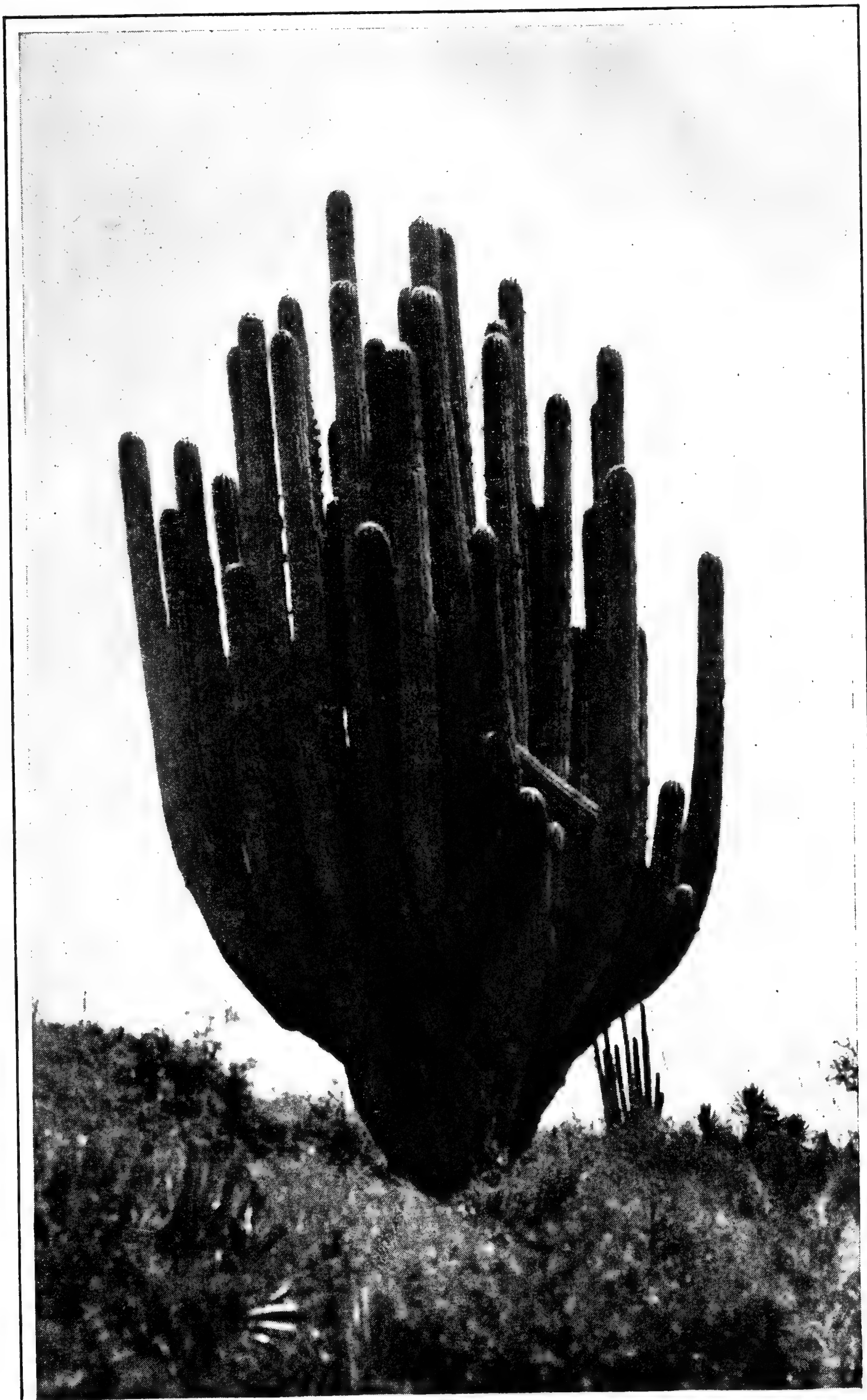
Beach formation on desert island in Guaymas Bay. Mangrove (*Rhizophora*) with its pneumatophores near margin of water, and *Cereus pringlei* within a few feet of it.



Abandoned irrigating ditch near El Riego, Tehuacan. The walls have been built up by lime deposits until the conduit became useless, and it has been cut for a roadway.



Cephalocereus macrocephalus, a tree-cactus near Tehuacan. An epiphyte, a bromeliad, is seen attached to the branches.



Pilocereus fulviceps, a massive tree-cactus near Tehuacan.

free of organic matter. On drying at 110° to 120° C. no change in appearance occurred. This sample contained also minute amounts of calcium, sodium, fluoride sulphate, phosphate, titanite.

Quantitative Analysis.—Preliminary Data.

A. Sand dried in an air-bath at 30° to 35° C.:

(*a*) On drying to constant weight in an air-bath at 50° to 60° C. the quantity of water eliminated was 0.11 per cent.

(*b*) On drying to constant weight in an air-bath at 110° to 120° C. the quantity of water eliminated was 0.19 per cent.

B. Sand dried in an air-bath at 110° to 120° C.:

(*a*) On ignition in platinum over a blowpipe the quantity of water eliminated was 0.5 per cent.

(*b*) On treatment for 3 hours with about 100 parts of hot acids, hot water or cold water per unit of substance the following data were obtained:

	Solvent.	Substance dissolved.	Residue.
		P. ct.	*P. ct.*
1	One part HCl and three parts H_2O	3.0	97.0
2	Two parts HNO_3 two parts H_2O	2.6	97.4
3	Boiling H_2O	0.5	99.5
4	Cold H_2O (15° C.)	0.6	99.4

(*c*) In a percolation experiment similar to those on Sample I, only 0.4 per cent of the substance dissolved, 99.6 per cent remaining as residue.

Percentage Composition. (Sand dried at 110° to 120° C.)

	I.	II.	Average.
	P. ct.	*P. ct.*	*P. ct.*
SiO	85.9	86.1	86.0
Al_2O_3 Fe_2O_3	8.1	8.3	8.2
Water	0.6	0.4	0.5
O in silicate, plus traces, Ca, Fl, SO_4, etc.	....	....	5.3
Silica and insoluble silicate, not less than	....	....	95.0

General Conclusions.—This sand consists chiefly of silica and of insoluble silicates of iron and aluminum. The results of the extraction experiments, in which relatively large amounts of acid, alkali, and water affected it very little, show that the sand is one of the most insoluble and resistant varieties, and that it is not rapidly altered by weathering influences.

COMPARATIVE COMPOSITION, SAMPLES I AND II.

Direct comparison of results for composition of the two sands is made in the appended summary of average analytic data for substance dried to constant weight at 110° to 120° C.:

(Sand dried at 110° to 120° C.)

	Sample I.	Sample II.
	P. ct.	*P. ct.*
CaO	38.5	trace
SO_3	55.1	trace
SiO_2	3.4	86.0
Al_2O_3 / Fe_2O_3	0.5	8.2
H_2O	1.1	0.5
O in silicate and traces of other elements (by difference)	1.4	5.3
Chief constituents: Calcium sulphate	93.6	....
Silica and silicates	3.9+	94.2+

Sample I, from Tularosa Desert, consists mainly of gypsum.
Sample II, from Samalayuca, is almost entirely silicious.

NOGALES AND THE INTERNATIONAL BOUNDARY REGION.

The region immediately accessible from Nogales and to the westward along the international boundary comprises a series of valleys at altitudes between 3,000 and 4,000 feet, separated by ranges of mountains with a general trend of north and south.

The arid slopes are in the main characterized by yucca-like plants, including *Yucca*, *Nolina*, and *Dasylirion*, while agaves are also in evidence. Two species of oak are abundant. Arboreous opuntias are numerous, and a few species of *Echinocactus* and *Echinocereus* are found. One of the characteristic plants of this region is *Cactus heyderi*, the flattened globose body of which sets so deeply that its upper surface is flush with that of the ground. Spinose shrubs are a prominent feature, but along the streamways *Sambucus mexicana*, *Juglans*, and *Platanus* are fairly abundant. Much detailed work upon the natural history of the region has been accomplished by the members of the various boundary surveys. (See E. A. Mearns, Mammals of the Mexican Boundary Survey, U. S. National Museum Bulletin No. 56, 1907.)

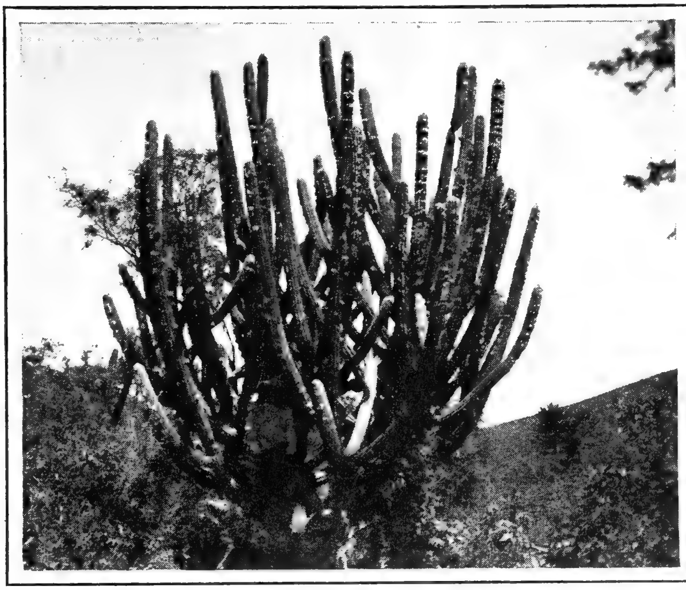
The dome-shaped hills have very steep slopes, which permit the rapid descent of precipitated water, with the result that the streamways often show currents of great volume which last for a few hours only, the channel then becoming dry for long periods, perhaps for months (plate 7). The main mountain ridges offer some fine examples of long alluvial slopes, which at the northern end of the Sierritas extend for 7 or 8 miles from the more abrupt rocky slopes (plate 7).

TORRES.

The plain in which lies the railroad station Torres has an elevation of about 800 feet above the sea. Its most characteristic vegetation is a growth of small leguminous trees, notably palo fierro (*Olneya tesota*) and palo verde (*Parkinsonia*), two species of *Cereus* of large dimensions (*C. thurberi* and *C. schottii*) (plate 8), and two cylindrical-stemmed species of *Opuntia*. The palo fierro, meaning iron-wood, produces a very hard wood, which, with the lighter but still hard mesquite (*Prosopis*) and the zygophyllaceous guaiacan, or lignum-vitæ (*Guaiacum coulteri*), constitutes the greater part of the fuel used on the railroad locomotives. Palo fierro is considered by the railroad officials a better fuel, by about 25 per cent, than mesquite, and guaiacan about 10 per cent better than palo fierro (plate 9). A metric cord (that is, a pile 3 meters long by 1 meter high and 0.75 meter in length of stick) of mixed palo fierro and guaiacan was considered by an engineer of experience as the equivalent, for fuel, of a ton and a half of the ordinary soft coal available in the Southwest. The palo verde, of which the region contains two species and perhaps more, is an especially abundant tree. It is in use everywhere for household fuel, and one of the species (*Parkinsonia microphylla*) is commonly employed as green forage for horses in winter, the branches being cut and thrown into the corrals, where the horses eat the twigs to the diameter of nearly half an inch. It is probable that at this season the twigs contain a large amount of stored food. *Cereus schottii*, as well as another smaller species of the same genus, is known as sina. *Cereus thurberi* is called pitahaya. One of the common species of *Opuntia*, probably *O. thurberi*, known as siviri, forms a small tree 8 to 15 feet high, with cylindrical joints about half an inch in diameter. It possesses a sour fruit which during the season of drought is an important source of refreshment to wild animals and even to man. The other common cylindrical-stemmed *Opuntia*, called cholla, has joints several times thicker and grows only 2 or 3 feet high, but forms large patches which are a conspicuous feature of the vegetation. Other woody plants showing adaptations to desert conditions are sangre de drago (*Jatropha*), a shrub with whip-like, at this season wholly leafless, brown stems, from which the Papago Indians make some of their baskets; vinorama, a tree acacia (*A. farnesiana*) with yellow scented flowers; papachi, a small rubiaceous tree (*Randia thurberi*) with fruit resembling in appearance a small green orange; bebelama, an unidentified tree with a trunk sometimes 18 inches in diameter, its wood so hard and tough that it is commonly used for wagon fellies; and desota, or tree mimosa, with pink flowers which have the delicious odor of the black locust flower (*Robinia pseudacacia*). This desert produces also several malpighiaceous and other woody vines which associate themselves with clumps of the trees and shrubs. Among these vines are the saramatraka (*Cereus striata*), with branching stems 0.2 to 0.3 inch in diameter, which reach a length of 4 feet or more, growing through and reclining upon the bushes; and the guarequi (*Ibervillea sonoræ*), a cucurbitaceous tendril-bearing plant whose inordinately thickened root and stem base lies gray and half exposed upon the ground beneath some trellising shrub (plate 10). These tuberous formations may be seen during the dry season lying about wholly unanchored, as the slender roots dry up with the close of the vegetative season, which lasts but a few weeks. In February, 1902, some of these tubers were taken to the New York Botanical Garden, and a large specimen not treated in any way was placed in a museum case, where it has since remained. Annually, at a time fairly coincident with the natural vegetative season in its native habitat, the major vegetative points awaken and send up a few thin shoots which reach a length of about 2 feet only, since they do not obtain sunlight. After a period of a few weeks they die down again and the material in them retreats to the tuber, to await another season. Seven periods of activity have thus been displayed by this specimen with no apparent change in its structure or size. It does not seem unreasonable to suppose, therefore, that the guarequi is a storage structure of such great efficiency that water and other material sufficient to meet the needs of the plant for a quarter of a century are held in reserve in its reservoirs.

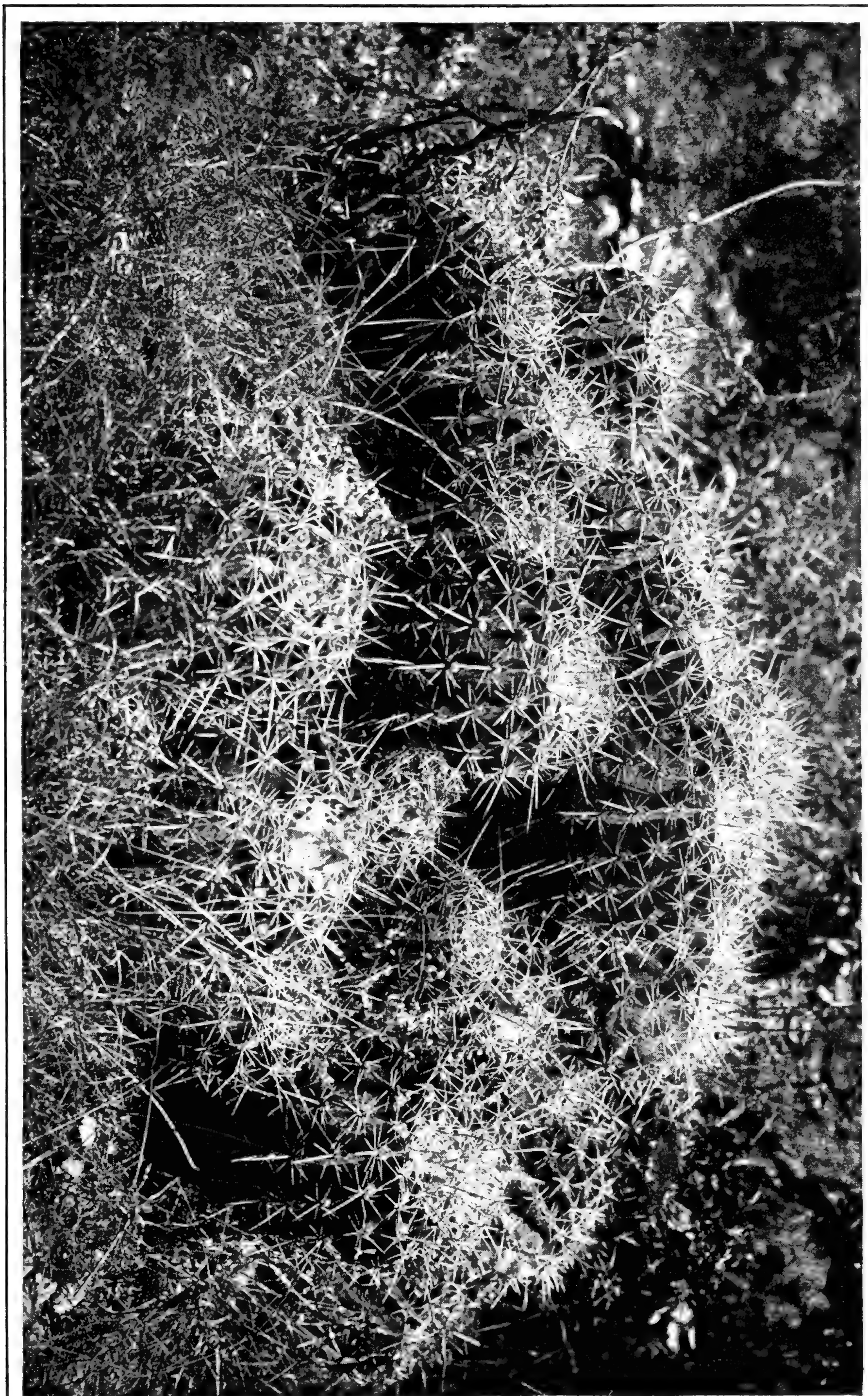
The guarequi is reputed locally to be very poisonous, but repeated tests by Dr. William J. Gies and Miss Julia Emerson, with living material, hot and cold water extracts, and alcoholic extracts fail to produce any results with the various animals used as test objects. It is quite possible, however, that the living vines or the fruits might yield substances upon which the prevailing opinion is based.

Westward from Torres the vegetation of the desert continues with little change until the line of hills is approached beyond which the country drops down to a plain still lower and nearer the waters of the Gulf. Here are the tree ocotillo (*Fouquieria*), a brasil (*Hæmatoxylon*), torote prieto (*Terebinthus*), the tree morning-glory (*Ipomœa arborescens*), and the beautiful palo lisso (*Acacia willardiana*). This last is a small tree with the whitest of bark peeling off in tissue-paper films, a slender trunk with graceful spreading branches, and curious compound leaves made up mostly of flat green rachis with an extremely small leaflet area toward the summit. The morning-glory is a tree 20 to 30 feet high, with smooth chalky gray trunk and branches, leafless at this season throughout, its large white flowers opening one by one on the ends of the naked branches. From its white bark the tree is sometimes known as palo blanco, and from the gum or resin which exudes from incisions made in it for the purpose and which is used as incense in religious ceremonies it is called also palo santo.



Pilocereus chrysantha, a small, much-branched tree-cactus near Tehuacan.

Echinocactus grande, Tehuacan. A plant of great age and of maximum size.



Echinocactus flavescens, Tehuacan.

Beaucarnea oedipus, near El Riego, Tehuacan. An inflorescence is seen on the right.

Group of desert vegetation on limestone slopes near El Riego, Tehuacan. *Hectia*, *Agave*, *Yucca*, *Euphorbia*, *Opuntia*, and a leguminous tree are to be seen.

Two trees pass under the name torote blanco; one is a *Terebinthus* with papery buff-colored exfoliating bark; the other is a tree of very similar appearance, but leafless in the winter season and suggestive of *Jatropha* (plate 11).

It was among these desert hills west of Torres that an opportunity was offered to see a Papago Indian extract from a bisnaga (*Echinocactus emoryi*), or barrel cactus, water with which to quench his thirst. He cut the top from a plant about 5 feet high and with a blunt stake of palo verde pounded to a pulp the upper 6 or 8 inches of white flesh in the standing trunk. From this, handful by handful, he squeezed the water into the bowl he had made in the top of the trunk, throwing the discarded pulp on the ground. By this process he secured 2 or 3 quarts of clear liquid, slightly salty and slightly bitter to the taste, but of far better quality than some of the water a desert traveler is occasionally compelled to use. The Papago, dipping this water up in his hands, drank it with evident pleasure, and said that his people were accustomed not only to secure their drinking water in this way in times of extreme drought, but that they used it also to mix their meal preparatory to cooking it into bread.

GUAYMAS.

The flora in the harbor of Guaymas is of a xerophytic character similar to that at Torres, but apparently subjected to severer conditions of aridity. The creosote-bush (*Covillea tridentata*), the plant most widely distributed in the more severely dry deserts of the southwestern United States, appears here again after a long intermission across the plains of northern and middle Sonora. Many of the trees and shrubs are of the same species as those found in the vicinity of Torres, but are of smaller growth.

The hecho (*Cereus pecten-aboriginum*), whose bur-like fruits are used for hair-brushes by the Indians, had appeared along the railroad near the station of Escalante south of Torres, but at Guaymas it was replaced by a species of similar habit, with different fruit, *Cereus pringlei*. A remarkable mixture of plants occurred along the beach in the salt waters of the harbor where small mangroves (*Avicennia* and *Rhizophora*), which we are accustomed to associate with the humid tropics, grew side by side with *Cereus thurberi*, *C. pringlei*, and other characteristic desert plants (plates 12 and 13).

TEHUACAN.

In 1906 a visit was made to southern Mexico for the purpose of making some observations upon the species with storage organs which were known to be abundant in that region, and also to get living material of these plants and of the cacti for experimentation.

It was found convenient to make Tehuacan one of the bases of work. The name of this city is used to characterize an arid region consisting of a series of valleys and plains lying between abrupt limestone hills at an elevation of 4,000 to 5,400 feet, in latitudes 16° to 18°, on the eastern side of the continental divide, the drainage being through the Rio Salado, Rio Quitopec, and Rio Papaloapan into the Gulf of Mexico.

The great valley in which Tehuacan is situated slopes to the eastern margin, where, lying against the base of the mountain, is the streamway of the Rio Salado, the waters of which are wholly used for irrigation. Throughout this valley springs occur on the upper terraces, which in many cases have sufficient volume to be of great service in irrigation. The water appears to be collected under or behind a tilted stratum of clay, and in many places where it does not break through, as in the springs, it is conducted to the surface by tunnels. So far as limited opportunities permitted examination, the construction of these tunnels was begun by digging a well or shaft at the lowest point on the slope or terrace below which water might be expected. If a supply was not obtained by the first, a second was sunk 100 to 200 feet up the slope, and this was continued until water in plenty was obtained. The wells were then joined by sections of tunnel at a level which would allow the water to flow toward the surface lower down, and when it emerged it was run in acequias of the ordinary type.

Most of the shafts examined were from 20 to 40 feet in extreme depth. The excavations were all made by hand labor, the rock and dirt being brought to the surface by means of baskets and vessels, drawn up by a rope of ixtle, the only mechanical aid seen being a single forked branch planted in the ground at one side of the shaft or perhaps two on opposite sides with a cross-bar between.

The accompanying analysis, furnished by Señor Mont of the El Riego Hot Springs, shows that the waters are highly charged with sodium, calcium, and magnesium, besides small proportions of a number of other substances:

Iodine	0. 000004	Carbonic acid	0. 247872
Sodium	0. 204575	Sulphuric acid	0. 059244
Potassium	0. 015038	Nitric acid	0. 009154
Lithium	0. 000902	Phosphoric acid	0. 000041
Ammonium oxide	0. 000952	Arsenious acid	0. 000051
Calcium	0. 179440	Chlorine	0. 131602
Strontium	0. 000556	Bromine	0. 000187
Barium	0. 000081	Boracic acid	0. 001920
Magnesium	0. 064832	Silicic acid	0. 052925
Ferric oxide	0. 000255	Residue	0. 000009
Manganese dioxide	0. 000014		
		Total	0. 969654

When the waters of these springs are conducted through the irrigation channels the lime and magnesia are deposited in great quantity on the floor and walls of the ditches. These are constantly built up higher by the use of more soil, which in turn becomes highly charged with lime, and the ditches soon become raised much above the fields. In some cases they reach a level with the source of supply, and a new ditch is started nearby and parallel to the older one (plate 14).

Even with care in the use of water, the soil soon becomes so heavily limed that its usefulness is soon destroyed, and extensive areas were seen upon which cultivation was no longer attempted. The information was also gained that, in some places in the neighborhood of the springs where small intensive gardens were kept, the necessary free and constant use of the water charged the soil so quickly that in about three years it was necessary to remove the surface layer and fill in with top-soil brought from the mountain valleys in which the only irrigation was by surface water of precipitation. Supplies of soil were being brought to the Hacienda El Riego for this purpose during the visit to that place.

So far as general information may be relied upon, the rainfall of this region comes in mid and late summer and can not exceed 15 inches, if the character of the vegetation may be taken as index, although the following record transmitted by the U. S. Weather Bureau shows that Puebla, 70 miles to the northwestward, at an elevation of 7,091 feet, 1,683 feet above Tehuacan, has an annual average precipitation of 36.34 inches.

Months.	Average precipitation, 12 years.	Average temperature, 8 years.	Months.	Average precipitation, 12 years.	Average temperature, 8 years.
January	0.20	53.4	July	5.71	63.3
February	0.35	55.8	August	7.16	62.8
March	0.32	60.8	September	6.22	62.1
April	1.26	65.0	October	2.91	60.8
May	3.31	65.0	November	1.06	57.6
June	7.56	64.6	December	0.28	54.3
			Annual	36.34	60.4

The difference in question might very well be due to the difference in altitude and to the topographical features involved.

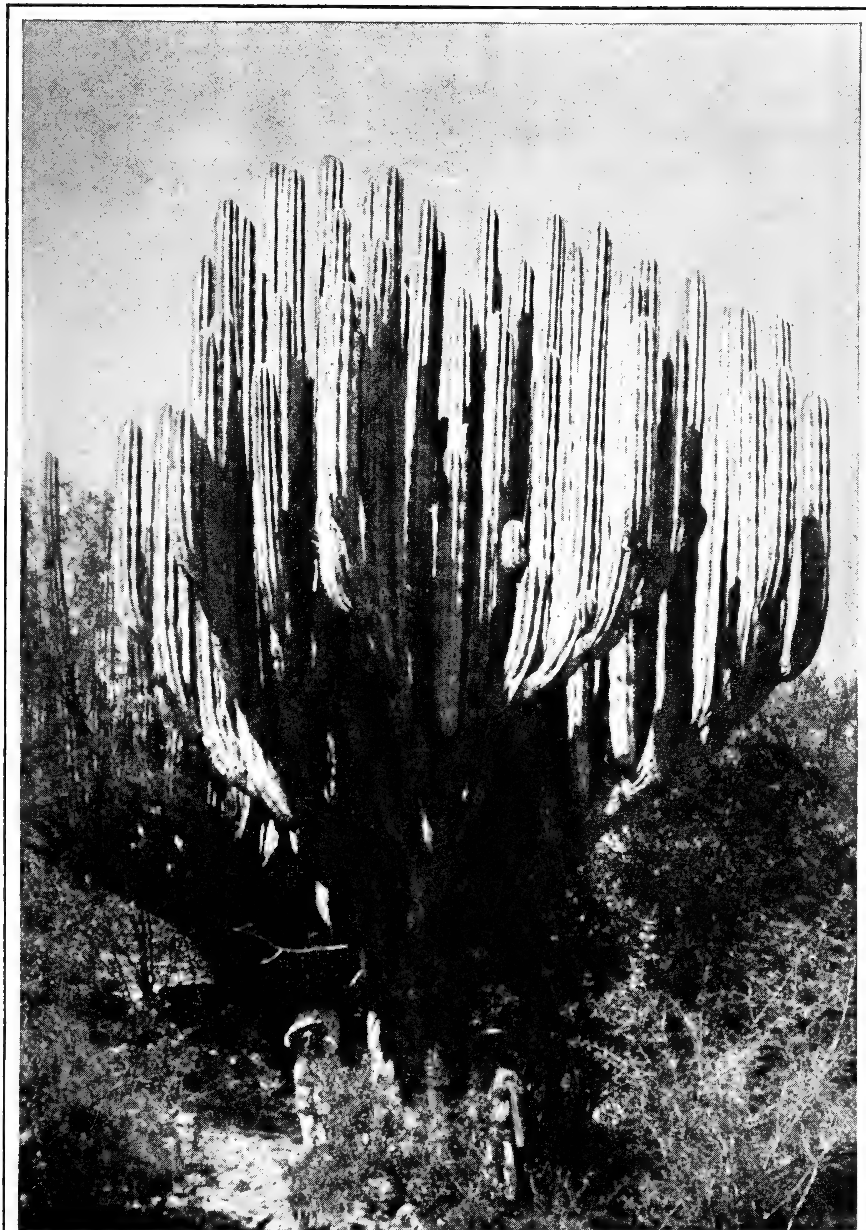
Among the agricultural products may be mentioned chilies, maize, the fruits of prickly-pears of various kinds, and sugar-cane. With the combination of desert conditions and the composition of the water, it might be expected that this region would offer some adaptations and features of distribution not encountered elsewhere. Cactaceæ and Liliaceæ furnish the more highly specialized structures, while the Leguminosæ contribute the greater number of the woody trees and shrubs.

One of the striking features of this region is the extreme localization, or strictness of colonization, exhibited by many species which are found to cover an area of a few square yards, the face of a slope, the crest of a cliff, or the floor of a barranca, with no outliers and with the nearest colony perhaps many miles away.

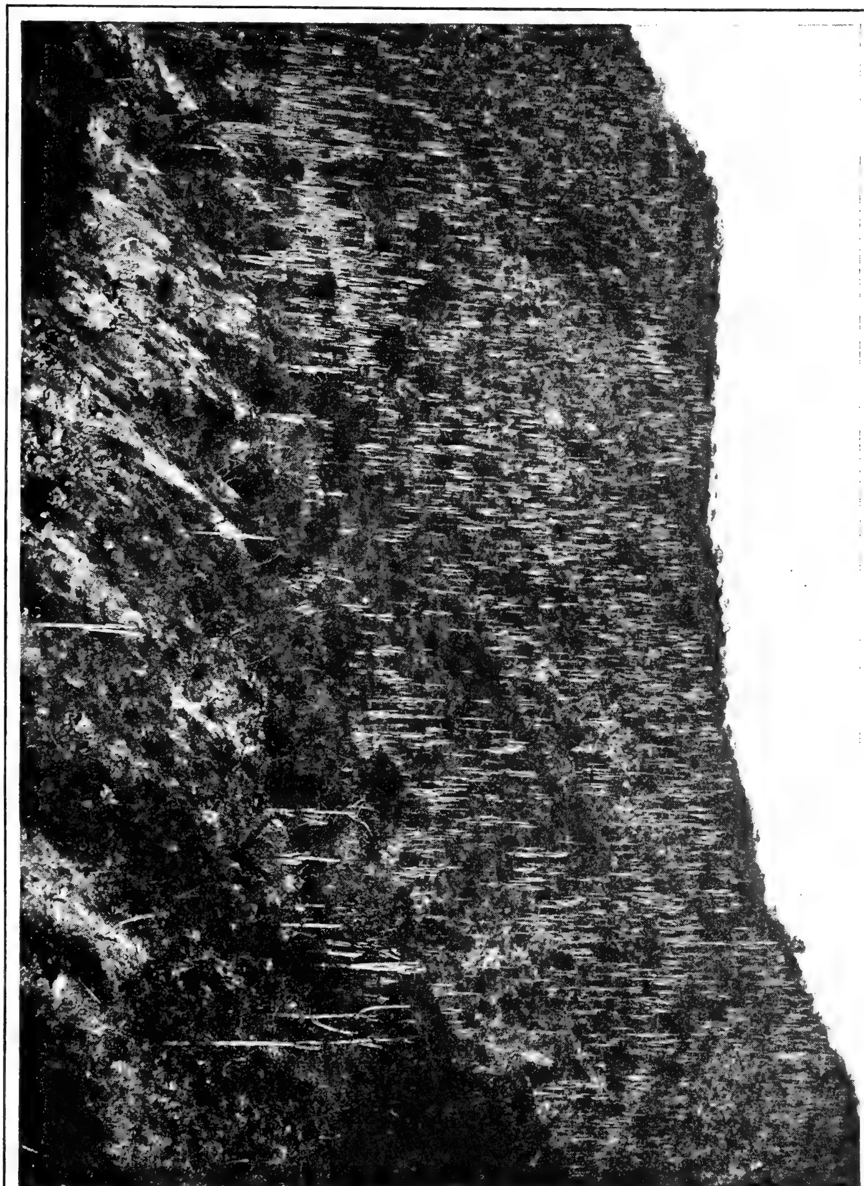
The Cactaceæ are more abundant here than in any other part of the world yet visited, several of the species being massive forms, which constitute very prominent features of the landscape.

Cereus geometrizans has a short stem with branches reaching a height as great as 15 feet, and is to be found in great abundance in the valleys and canyons that come down into the valley from the west. *Cephalocereus macrocephalus* (plate 15) is a tall species of the massiveness of the sahuaro and like it having a central shaft bearing numbers of branches which are more closely appressed. It was seen only along the cliff near the Rancho San Diego, along the eastern edge of the valley. *Pilocereus fulviceps* (plate 16), of more general distribution on slopes, has a series of branches, in many instances 40 or 50 in number, densely clustered and arising from a short trunk, which barely rises from the ground before it branches. *P. chrysocantha* (plate 17) has more slender branches and frequents the slopes to the northward. Opuntias were much in evidence as inclosures for small plots around dwellings, embracing several varieties and furnishing an edible fruit. *Echinocactus* was represented by a half dozen species, of which one, *E. grande* (plate 17), is undoubtedly the most massive of all the genus, being as much as 8 or 9 feet in height and 30 or even 36 inches in thickness, which, with the many convolutions of its surface, makes it a very grotesque feature of the scenery. The young of this species are characterized by very striking cross-stripes which disappear with age. Upon testing the pith to compare the watery content with the northern species, it was found that so much calcium had been taken up and stored in the form of calcium oxalate or carbonate that the tissue was unpleasantly gritty when chewed, and that its crispness made it difficult to express the juice. *E. flavescens* (plate 18) forms small heads in clusters, while in *E. robusta* colonies 10 or 15 feet across, making mounds 2 or 3 feet high, include hundreds of heads.

No systematic account of any desert is to be found in which the storage function appears so highly developed and by so many species. Of course all of the cacti exhibit this feature in a very marked degree, and a single plant of *Pilocereus fulviceps* may retain several hundred gallons of water. The large stems of *Yucca*, which is a prominent member of the flora of the slopes, function to this purpose to some extent, while the fleshy leaves of *Agave marmorata* and other species, and of *Hectia*, are essentially storage organs for reserve food and surplus water. Here is

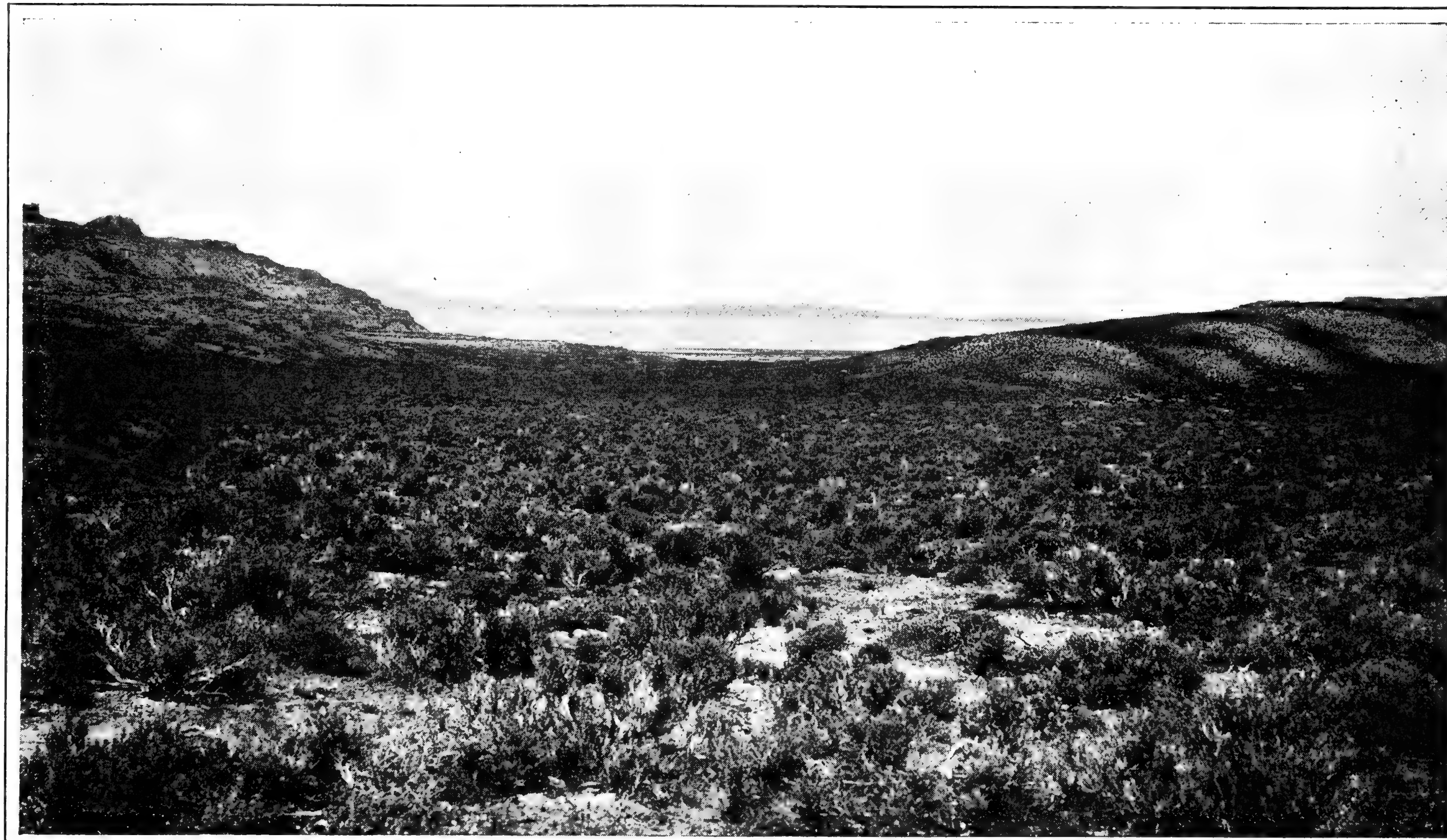


Cereus weberi, Tomellin, Mexico.



A forest of *Pilocereus tetetzo*, on mountain slope south of Tomellin, Mexico.

Cereus eburneus and *Agave karwinskii* in margin of field of maize, Oaxaca



View of portion of Salt Lake Desert from near Lakeside, Utah; *Artemisia* in foreground.

also a *Euphorbia* and a *Pedilanthus* with thick upright cylindrical stems, in which the storage function is made more effective by the possession of a thick milky juice.

The tree morning-glory (*Ipomœa*) has a soft, thick trunk, into which a knife may be easily thrust to the hilt, the medullary tissues being highly charged with water and containing some reserve food material.

Perhaps of all of the plants which show this capacity, however, *Beaucarnea œdipus* (plate 19) is the most remarkable. This relative of the *Yucca*, like all plants of this group with narrow leaves, is known as "sotol" and has the bases of the trunks swollen in adult specimens to a diameter of 7 or 8 feet, the topmost branch not reaching a height of more than 25. This trunk has a truncate base resting almost upon the top of the ground, to which it is attached by a few slender roots. This storage organ is composed of a mass of parenchymatous tissue through which run irregularly strands of fibrovascular bundles. After death the loss of water reduces the weight of the storage organ so much that a large plant may be easily toppled over as it stands.

From experimental cultures under way at the Desert Laboratory, the roots appear to have their origin in some deeply internal layer and to push their way forcibly through the thick mass of the storage tissue until the soil is reached. The peculiar form of the stem is predicated by its development in the first three months of the growth of the seedling. The sap has a very bitter taste and it could not be found that any animal makes use of it, no matter how badly in need of water.

Two species of grape were found (*Cissus*) in which enlargements of the climbing stems occurred at the bases or at various heights from the ground, making globoid tubers as much as 5 or 6 inches in diameter, which served as efficient storage and propagative organs. The storage function in this plant is taken on very early in the history of the sporophyte, as was found by the cultivation of seedlings in the Desert Laboratory. In these experiments the hypocotyl and the first internode of the stem were seen to undergo a thickening even when the plantlet bore but one or two leaves and the resulting tuber eventually reached a thickness of 1 to 2 inches.

No reliable records are at hand, but if the character of the vegetation may be relied upon it may be assumed that the precipitation of the Tehuacan region comes within a brief period during the year, during which time a reserve supply may be stored up by plants. By reference to the data given for Puebla, it is to be seen that five-sixths of the rainfall occurs within five months, and five-sevenths within four months, at Puebla, and the general aspect of the vegetation of Tehuacan indicates a shorter rainy season.

The epiphytic habit was prominently displayed by a number of species, including the opuntias and bromeliads. Prickly-pears were seen growing on adobe and stone walls, and high up among the bricks and stones of cathedrals and other tall buildings. Various species of *Tillandsia* were abundant on *Fouquieria* sp., shrubs, opuntias, and yuccas. A form with broader leaves formed striking tufts on the stems of *Cephalocereus*, to which it simply clung, and no evidence could be obtained of parasitism. One group was seen in which an opuntia had found lodgment in the sinus of a trunk of a *Yucca valida*, forming several internodes, making a stem a yard in length, to which there was clinging tufts of a filiform *Tillandsia*.

While making an examination of these numerous examples of the storage function, which appear to be more numerous here than elsewhere, one can not escape the suggestion that possibly the high lime content of the soil may facilitate it to some extent.

The Tehuacan region furnishes a fair proportion of spinose shrubs, including *Fouquieria* sp., but outside of the cacti very few with markedly reduced leaf surfaces such as exhibited by *Parkinsonia*, *Parosela*, *Cassia*, *Prosopis*, and other leguminous shrubs (plate 20). Of these the sweet mesquite, *Prosopis dulce*, has a pod in which considerable sweetish tissue surrounds the hard seeds. Loranths are common and fasten to several species, including the harder shrubs as well as the soft *Ipomœa*. So far as could be learned during the brief examination, no species were especially protected by poisonous substances except *Rhus potentillæfolia*, which grows on western slopes among other shrubs, looking most unlike a poison ivy. Not being acquainted with its properties, it was handled carelessly, with the result that its dermatitic effects were found to be severe and lasting.

TOMELLIN.

One day was spent in a portion of the same drainage system with Tehuacan at Tomellin, at an elevation of 1,200 feet, which in latitude 19° N. gives distinctly tropical conditions. Here is perhaps the most massive of all cacti, *Cereus weberi* (plate 21), which with its numerous thick branches arising from a central stem within a short distance from the ground, is found on the hill slopes and valleys. Near it was the much-branched slender *Escontria chiotilla*, while an *Echinocactus* and a few species of *Opuntia* are found in among the woody shrubs. Leguminous trees and shrubs come in to form a greater part of the landscape, showing a distinctly tropical influence, and some trees of *Juliana* of the newly erected family of Julianaceæ were found near the station. A short distance to the southward *Pilocereus tetetzo* formed great forests on the slopes facing the afternoon sun (plate 22).

OAXACA AND MITLA.

The city of Oaxaca de Juarez lies on an elevated plain at an elevation of 5,067 feet, the adjacent areas being in the drainage which eventually reaches the Pacific by the Rio Tehuantepec and the Rio Verde. Although near some mountains of considerable altitude, the precipitation is comparatively small, as may be seen from the following transcript furnished by the U. S. Weather Bureau, which shows the average precipitation at Oaxaca for a period of ten years:

January	0.12	July	4.09
February	0.55	August	4.25
March	0.59	September	5.94
April	1.77	October	2.91
May	3.94	November	0.39
June	8.62	December	0.04
		Annual	33.21

As one proceeds to the ancient ruins of Mitla, 36 miles to the southeastward, the aridity increases until in the vicinity of the hacienda of that name extreme desert conditions are found. The ancient structures here are indicative of a type of civilization characteristic of the desert, in which coöperation or communism was carried to as great lengths as it must have been in the pueblos of the northern deserts in America.

A short distance to the eastward from Oaxaca lies the village of El Tule, in which grow a large number of cypress trees (*Taxodium mucronatum*), one of which stands in the churchyard, and by the claims of local patriotism is the greatest in the world, while for a long time it has been cited as the oldest living. Both of these claims are incapable of actual proof, although the tree has much to justify an interest in it. Six feet from the ground it measures 154 feet in circumference, but it may be really two or three individuals fused together, as it divides into that many main branches within 50 feet. This tree has been an object of observation for more than two centuries, and on one side is a tablet, partly covered by the growth of the outer layers of the trunk, signed by the great naturalist, Baron von Humboldt, and probably placed there by his direction a century ago.

From El Tule to Mitla the way passes between fields illustrating methods of agriculture in an arid tropical climate. Not the least interesting of these features are the crops of maize of species either primitive or directly derived from one of the elementary species of *Zea*. The highway, especially where it passes through small villages or near a hacienda, is marked off from the fields and compounds by barriers of cacti grown in dense rows. Two or three species of *Cereus* and several pricklypears are used for this purpose and also yield a valuable crop of fruit for the owners (plate 23).

More than one of the species in both groups assume an arboreal form, while several were encountered which were definitely known to be as yet undescribed.

A great number of woody shrubs of the type known in such arid regions were seen on the hill-slopes, while down near the streamways an ash (*Fraxinus*) assumed well-developed proportions. The plant most reminiscent of the tropics, however, is the *Ficus*, which in favorable situations shows a great spread of branches and makes a large number of roots above the surface of the ground.

In the markets of the villages from Oaxaca to Mitla trimmed root-stocks of a yucca were on sale which are used by the native population for soap, especially in dressing the hair, although it probably is applied otherwise also.

At Mitla were seen a few living specimens of *Nopalea*, a cactus not encountered elsewhere on the trip, while a similarly rare form, *Pereskiopsis chapistle*, was seen in the suburbs of Oaxaca. The latter was in close proximity to a huge shrub, probably a *Boehmeria*, or some other member of the nettle family, which was sedulously avoided by our driver as being capable of inflicting very painful stings.

At Mitla the opportunity was offered for seeing the manufacture of mescal from *Agave*. Plants of several species and horticultural varieties of *Agave*, as well as of *Yucca* and *Dasylirion*, are uprooted at a time when the plant is about to send up its long inflorescence axis and is loaded with sugary substances. The leaves and roots are trimmed away, leaving a huge core in the case of the large agaves. A large pit is heated by means of a hardwood fire built in it, and after being cleansed of ashes and the remains of the fire the cores are piled in the cavity and covered, and allowed to bake slowly for two or three days. Next the pit is uncovered and the cores removed to a large vat made by sewing the edges of three or four cowskins together and suspending them from a framework of rough branches. Fermentation is allowed to act upon the sugary material for a week or ten days, and then the unpleasantly smelling liquid is dipped out and put in the kettle of a rude still, the cap of which is connected with pipes cooled with water run in wooden conduits from a stream or acequia near by. The resulting liquor contains a mixture of several alcohols and is exceedingly fiery, being a true whisky of a desert people.

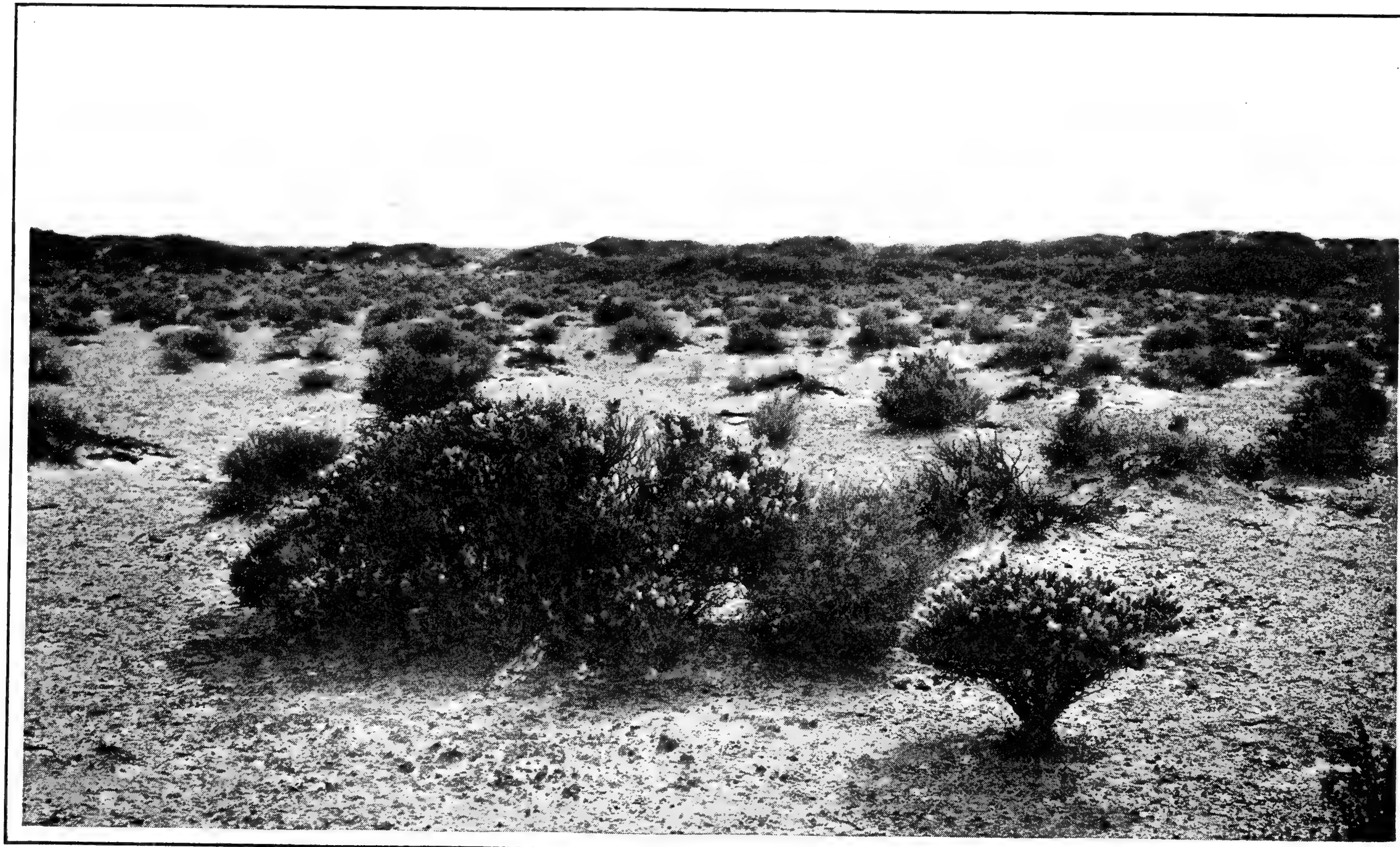
SAGE-BRUSH DESERTS OF NEVADA AND UTAH.

A large area in Nevada and Utah, lying at elevations up to 5,000 feet, includes numerous valleys and widely extended plains with no outlet for the drainage. Into these the streams from the mountains flow and terminate in lakes at the lowermost part of the natural basin formed, or spread out in great flats or playas in such manner that the waters disappear in the ground, forming what are known as sinks, of which that of

Ants' nest among sage-brush (*Artemisia tridentata*) Elko, Nevada.

Opuntia pusilla, and low spinose shrubs of desert near Hazen, Nevada.

The desert plain of Las Vegas, Nevada, showing expanses of loose alkaline soil.



Clumps of desert vegetation near Las Vegas, Nevada. *Petalomyx nitidens* in foreground.

the Humboldt River is an example. The Great Salt Lake of Utah is an illustration of the survival of a lake in the bottom of the basin. In either case the soil of the basin in many places becomes highly charged with salts, especially in the sinks and in the vicinity of the lakes, which show a decreasing or widely varying volume.

In addition, the precipitation on areas outside of the mountain peaks and slopes is low in comparison with the annual rate of evaporation. This is true also of regions in these two States in the drainage system of the Colorado River, with the result that a highly xerophilous vegetation of great extent is encountered. The predominant forms in this flora consist of perennial compositaceous shrubs, of which the genus *Artemisia* furnishes three or four species. These constitute the most prominent feature of the deserts in question under the local appellations of sage-brush, greasewood, and desert-sage (plate 24).

Such a flora is to be seen to advantage in the vicinity of Great Salt Lake, Utah. To the southwest of this lake lies the area formerly known as the Great American Desert, in which the soil is so highly charged with salts that extensive areas are devoid of any covering of seed-plants (plate 24). The main stretch of this arid area is about 125 miles from north to south and is about 50 miles at its greatest width. It was traversed by one of the main routes of the old emigrant trail to California, and consequently finds prominent mention in the descriptions of travel and surveys of half a century ago. Perhaps no better characterization of the general aspect of the region could be given than by the following citations from Bryant (What I saw in California, 1848, New York). He says:

> From the western terminus of this ominous-looking passage we had a view of the vast desert-plain before us, which, as far as the eye could penetrate, was of a snowy whiteness and resembled a scene of wintry frosts and icy desolation. Not a shrub or object of any kind rose above the surface for the eye to rest upon. * * * Descending the precipitous elevation upon which we stood, we entered upon the smooth, hard plain we had just been surveying with so much doubt and interest, composed of bluish clay, incrusted in wavy lines with a white saline incrustation. * * * * Beyond this we crossed what appeared to have been the beds of several small lakes, the waters of which have evaporated, thickly incrusted with salt and separated from each other by small mound-shaped elevations of white, sandy or ashy earth, so imponderous that it has been driven by the action of the winds into these heaps, which are constantly changing their positions and their shapes. Our mules waded through these ashy undulations, sometimes sinking to their knees and at other times to their bellies, creating a dust that rose above and hung over us like a dense fog.

At elevations of about 4,000 feet the soil, which is subject to the leaching action of natural drainage, bears the sage-brush, *Artemisia tridentata* (plate 25), as the predominant form, both as to general landscape effect and actual population, over many thousands of square miles, in which but little else besides low annuals occur. Succulents are rare and comprise not more than two or three species of cacti.

At levels slightly lower than the above, such as a locality examined near Hazen, Nevada, many other small shrubs and annuals gain in number, such as *Sarcobatus vermiculatus*, *Artemisia spinosa*, *Chrysothamnus*, *Thamnus montana*, *Tetradymia glabrata*, and *Lycium andersonii*. An *Ephedra* is also prominent, while *Lepidium fremontii* is abundant in many places. With these is also to befound *Opuntia pusilla*, which forms small mounds or tufts of dead branches and gathers débris blown by the wind, from which the living stems barely emerge (plate 26). One or perhaps two species of prickly-pear are also encountered.

The absence of succulents and of plants with storage structures is quite noticeable at elevations above 3,000 feet and in the northern part of the region under discussion, although the conditions of precipitation would render such capacity highly advantageous. The low winter and night temperatures, however, probably render such structures impossible because of the liability to freezing. As one descends the valleys and canyons leading to the drainage of the Colorado River in southern Nevada quite a variety of such forms are encountered, among which are numerous opuntias and a large *Echinocactus*, with the tree *Yucca* coming in still lower down.

A characteristic area is that around Las Vegas, Nevada, a bolson of great extent (plates 27 and 28), the surface of which includes great spaces covered with a loose alkaline soil which is hardened to a thin, fragile crust on the surface, while there also occur soft, slippery patches of moist alkali bearing *Allenrolfea*. Small arrested dunes bearing low mesquite shrubs are numerous, but in no place were free, moving dunes encountered. In general the vegetation consists chiefly of spinose types, or of forms either with heavily coated leaves or with very restricted blades (plate 28). The geological studies of the great basins of this region lead to well-founded conclusions as to major oscillations in climate in which long periods of aridity and humidity have alternated. It is concluded that one climax of aridity was reached about three centuries ago and that the precipitation is now slowly increasing, at a rate not appreciable by direct methods of measurement, however. (See page 104.)

THE MOHAVE DESERT.

Ascending from the San Bernardino Valley northward through the long climb of Cajon Pass, the railroad at last emerges from the dense growth of chaparral and comes out upon the elevated plain of the Mohave Desert. About 4 miles north of the summit begin to occur small groves of the strange tree for which the western part of the Mohave Desert is most widely known, the tree-yucca (*Yucca arborescens*). Within a few miles the desert becomes almost a forest of yucca and juniper (*Juniperus californica*), the former reaching a height, ordinarily, of 12 to 15 feet, though occasionally exceeding 25 feet and attaining a diameter of nearly

2 feet. At the station Hesperia the juniper ends and the creosote-bush (*Covillea tridentata*) begins. As still lower elevations are reached, the creosote-bush becomes, except in the washes, the prevailing bush, and continues throughout the long waste of desert to the Colorado River. (See F. V. Coville, Botany of the Death Valley Expedition, Cont. U. S. Nat. Herb., 4, 1893, for a fuller account of the vegetation.)

DEATH VALLEY.

In 1891 Mr. Frederick V. Coville made a botanical examination of the Mohave Desert and of the Death Valley regions in southern California. The work was designed to be both systematic and comprehensive. It embraced a delineation of the principal vegetative conditions to be met with in deserts, some investigations of the relations of the chief environmental factors to the characteristic plants, and an examination of the more important adaptations of a large number of species. One of the features of this contribution of great importance was the recognition of the major problems to be encountered and an outline of further researches needed upon the subject. The region included in this survey consists, in large part, of mesas in which *Covillea* and *Gaertneria* are the prevailing plants. The surface layers of the soil consist of gravel, sand, and boulders. An average of the data obtained by the ten Weather Bureau stations nearest the region showed a rainfall of about 5 inches annually, and a precipitation amounting to 1.54 inches was observed in the region itself from January to June, inclusive, in 1891. The extreme dryness of the atmosphere is illustrated by the fact that the relative humidity at 5 p.m., taken daily during the five months mentioned, was 15.6 per cent. On the 4th and 5th of August of the same season a minimum of 5 per cent was recorded. A maximum temperature of 122° F. was recorded five times during the summer season of 1891 and a minimum of 30° was reached in January and February of the same year. Vegetation in this district was seen to exhibit its greatest activity during the period of maximum precipitation, with medium temperatures from February to May; a quiescent condition during the season of maximum temperature and dryness during June to November; and a condition of slow growth during the low temperatures of December and January.

Perhaps the most noteworthy result of this study of the flora consisted in the discovery that the vegetation was composed almost wholly of perennial shrubs and annual herbs, and but few structures for storage of water were found. The tendency to form fleshy fruits was almost lacking, and even the fruits of *Opuntia* were comparatively dry and hard. The root-systems of a number of plants were examined and the mesquite (*Prosopis*) was found to have roots more than 50 feet long. Growth or increase in length and thickness was found to be extremely slow in the perennials, though very rapid in the annuals which carry out their entire vegetative and reproductive cycle during the period of maximum precipitation. Many interesting facts are also cited as to the uses of hairy coverings and resinous coating in the prevention of damage by extreme evaporation of water and intense radiation.

GRAND CANYON OF THE COLORADO RIVER.

The Colorado River comes down into the great Nevadan-Sonoran Desert through the deep canyon in northern Arizona, from which it emerges to be directly bordered on either hand by pronounced arid areas at low altitudes. An examination was therefore made to ascertain to what extent the xerophilous plants of the lower deserts had extended up along the shelves and terraces of the canyon at the elevation of the open deserts. Three visits in all were made to the canyon, one solely for the purpose of getting an impression of the range of vegetation from the timbered rim at 6,866 feet at the end of the railway leading to it, down the Bright Angel trail to the river at 2,436 feet.

For the first 2,600 feet of the descent the trees continue, but from that point to the river the slopes are treeless and the vegetation of a desert character. A very striking feature is extensive fields of a rosaceous shrub, *Coleogyne ramosissima*, which extends in an almost pure growth over the canyon terrace at an elevation of about 3,600 feet in a soil seemingly well supplied with lime (plate 29). There is a notable absence of many shrubs which would be present in the open desert at the elevation afforded by the lower parts of the canyon, and which have a seemingly good route for extension up the canyon from the Mohave Desert. The absence of these plants is presumably connected with the narrowness of the canyon, which, besides producing abnormal air-currents and temperature conditions, is responsible for a rainfall greater than would occur at the same elevations in the open desert. A cloud sheet precipitating rain on the 7,000-foot plateau through which the canyon passes would presumably continue to condense as it drifted across the canyon, whereas if it should drift off the plateau over a desert of low elevation its precipitation would be greatly lessened or would cease altogether.

Furthermore, the canyon exerts some influence upon the conditions affecting vegetation on its rim. The heated air from the lower warmer levels rises, expanding as it does so and increasing its relative humidity, with the result that during the daytime a current of air, cooler and moister than the air on the mesa, pours out of the canyon over its rim. The effect of this is strikingly illustrated in the region of the Coconino Forest, where many species not seen elsewhere on the mesa are to be found fringing the rim of the canyon. *Razoumofskya vaginata* (Willd.) Kuntze is a loranthaceous parasite growing on the branches of the bull pine (*Pinus scopulorum*) throughout the transition zone. It is most abundant, however, along the margins of mesas, the rims of canyons, and certain hilltops.

Along the Bright Angel trail, Grand Canyon of the Colorado, Arizona. The prevailing plant is a rosaceous shrub (*Coleogyne ramosissima*). (Reprinted from Publication No. 6.)

Delta of Colorado River in flood as seen from Cucopa Mountains. The main channel is that of the Hardy. Islands of vegetation visible above the water. April, 1905.

Newly made land in the delta of the Colorado River, on which *Atriplex* and *Prosopis* have become established.

Colorado River and margin of Sonoran desert near international boundary. Groves of *Populus* and *Salix* in the alluvial land to right and center. Gravel mesa with *Covillea* and *Ephedra* to left.

It reaches its greatest abundance along the Grand Canyon of the Colorado River. Here the heated air, rising from the river-bed under the influence of a subtropical sun, loses about 20° F. in its ascent of about a mile, and as a consequence it pours over the mesa much cooler and with its relative humidity increased to near the point of saturation. The *Razoumofskya* finds the strip of territory where the full effect of the moist current is greatest most advantageous in the germination of its seeds and the attachment of the seedlings to the host plant. It is therefore most abundant in a belt 1 or 2 miles in width running parallel to the rim of the canyon, while it is comparatively infrequent at greater distances. Within this belt it is estimated to have gained a foothold on 60 to 80 per cent of the pines.

THE DELTA OF THE COLORADO RIVER.

The action of the Colorado River in its delta, in its occasional overflows of the Salton and Pattie basins, and the interwoven conditions affecting the origin and development of the floras of the delta and contiguous deserts, are such that the principal features of the delta must be considered.

The main portion of this delta consists of an alluvial plain a few feet above low-water mark, cut in all directions by sloughs and bayous, which are filled at irregular intervals, but principally by the annual floods of May, June, and July, resulting from melting snows in the headwater region of the river. Occasionally, however, midwinter floods occur, due to rain and melting snow in the region drained by the Little Colorado, the Bill Williams River, and the Gila (plate 30).

In contrast with the desert the delta is characterized by almost pure cultures of various plants in different areas. Thus in places seedling willows and poplars occupy areas of great extent to the almost total exclusion of all other seed plants. The cat-tail tule (*Typha angustifolia*) lines the shore of the river for many miles and extends back from it so densely that, except an occasional mesquite or screw-bean, nothing else may compete with it. In other places the arrow-weed (*Pluchea sericea*), quelite (*Amarantus palmeri*), wild hemp (*Sesbania macrocarpa*), salt-grass (*Distichlis spicata*), *Cressa*, and wild rice (*Uniola palmeri*) occur in similar density. Filling in the interstices, as it were, between the larger blocks occupied by these colonies are the mesquite and screw-bean (*Prosopis velutinea* and *P. pubescens*), cane or carrizo (*Phragmites phragmites*), *Scirpus fluviatilis*, and *S. californicus*, the two sedges of the delta, cow-pumpkin (*Cucurbita palmata*), *Lippia cuneifolia*, *Eclipta alba*, *Echinochloa crus-galli*, *Diplachne imbricata*, and dock (*Rumex*).

The tidal action of the waters of the Gulf of California is felt as far up the river as Colonia Lerdo, 75 miles from the mouth, and shortly below the limit of such action the trees begin to find the soil too highly charged with sea-salts, and great flats occur in which an occasional mesquite and salt bushes (*Atriplex*) find a foothold. Within the memory of men now living the trees have moved southward toward the Gulf a distance of 8 or 10 miles, indicative of the extension of the delta conditions by accretions to the deposits around the mouth of the river (plate 31).

The river cuts directly into the gravelly plain or mesa of the Sonoran Desert at four points on the eastern margin of the delta (plate 32). At these places may be found within a compass of 100 feet the most vivid contrasts of rank swamp vegetation and water-loving plants having broad leaves and delicate tissues with the toughened, spinose and hairy xerophytic forms of the desert. The presence of the moist area of the delta has but little effect upon the climate of contiguous arid regions, although a popular supposition to the contrary promises fairly to be immortal. The relative humidity here is often as low as 17 per cent within 50 feet of the margin of the water. During the recent visit to this region, however, clouds of mosquitoes from the delta had been blown for many miles across the sandy plains, and these pestiferous swarms among the creosote and sage bushes gave a deceptive but unalluring appearance of alteration of climatic factors.

A shallow depression extends up from the eastern side of the Gulf of California to the main channel of the Colorado River about the head of tidewater, but its upper end is above the ordinary level of the river. Seepage water gathers in the channel at a point within a few miles of the river and finds its way to the sea, gathering salt from the soil and from the tides that push up into it, the whole being designated as the Santa Clara Slough. Here are found interesting combinations of xerophytic plants on the sand-dunes near the water, and of the halophytes or fleshy, salt-loving plants that border the water and cover the mud-flats adjacent to it. During some explorations in this region in 1905 the flood-waters of the Colorado River were seen to be making their way down through this channel to the Gulf, and a slight cutting action of the current might readily make this the main outlet.

Late in 1907 it was found that the main current of the river was actually making its way to the Gulf through this channel, even at the low-water stage, a change which might have the profoundest influence on all life in several hundred square miles of the delta.

THE SONORAN DESERT.

The region east of the delta of the Colorado River and extending southward along the Gulf of California consists principally of a series of sandy, gravelly plains near the delta and the coast, with moving dunes or "sables" in places, while in some localities these are replaced with mounds a few yards in height bearing *Ephedra*, *Covillea*, and *Prosopis*. (See plate 33.)

In addition to the few herbaceous annuals which arise during the season favorable for growth, the principal types are perennials with spinose branches and reduced deciduous leaves, although a few species with hardy leaves are included. *Ephedra*, *Gaertneria albicaulis*, *Oenothera claviformis*, *Lupinus mexicanus*, *Abronia villosa*, *Astragalus vaseyi*, *Plantago scariosa*, *Langloisia schottii*, *Stillingia annua*, *Asclepias subulata*, and *Fouquieria splendens* are typical examples, while a few forms with deeply lying bulbs are also found here, including *Hesperocallis undulatus*.

To the eastward are to be found series of mountain ranges, generally of considerable height and including many old volcanic cones, in which the water-supply and the precipitation are extremely scanty. Among the ranges, and in a manner inclosed between them, are gently sloping valleys and great plains with no well-defined drainage, which bear a characteristic shrubby vegetation. In the higher levels are encountered succulents and storage forms of the general character found in the Torres district. Burseras, known as "torote," are abundant, and a copal tree (*Terebinthus macdougali*, plate 40) is found near the Gulf. Accurate information concerning this region is, however, difficult to obtain, and it may be made the object of explorations from the Desert Laboratory. Accounts of some explorations in this region are to be found in Bull. Amer. Geog. Soc. 1907 (plate 34).

THE COLORADO DESERT.

The Colorado Desert, which has been mistakenly supposed by many writers to lie in the State of that name, in reality is situated in the south-eastern part of California. Perhaps no better description of its limits could be made than from the following citation from Prof. W. P. Blake (Explorations and Surveys for a Railroad Route from the Mississippi River to the Pacific Ocean, War Department, 1855, p. 228), who examined this region in 1852, and by his barometric observations first established the fact that it included a basin lying below sea-level.

> The region of country known as the Colorado Desert is a long plain or valley west of the Colorado River, near its mouth. It extends from the base of Mount San Bernardino to the head of the Gulf of California, and is separated from the coast slope by the Peninsula Mountains. The limits of the plain on the north and northeast are determined by the ranges of mountains which extend from San Bernardino Mountain to the mouth of the Gila and beyond into Sonora. On the south and east the desert is bounded by the Colorado River and the Gulf. The area thus bounded is a long and nearly level plain, extending in a northwest and southeast direction from latitude 43° on the north to the parallel of 32° on the south. Its greatest length in this direction, from the base of San Bernardino Pass to the Gulf, is 180 miles, or, measuring from the base of the pass to the mouth of the Gila, it is 140 miles. Its greatest width is about 75 miles, measured in a north-and-south direction along the Colorado River, between the head of the Gulf and the mountains north of Fort Yuma. The plain narrows as it extends back from the Colorado River and opposite Carrizo Creek its width is reduced to between 60 and 70 miles, and still farther westward, near to its extremity at the San Bernardino Pass, it will not average over 25 miles. These measurements are approximate, and give for the whole area west of the Colorado about 8,250 square miles; or, including a portion of the plain beyond the river, about 9,000 square miles.

The desert conditions extend across the Colorado River and southward, including the mesas of western Sonora. To the southward the Colorado Desert proper passes into the Pattie Basin and the low Eastern coastal plain of the Peninsula of California, portions of which are of an extremely arid character.

Chief interest centers in the Salton Basin and the region inclosed by the ancient beach-line, which is 20 to 30 feet above mean tidewater. Slightly above this, on the northern side of the basin, is exposed the edge of a clay stratum in the foothills of the San Bernardino Mountains which serves to bring to the surface all of the water percolating from the gravel above them. Along this ledge is a belt of palms (*Neowashingtonia*) (plate 35), which in some places follows the clay exposure so closely as to make a horizontal line in the landscape, while in other places the seepage collects in the mouths of canyons and below the clay in sufficient volume to support colonies or oases of this beautiful tree (plate 36).

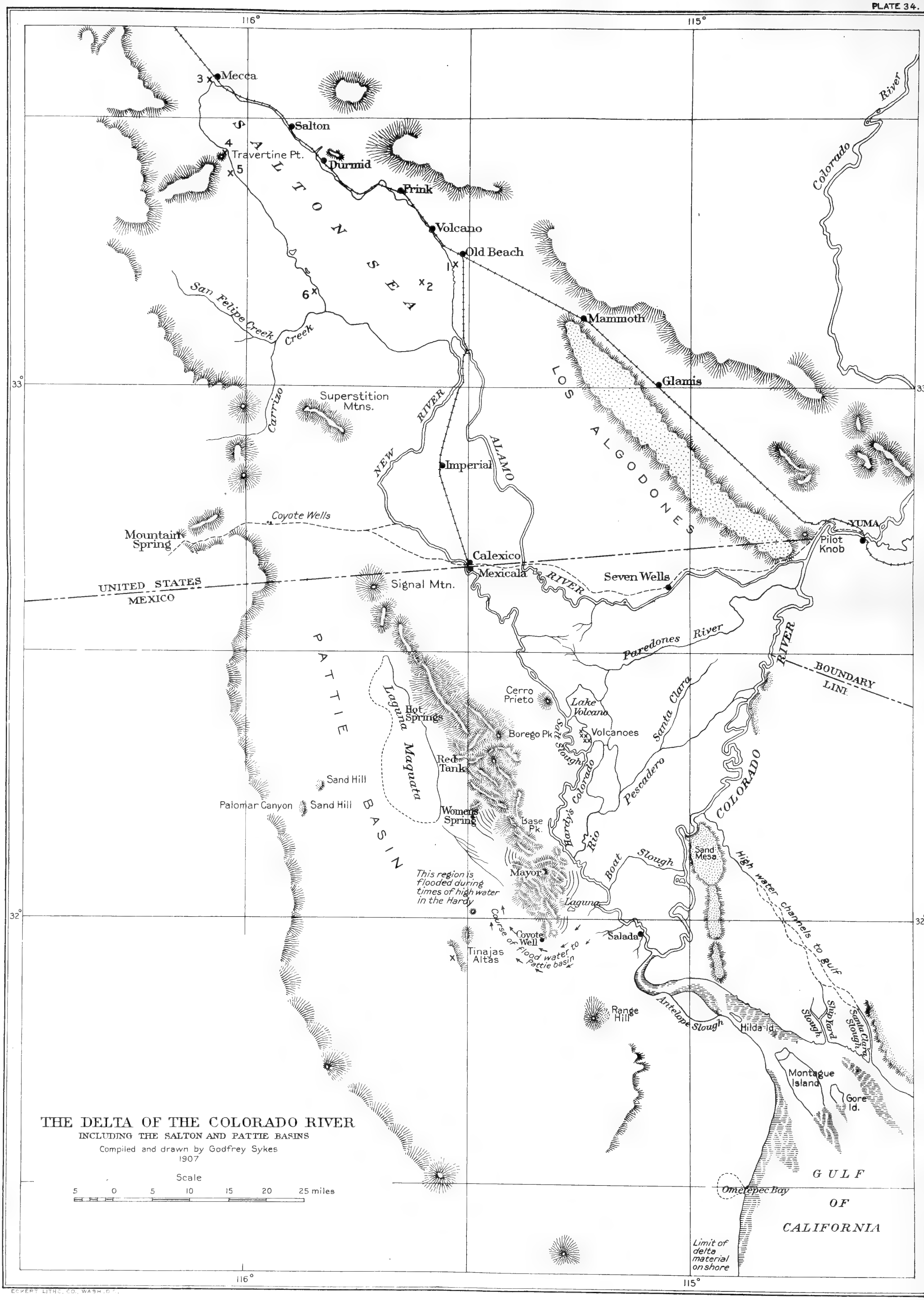
One of the most convenient points from which to visit the native palm groves of the Colorado Desert is the town of Indio. The San Bernardino Mountains, high and timbered in their main western portion, send out eastward for many miles into the desert a low timberless spur. Its parched rocky slopes seem, at the distance of a few miles, to be devoid of any vegetation whatever, but upon closer inspection are found to be sparsely dotted with bushes, like the plains portion of the desert. The canyons of this spur open out upon the valley in broad deltas of gravel brought down by occasional torrents. Just within the mouths of some of the canyons occur groves of a native fan-leaved palm (*Neowashingtonia robusta*).

The ordinary diameter of the trunk is about 2 feet and the trees at full maturity are about 50 feet high. Most of the old trunks are blackened, apparently by fire. The younger trees retain their dead leaves for several years, folded downward over the trunk and forming a cylindrical mass about 8 feet through and sometimes 18 feet in height. As the trees grow taller the lower of these dead leaves fall to the ground, leaving a naked trunk with a head of green leaves at the summit and a collar of dead leaves just underneath.

All the trees seem to stand on the same general level, not far above the base of the range. A close inspection showed that they grew in a moist clay soil, incrusted with alkali. Apparently such rain as falls upon the mountains and sinks into the earth is caught upon this clay table and runs over it to the exposed margin, where for several miles it forms a line of miniature oases containing the palms and various plants characteristic of alkaline springs. These include mesquite bushes (*Prosopis*), salt-grass (*Distichlis spicata*), a rush (*Juncus*), a sedge (*Cyperus*), and an orchid (*Epipactis gigantea*). Within the canyon and upon the delta were found a few desert shrubs not met with earlier, the leguminous

Gravelly desert in Sonora near Colonia Lerdo. The surface is composed of polished pebbles, from among which the sand has been carried by the wind. The scattered vegetation includes *Covillea*, *Ephedra*, *Gaertneria*, and a few stunted mesquite shrubs.

PLATE 24



THE DELTA OF THE COLORADO RIVER
INCLUDING THE SALTON AND PATTIE BASINS
Compiled and drawn by Godfrey Sykes
1907

ECKERT LITHO. CO. WASH. D.C.

Oasis of palms (*Neowashingtonia filifera*, in the mouth of a canyon near Indio, Colorado Desert.

Belt of palms (*Neowashingtonia filifera*) in the Colorado desert, California. The whitish soil about the palms is incrusted with alkali. Mesquite bushes grow among the palms. (Reprinted from Publication No. 6.)

Parosela spinosa and another species of the same genus, and the composite green-leaved *Peucephyllum schottii*.

West of Indio the railroad passes through a strip of mesquite dunes. Most of the sand here lies in hummocks, each produced by a mesquite tree (*Prosopis*), about which, and finally through the branches of which, the sand has drifted until only the ends of the branches project and the hummock presents the appearance of being covered with a growth of brambles.

The total precipitation in this region is probably not more than 3 inches annually, and as this comes uncertainly and irregularly one finds but few forms with pronounced storage organs, although on the mountain slopes several species of *Opuntia* find lodgment, and a barrel-cactus (*Echinocactus cylindraceus*) grows in places where it must depend chiefly upon drainage from the slopes above, which receive a greater amount, or where the total of a large area is collected in underground conduits. It would be difficult to give accurate records of temperature, although as high as 128° F. is reported from certain places in this basin in midsummer. Ice may be formed in the winter, however. The mountains to the west of the Colorado Desert are subject to sudden storms, in which the rainfall is very heavy for short periods. Thus at Campo a precipitation of 16.10 inches was measured within a few hours in one day. The "Sonoras," or storms, which give this precipitation are usually confined to the main mountain ridges in their effects, but occasionally one drifts to the eastward far enough to cast some water upon the Colorado Desert; and in fact most of its total precipitation may come in this manner.

The surface of the basin consists for the most part of loam, which in places is gravelly and in other places very sandy, while elsewhere fragments of rock cover the entire surface, particularly on the western slopes. Almost all of the loam is more or less saline and alkaline, the proportion of salts present being the principal factor determining the character of the vegetation on any area, with the physical characters of secondary importance.

The leached gravelly slopes bear *Covillea* and a variety of woody perennials, among which are to be included *Fouquieria splendens*, *Olneya tesota*, *Ephedra*, and *Parkinsonia torreyana* (plate 37), while along the beds of the dry streamways *Parosela spinosa* is abundant and also the composite bush with bur-like fruits, *Gaertneria dumosa*. The salt-bushes *Atriplex canescens* and *A. polycarpa* inhabit saline areas, the latter showing a wide range of capacity in being able to live not only in slightly saline but highly alkaline soils.

The more highly alkaline areas bear *Allenrolfea* and *Sueda* (plate 38), chiefly, while in such places the small shallow drainage channels, not wider than a hand's breadth and less than an inch in depth, become sufficiently leached to permit the growth of a half dozen small annuals.

On various parts of the sloping walls of the basin are saline and alkaline springs. The flow in most of these springs is very slow, and low mounds are built up around the small pool of water, the soil becoming incrusted with the salts by evaporation. Four plants make up most of the vegetation, salt-grass (*Distichlis spicata*), *Allenrolfea occidentalis*, reed (*Phragmites phragmites*), and a rush (*Juncus cooperi*). This last plant grows in enormous tufts and is of pronounced effectiveness as a soil-builder. In some of the moister springs, with soft, deep black mud, a three-angled spike-rush (*Scirpus olneyi*) was found, and in others the arrow-weed of the desert marshes.

Between Rimlon and Palm Springs is an area in which the vegetation is subjected to strong sand-laden winds, a veritable sand-blast. The western faces of the wooden telegraph poles are deeply cut within 2 feet of the ground by the sharp, driving sand, and the railroad employees have found it necessary to pile stones about the bases of the poles in some spots to keep them from being actually cut off. The creosote-bushes have been molded into the most fantastic shapes. One of them standing in the lee of a small boulder ran its branches freely to the eastward, but the twigs that project upward and outward beyond the protection of the boulder were killed by the sand blast, so that the plant presented the appearance of a miniature box hedge about 1.5 feet high and wide and extending about 4 feet from the rock.

Clumps of *Ephedra* and plants of *Yucca mohavensis*, the cylindrical-stemmed *Opuntia bigelovii* and *O. echinocarpa*, and the flat-stemmed and spineless *O. basilaris* vary the desert vegetation until, in the vicinity of the station Cabezon, the creosote-bush ceases and the white sage (*Ramona polystachya*) and various other plants from the coastward side of the San Bernardino-San Jacinto Mountain barrier come out a little way through San Gorgonio Pass to meet the plants of the desert.

In the western part of the desert the clay forms the floor upon which in some places a thin layer of gravelly soil rests, while in other places the bare clay does not afford a foothold for seed-plants of any kind. Upon the eastern edge of the region lie the great sand-dunes which are known as "Los Algodones," a name of Indian origin. These dunes are the more ordinary rounded hillocks by reason of the varying direction of the wind and are moving in a general northeasterly direction as a resultant. Such dunes actually support a very scant vegetation.

A second series of lesser height, but scattered over a great area, are to be found in the great alluvial fan of the streamway of Carrizo Creek. Here the dunes are of the rarer crescentic form indicative of a steady wind in one direction with but little local deflection, the concave leeward face having a very steep slope and the convex windward slope being very gradual. Similar dunes on the Desert of Islay, in Peru, have recently been described by Prof. Solon Bailey (The Sand Dunes of the Desert of

Islay, Ann. Astronomical Observatory, Harvard College, vol. 39, pt. 2, 1906, p. 287) and are also found in the desert of Seistan, Persia. These dunes are rarely over 15 or 20 feet in height, and a plant in the way of the crest of the dune may be destroyed before it is uncovered by the advancing wave of sand.

Some of the woody plants exhibit many interesting capacities in the way of elongation of the stems with restoring curvatures, by which those encountering the thinner portions of the dune are enabled to survive the inundation even when it is greatly prolonged (plate 39).

The principal trail, still in use across the mountains in southern California, cuts across the southwestern portion of the Salton Basin and up the Carrizo Creek drainage system, passing for many miles through the sand of this region. During periods of high winds and storms the amount of sand carried along is so great as to make travel impossible. During such storms the experienced traveler shelters his animals as securely as he may against the cutting wind, and watches his wagons to prevent any deposit of sand, which might quickly grow into a dune of respectable size and impede his departure from the place after the storm.

The Carrizo slopes bear numerous seepages, or slow springs, and as the sand moves along some of it is wetted when it reaches such a spring and remains in place. To this small moist heap other particles become attached by moisture until a mound of some height may be formed, which affords lodgment for a few perennial shrubs such as the mesquite.

The growth of these bushes serves to bind the sand still further. The seepage may vary, or the wind, in conjunction with the sun, may dry out and move some of the sand, killing the shrubs. As a final result such dunes may be disintegrated, while others, still intact and serving as retreats for numerous desert rats and small rodents, will be encountered nearby (plate 40).

The bottom of the Salton Basin lies 286 feet below sea-level, and an ancient beach-line 20-30 feet above sea-level incloses it, showing unmistakably that the basin at one time was filled with water. Furthermore, an examination of the gravelly slopes reveals great numbers of minor beach-lines, indicative of levels at which the water has stood for extended periods. According to concurrent testimony of geologists, this basin was at one time the head of the Gulf of California and was cut off by the deposition of silt from the river entering it from one side, since which time the occurrence of water in the basin has been irregular. Until recently the flood-waters of the river overflowed the banks of the river and, spreading over the sloping alluvial plain, finally found their way into the basin in some volume, cutting indefinite channels here and there, the most prominent of which were designated as New River and Alamo River. These channels did not begin as definite outlets from the river, and simply ran across the plain for some distance, then widened and terminated. The string of pools found in their beds long after the flood-waters had subsided were a very important factor in desert travel.

In 1904, however, an irrigation system was instituted to lead the water from the river around onto a vast area of the slope of the basin, which was found to be unusually fertile and which was rapidly occupied with settlers. Canals and openings were connected with the river without proper headworks, with the result that the water rushed in with great cutting power and deepened the channels to such an extent that the entire current of the river was diverted into the basin for several months, inundating 500 square miles of desert and forming a lake, the deepest part of which gave soundings of 84 feet (plate 41).

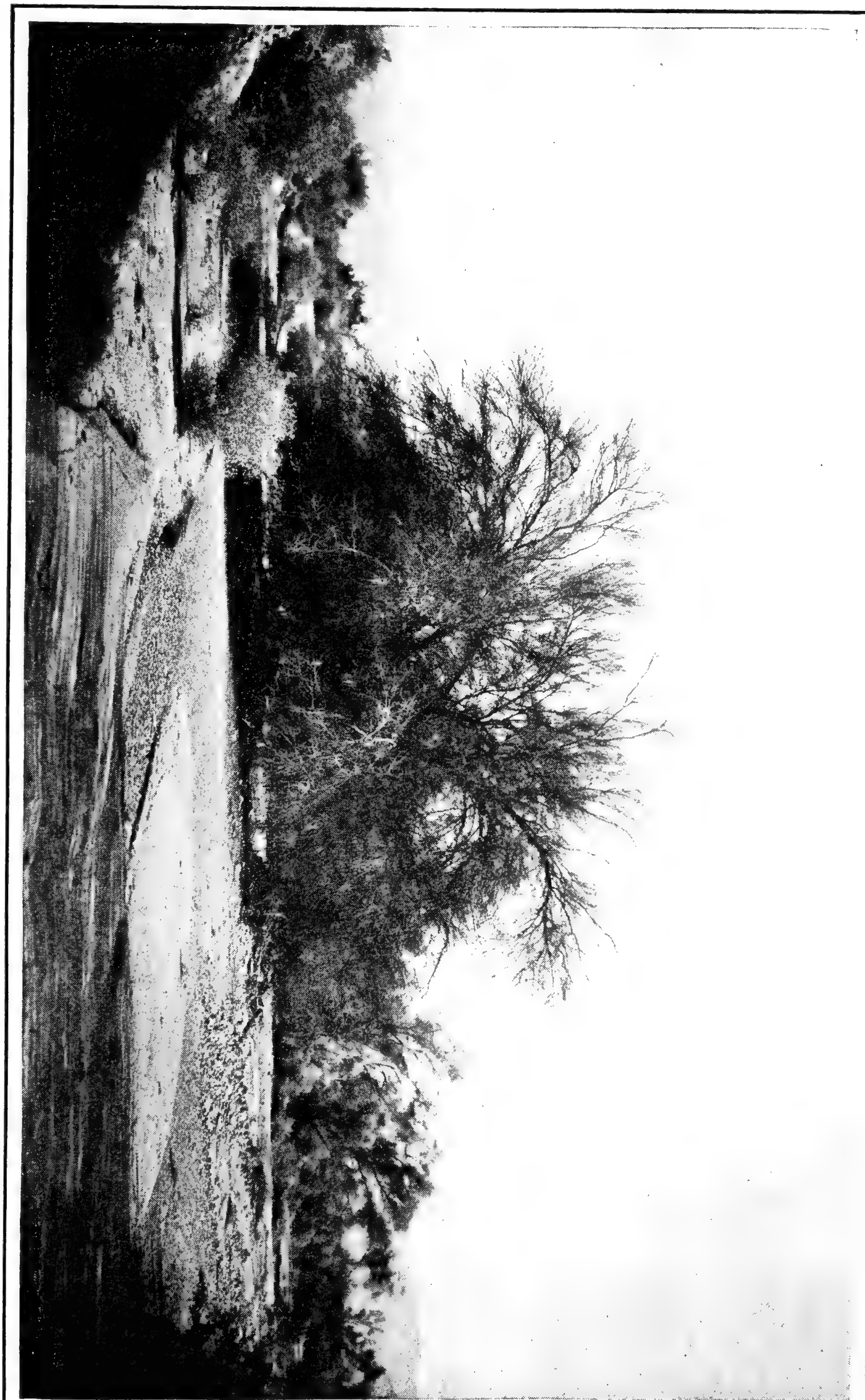
The fresh water thus poured into the basin took up the salts from the saline and alkaline soils, with the result that when the inflow of the river was checked, February 10, 1907, a total solid content of one-third of one per cent was present.

A detailed analysis of the salts taken up by the fresh water poured into the basin reveals the fact that their total composition resembles that of condensed river-water rather than sea-water. This agrees perfectly with the supposition that since the last waters from the Gulf evaporated in this basin directly after connection had been closed by alluvial deposits the river has poured flood-water into the basin scores, perhaps hundreds, of times, and with it much salt, so that the bottom of the ancient head of the Gulf has been buried beneath a layer of river deposits, and that on top and with this deposit are the salts from the river, which are now redissolved by the present flood.

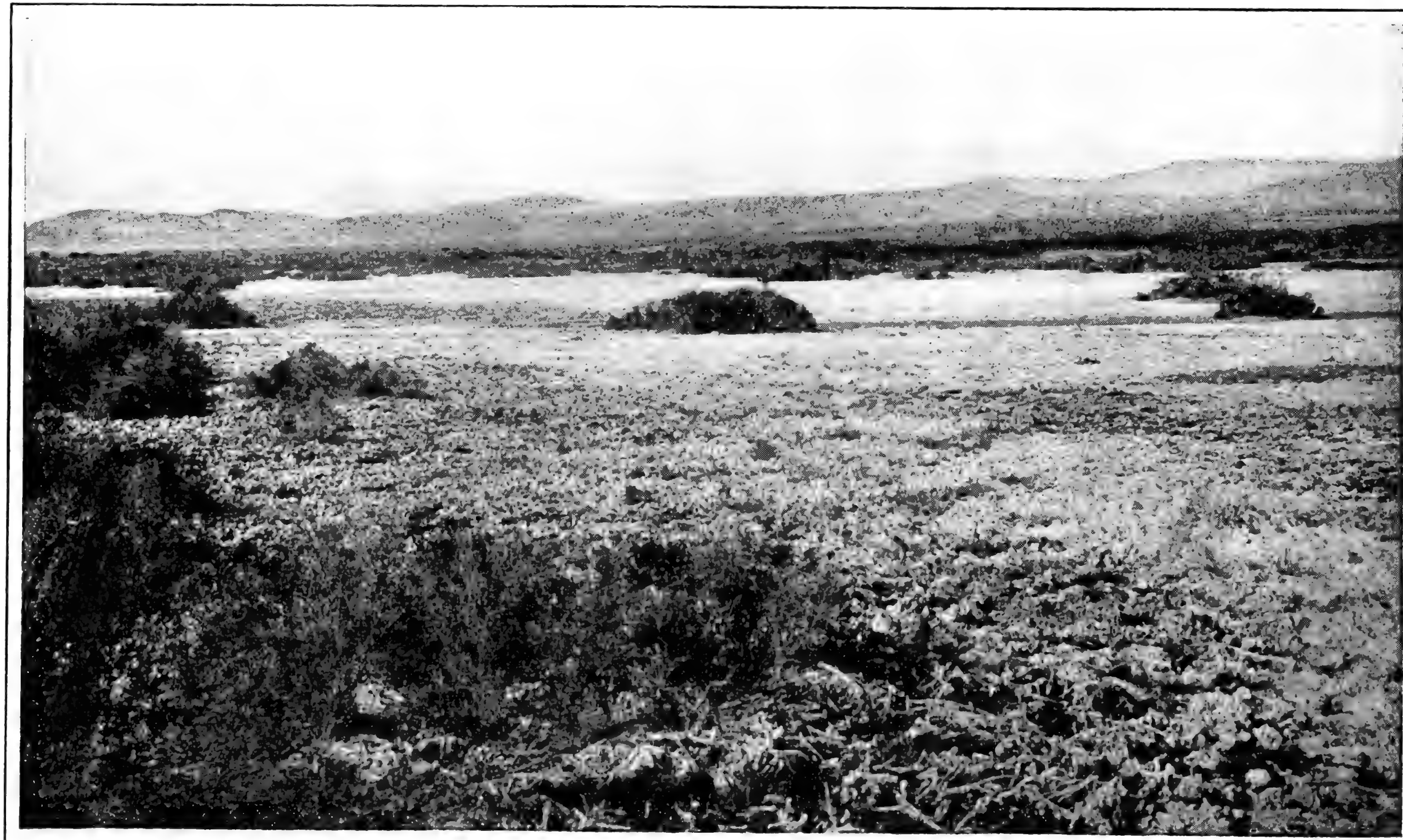
Preliminary examinations having already been made, the lake was circumnavigated at this time by an expedition from the Desert Laboratory, and localities selected for the observation of the movements of vegetation as the waters receded by evaporation. Among the major phenomena to be critically examined are possible introductions by reason of the inflow of the river-current, and the manner in which the submerged portion of the basin will be reoccupied by the plants that formerly inhabited it. Fortunately the bottom of the basin had been examined in 1903 and a sketch of the vegetation made as it then existed, which will afford some basis for comparison (plate 42).

THE CUCOPA MOUNTAINS AND THE PATTIE BASIN.

To the northward of the Cucopa Mountains lies the depression of the Salton Basin which is subject to flooding; to the eastward is the strait which formerly connected this basin with the Gulf of California, and which is now a part of the delta of the Colorado River. As the water in the various channels makes its way across the delta it comes against the eastern base of the mountains and gathers in the Hardy River, the current of which actually bathes the foot of the rocky slopes in places (plate 34).

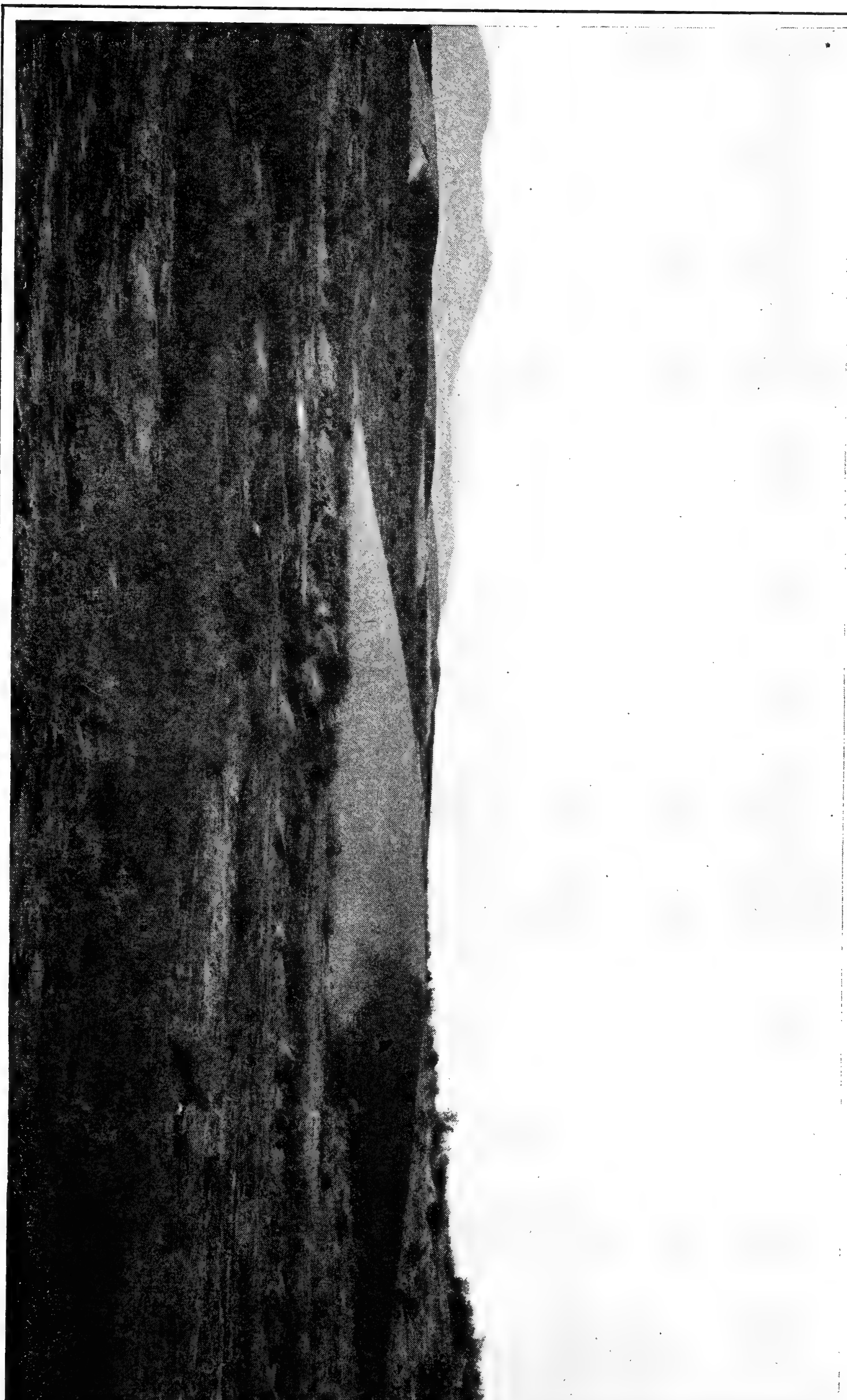


Dry streamway in Salton basin. *Parkinsonia torreyana* in center, with smaller trees of *Parosela spinosa* to right and left.

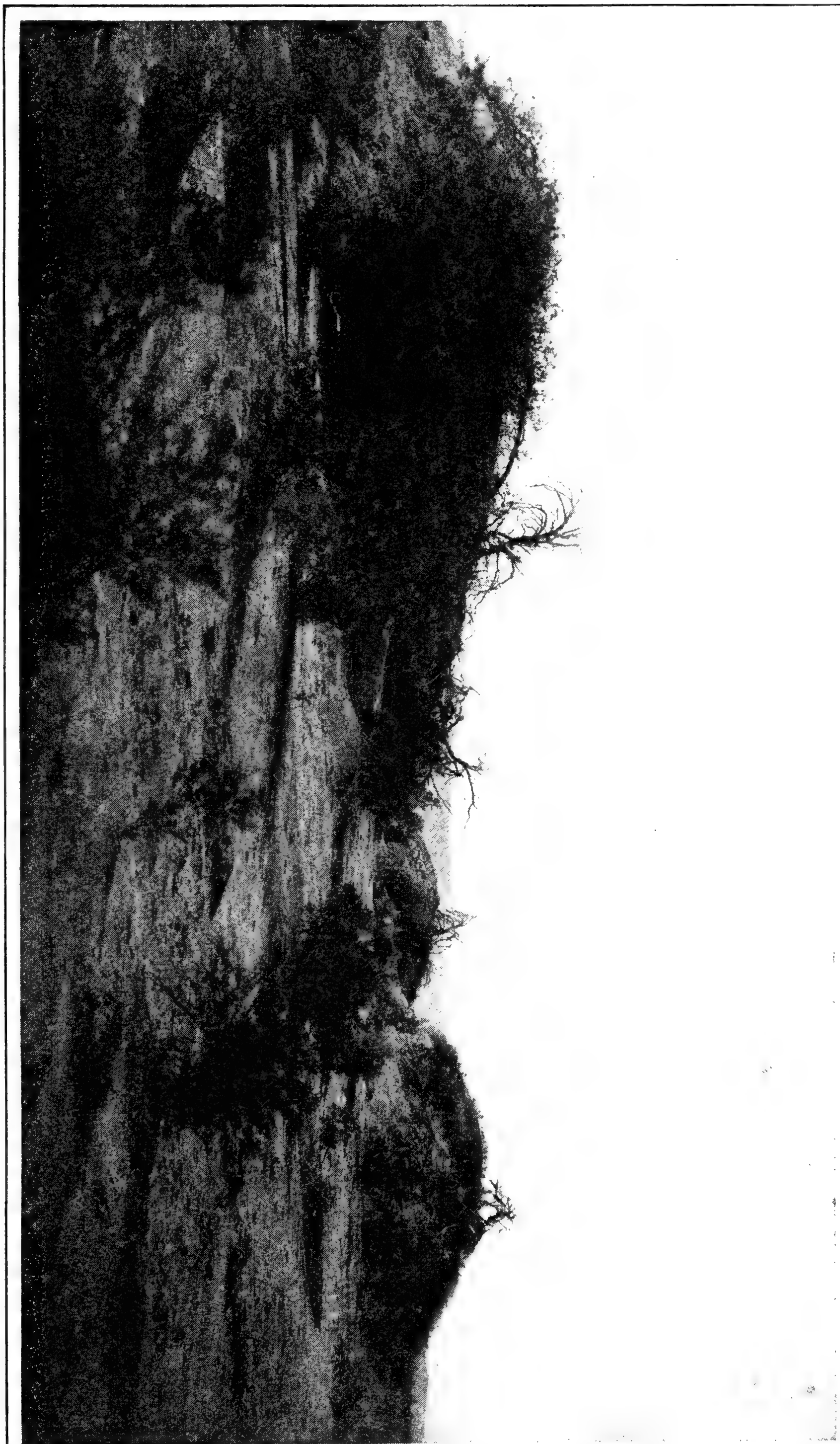


Saline deposits in lower part of Salton basin, 1903. The principal plant is *Allenrolfea*. This area is now covered by the lake.

Plate 39



Crescentic dunes in Carrizo Sands, moving to northeastward.



Moist dunes in Carrizo Sands, bearing mesquite and cats-claw, *Covillea*, nearly uprooted by action of wind in foreground.

During periods of high water the flood passes close against the eastern base of the southern end of this range and spreads out as it passes the southern end to cover a bare clay plain 6 to 15 miles wide, and by a slow current finds its way northward into a bowl-shaped depression, which has been designated the Pattie Basin, and the lake thus formed has long been known to the Indians as Laguna Maquata.

As the flood-waters pass down the slope to the laguna a series of channels have been eroded in the clay, which are known as Los Barrancas. The whole system offers a general parallel to the Salton Basin and Salton Lake. Between the two the Cucopa Mountains form a peninsula connected with high land by a strip running northwest across the international boundary.

The bases of the granite slopes are fringed with palo fierro (*Olneya tesota*), while *Terebinthus*, *Gaertneria*, *Opuntia bigelovi*, *O. prolifera*, *Cactus*, and *Echinocactus* find suitable habitats to within a few feet of the summit, at 3,500 feet altitude. At various places in the granite and conglomerate water collects in cavities and pools, forming tinajas, some of which are fairly permanent with the limited demand made upon them.

No exact study has yet been made of the flora of the Cucopa Range, but the preliminary examination seems to show several endemic species and that in general the forms present belong to the mainland to the eastward, although a careful analysis may reverse the latter inference. A single colony of palms (*Neowashingtonia*) is reported from a spring high up in a branch of a large canyon on the eastern side of the range.

The Pattie Basin offers some of the most interesting combinations of salt lake—of widely varying level—and desert yet examined. The extreme limit of the lake is 30 miles in length and 15 in width, but this limit is reached only on rare occasions. Marking the upper shore of the lake is a belt of mesquite from a few yards to a half mile in width, except where the lake comes against the granite slopes. Inside of this are several minor beach-lines which show that this lake refills quite frequently, much more so than Salton Lake (plate 43).

The beach of two years since is occupied by a zone of *Sesuvium sessile*, indicating a level at which the lake stood for a few months. With the cessation of the inflow, however, the decrease takes place rapidly, with deposition of salts, so that occasionally there is presented a bare desert with an area of 500 square miles absolutely devoid of vegetation, resembling in some respects the desert near Great Salt Lake. The movements of the fringing zones of vegetation will form a subject for investigation by the staff of the Desert Laboratory in conjunction with similar studies in the Salton Basin (plate 44).

The expedition to this region in February, 1907, encountered a thermal spring, the water of which showed temperatures from 112° to 128° F. at the margin of the lake. The surface of the warm pools was matted with a felt composed of two algæ, *Phormidium tenue* and *P. tenuissimum*, both of which are identical with or nearly related to forms in the Hot Springs of Yellowstone Park. The water of the spring was also inhabited by a small rain-water fish. Specimens of this were submitted to Dr. D. S. Jordan, of Stanford University, who found that it belonged to a hitherto unknown species; and it was given the name of *Lucania brownii*, in honor of Mr. Herbert Brown, a member of the expedition. A dozen of these fish, taken from the spring, were placed in a vessel of water which cooled to air temperatures during the day and the following night without apparent discomfort to the animals. The water of the spring itself is highly charged with several salts, of which chloride of lime is one of the most abundant. It is to be seen, therefore, that this fish not only endures a water highly charged with salts, but is also capable of accommodating itself to great range of temperature. The entire spring is submerged to a depth of a half foot by the waters of the laguna at flood.

THE SAN FELIPE DESERT IN BAJA CALIFORNIA.

The western shore of the Gulf of California is made up of a continuation of mud flats and saline plains for some distance south of the mouth of the Colorado River. South of this formation the gravelly slopes and granite and volcanic ridges of the mountains come out to the shores, and here, to the leeward of the main ridge of the peninsula, are to be found some of the most arid conditions in North America (plate 45).

The central elevation consists of the mountain ridge which culminates in the peak of Calamahuie at an elevation estimated at 10,000 feet. To the eastward it breaks into lofty precipices and steep slopes which have not been surmounted between 30° 30′ and 32° 30′ N.

The lower coastal slopes are sandy and gravelly, the depressions and dunes near the shore furnishing suitable conditions for *Lycium torreyi* (plate 47) and *Parosela spinosa*, which latter becomes a tree 25 feet in height. *Ascelepias subulata* was abundant in clumps, and *Ditaxis serrata* grew on level areas. Other species which were characteristic of the lower levels were *Ibervillea* sp., *Croton californicum*, *Lupinus mexicanus*, and the curious *Frankenia palmeri*. The low alkaline pockets reached by the spring tides furnished conditions suitable for *Spirostachys occidentalis*. *Covillea*, with its enormous capacity of adjustment, extended from near the shore across the entire slope and up the granite mountains through a range of over 2,000 feet in elevation. The various portions of the slope between the sea and the first range of coastal mountains supported ocotillo (*Fouquieria splendens*), which attained its maximum height of 30 feet, palo verde (*Parkinsonia microphylla*), palo fierro (*Olneya tesota*), and *Gaertneria ilicifolia*. On an expedition to this place in 1904 a new copal tree was found, *Terebinthus macdougali* (plate 46), which also is now known to occur on the eastern shore of the Gulf, and which secretes a resin so copiously as to make a distinct deposit on the ground underneath the low-spreading branches.

The streamways leading down from the mountains were inhabited by a number of eriogonums and euphorbiaceous herbs. A few opuntias of the cylindrical arboreous type (plate 47), an *Echinocactus*, a *Cactus*, and a small *Cereus* were also seen. *Pilocereus sargentianus*, which is found on the mainland far southward, here reaches the greatest density yet observed, forming forests many acres in extent. Perhaps the most notable feature from a geographical point of view was shown by the presence of a great tree-cactus having the appearance of *Cereus pecten-aboriginum*. *Cereus pringlei* is known to be abundant, under the common name of "cardon" farther south, but this plant appears to agree with the former and makes a splendid picture in the arid landscape, finding here its extreme northern limit of known occurrence.

The large number of species with laticiferous juices was especially noticeable, but with the exception of the dozen cacti no plants with organs for storage of water were seen, a fact possibly connected with the extremely low precipitation and low water content of the soil at all times. Seeds of a *Cenchrus* were very abundant and were used by burrowing rodents as a means of fortification of the entrances to their burrows, in the same manner that the joints of the "cholla" are employed elsewhere.

A mountain to the southwestward of San Felipe Bay was climbed and a summit reached at an elevation of about 3,500 feet. The granite slopes supported a sparse vegetation of such types as *Cactus*, *Ephedra*, *Terebinthus microphylla*, *Asclepias albicans*, *Eriogonum inflatum*, *Yucca*, *Agave*, and *Opuntia*. So far as might be estimated by the instruments at hand, the mountain is probably the one on the hydrographic map of 1873–75 designated as a "sharp white peak 4,288 feet," which had not previously been ascended and still bears no name.

The rainfall is apparently distributed throughout the year, so that only a small proportion of the total is received within any month; furthermore, this distribution is irregular in any series of seasons, so that the native plants have but little opportunity of acquiring a rhythm of activity in response to the annual supply of moisture, a fact not without its influence on the general anatomical character of the plants.

Dr. Edward Palmer visited the Raza Islands, in the lower part of the Gulf, 200 miles northwest from Guaymas, in February, 1890, and noted that no rainfall had been received there for more than a year. Nothing can be hazarded as to the extent of the region with this extreme limit of aridity on the Sonoran side of the Gulf, except that it does not appear to include the western slope of the central range in Baja California, although no definite information is available. It is evident, however, that a further investigation is necessary to determine the exact meteorological status of this region, as well as the general character, derivation, and relationship of its flora. The extreme type of strict desert offered by the area in question points to the possibility of finding here the readiest solution of some of the more important problems presented by desert vegetation.

TUCSON, THE SITE OF THE DESERT LABORATORY.

In the original selection of Tucson as a laboratory site the following conditions were taken into consideration as being desirable:

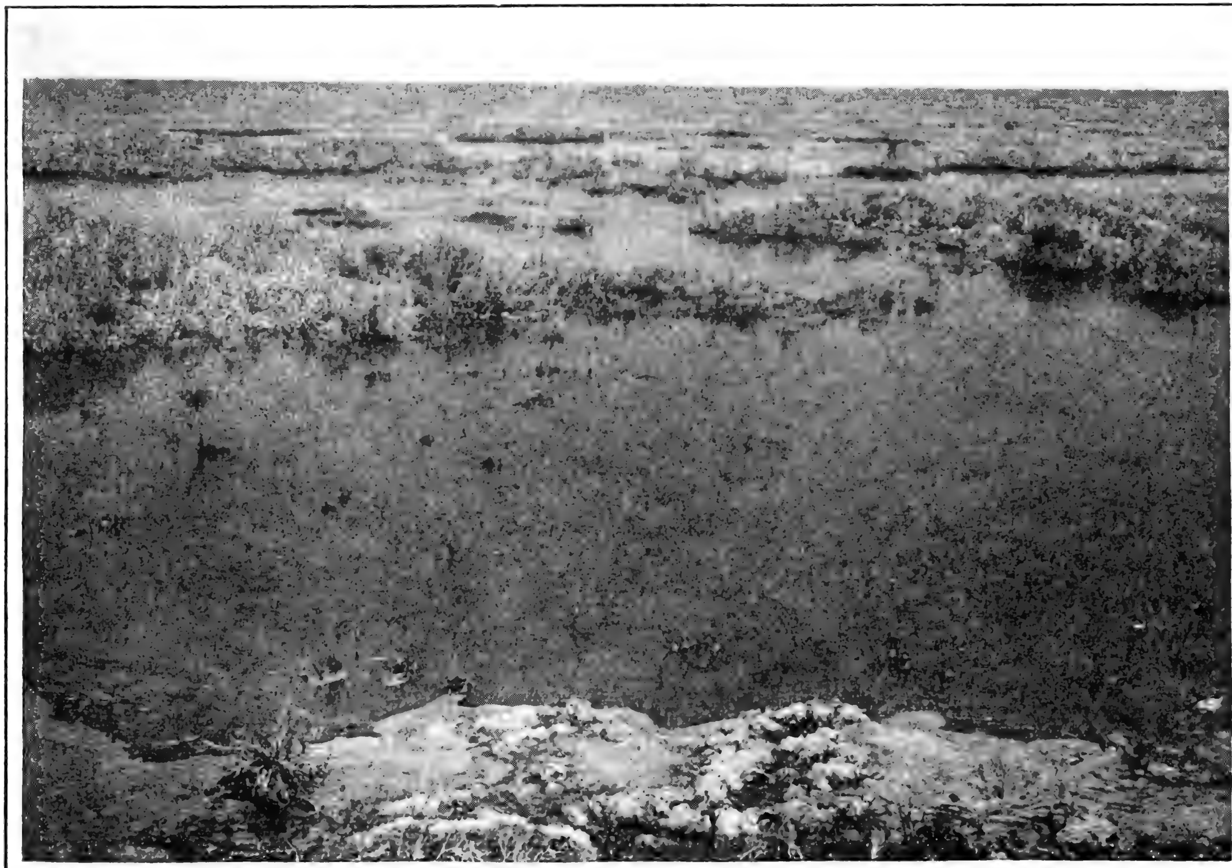
1. A distinctly desert climate and flora.
2. A flora as rich and varied as possible, while still of a distinctly desert character.
3. Ready accessibility.
4. Habitability.

Much of the arid region of the western United States is only partially or relatively arid and does not therefore contain those pronounced types of drought-resistant vegetation which it is the first object of the Laboratory to investigate. Such semi-desert areas are the western portions of Kansas and Nebraska, and the intramontane valleys of southern California. Another sort of location, to be avoided for a like reason, was a desert which was likely to be reclaimed by irrigation. The desert character of a small area, even though carefully reserved, might be seriously modified by seepage or other changes following irrigation development in the vicinity.

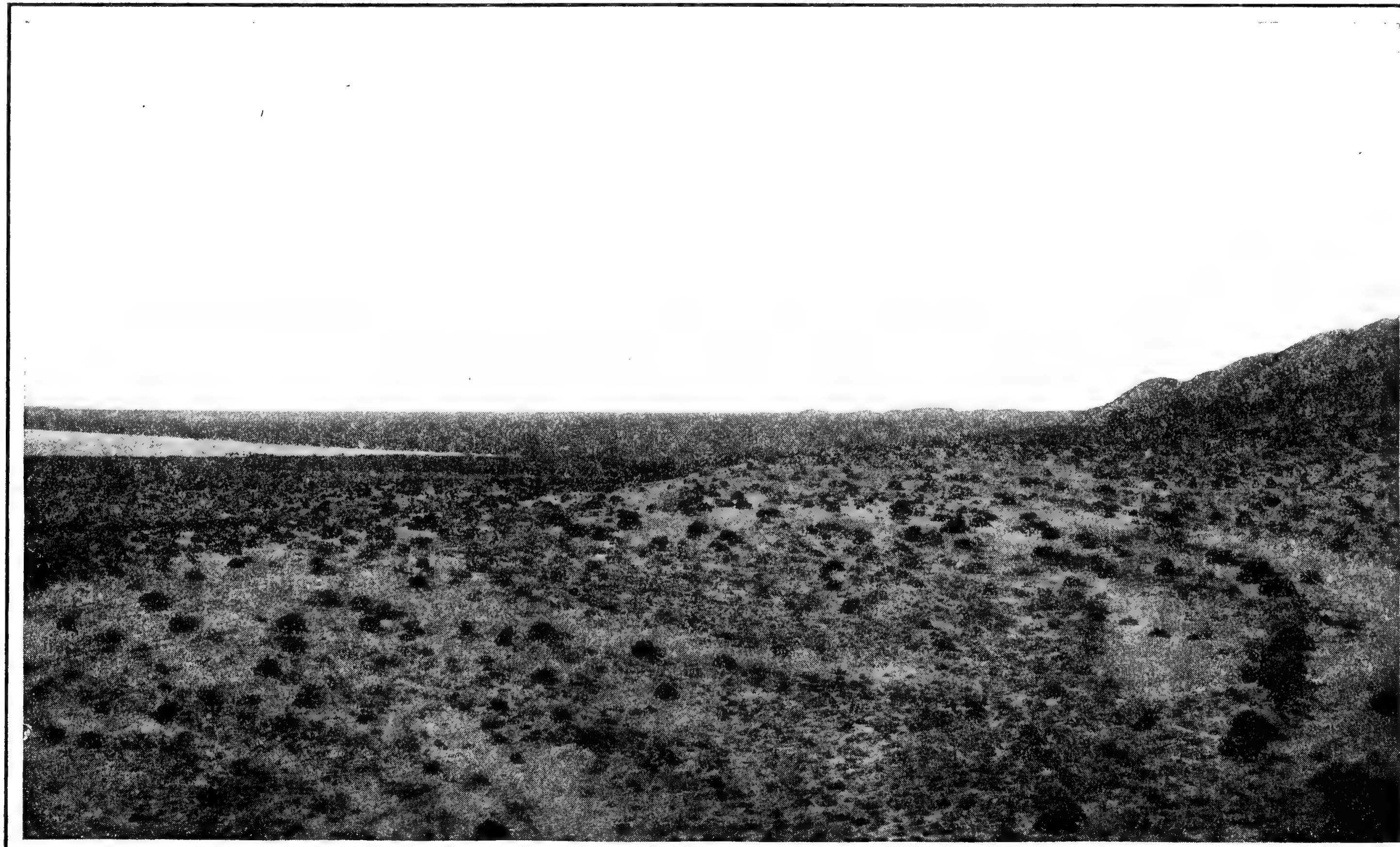
Some of our deserts, such as the Mohave, the Colorado, and the lower part of the Gila, are of such extreme aridity that only a small number of vegetative types occur in them. The same paucity of vegetative types is usually characteristic of any flat area of desert as distinguished from a foothill, canyon, or mountain area, a broken and rocky soil giving a wider range of temperature and moisture conditions of both soil and air, and furnishing lodgment for a greater variety of plants. The yucca plains of the Otero Basin in New Mexico and the sage plains along the Snake and Columbia rivers in Idaho, Washington, and Oregon are examples of deserts in which a pronounced paucity of woody species is correlated not with extreme conditions of aridity but with flatness of surface.

The conditions of living at some spots in the desert suitable in other respects for laboratory purposes are so severe as to offer an obstacle to the best work. A period of such extreme heat as occurs in summer at some points of very low elevation, as for example, along the lower Colorado River or in the vicinity of Guaymas, Sonora, or the difficulty of getting pure water and good food, has been an effective argument against some otherwise good locations.

Viewed from the standpoint of these primary requirements, Tucson has a climate of a thoroughly desert character, and a flora, including mountains and plain, rich in species and genera. In addition to its situation in the heart of the desert of Arizona, it is centrally located, both as to



Shore of Salton Lake in May, 1906, at which time the level was rising at the rate of 6 inches daily.



Ancient beach line of Salton basin denoted by terrace on right. Lake at maximum height, February, 1907. The vegetation is arranged in bands denoting minor beaches.

Pattie basin, looking northwestward across the Laguna Maquata. *Sesuvium sessile* or sea-purslane in foreground.

Eastern margin of Pattie basin and Cucopa Mountains. Sea-purslane (*Sesuvium sessile*) in the foreground, denoting recent level of the Laguna Maquata. Next to it is a zone of salt-bushes (*Atriplex*), then mallows and shrubs, while a zone of mesquite denotes the maximum level of the water.

position and transportation, with reference to the deserts of Texas, Chihuahua, New Mexico, California, and Sonora. The city has a population of nearly 22,000. It is situated on one transcontinental railway, and has good connections with others, as well as shorter lines to various regions of interest.

The business of the city and the conduct of its municipal affairs are largely in the hands of progressive Americans. The elevation of Tucson is 2,390 feet, while the highest of the mountains that surround the plain in which the city lies, the Santa Catalina Range, reaches about 7,000 feet higher. The University of Arizona, with its School of Mines, and the Arizona Agricultural Experiment Station are located at Tucson.

Not the least of the advantages of Tucson as a center for the activities of the Laboratory is the broadminded comprehension of the importance of the purposes of the institution evinced by the citizens, accompanied by an earnest desire to coöperate in its establishment. This appreciation was expressed in the practical form of subsidies of land for the site of the building and to serve as a preserve for desert vegetation, the installation and construction of telephone, light, and power connections, and of a road to the site of the Laboratory, about 2 miles from Tucson. The monetary value of these concessions is by no means small, and is much enhanced by the generous spirit in which they were tendered. This spirit of hearty coöperation has animated every organization in the city, and has enabled the Laboratory to gain control of a domain of 860 acres, of the greatest usefulness for general experimental work (plate 48).

GEOLOGICAL SKETCH OF THE REGION OF TUCSON, ARIZONA.*

PHYSIOGRAPHY AND GEOLOGY.

The valley of the ancient Pueblo of Tucson, in Pima County, Arizona, is an expanded portion of the valley of the Santa Cruz River. This stream has great historic interest as one of the most direct routes by which the early Spanish explorers made their way from Mexico into the then unknown regions of the north. At Tucson the river occupies the western side of the valley at the eastern base of the Tucson Mountains, and flows northward toward the Gila River, but sinks in the sand before reaching it. In seasons of little rain it is an insignificant stream, but is subject to great floods in the rainy seasons, which sweep away acres of rich alluvions and change the position of the main channel. The city of Tucson is built upon the right bank of the stream, and Tumamoc Hill, the site of the Desert Laboratory, is on the opposite or left bank.

The broad valley of Tucson has the appearance of being surrounded by mountain ranges on all sides. The view on the north and northeast is

* Prepared by request and contributed by Prof. Wm. P. Blake, Sc.D., LL.D., Territorial Geologist of Arizona.

bounded by the high and rugged range of the Catalina Mountains and their continuation southward known as the Rincons, on the east and south by the Whetstones and the Santa Ritas, on the southwest by the Sierritas, and west by the Tucson Mountains, of which Tumamoc Hill is an outlying spur. The Tortolita Mountains, a detached group of mountains lying west of the Santa Catalina Mountains, may be regarded as forming a part of the northern and western boundary of the valley. The region so apparently inclosed by mountains has an approximate breadth of 18 to 30 miles; a length of 40 miles; in the aggregate an area of over 1,000 square miles. The elevation is generally from 2,400 feet above tide at Tucson to 3,500 feet at the upper margin of the detrital slopes bordering the higher ridges.

From this upper margin, the ground descends toward the Santa Cruz River, and in the middle and lower portions constitutes what is known as the "mesa," apparently a great plain but in reality a continuous slope, modified locally by the erosion due to the rains and rivers. In traveling over the lower portion of the extended mesa, the horizon line appears perfectly level, like the horizon line at sea.

There is a great variety in the age and the composition of the rocky ridges, which, rising to a height of 5,000 feet or more above the general level of the mesa region, give a wide range of climatic conditions and of vegetation. In the season of winter rains in the valley, the summits receive a coating of snow which by gradual melting maintains a supply for springs and rivulets until the season of summer rains.

The principal streams of the region, in addition to the Santa Cruz, are the Rillito, at the foot of the Catalinas, north of Tucson; the Pantano Wash, rising in the Whetstone Mountains east of the Santa Ritas, receiving several accessions, including Rincon Creek and an underground flow of Davidson's Canyon.

The principal canyons of the south slope of the Catalinas are the Pima, Ventana, Sabino, Bear Canyon, Soldier's Canyon, and Agua Caliente. The Sabino with Bear Canyon drains an extended portion of the pine-forest region of the summit and has running water throughout the year, which it is proposed to utilize for power and water for the city of Tucson.

The Ventana Canyon is so named from the peculiar window-like opening through the rocks at the crest of the mountain. The opening is visible from Tucson.

THE SANTA CATALINA RANGE.

The Santa Catalina Mountain range is one of the most prominent and picturesque of the central mountain system of Arizona. It presents a bold rocky front towards Tucson, and rises to an altitude of 9,125 feet in Mount Lemon and to 9,225 feet in Mount Rice. Its general trend is northwest and southeast. Considered together with the Graham Mountains, a high and nearly parallel range farther east, they represent a large part of the southward continuation of the Bradshaw Mountains of Central Arizona.

The central nuclei of these ranges consist of crystalline rocks, chiefly granitic and gneissic.

The rock formations on the southern side of the Catalinas, toward the valley of Tucson, are for the most part pre-Cambrian gneiss and mica-schists in tabular form, regularly stratified and with included sericitic schist, all believed to represent some of the oldest rocks known, equivalents of the ancient Huronian, the Keweenawan, and Laurentian formations of Canada.

The complete penetration of the schistose slates by veins and layers of potash or soda feldspar, forms what is known as "augen-gneiss," so called because of the many white protuberances on the surfaces. This rock, particularly near the mouths of Sabino and Bear canyons, can be broken out in tabular masses well adapted to constructive purposes. It also can be quarried in prismatic or post-like blocks from 3 to 4 feet long, such as were utilized by the prehistoric people for foundations of houses by setting them upright in the ground, as may be seen in the remains of an extensive village at the mouth of Bear Canyon.

Pre-Cambrian gneissic rocks are also largely developed on the northeastern flanks of the Catalinas, and are there associated with highly laminated mica-schists; the Arizonian, a formation largely developed at several widely separated localities in southern Arizona, notably at Pinal and the Salt River Valley. These schists are characterized by extreme foliation and sharp angular plications presenting zigzag lines upon exposed surfaces.

Here also, on the northeastern side of the Catalinas, we find Paleozoic strata resting uncomformably upon the crystalline schists of the pre-Cambrian, or upon a broad area of coarse granite as at Oracle and at the sources of the Canada de Oro on the northeast side of the range.

The foundation granites are penetrated by great dikes of diorite which, coming in contact with limestone of a dark bluish-gray color, have changed it to a crystalline white marble, seen to good advantage at Giesman's Camp and Marble Peak. Copper ores are developed along the contact, notably at the Apache Spring and Leatherwood's Camp.

DEVONIAN ROCKS.

Between the Southern Belle Canyon and Pepper-Sauce Gulch, a high and long ridge extending eastward and named Coral Ridge is made up of quartzite, limestone, and shaly limestones in which there is a bed of corals and shells of Devonian age. These fossils are interesting, not only as evidence of the geological age of the rocks and records of the life of that early period, but for their wonderful preservation in every detail of structure. This preservation is due to the permeation of the rock by silicious waters which have changed the organized structures from carbonate of lime to silica, while the investing, or surrounding, limestone remained unchanged. The fossils thus became silicified and then, being less soluble than the limestone, are left by the weathering standing out above the general surface in bold relief.

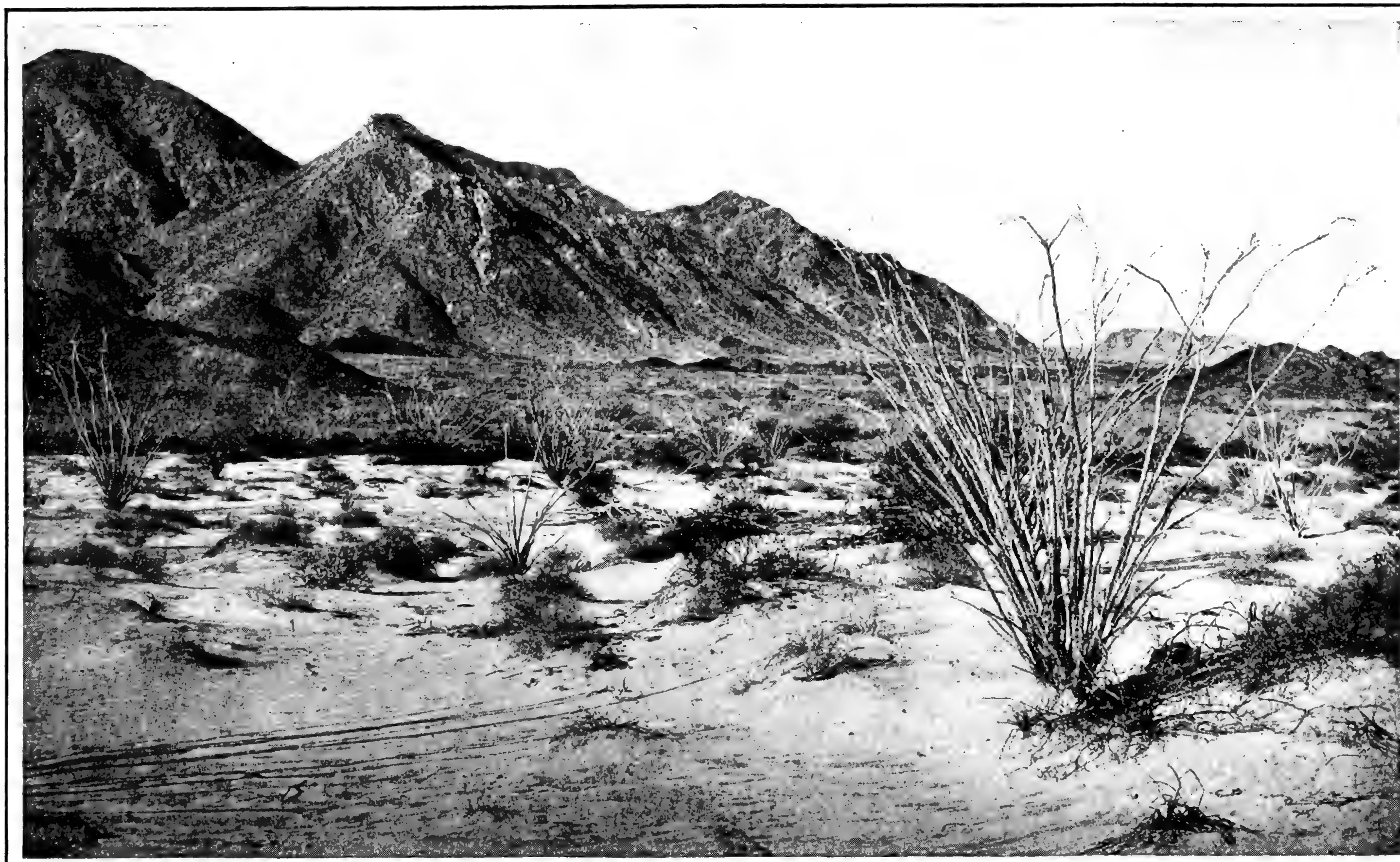
Silicified fossils in limestone are common at many localities in Arizona.

A fine section of the stratified rock formations of the northern end of the range is found along the Southern Belle Creek, which extends from the summit of the range eastward. The strata are uplifted and dip eastwardly at an angle of about 15 degrees. The series consists of regular strata of red sandstone and shale, quartzites, sandstones, and limestone, resting upon diorite at the west end, where also we find a strong vein of auriferous quartz traversing the red rock approximately parallel with the contact. At the eastern end of the section strata of sandstone and limestone abut upon granite and are much altered in composition. These limestone beds are the upper members of the series of the section and are probably Devonian, as indicated by beds of corals. The underlying strata of sandy shales are distinctly fucoidal. The most prominent strata of the series are the massive white quartzites, with repeated outcrops due probably to faulting. The red shales of the lower series pass into beds of red sandstone of compact and even grain, regular freestone, suitable for buildings. The underlying diorite penetrates this series of shales and sandstones and is itself underlaid by the coarsely crystalline porphyritic gray granite which is largely developed around the northern portion of the Catalinas, extending to Oracle and beyond. It has a wide extension toward the east and north, reaching nearly to the San Pedro River, and on the west it extends to the Canada de Oro, where strata of quartzite and limestone rest against it. At and near Oracle the granite weathers into huge boulders of decomposition, giving a very picturesque and diversified surface overgrown by groves of evergreen oaks.

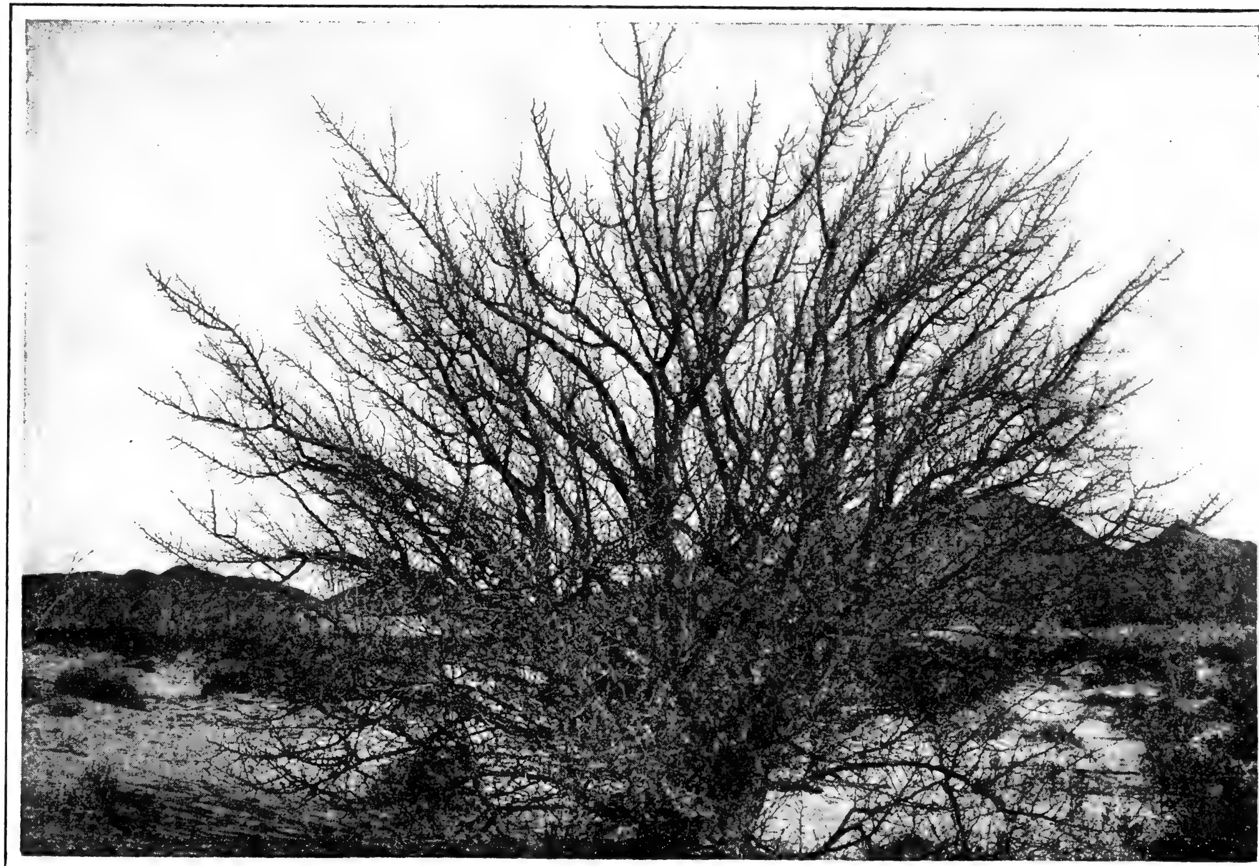
There are several localities of remarkable conglomerate in the northern and central portions of the Santa Catalinas. The component pebbles are chiefly from quartzite; they are all much rounded and show the violent action of currents and waves indicative of shallow seas and insular conditions in remote geologic time.

THE RINCON RANGE.

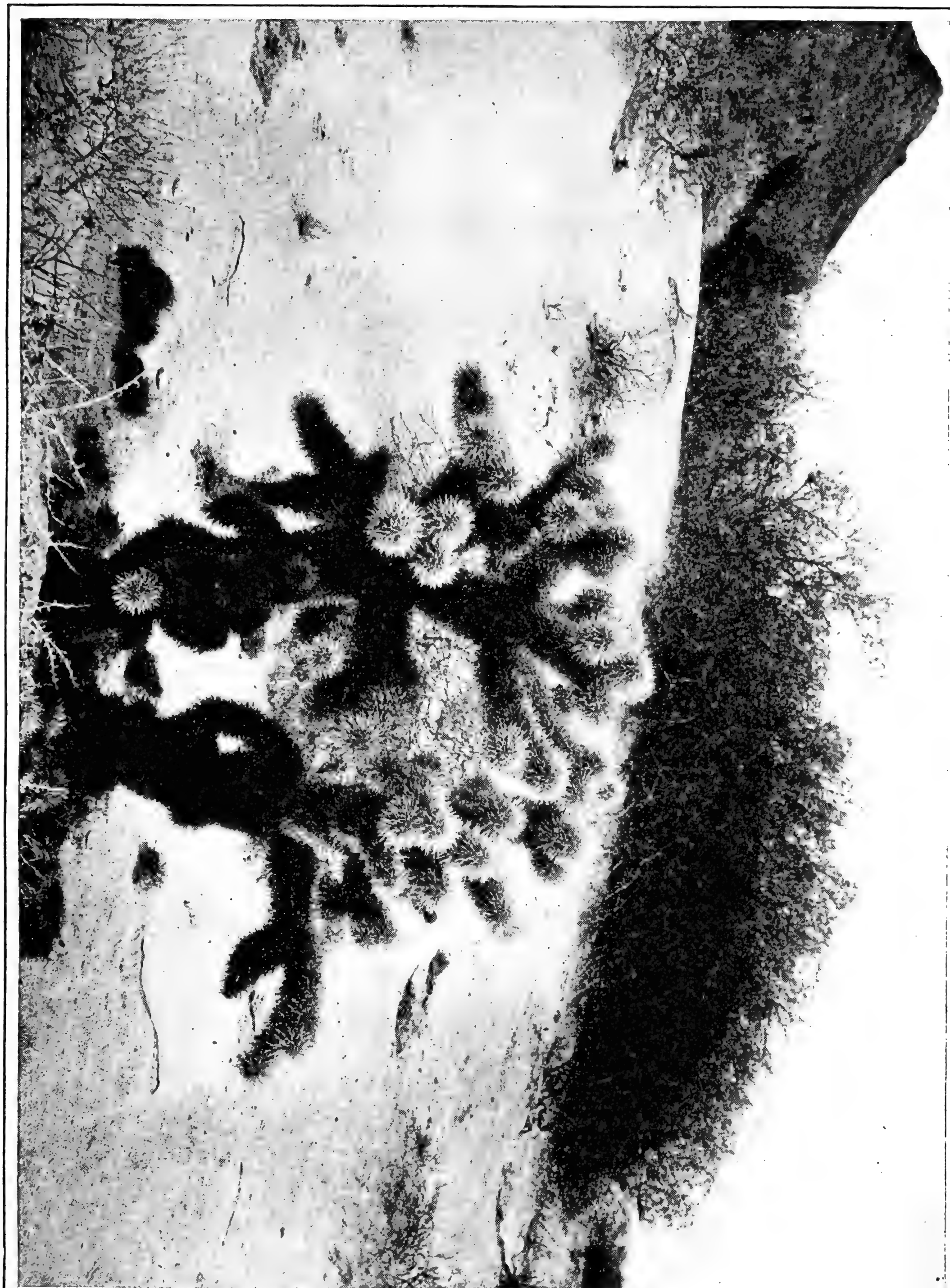
In the southern prolongation of the Catalinas known as the Rincons the central and higher portion consists of gneissic rocks like those of the Catalinas, but toward the railroad pass to Benson these crystalline rocks are flanked by an extensive development of Paleozoic strata, chiefly quartzites, shales, and limestones uplifted and contorted, and underlaid by a coarse granite. Silicified corals abound in places and indicate a



Desert of San Felipe de Jesus, Baja California. Ocotillo, creosote-bush, chamiso, and copal-trees.



Copal-tree (*Terebinthus macdougali*) of desert of San Felipe.



Opuntia bigelowii growing on sandy beach above high water, Bay of San Felipe de Jesus. *Lycium torreyana* in background.

Devonian horizon above the basal quartzites, which are probably Cambrian in age.

The plutonic rocks are represented by intrusive dikes traversing the older crystallines. There is good reason to believe upon stratigraphical and lithological evidence that the Carboniferous and the Jura-Trias series and later Secondary rocks are developed in the region between Vail's Station and the summit of the railway pass leading over to the valley of the San Pedro.

THE VALLEY OF THE SAN PEDRO RIVER.

The geographic and geologic relations of the valley of the San Pedro to the Tucson region are such as to require more than a passing allusion. This valley east of the Santa Catalina Mountains was once the bed of a lake-like or estuarine sheet of water, described in 1902 and named Lake Quiburis.*

The San Pedro River, anciently the Quiburis, though in times of drought a small and insignificant stream, drains a considerable area, and is bordered throughout its course by mountain ranges forming a valley from 10 to 20 miles in width and nearly 150 miles in length. The chief ranges on the right bank, or eastern side, are the Mule Mountains (Tombstone), the Dragoons, and the Galiuros; and on the west, the Huachucas, the Whetstones, Rincons, and Santa Catalinas. The valley is in general parallel with that of the Santa Cruz, the next great valley to the westward, and with the Sulphur Springs Valley eastward. This river has cut its way through extensive horizontal beds of unconsolidated light red clays and sediments of great thickness, often terraced by the river erosion and extending high up on the sides of the bordering mountains. One of the best cross-sections is found on the line of the Southern Pacific Railway, which crosses the valley nearly at right angles to its course at Benson.

Benson, in the bottom of the valley, has an altitude of 3,576 feet above the sea. The river is about 50 feet lower. The lacustrine clays rise from this point on each side to the height of about 3,000 feet. The exact limit of clay deposition is not easily determined. It appears most probable that the height of the water was about 4,000 feet above the tide. Wells bored in the valley pass through similar sediments for 500 feet without reaching bed-rock.

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*Lake Quiburis, an Ancient Pliocene Lake in Arizona. *University of Arizona Monthly*, vol. IV, No. 4, February, 1902. A paper read by invitation at the meeting of the Cordilleran Section of the Geological Society of America at Berkeley, California, January, 1902.

"Rio Quiburis, now more generally known as the San Pedro, was explored in 1697 by a party of 20 men and a sergeant, commanded by Cristobal Martin Bernal, who was joined at Quiburis Rancheria by another party under Kino. The united force, with 30 Indians, marched down the river to the Gila, thence to Casa Grande and returned up the Santa Cruz." (Bancroft's Works, vol. XVII, pp. 355–356).

The extensive strata of diatomite and volcanic ash, upward of 100 feet thick, are cut through by the San Pedro, exposing a succession of snow-white cliffs.

THE SANTA RITA RANGE.

The elevated and picturesque range on the east and south side of the valley of Tucson is noted for its rugged outline and sharp summit, known as Wrightson's Peak or Old Baldy, rising to an elevation of 9,432 feet, on which, in the rainy season, clouds are the first to gather like storm signals, and in the winter season its peak is the first to become whitened with snow.

This range extends in a general northerly direction from Patagonia, on the Sonoita, in Santa Cruz County, to the Rincon Mountains, a distance of nearly 40 miles. It is characterized by a great diversity of rock formations—granitic, volcanic, plutonic, and sedimentary.

Its northern portion consists of a broad development of Paleozoic strata in a succession of hills and ridges eastward to the Whetstone Mountains, which border the valley of the San Pedro. Southward toward the Box Canyon the strata, consisting chiefly of red shales, limestone, and a basal quartzite, are uplifted at high angles and form the crest of the range, resting upon granite and facing the valley of Tucson, as at Helvetia, where copper ores are mined near the contact of the strata with the granite. The quartzites are probably Cambrian. Their outcrops form a sharp ridge with a serrated outline, as seen from the valley of Tucson.

The Box Canyon is a notable geologic feature, bisecting as it does the entire range from east to west like a gigantic vertical cleft, and probably follows an east and west faulting plane. It drains an extensive area on the eastern side toward Rosemont and Greaterville, but delivers its waters into the Santa Cruz Valley on the western side. It exposes the edges of inclined strata right and left, but especially on the south side, where we find the succession of strata to be approximately as follows:

At the base is a massively brecciated granite, with small veins of gold-bearing quartz. Resting upon this granite and dipping east we find a conglomerate and coarse sandstone succeeded by red shales, sandstones, and limestones and a conglomerate of limestone pebbles resembling a conglomerate in the Huachuca Mountains. The limestone beds near Greaterville contain fossils of the Devonian age.*

South of the Box Canyon the structure of the Santa Rita becomes much more complex. The Paleozoic sandstones and limestones resting upon a granite foundation give place to granite hills and rocks of volcanic origin chiefly in the form of rhyolitic tuffs, consolidated ashes, agglomer-

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*For a list of fossils and other data concerning this section of the range reference is made to a paper in the *American Geologist*, vol. XXVII, March, 1901.

ates, and porphyries. These formations of volcanic origin appear to constitute the bulk of the main range south of Greaterville and to extend to the very summit of the highest peak.

The detrital bordering slopes so characteristic of the mountain ranges of the Southwest are well developed on both sides of the Santa Rita, not alone toward the Santa Cruz on the west, but on the eastern side north and south of Greaterville, where there are extensive detrital deposits of great thickness and regularity of slope. This formerly continuous slope is now cut through by several channels due to modern drainage, and these trenching channels, or washes, of reassorted gravels and coarse detritus of the ancient slopes are found to be gold-bearing and have been largely worked.

On the western side of the Santa Ritas, south of Box Canyon, there are several deeply cut valleys. A wide and deep valley between Old Baldy and Mount Hopkins is drained by Madera Creek, which rises in Santa Cruz County.

The celebrated large ring meteorite known as the Irwin-Ainsa meteorite, now in the National Museum at Washington, was found at the mouth of this canyon.

Still farther south Montosa Creek, nearly opposite Tubac, cuts through the most western of the rock exposures at the head of the slope and reveals strata of compact blue limestone trending northwest and southeast and dipping westerly about 45°. It contains obscure brachiopod fossils. It is underlaid conformably by a thick series of red shales which in turn rest upon a pegmatoid granular granite with very little or no mica. A diagrammatic sketch section across the cropping shows the relations of the rocks.

There are intrusions of porphyry in dikes which have changed portions of the blue limestone to white and the red shales in great part to green epidote associated with beds and seams of specular iron. These shales are estimated to have a thickness of over 500 feet. They become more sandy and granular, like sandstones, near the granite. They may be known by the name of the locality, as the Montosa shales. The pegmatitic granite, against which these formations lie, contains in places pyritous impregnations without distinct veins. These sulphides on decomposing give rusty outcrops and gold is liberated in fine grains.

Montosa Creek brings down from the high ridges a great variety of crystalline rocks, in boulders, such as granite, syenite, gabbro, and feldspar-porphyry. At the south end of the higher parts of the range there is an extensive development of intrusive diorite with many mineral veins and mines, known since the occupation of the country as the Saléro. This diorite is partly overlaid on the east and south by the extensively developed stratified tufas of the Santa Rita series. They consist of granular mixtures, agglomerations, and breccias of rhyolitic volcanic porphyries, pumice, and volcanic ash.

At the base of the highest peak of the Santa Rita and underlying the tufas, there is one of the most remarkable beds of large rounded boulders of porphyry known. It is exposed to view for a mile or more by the excavation of an aqueduct for the conveyance of water for the placers at Greaterville. The boulders vary in size from a few inches to a yard or more in diameter. They are of various colors, are closely compacted, and form a thick bed at a low horizon in the series and may be regarded as evidence of stupendous cataclysmic action.

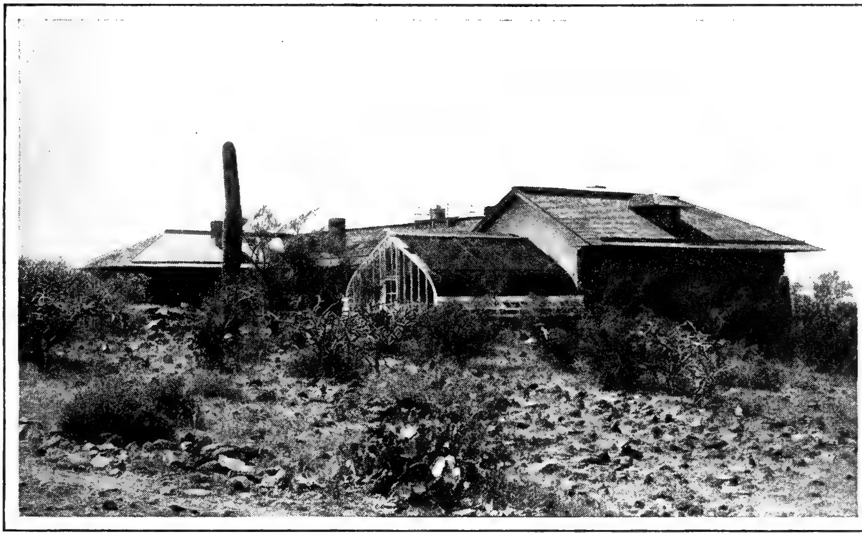
At Poston's Mountain and Mount Allen and in the Grosvenor Hills, southwest of Saléro, there are remarkable strata of snow-white tufaceous flagstones so thinly and regularly stratified that slabs yards in area and only a few inches thick may be broken out. These tabular masses are well fitted for pavements or for building walls. They show ripple-marks on their surfaces and little annular projections around what are seemingly little pebbles which had fallen upon the surface of the rock when it was in a plastic state or in a thick creamy consistency left by a receding tide. The whole series gives evidence of deposition in shallow water, and this is shown elsewhere by regular bedding and stratification of the Santa Rita tufas.

SANTA RITA TUFAS.

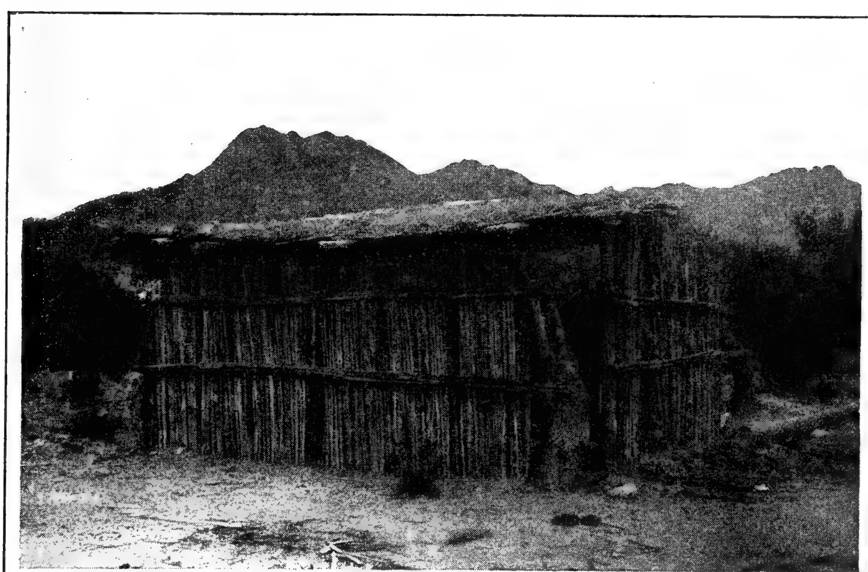
At the peculiar outcrop of rock west of the arroyo of Josephine Canyon and at the head of the great slope down to the Santa Cruz at Tubac the tufas from the Santa Rita are in massive and horizontal beds, regularly stratified and made up of granular and generally rounded fragments of rhyolites and porphyries cemented together with volcanic mud or volcanic ashes. The regularity of the stratification and the average composition is such that pillars are left standing by the weathering away of the surrounding rock, and hence the name Los Pilares. The formation appears to have a wide extension. It underlies the ancient detrital slope which is spread out over it, except where removed by stream erosion.

The high peak of the Santa Rita with its enormous flanking ridges of volcanic ejecta is certainly a monumental relic of a great center or region of volcanic activity from which an immense volume of broken rock, rhyolites, and ashes was spread far and wide. No distinct crater has yet been found, but there is a broad area between the higher peaks which has not yet been explored. We are at least certain that in the Santa Rita we have an ancient uplift of a thick series of tufaceous and rhyolitic deposits at higher levels than in other localities in the region.

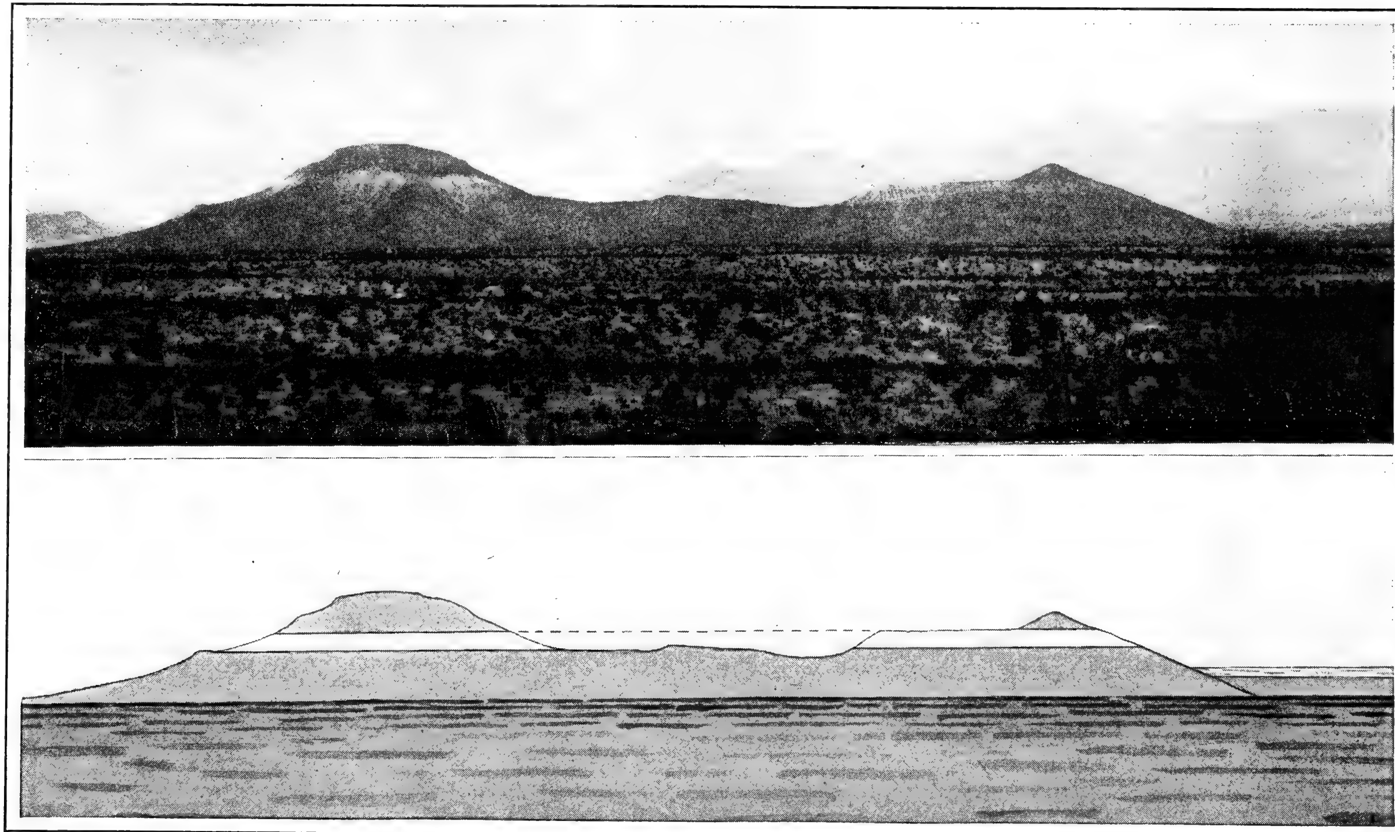
The evidence is conclusive that the greater part of this vast mass of volcanic ejecta was spread under water. We not only have the stratification of the beds of the Santa Rita, but of its many spurs and of the distant ridges of the Grosvenor Mountains, where the white feldspathic flagstones are covered with ripple-marks.



Desert Botanical Laboratory.

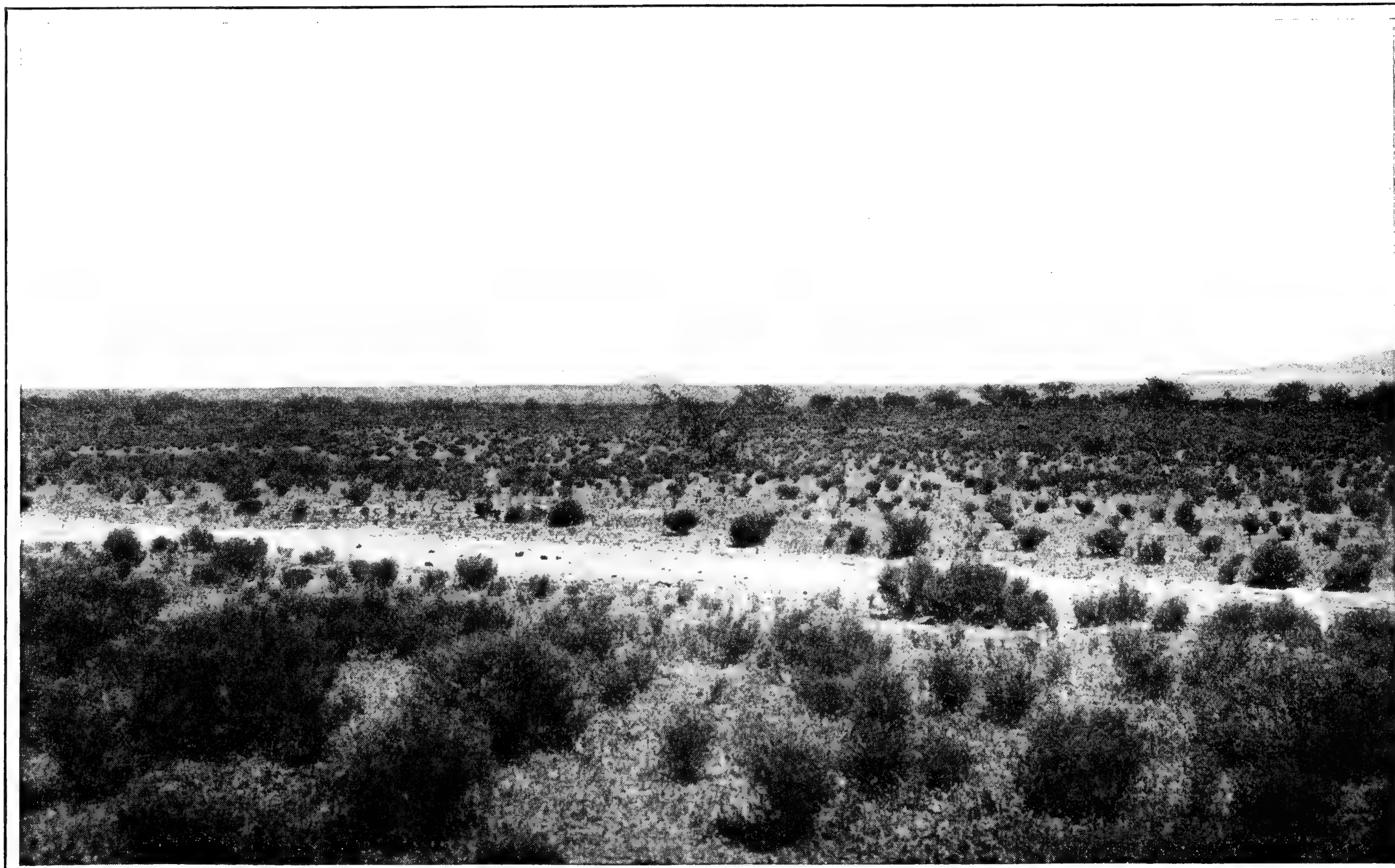


Papago house built of ribs of saguaro (*Cereus giganteus*) with corner-posts of mesquite (*Prosopis*), near Desert Laboratory.



Tumamoc and Sentinel Hills from the southward, with the Santa Catalina Mountains in the distance across the valley of the Santa Cruz River. Vertical section in lower figure.

Western end of Santa Catalina Mountains, showing flanking slopes.



Slope of the Sierritas as seen from the Tucson Mountains.

We can not doubt that the enormous deposits around the Santa Rita are of remote antiquity, probably pre-Tertiary, antedating the continental uplift at the close of the Miocene. They may be known as the Santa Rita tufas.

THE SIERRITAS AND THE TUCSON MOUNTAINS.

The mountains forming the southwestern limit of the valley and on the right bank of the Santa Cruz River are largely granitic, with strata of subcarboniferous limestone and shales partly metamorphosed and copper-bearing. The Twin Buttes copper mine is found here, and other mines at Mineral Hill, and at the Azurite Camp, all in association with porphyritic dikes and garnetiferous veins, the result of alteration of the limestone.

The Sierritas give place farther north to the Tucson Mountains, composed in great part, opposite Tucson, of volcanic tufas and agglomerates, forming hills of very picturesque and uneven outline, as may be seen by reference to plate 51, made from a photograph taken a mile or two south and west of the Desert Laboratory. These tufas are regularly stratified and are upraised. They are probably pre-Tertiary or Cretaceous in age, the equivalents in this respect of the stratified tufas of the Santa Rita Mountains on the opposite side of the valley. Similar tufas are found as far south as the Cerro Colorado and beyond toward Nogales and Sonora, Mexico.

The prolongation northward of similar rhyolitic tufas is found beyond Tucson, especially in the foothills bordering the Santa Cruz, where there are extensive outcrops of stratified tuffs, rhyolites, and andesitic rocks which are uplifted at various angles.

At the Pictured Rocks the stratification is very distinct, with ripple-marks upon the surfaces of the slabs of rock, which have the composition of porphyritic andesite. These rocks are near the Old Yuma Mine, opened upon a quartz-vein bearing lead-ore and gold.

The western portion of the Tucson Mountains is made up in part of ancient sediments of Paleozoic age—limestones, sandstones, and shales. Blue limestone, probably lower Carboniferous, much traversed by flint, crops out in Snyder's Mountain, and is quarried and burned for lime. There are plutonic rocks in great variety in the form of dikes.

A fine-grained gray andesite in the hills west of Tucson affords an excellent building stone, used especially for rubble walls.

The extensive rhyolitic intrusions north and south and on both sides of the Santa Cruz Valley command attention as marking a long line of disruption and faulting of the crust, accompanied, no doubt, by crustal movements at different periods, parallel to the axes of the uplift of the Paleozoic strata. The more distinctly characterized and more fusible volcanic rocks, less viscid than the older rhyolites were, are of a later age and are present in the form of basaltic lavas spread out originally in great sheets in igneous outpourings upon the upturned edges of the rhyolites and other rocks, as, for example, in the Galiuro Mountains east of the Catalinas. Remnants and detached areas of such floods of liquid lava are found at the western side of the Babiquivari Valley, at the Mission of San Xavier, 9 miles south of Tucson, and at the Sentinel and Tumamoc hills opposite the city.

TUMAMOC.

The Tumamoc group as seen from a point a few miles north shows two summits, one rising in conical form from the Santa Cruz and known as Sentinel Peak; the other has a broad, flattened summit of greater area and is connected with the peak by a long, comparatively level ridge. The flat-topped Tumamoc Hill is formed largely at the surface of loose rough blocks of basalt anciently used by the aborigines for the construction of a rude fortification as a place of refuge when driven by roaming bands from predatory tribes from their fields and dwellings on the fertile bottom-lands of the Santa Cruz.

A great number of partitions of rude apartments inside of the circumvallation indicate that many people made their homes, for a time at least, upon this rocky summit, 700 feet above the valley.

The buildings of the Desert Laboratory are upon the northern slope of this hill, about half-way down and at an elevation of 329 feet above the Santa Cruz River, and, like the prehistoric fortress, are built of the loose boulders of basalt which abound upon the surface.

These basaltic hills, of which Tumamoc is one only of a series, present to the eye a black, barren rocky surface, with but little visible soil or earth for the support of the scanty but peculiar vegetation which finds a foothold in the clefts and crevices.

That these rocks are volcanic in origin there is no doubt, but without any crater or indication, by form, of an extinct volcano. There is evidence in the structure and the interstratification of beds of tufa, and in the amygdaloidal interior structure of the basalts, of an igneous outflow from some higher ground, but satisfactory evidence of the source has not yet been found.

The basalts of Tumamoc and of Sentinel and southward to the Mission present a variety in chemical composition and structure, giving evidence of flows or outpourings of different ages. These rocks have been carefully studied petrologically by Prof. F. N. Guild, of the University of Arizona, who finds three varieties: (1) Fine-grained olivine basalt; (2) porphyritic basalt with feldspar crystals; (3) quartz basalt.

In places, notably in the quartz basalt, on the southern base of Sentinel Peak, the amygdular cavities are filled with silica in the form of agate and also in the form of geodes.*

**American Journal of Science*, vol. xx, October, 1906.

The photograph in plate 49, together with the diagrammatic sketch section, will serve to give an idea of the general outline of these hills and to show their geologic relation to the alluvions of the Santa Cruz River.

This section also shows the interstratification of a nearly horizontal bed of volcanic tufa capped by a basalt on both Tumamoc and Sentinel hills. This, which was doubtless a continuous bed, has been largely swept away by denudation, as indicated by the broken lines. The remaining portions of this tufa bed, protected by the overlying hard basaltic rock, were evidently spread out in the condition of plastic mud upon a foundation layer of basalt. It is now solidified and is sufficiently firm to be extensively used for building purposes. Its color is white or gray and it is thus in strong contrast with the black of the basalt.

There are several quarries of this tufa around Tumamoc Hill and at other places in this volcanic group. A quarry on the Quijotoa road near the Mission of San Xavier yields a light-gray, nearly white, building stone of excellent quality for construction. It supplied the stone for the large dormitory building at the university. This stone is essentially silicious in composition and includes in its substance angular fragments of rock, evidently broken by violence from their parent sources and borne along in the viscous mass. In the same rock we find interesting orbicular concretions consisting of concentric layers of different colors and chemical composition,* giving evidence of internal chemical changes around fragments of soluble rocks.

The tufa bed at Tumamoc is about 25 feet thick, so far as exposed. It has a slight easterly dip and passes under and through Sentinel Hill, forming the nearly level ridge extending between and connecting the two hills. It is underlaid by a bed of sandy material consisting of a mixture of grains of clear glass and fragments of feldspar. This vitreous sandy bed, some 6 feet or more in thickness, is in turn underlaid by a distinctly stratified body of small black, pebble-like but crystalline fragments of rhyolitic basalt in an earthy magma. It is a soft, unconsolidated substratum, which being easily removed by erosion hastened, by undermining, the downfall of the overlying basalt, which once covered the entire area of the tufa. This process of degradation, especially during partial submergence, would explain the origin of the great accumulation of boulders over the surface of both Tumamoc and Sentinel hills. The boulders are often so thickly laid down as to cover the solid basalt from view. In many places they are cemented together by caliche which has been deposited around them, forming a cemented aggregate of great hardness. The boulders have for many years been drawn upon for building purposes, particularly for foundations in the city. The walls of the Desert Laboratory are built of them.

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*For a description of these orbiculites, see *Transactions American Institute of Mining Engineers,* May, 1905.

The basalt is now also being largely utilized for broken stone for the streets and pavements of Tucson and for concrete constructions.

In addition to the amygdaloidal structure of portions of the massive basalt, there is a remarkable development of laminated or schistose structure, apparently the result of pressure and flow or of shearing stress. The northern slope of Tumamoc exhibits a succession of transverse subordinate or low ridges some six in number, as viewed from the Hospital road approximately parallel in direction, but largely of the vertically laminated portions. One of the more striking examples of such laminations is found on Sentinel Peak. The laminated structure is in curves nearly vertical at the cropping and then inclining downward till they become nearly horizontal. The layering is very distinct in the gray basalt of the lower summit of the peaks. The trend or direction of the layers is about north 70° east, the result apparently of the local direction of the flowing mass.

THE MOUNTAIN SLOPES.

The mountain ranges about Tucson, and generally in the Southwest, are separated by broad valleys, commonly regarded as plains or mesas, but in reality sloping surfaces stretching outward and downward at a gentle inclination from the rugged ridges of the mountains. The topography changes suddenly from rocky precipitous acclivities to gently inclined surfaces of gravel and loosely aggregated material—the detrital accumulations washed out from the ridges by streams and floods. These deposits consist of boulders and fragments of the rocks, broken up and partially rounded, together with gravel and sand and argillaceous layers all rudely stratified. These materials are coarser and heavier near the mountains than at some distance away, where they become more waterworn and are finer, but large boulders and coarse gravels are distributed to great distances, even miles away from their sources, and form thick deposits evidently of great age.

The great horizontal extent of these slopes, together with their regularity and evenness of outline, bounding the vision like the horizon line at sea, form, with the exception of the mountains, the most striking of the scenic features of the Southwest. They constitute the greater portion of the surface area, estimated together with the alluvions at not less than nine-tenths of the whole.

The angle of inclination is greatest near the ridges, but for the middle and lower parts of the slope, from 80 to 100 feet per mile is a common gradient.

Although the outlines of these long slopes form such conspicuous features of the landscape in the Southwest, it is difficult to illustrate them by photographs, as they are so extensive and panoramic, but an attempt has been made, with the results shown in plates 50 and 51.

Plate 50 represents a familiar example of a flanking slope in full view from the Desert Laboratory and from Tucson, on the south side of the Santa Catalina Mountains. It shows the western end of the range and a profile view of the upper portion of the western slope. The continuous slope along the base of the range, being inclined in the line of vision, is shortened to the view and is not so distinct, but represents a breadth of about 4 miles from the upper margin down to the Rillito, a difference of elevation of about 1,000 feet. The course of the Rillito is shown by the line of white bluffs on its right bank where it has cut across and eroded the slope.

It is practically a continuous slope, along the whole length of the range, for nearly 15 miles, though much eroded, trenched, and cut away by floods and by the Rillito. This erosion is well shown by the contour lines on the map of Tucson Quadrangle by the U. S. Geological Survey.

The Tortillita Mountains are also bordered by slopes of great evenness and extent on all sides. The angle of intersection of the slope with the ridges has apparently the same altitude as on the Santa Catalinas. The ridges, however, do not compare in height or bulk with the Catalinas, but are formed of similar rocks.

The Santa Rita Range is similarly flanked by the gravelly deposits. The slope toward the Santa Cruz is remarkably regular and is well shown by the parallelism of the contour lines upon the map of the Santa Rita Quadrangle issued by the U. S. Geological Survey. The length of this slope from Helvetia to the river near Garcias Ranch is 13 miles and the rise is 1,500 feet, averaging 116 feet to the mile.

In the region of Tucson the upper or higher margin or limit of the detrital slopes has a general level or altitude of between 3,500 and 4,000 feet. In the Santa Catalinas it corresponds approximately to the 3,500-foot contour line, and in the Santa Ritas to that of 4,000 feet. The Catalina slope is much reduced by erosion, but the general uniformity of altitude of the intersection of the detrital accumulations with the rocky ridges is very distinctly visible from all parts of the valley.

The upper limit of detrital deposits is higher on the east side of the Santa Catalinas and of the Santa Ritas than on the west side. It no doubt bears a close relation to and was dependent upon the amount of erosion and of detritus washed from the mountains. The fan-shaped structure often seen in arid regions and the scalloped outline of the intersection with the ridges, due to the greater accumulation of detritus at the mouths of the canyons, are not strongly in evidence anywhere in the region, the detritus having been very evenly distributed along the ridges between the canyons.

The greatest slope of least grade of the Tucson Valley is that from Tucson up to Vail's Station and Pantano, a distance of approximately 28 miles and a rise of 1,150 feet, an average of a little over 41 feet per mile.

The Southern Pacific Railroad is built upon this slope. For the upper part of the slope, or from Vail's to Pantano, the grade parallels the Pantano Wash, which cuts its way through the slopes from the Rincon Mountains on the north and the Empire Mountains on the south, and is bordered by high terraced banks on its way to the junction with the Rillito at Old Fort Lowell.

The Sierritas Range presents one of the best examples of long, continuous slopes flanking it on all sides, but particularly on the east, north, and west. The most accessible and best-known portion of the slopes is found in the gradual rise of the ground from near the Mission of San Xavier to the base of the ridges, a distance of about 10 miles and a rise of about 1,000 feet, or about 100 feet to the mile, but apparently a plain.

The Sierritas slope as seen from the Tucson Mountains a few miles south of Tumamoc Hill is shown by plate 51.

MATERIALS OF THE SLOPES.

The sections of the higher detrital slopes shown by the banks of arroyos all show approximately the same general composition and arrangement of the detritus in rude strata. The boulders and gravels correspond in mineral composition to the nature of the rocks in the ridges from which they were derived. Thus the slopes from the Catalinas and the Rincons are made up of granitic and gneissic detritus and those from the Santa Ritas and Tucson Mountains of tufaceous and porphyritic materials. The alternation of coarse and fine materials, such as gravels and sandy clays, is found in all the sections and is regarded as significant of other conditions than those of ordinary stream deposition. It is also noteworthy that the clay-like beds increase in frequency and in thickness as depth is reached.

Wells dug in the mesa at Tucson show a series of rudely stratified layers of boulders, gravel, and sandy clays with caliche near the surface and carbonate of lime in small disseminated crystals lower down. The gravels and boulders are clearly such as were washed from the Santa Catalina and the Rincons, though now separated from those sources by the valley of the Rillito and the Pantano Wash.

Thin layers of fibrous gypsum are occasionally found in digging wells upon the Tucson Mesa. It also occurs under the tufa of Sentinel Hill, near the Laboratory.

By the courtesy of W. A. McGovern, superintendent of the Southern Pacific Railway at Tucson, I am able to give a copy of the record of the nature of the material passed through from the surface to the depth of 1,480 feet at one of the company's wells bored at Esmond, a station on the mesa 15 miles east of Tucson and about half-way between Tucson and Pantano and nearly on the 3,000-foot contour line. This section shows in a general way a succession of beds of gravel and clay, with the thickest bed, 400 feet, of yellow "cement clay" at the bottom. Water was found at the depth of 868 feet, and rose in the well to within 432 feet of the surface. This well yields approximately from 3,000 to 4,000 gallons of water per hour.

Section at the Esmond Well.

Depth.	Formation.	Thickness in feet.	Depth.	Formation.	Thickness in feet.
0	Caliche and boulders	13	424	Gravel	6
19	Yellow clay	6	430	Yellow clay	6
25	Caliche and sand	6	432	Water rises to this level	—
29	Yellow clay	4	440	Cement gravel	10
45	Caliche and sand	16	470	Clay	30
80	Yellow clay	35	478	Cement gravel	8
86	Gravel	6	506	Clay	28
96	Yellow clay	10	526	Cement gravel	20
100	Gravel	4	530	Clay	4
119	Yellow clay	19	535	Cement gravel	5
127	Gravel	8	555	Clay	20
145	Yellow clay	18	563	Cement gravel	8
150	Gravel and boulders	5	585	Clay	22
160	Yellow clay	10	590	Cement gravel	5
164	Gravel	4	660	Clay	70
184	Yellow clay	20	670	Cement gravel	10
188	Cement gravel	4	680	Clay	10
220	Yellow clay	32	725	Cement gravel, boulders	45
227	Cement gravel	7	868	Cement gravel	143
236	Yellow clay	9	871	Water gravel—water here	3
240	Cement gravel, boulders	4	904	Cement clay	33
255	Yellow clay	15	950	Cement gravel	46
258	Cement gravel	3	965	Clay	15
280	Yellow clay	22	975	Cement gravel	10
314	Cement gravel, boulders	34	1012	Cement clay	37
330	Yellow clay	16	1056	Cement gravel, boulders	44
385	Cement gravel, boulders	55	1064	Bottom of 11⅝ casing	8
400	Yellow clay	15	1075	Clay	11
410	Cement gravel	10	1084	Coarse gravel	9
413	Yellow clay	3	1480	Yellow cement clay and bottom of the well	396
418	Cement clay	5			

The thickness so represented may be regarded as only a fractional part of the whole thickness of the formation. We have at present no means of ascertaining what this thickness is, or the depth below the surface at which bed-rock may be reached. The coarse gravels at the depth of over 1,000 feet indicate very ancient stream distribution when the region was at a greater elevation above the sea, or possibly wave-action of an encroaching sea during slow subsidence of the land.

ORIGIN OF THE SLOPES.

The origin, age, and general phenomena of the broad slopes have been elsewhere considered in detail.*

They are generally regarded by geologists as wholly sub-aerial in origin, and as deposited without oceanic aid in the distribution of the detritus. A prolonged study of these slopes leads to a different view. While recognizing the present sub-aerial distribution, it is found to be below the level of higher and older slopes which were evidently formed under different conditions. These higher portions are above the reach of the streams and floods of the present. They supply the detrital materials, in a large degree, to the present streams. We thus have slopes of different ages. The older and higher may be said to be the initial slopes, and the materials washed out from them and reassorted, distributed, and laid down at lower levels may be called derivative, and the slopes so formed derivative slopes.

The initial slopes are those which give the characteristic topography and the scenic effects of the region. The derivative slopes are lower and are generally out of view and confined to the arroyos and washes cut in the older initial slopes. While these derivative accumulations are evidently sub-aerial in their distribution, the higher initial slopes have the appearance of being shaped by oceanic action during a period of slow subsidence of the land.

The general leveling distributing action of oceanic tides and currents appears to be recorded by the regularity of the surface of the slopes and their general uniformity of elevation, at their upper margins, around the Valley of Tucson.

The study of the topography of the valley, and especially of the higher parts of the slopes, reveals the fact that the deposits are older than the existing river and other drainage channels. The slopes were evidently first formed and have since been extensively eroded and cut away by the river and flood-waters, and to such a degree that in many places portions only of the original slope remain; but such portions show that they were once parts of a continuous sloping surface or inclined plane. It would appear that such deposits antedating the drainage must have been built up during a period of subsidence succeeded by elevation. The streams flowing from the mountains to-day are destroying and not building up such slopes. They cut through and erode the old slopes, in some instances cutting across the slope, as, for example, on the San Pedro River, where a long slope is bisected by the river, leaving a ridge of detrital slope-deposits on each side. So also the Rillito north of Tucson cuts

*The flanking detrital slopes of the mountains of the southwest portion of the U. S.; Meeting of the American Association for the Advancement of Science, New York, December, 1906. Published in *Science*, N. S., vol. xxv, No. 651, p. 974.

across the Santa Catalina slopes and leaves a steep bank for miles on the north side, as already represented. Similar conditions exist along the Santa Cruz opposite Tubac, where the ancient slope from the Santa Rita is cut across and shortened with the formation of high bluffs. In the deep arroyos trenching the slopes the nearly vertical banks exhibit rude stratification of gravels and sand, together with clay-like layers, not unlike the succession of gravels, sands, and clays revealed by the boring at the Esmond well.

FORMER LACUSTRINE CONDITIONS.

The evidences of submergence and uplift given by the detrital slopes are supported and strengthened by the phenomena of ancient lakes or estuarine deposits. These deposits show the long-continued existence of a large body of water with its surface at or about the 4,000-foot contour line.

The presence of a body of clay in the lower portion of the valley of the Santa Cruz at Tucson is evidence of the former existence there of a body of comparatively quiet water. It would appear that this deposit was anterior to the excavation or erosion of the river valley. It may be explained upon the hypothesis of a sink or depression at the intersection of the slopes from the Catalinas, the Rincons, Santa Ritas, and the Tucson Mountains, while the region was submerged. The uplift of the region and the advent of the Santa Cruz with the cutting down of its channel brought this clay deposit to view.

The excavation of a deep well for the city water-works passed through this clay and showed a heavy deposit of boulders below, marking an old channel. The trunk or large branch of a tree was also found, but in the condition of lignite, which speedily fell to pieces on drying.

These phenomena indicate a very ancient river-valley antedating the formation of the mountain slopes.

The fact of the submergence of the continent and its elevation above the sea in the late Miocene Tertiary is well known. There have been later changes of the relation of land and sea, but generally of less amplitude. Some of the effects herein attributed to oceanic action may date back to the earlier period of emergence.

The enormous volume of detrital materials filling the valleys and composing the slopes, whatever their relationship to oceanic distribution, bear testimony to long periods of erosion and degradation of the land and to eras of greater rainfall than we now have.

THE SOILS OF THE REGION.

The soils of the region of Tucson may be grouped in three classes:

1. The gravelly and sandy washes of the mountain slopes.
2. The red argillaceous deposits of the older slopes and of Tumamoc Hill and other hills of basalt.
3. The alluvions of the streams, chiefly of the Santa Cruz and of the Rillito.

The first class includes the detrital deposits of the mountain slopes, the boulders, gravel, and sands broken from the rocks of the ridges and spread out in the valley forming the "mesas." The area of such deposits is nearly that of the area of the valley. The deposits of the two other classes are really comparatively insignificant. As a general rule, the heavier and coarser materials are found near the mountains, while the finer gravels and sands are distributed at a greater distance and at the lower levels; yet large boulders up to 12 inches in diameter are found in digging wells far out on the mesa east of Tucson and south of the valley of the Rillito. The surface is generally free from large boulders or coarse gravel. A vertical section shows that the materials are rudely stratified, layers of coarse boulders, partly rounded, alternating with gravelly and sandy layers and with the red clays of class No. 2. There are also the included calcareous beds of caliche, and in places thin layers of gypsum. At a depth of 90 to 100 feet permanent water is found under the mesa slope for a few miles east and north of the city.

The surface earth of the mesa is essentially arenaceous and affords good natural roads. The prevailing color is white or gray, rather than red, though in some low places there are local deposits of red claylike loam, derived probably from the interstratified red clays of class No. 2.

There is a notable absence of humus in all the soils of this class. The conditions do not appear to have been favorable to the presence of organic matter in any form. Decay of vegetation, promoted by moisture, has not been possible. The nearest semblance to a soil favorable to vegetation upon the mesa lands about Tucson is found around and under the low-growing shrubs, which are important factors in the distribution and conservation of the sandy loams. This growth of plants, and especially that of the creosote bush, *Covillea tridentata*, not only protects the surface of the desert, so called, from the sweeping action of furious winds, but by checking the velocity of the wind causes the deposition of the wind-driven earth and sand about the roots.

RED CLAY SOILS.

The soils of class No. 2 are derived largely from the red argillaceous deposits interstratified with the gray gravels of the slopes. These red beds are most developed and visible in the section of the detrital slopes of the western end of the Catalina Range and on the road northward to Oracle. They are found at other localities where the detrital slopes have been cut through and exposed by erosion.

On Tumamoc Hill, although little can be seen beside the surface of black rock, the hill is not wholly without what may be called a soil—a soft brown-colored or red clay accumulation largely hidden under the loose rocks or in clefts and hollows protected from the washing action of rain. This red-brown clay does not appear to be the result of the decay of the rocks, but rather a residue of a once more extended deposit upon the hill when under water. It much resembles the widely distributed red clay of the older slopes, but is darker in color.

Some soils or loamy deposits of the mesa have noxious qualities. A red-colored soil found in rather limited areas near to Tucson, for, example, in a strip a few rods long and wide on the grounds of the university, is noted for its infertility and the death of trees planted in it, although they are as well watered as trees a short distance beyond, which flourish luxuriantly. For convenience, it is designated as "red adobe." It is characterized by a large amount of sesquioxide of iron and by its compactness. A mechanical analysis reported by Professor Forbes* of a similar soil in which plants died, showed that it was more than three-fourths composed of coarse material, with one-fifth of silt and fine clay and very little organic matter. The same authority notes that an abundance of lime is characteristic of soils of arid regions and is one reason for the fertility of these soils under irrigation. It is also noted that such soils are deficient in nitrogen. The chemical investigations of soils by the Experiment Station have been mostly upon the soils of the Salt River Valley.

The general resemblance of the red clays of the slopes to the red argillaceous lacustrine beds of the ancient Lake Quiburis in the San Pedro Valley should be noted.

ALLUVIAL SOILS.

Class No. 3 includes the alluvions of the streams—the Santa Cruz, the Rillito, and the Pantano Wash. All are noted for their fertility and depth, requiring only water to produce abundantly.

The soils of the Rillito are more silicious, sandy, and feldspathic than those of the Santa Cruz, as would be expected from their source in the granite rocks of the Catalinas and the Rincons. The soils of the Santa Cruz are finer and darker in color and have their source, to a great degree, in the volcanic tuffs along the river from Nogales to Tucson, receiving additions from the granite and limestones of the Santa Rita and the Sierritas.

A deposit of calcareous clay already mentioned, in the lower part of the valley at Tucson, is indicative of a former lake-bed, or a formerly submerged area, at the lower intersection of the slopes; or, possibly, it may represent conditions analogous to those under which the playas of Nevada and of Arizona were formed, i. e., sediment from clay-laden meteoric flood-waters.

Several miles south of the Tucson region we find along the upper Sopori an extensive area of rich, dark-colored loam, evidently a deposit from a former fresh-water lake. The eastern barrier of the water has been lowered or swept away by erosion, permitting the drainage of the area.

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*Arizona Agricultural Experiment Station Bulletin No. 28, March, 1898, p. 91.

CALICHE.

The widespread calcareous formation below the surface of the soil in the Southwest, known as ca iche, is a variety of travertine (carbonate of lime) of terrigenous origin and deposit. The composition of caliche, its form and distribution are factors of prime importance in any discussion of the growth and distribution of plants in regions where it occurs. Its influences in the soil are not only chemical but mechanical, and it exercises an important influence in the distribution of surfaces and underground waters.

Although the phenomena of distribution and the origin of caliche have been elsewhere described,* it seems appropriate in this place to review the principal facts relating to it, especially those which have a bearing upon plant-life.

The broad valley of Tucson affords good opportunities for the study of the phenomena of caliche, but although the deposit is generally present except in the bottom-lands, it is usually covered from view by a foot or two of earth. A furrow can not be turned by a plow without revealing it, and if trees are to be planted, the hole must be deepened by a sharp pick or by blasting. Caliche forms practically a continuous sheet, a foot or two under the surface, from 3 to 15 feet or more in thickness, of travertine-like lime deposit, with the more dense and impervious layers at the top. This upper surface is comparatively smooth, though undulating, and often has knob-like excrescences. In fracture the upper or thicker crust exhibits fine lines of edges of layers or successive coats, along which separation may take place. There is also a rude columnar structure transverse to the layers.

This hard upper crust, which seems like a layer of impervious cement, and which certainly retards the downward percolation of water, has, however, here and there minute perforations like pin-holes, at the top, which gradually enlarge downward and become lost in the more porous portions. These little holes are often occupied by the rootlets of plants.

This deposition of lime-carbonate appears to be the result of the gradual upward percolation of the calcareous phreatic water supplied from the subterranean streams, induced largely by the excessive surface evaporation under continued desiccating conditions. Its absence in the soil at the immediate surface may be explained as due to the solvent action of meteoric water soaking downward, carrying the lime with it.

Dr. B. E. Livingston in his discussion of caliche† has suggested that

*The Caliche of Southern Arizona, an example of deposition by the vadose circulation. *Transactions American Institute of Mining Engineers,* vol. XXXI, pp. 220–226, 1906.

†The Relation of Desert Plants to Soil Moisture and Evaporation, by Burton Edward Livingston. Carnegie Institution of Washington Publication No. 50, August, 1906, p. 8.

the upper layer is formed at the level where the water of the soil is vaporized faster than it can be supplied from below.

The conditions of the upward movement of the water must vary greatly with the subjacent supply and with the nature of the formation. Thus at the site of the Laboratory at Tumamoc the conditions of flow and moisture from below upward are very different from those of the gravelly plains of Tucson. The basaltic rock appears as an almost impermeable barrier to the upward flow of solutions, except where there are structural planes or seams and cracks, and it is in precisely such places we find the calcareous deposits on Tumamoc Hill, where also it fills fissures in vein-like forms. In one or more such fissures the deposit is in considerable quantity. Near the top of the ridge, on the east side, a large crevice or vein-like space is filled with the calcareous deposit and, having the semblance of a mineral vein, has been dug into by prospectors in the hope of finding valuable ore. The deposit is in successive layers on the walls and is like some of the deposits of lime-onyx, and is possibly in this instance the result of a downward flow of calcareous water in a fissure, supplied from the formerly overlying tufaceous deposits.

In ascending the north slope of the hill it may be noted that in places the otherwise loose blocks of black basalt are firmly cemented together with the lime deposit, so as to form a compact mass as if by the hands of a mason, as already described.

A similar cementation of boulders is found at the tufa quarry on the west side of the hill.

A chemical analysis of caliche, excluding the mechanically inclosed sand, shows the presence of:

Calcium carbonate	78.28	Aluminum silicate	7.37
Magnesium carbonate	2.13	Ferric oxide	1.88
Calcium silicate	5.57	Moisture	1.20

The concentration of salts more soluble than lime carbonate by surface evaporation in the dry season, such as salt, sulphate of soda, and in some cases carbonate of soda, or "black alkali," are other examples of the same conditions of origin. In the rainy season these soluble salts are carried downward and disappear in the soil, reappearing as efflorescences at the surface when the rains cease and the dry air turns the direction of the movement of the solutions.*

The general occurrence of travertine about the shores of ancient lakes, notably of Lake Cahuilla; at the sink of the Carson in Nevada, and at Lake Bonneville, Utah, taken in view of the evidences of an ancient submergence of the Tucson Valley, leads to the question whether or not the caliche is a deposit from overladen calcareous waters during submergence.

*I have elsewhere directed attention to the possible enrichment of the croppings of secondary ores in mineral veins by an analogous process of concentration under desert or desiccating conditions.

It is also to be noted that the absence of caliche from the alluvial deposits tends to support the view of deposition from overlying water. Further evidence and the careful study of all the phenomena are desirable.

CHANGE OF CLIMATE.

A change of the climatic conditions throughout the Southwest, and especially in the semi-desert region of Arizona and New Mexico, is marked everywhere by the evidence of a much heavier rainfall than we now have. River valleys in many cases show only dry gravelly or sandy beds which evidently were formerly occupied by continuous streams. The floods that once carved their way across the slopes or over the plains are no longer seen, at least not in the same volume as in former time. Even existing streams do not reach in times of great flood their former volume and carrying capacity. All tell of diminished volume, whether in the desert regions or in the regions of abundant plant-growth.

We may believe that the cause is extraterrestrial and cosmic, and a part of the great era of climatic changes giving to the earth the glacial era, and its gradual decay. We may believe that the era of greatest precipitation in the Southwest and elsewhere was coincident with the widest extension of the glaciers and that while the higher mountains were being loaded with snow, the lower slopes were deluged with rain or watered freely by the melting snows and enjoyed a verdure no longer possible.

The gradual desiccation of Arizona and other regions may be regarded as synchronous with the gradual disappearance of glaciers, a condition now in progress, as shown by the retrocession of glaciers still in existence, even in the Sierra Nevada of California, where only remnants remain of the once mighty sheets of ice which covered that region.

EXTINCTION OF THE GREAT MAMMALS.

The vast extent of the ancient detrital deposits anterior to the uplift indicate a much greater rainfall than we now have, and this greater precipitation must have continued during and possibly long after the uplift, and have exerted a great influence upon the nature and distribution of vegetation.

The fact of the existence and wide geographical range in Arizona of the great mammals, the mammoth and the mastodon, shows a very different condition of vegetation up to comparatively recent geologic time. The extinction of these giant herbivores may be best explained upon the theory of the desiccation of the region rather than by a change of temperature or increasing cold, as apparently was the case in Siberia, and may have been in the glaciated regions of California. A great change in the rainfall and the drying up of the slopes and mesas of Arizona must of necessity have caused a great change in the growth of plants, involving their destruction over great areas. It would appear that the extinction of the giant mammals and the disappearance of suitable vegetation for their sustenance proceeded together, and were due to increasing heat and dryness rather than to increasing cold.

We have ample evidence that in the Cretaceous era conditions in Arizona were favorable to forest growth and luxuriant vegetation. The coal-beds of Deer Creek near Saddle Mountain in Pinal County, described by Emerson, reveal such conditions.

Quantities of silicified tree-trunks in the vicinity of Yuma and the prostrate forms of giant trees turned to stone in the Petrified Forest Park bear eloquent testimony to such forest growths and to destructive climatic changes in Tertiary time.

More recent evidence is found in springs surrounded by relics of vegetation, such, for example, as Andrade's Spring east of Tucson and on the right bank of Davidson's Canyon, where there is a thick accumulation of sphagnum with stumps of trees and, at the bottom, teeth of the mastodon.

The former existence in Arizona of a species of *Bos* of unusual size is shown by the discovery of enormous horn-cores in the gravels of the secondary or derivative slopes of the Santa Ritas at Greaterville.

SUBMERGENCE AND ELEVATION.

In addition to other evidences of change of level of the Tucson region in comparatively recent geologic times, we have the ancient Lake Quiburis, already described, which occupied the adjoining valley on the east.

The vast accumulation in this valley of lacustrine clays and silt, now exposed to view on each side by erosion, bears good evidence of the long duration of the submergence of the valley and of the height of the water at about 4,000 feet, or nearly the height of the divide between the Tucson Valley and San Pedro, corresponding to the indications of the ancient level about Tucson. Without assigning this figure as the limit of the depression or of the total elevation of the region of the southwest, the comparatively general and uniform altitude of the detrital slopes favors the view that the sea-level rested for a long period at about that altitude.

Upon this assumption it becomes interesting to note what the form of the coast-line must have been during the period of depression, and to illustrate it the accompanying sketch-map has been prepared (plate 52).*

It presents the land areas of the southwest, including Arizona and the southern portion of California, which rise above the contour line of 4,000 feet. The areas of less altitude are represented as under water.

Without claiming absolute accuracy in delineation, the map serves to give a general idea of the coast-line before the Pliocene uplift and to help elucidate some phenomena of the geographical distribution of the plants of the area and of the probable climatic conditions in Tertiary time.

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*This was exhibited by the author at a meeting of the Cosmos Club of Tucson, in May, 1906.

The salient features of the representation are:

1. The wide extension northward and eastward of the Gulf of California; northward up the valley of the Colorado River to and into the Grand Canyon and into Nevada; eastward to the upper Gila and the Salt River.

2. The deeply indented and rocky coast-line of Arizona, with many estuaries and bold headlands.

3. The insular condition of the region of Tucson east and west of the long valleys of the Santa Cruz, of the San Pedro and Sulphur Springs, forming a veritable archipelago in which the Santa Catalinas, the Rincons, the Santa Ritas, the Huachucas, and the Tucson Mountains formed prominent islands, while Tumamoc and other basaltic hills were under water.

4. The southern coast ranges of California disappear under water, while the southern end of the Sierra Nevada appears as a long, narrow promontory disconnected at the Canada de las Uvas from the Sierra Madre, and at San Bernardino from the San Jacinto and Peninsula Range of Mountains.

ASPECT OF THE VEGETATION ABOUT TUCSON.

The secondary maximum of precipitation in southern Arizona occurs in December and January, and amounts to 2 or 3 inches during these two months. On the higher levels this comes in the form of snow, and generally melts under the noonday sun and is almost entirely absorbed by the soil, thus yielding the greatest efficiency in promoting the growth of plants. At levels between 2,000 and 3,000 feet, vegetation begins to awaken in January and a large number of forms begin to bloom early in February, and mature fruit in March and April with the diminution of the rainfall. In all of this winter wet season, as it may be termed, the checking action is due to the low night temperatures, which drop to 30° and even 20° F. on many occasions; and a few warm days may bring a luxuriant crop of low herbaceous annuals almost to bloom, which may then be blighted by the frost in January. In the general average of such conditions it rarely occurs that the more precocious forms bloom before the first week in February (plate 53).

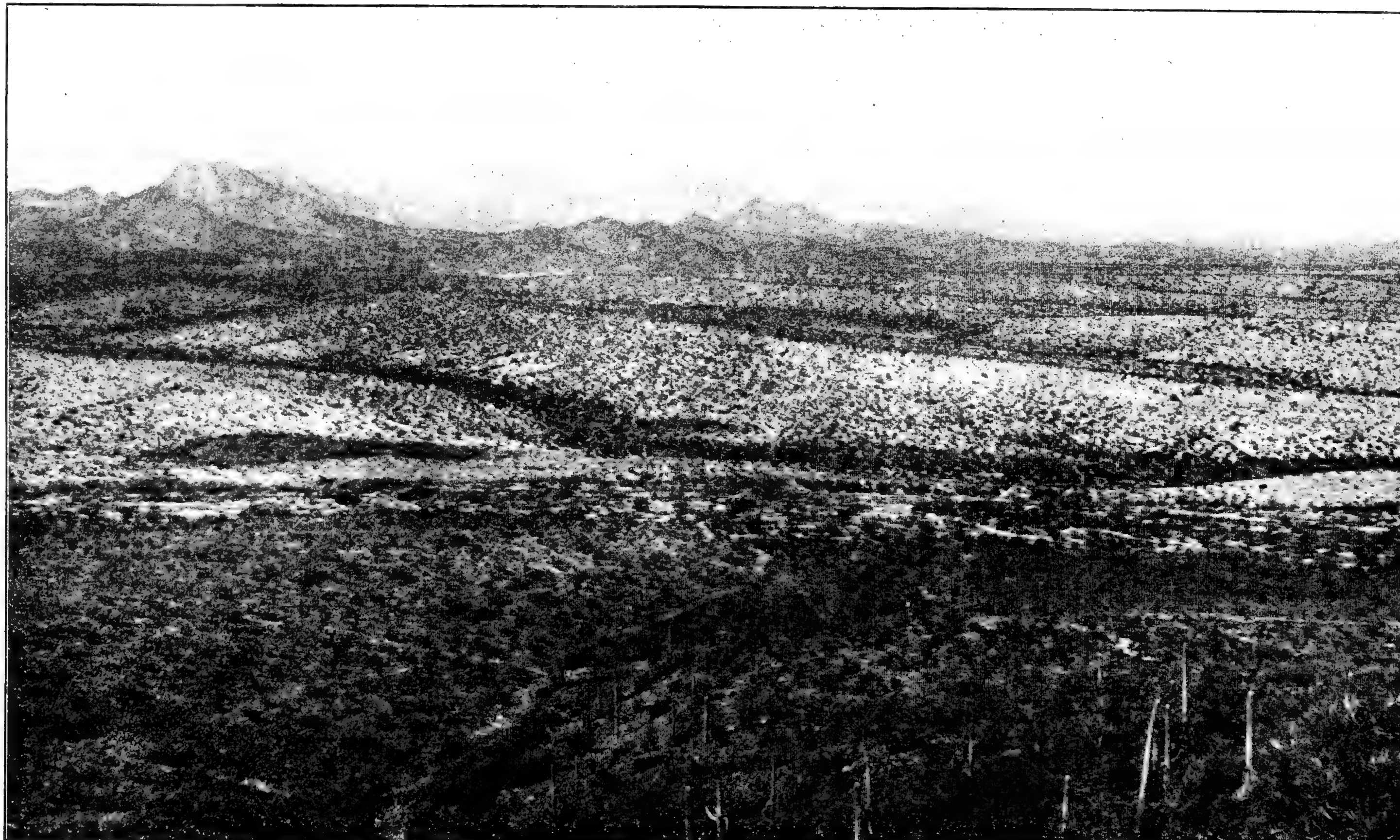
WINTER PERENNIALS.

A large number of shrubs and species with perennial root-stocks and bulbs push up shoots, leaves, and flowers under the stimulus of the rising temperature and the moisture supply, including the following:

Brodiæa capitata, with a few blue or white flowers borne on a slender scape with a deeply buried bulb; *Anemone sphænophylla*, a relative of the crowfoot, with long-stalked cylindrical fruits; *Penstemon wrightii*, with its crimson tubular flowers, a succession of which follow through March and April; and *P. parryi*, on the slopes, with a metallic luster to the flowers. Stalks of the last two species are a favorite food of rock-squirrels, which

THE COAST OF ARIZONA AND SOUTHERN CALIFORNIA IN THE POST-PLIOCENE.

The topographic basis of this sketch is from a hypsometric map published by the U. S. Geological Survey.



Looking westward from Laboratory site. In the middle distance is shown a strictly desert vegetation, consisting of giant cactus, palo verde, ocotillo, creosote-bush, prickly-pears, chollas, etc. (Reprinted from Publication No. 6.)

cut them off near the base and carry them away to their retreats. *Hilaria mutica* is a true desert grass which finds a place high up on the slopes, where it makes patches of color visible for miles. *Cassia covesii* opens its yellow flowers and forms its pods early, while *Franseria deltoidea*, a low shrub, has its bur-like fruits ready to be carried away by any moving thing that touches them early in April. The most striking color of this period, however, is that of the globose clusters of *Encelia farinosa*, nearly a yard in diameter, which are so numerous and so dense on the slopes as to give a golden color that may be caught by the unaided eye for 7 or 8 miles. One of the wild tobaccos, *Nicotiana trigonophylla*, grows among piles of rocks or on the edge of escarpments, and its creamy yellow flowers open early in February. *Verbena ciliata* forms low clusters, and the individuals in any locality show a range of variation of color of flowers from deep pink to pure white, while the flowering season is ended only by the spring drought. The creosote-bush, *Covillea tridentata*, begins to open flowers and make new leaves in February and continues in flower for two or three months. On the mesas and sandy washes the composite *Baileya multiradiata* opens numerous yellow flowers from its clumps of stems, that last with their brilliant yellow effects for many days. Low and decumbent on the hill-slopes are the crooked branches of a small shrub, *Calliandra eriophylla*, which forms clusters of flowers of a delicate pink and soon matures its fruits, while a second species of the genus, less inconspicuous, abounds on the lower mesas.

The greater number of these perennials cast away their leaves with the approach of the high temperatures of April and May, and the stem, bulbs, or root-stocks go into a quiescent condition from which they do not awaken until the following December or January, eight or nine months later, the entire period of activity being comprised within a compass of a hundred days. Some, however, like *Covillea*, with varnished leaves, and a few other species with heavy protective coatings of cutin or hairs on the foliar surfaces retain these organs during a great part of the year, and derive some benefit from the activity of the chlorophyl during the intense insolation of the summer months. While the soil is supplied with water in fair plenty, at least during the early part of this season, the humidity of the air ranges between 30 and 40 per cent and only plants with protected surfaces may functionate to advantage in it.

WINTER ANNUALS.

Of the large number of herbaceous forms which spring from germinating seeds in the wet winter season and soon pass the whole cycle of existence, a few of the more prominent may be mentioned.

Astragalus nuttallianus, an innocuous relative of the "loco" weed, ripens its curved reddish pods early in March and scatters the seeds in the gravel, the small stems withering away long before the summer comes.

Streptanthus, one of the mustard family, soon reaches the adult stage, with its deep greenish stems and rather lush leaves, which show but little indication of belonging to the desert. Two of the borages, *Harpagonella* and *Pectocarya*, occupy the most prominent place in this group of plants, the soil being generally so thickly sown with their seeds that the rains bring up a dense carpet of these plants; every square inch of available space on Tumamoc Hill is occupied with their short hairy stems, the burs being quickly matured, and in the dry weeks of April forming an unpleasant feature of a walk off the trail. Two plantains abound: *Plantago aristata* stays on the slopes, while *P. ignota* is abundant over vast areas of gravelly or sandy mesa, the silvery hairy and grayish appearance of the leaves being such that it is difficult to determine at a glance whether the plants are alive or dead. Of the annuals these two are furnished with the structures most generally characteristic of forms that live in dry places. *Phacelia tanacetifolia*, with its scorpioid inflorescence, is scattered among the rocks and on the slopes over a wide range, and as it does not come into bloom until well on with the coming of dry weather, it and its neighbor, *Amsinckia*, with yellow flowers, have some of the features of desert plants. Early in April, shining silvery balls of fruit, reminiscent of the dandelion, are met frequently, and these prove to be relatives of that weed, being *Microseris linearis*, with erect linear leaves around the scape which bears the fruit, and *Rafineskia*, with shorter laciniate leaves on its thicker stems. The wild carrot, *Daucus pusillus*, holds its umbels of inconspicuous flowers but a few inches above the ground, and these ripen seeds in April, when the entire plant quickly dries up. *Bowlesia lobata* is abundant in certain localities, while two gilias, relatives of the phlox of the gardens, are abundant. *Gilia floccosa* displays its small star-shaped flowers everywhere on short simple or branched stems, which, with a supply of water, take on some stature and throw out laterals, but which usually send up a single stem with a hairy globose head, from which every day a flower opens that may vary in color from pure white to deep blue. The other species, *G. bigelovii*, stays mostly on the slopes, and its slender shiny stems are taller than the species described above. Here and there are to be found small compact clusters of flowers like small white daisies borne on short stems, *Eremiastrum belliodes*, which also exhibits the marks of the desert. Finding its way about, across the mesas and over the hill-slopes, is the alfilerilla, *Erodium cicutarium*, a relative of the geranium, which spreads its flat rosettes of greenish laciniate leaves wherever it may find a foothold, and after its pinkish flowers come the long fruits, which sow the seeds so abundantly and efficiently that this plant travels by leaps and bounds. Small straight stems, clothed with hairy linear leaves, terminate in spikes of delicate purple flowers in *Orthocarpus purpurascens palmeri*, and single individuals occur here and there on the mesas, in the sand and gravel, but in some places so densely are they crowded that great purple patches are formed on the slopes. Occasionally an individual is found which has lost entirely the power of making the characteristic color of the flowers, while others lack it only partially, and of these an experimental study has been begun. The Mexican poppy, *Eschscholtzia mexicana*, likewise offers many things of interest. Its flowers are light yellow or have a distinct admixture of red; its petals show entire margins or are deeply cut; the orange eye at the bottom of the corolla cup may be clearly defined and sharp or diffuse; but, most striking of all, a number of individuals have been found in which the foliage has a paler color than ordinary and the flowers are of a clear creamy white, the eye at the bottom being the only color retained, and at the same time the margins of the petals are delicately frilled, making a most striking deviation from the main type, between which numerous intermediates are to be found.

The more prominent structures by which these annuals are fitted for life in the desert are not to be looked for in the shoots or leaves, but in the seeds and their powers of endurance. Seeds are ripened and thrown on the ground in March and April. The surface layers of the soil reach a temperature of over 100° F. during the summer months, the summer rains come and soak both the soil and seeds, but still no activity is shown, and the experimentalist who attempts to use these plants during the summer will find that he might as well have sown so many pebbles in his pans. The summer cools into the autumn, and cooler nights come, followed by the winter rains of December; then and not until then do these refractory seeds begin to show signs of life. Two features are possibly involved in this delayed germination. One is that the seeds need a certain length of time for the carrying out of slow changes toward maturity, which take place during the so-called resting season and which need a period of determinate length not to be shortened. Secondly, it is quite possible that in some species the baking summer heats, the moist soil, the cool nights of autumn, and the rains are a series of stimuli which must follow each other in turn and act for a length of time before the seedling emerges from its protecting coats. Favor is lent to this view by the fact that in some species germination may be induced earlier by simulating the summer heats and the winter coolness by the use of the oven and the refrigerator.

SPINOSE AND SUCCULENT FORMS OF THE DRY FORESUMMER.

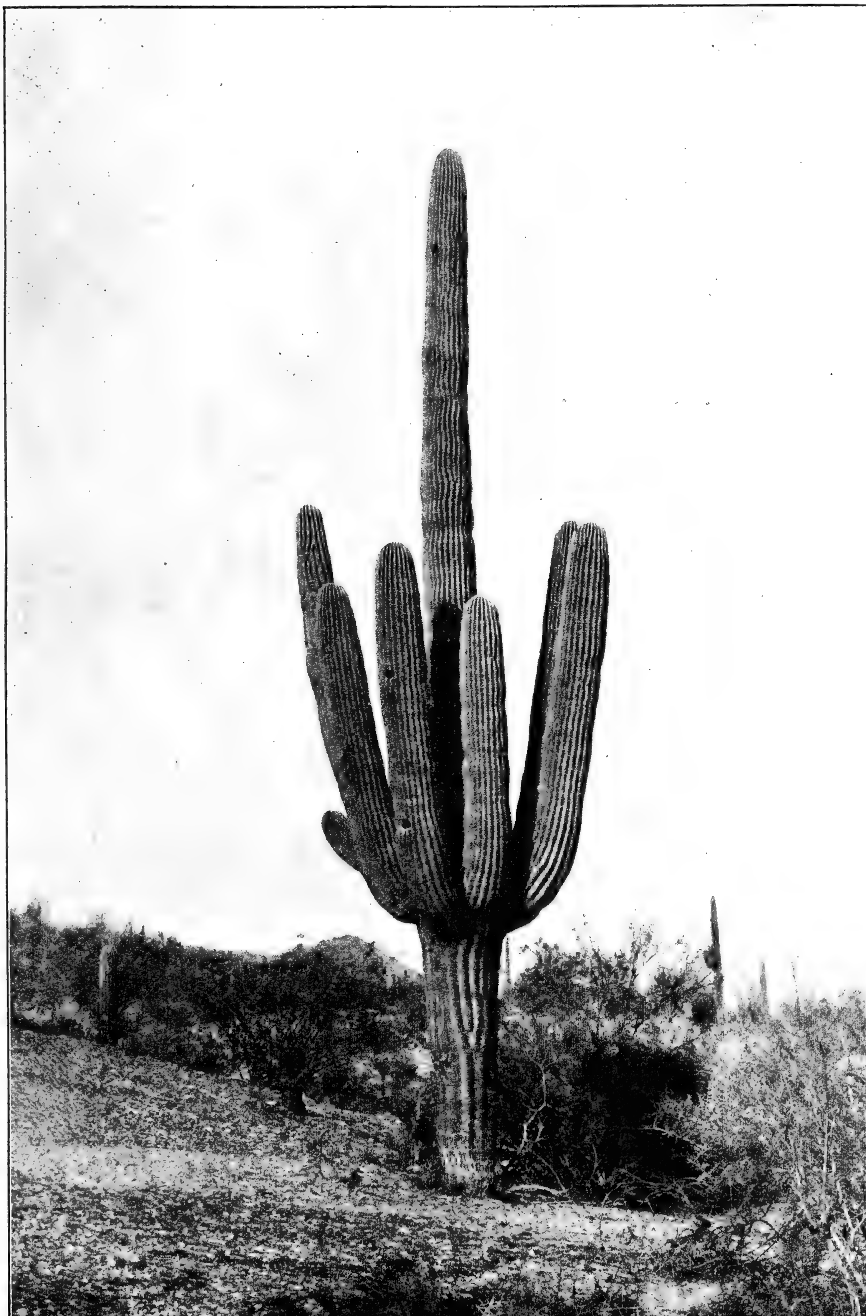
The precipitation shows a decrease to 0.90 of an inch during February, and this, with a further diminution to 0.77 inch during March, coupled with the steadily rising temperature, brings to an end the lush and luxuriant vegetation of the moist winter season. Late in March or early in April the xerophilous conditions come to full expression. The stimulus of the still increasing temperatures and of the decreasing relative humidity now brings into activity the succulent, spinose and xerophytic types which especially characterize the season. This dry foresummer may be said to comprise April, May, and June, with a total average precipitation of 0.67 inch, while the maximum temperatures range from 95 to 112° F. The evaporation of course exceeds the precipitation in an enormous ratio.

The succulents comprise two general types, one of which is represented by the cacti with atrophied foliar organs and storage stems, and the other by the yuccas and agaves with the thickened leaves and short stems functioning as reservoirs for the water which was accumulated during the latter part of the winter wet season.

The greatest activity among the cacti is displayed by the cereuses and opuntias. The earliest of these in the vicinity of Tucson is generally *Echinocereus fendleri*, in which a few brilliant crimson flowers are displayed from the clumps of short, thickened, cylindrical stems late in March, and continue for a month, to be accompanied and followed by equally noticeable bloom of two or three other small species. Chief of the group, however, is the great sahuaro, the flower-buds of which develop as dense clusters on the portions of the apices of the stems most exposed to the sun, and have been seen to open on March 25. The whitish flowers each remain open but a short time and apparently are pollinated by insects. A succession of them ensues, and although practically finished during May or June, yet belated buds open at various times, one having been seen as late as the middle of November. The seedy fruits mature in great quantity in midsummer, and are much prized by the Papagoes, who make much use of them in various ways (plates 54, 55).

The prickly-pears, or opuntias with flat stems, begin to make some growth of new joints and to push out flower-buds in March, and late in that month or early in April bloom in great profusion, the fruits maturing early and dropping to the ground. Fifteen or twenty species are native to the Tucson region, but the greatest confusion prevails as to their identity. Of the various desert plants, this group has been the subject of the most inquiry as to its possible economic utilization. After a consideration of the various practical questions connected with open cattle ranges, it has been found that the best use of them for forage is made by growing or allowing to grow spinose species, from which the spines are burned when they are to be consumed by animals. This is now done with the plants growing in various places. Unarmed forms are subject to the attacks of so many animals that it is practically impossible to secure a crop without protecting fences. A few species are known in which the spines are very sparse. One of these, *Opuntia lævis*, occurs in the canyons of the Santa Catalina Mountains, but chiefly on rocks or in places inaccessible to grazing animals (plate 56).

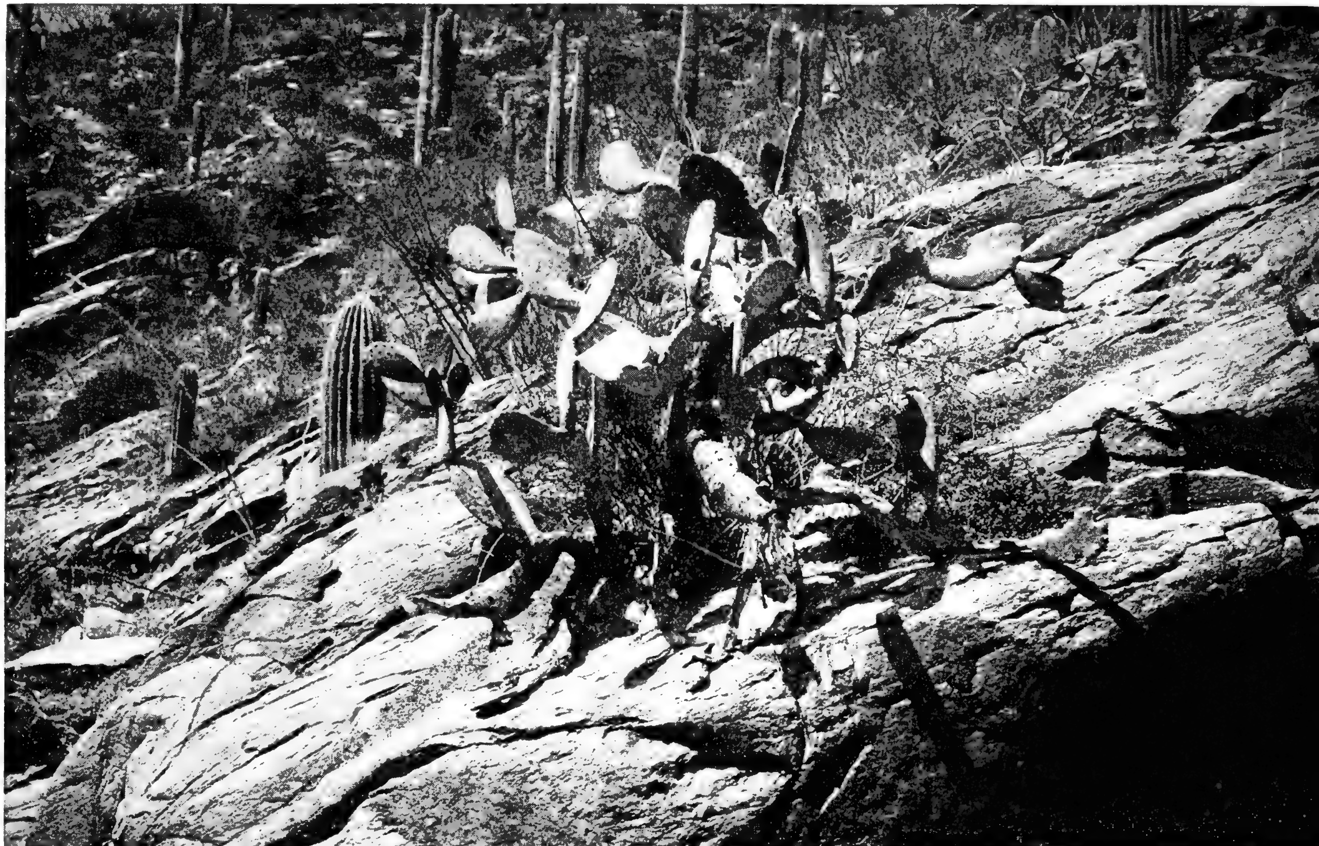
The cylindrical opuntias include many forms with a central stem and well-developed system of branches which give them the form and impos-



Saguaro or giant cactus (*Cereus giganteus*), near mouth of Sabina Canyon, Santa Catalina Mountains. The openings in the trunk and branches lead to large sac-shaped cavities originally excavated by woodpeckers for nests, and afterwards occupied by several other species, as well as colonies of honey-bees. This specimen is about 40 feet in height. (Reprinted from Publication No. 6.)

Cereus giganteus, with vertical branches, a form occurring around the base of the Santa Catalina Mountains and to the northward.

Plate 56



Opuntia lævis, a semi-spineless prickly-pear growing in the Santa Catalina Mountains. Young plants of *Cereus giganteus* in background.

Opuntia fulgida (cholla) and *O. mamillata*, two closely related prickly-pears growing with branches in contact. Both bear numerous maturing fruits.

ing appearance of trees. These begin activity early in April, two of the earlier ones being *O. versicolor* and *O. spinosior* (tasajo), with a puzzling range of color in the flowers. Thus, some individuals will be found which have bright crimson or reddish-purple flowers and others with light red; others with yellowish-red, yellow, and greenish-yellow, the shade also being reflected by the color of the stems, so that the color of the flower may be predicted upon seeing the plant from a long distance. In some instances two colors appear to be exhibited by a single plant, but a closer examination generally shows that what appears to be one plant is in reality two, grown together at the base.

O. fulgida is characterized by the silvery, shiny appearance of the sheaths of the spines, and is locally known as "cholla," although that name properly belongs to a species native to Baja California much farther south.

Nearly related to *O. fulgida* and growing intermingled with it is *O. mamillata*, with more greenish branches, shorter and sparser spines. Both of these species have easily detachable branches, and the separated portions act as cuttings in propagation. The facility with which the joints are cast loose and attach themselves to an animal by the sharp spines makes them much to be dreaded, and it is by this means that dissemination is effected in a very efficient manner. The fruits remain attached to the branches for one or two years, or even longer, and the seeds are exceedingly slow of germination (plate 57).

Opuntia bigelovii, which is so densely clothed with short silvery spines that a pencil-point can not be thrust against the stem without pushing several aside, shows an extremely wide range over the deserts of the Southwest from Death Valley across to the mesas of Arizona and southward along the shores of the Gulf, also propagates itself by means of detached joints, and an entire colony of these plants may be seen that have come from one older central individual.

Several species of birds make their nests in the branches of the cylindrical opuntias, where they are secure from hawks and marauding animals; and many rodents of the desert drag the detached joints about their burrows, making an effectual barricade against the coyote and fox.

The agaves form their great rosettes of thickened leaves on the slopes running up from the greater mesas, and after a period of development which varies from a few to many years a central flower-stalk is sent up in the foresummer with extraordinary rapidity, growing in length as much as a foot a day and quickly forming flowers and seeds. This effort exhausts the resources and terminates the life of the individual, and the entire cycle of these "century-plants" is directed to this one effort of arriving at mature size with an accumulated food-supply that will enable them to perfect a crop of fruits and seeds. This habit makes the agaves an important source of food for the southwestern Indians, who take the rosettes when nearly mature and after cutting away the tips of the leaves bake the central stem and attached leaf-bases for the sugary substances to be obtained, making what is known as mescal. The mescal-pits used a decade ago are numerous in the foothills of the mountains in this region, and even yet one may occasionally surprise an Indian feasting upon this prized delicacy.

The yuccas and the sotols (*Dasylirion*) form a great central stem several feet in height with a heavy plume of leaves which may live to a great age. The inflorescence in these plants arises some distance from the apex of the stem and the flowering period does not terminate the existence of the individual as in the agave. The yuccas occur at a higher level than Tucson, while the sotol (*Dasylirion wheeleri*) inhabits the rocky canyon slopes a thousand feet above, although stragglers are found nearer (plate 58). The southern slopes of the Catalinas and of other mountains in this region is also the habitat of the small agave (*A. schottii*), which has stiff spiny upright leaves less than a foot in length, and as the plants grow thickly together an ascent among them is tedious and painful. With this species is to be found also the rarer *A. treleasii*, which so far seems to be found only on the slopes of the Santa Catalina Mountains.

The yellow of the hillsides of the early part of the year due to *Encelia* has hardly faded when equally conspicuous clumps of *Riddellia* begin to show at the same level, and the globular clusters of this plant endure for many weeks. During their display the bright yellow bloom of the parkinsonias contributes to the yellow color-note. *Parkinsonia microphylla* (palo verde) and *P. torreyana* are true desert trees, having very minute leaf-blades which are cast at any time when the water-supply fails, and which use the green layers of the bark instead when the leaves are lacking (plate 59).

Two other pod-forming groups of trees are also active at this time, the acacias and the mesquites. Of acacia there are two species, one with white and the other yellow flowers, which are sweet-scented and are borne in globular clusters on the small trees. Mesquite attains its greatest growth on the alluvial bottom-lands, and it is capable of sending long roots to great depths in search of water. The delicate green of its leaves is an especial feature in contrast with the gray and yellow of the arid landscape. In April and May small racemes of whitish flowers are followed by the pods and bean-like seeds, which are such an important feature in the life of many animals and of the Indian (plate 60).

The hackberry (*Celtis*) and *Lycium* are also to be mentioned among the woody plants which bloom and mature their fruit during this season. Of the plants which grow from seed every year none are more striking than the thistle-poppy (*Argemone*), which affects sandy slopes and washes, the glistening spiny stems and leaves being of a grayish-green, a true desert color. A large number of buds are developed and one or more are opened every evening on many branches, so that a display of pure white flowers is offered by any individual for a period of 5 or 6 weeks.

PLANTS IN THE HUMID MIDSUMMER.

The course of the temperature rises irregularly during June until, in the latter part of this month and early in July, thermometers in the shade read as high as 112° F., and the surface layer of the soil warms up to a point where a thermograph with a buried bulb gives daily records of over 100° F., with but slight cooling at night. Lying quiescent in this soil are thousands of seeds of plants which are incapable of germination in the moist season of the cooler months, and which can not sprout in a soil which contains much less than 15 per cent of moisture. Snowy piles of cumuli begin to be seen on the mountain summits early in July, and the earlier short showers are followed by longer ones which spread out over the plain in fantastic patterns, generally giving the greatest rainfall of the year during July and August. As soon as the precipitation is sufficient to bring the soil-moisture up to the critical point, millions of seedlings spring into activity, and forty-eight hours may see the entire face of the landscape changed in appearance.

SUMMER PERENNIALS.

The great barrel-cacti, which have hitherto remained practically dormant, now having become thoroughly heated up and supplied with water drawn in by the network of roots, which ramify in all directions from the bases of their thick stems, immediately underneath the surface of the soil, now begin to open a series of reddish and lemon-yellow flowers, to be followed by the formation of a crown of maturing fruits which stay in place until the middle of the following summer. The seeds of the sahuaro, which are produced in enormous quantities, are devoured by the birds before being freed from the fruits, but of the great number that reach the ground and germinate, not one in a million survives and makes the curious globular plantlet a few inches in height eventually destined to become a giant cactus. The seedlings of all the cacti form a favorite food of a large number of small animals, being juicy reservoirs of water and containing enough other material to lead to their destruction before sufficient armament has been formed for their protection.

Some plants, in the lives of which the supply of moisture is the controlling factor, start up again with the summer rains in a season much warmer than that earlier in the year in which they have previously been active. A *Cassia* must be reckoned among these, and its brownish pods opening in August make a second liberal sowing of its seeds. A low straggling shrub, the dragon's-blood (locally known as "sangre engrado," as a corruption of sangre de drago), *Jatropha*, spreads its waxy green leaves amid many other plants of a grayer, more xerophytic aspect. The greater part of the yellowish note in the landscape is due to the masses of *Bigelovia* of two species which occur in abundance over the mesas and are plentifully supplied with resinous secretions. The pods of the leguminous trees, including the acacias and the mesquites, ripen during this season and offer abundant food to the larger grazing animals.

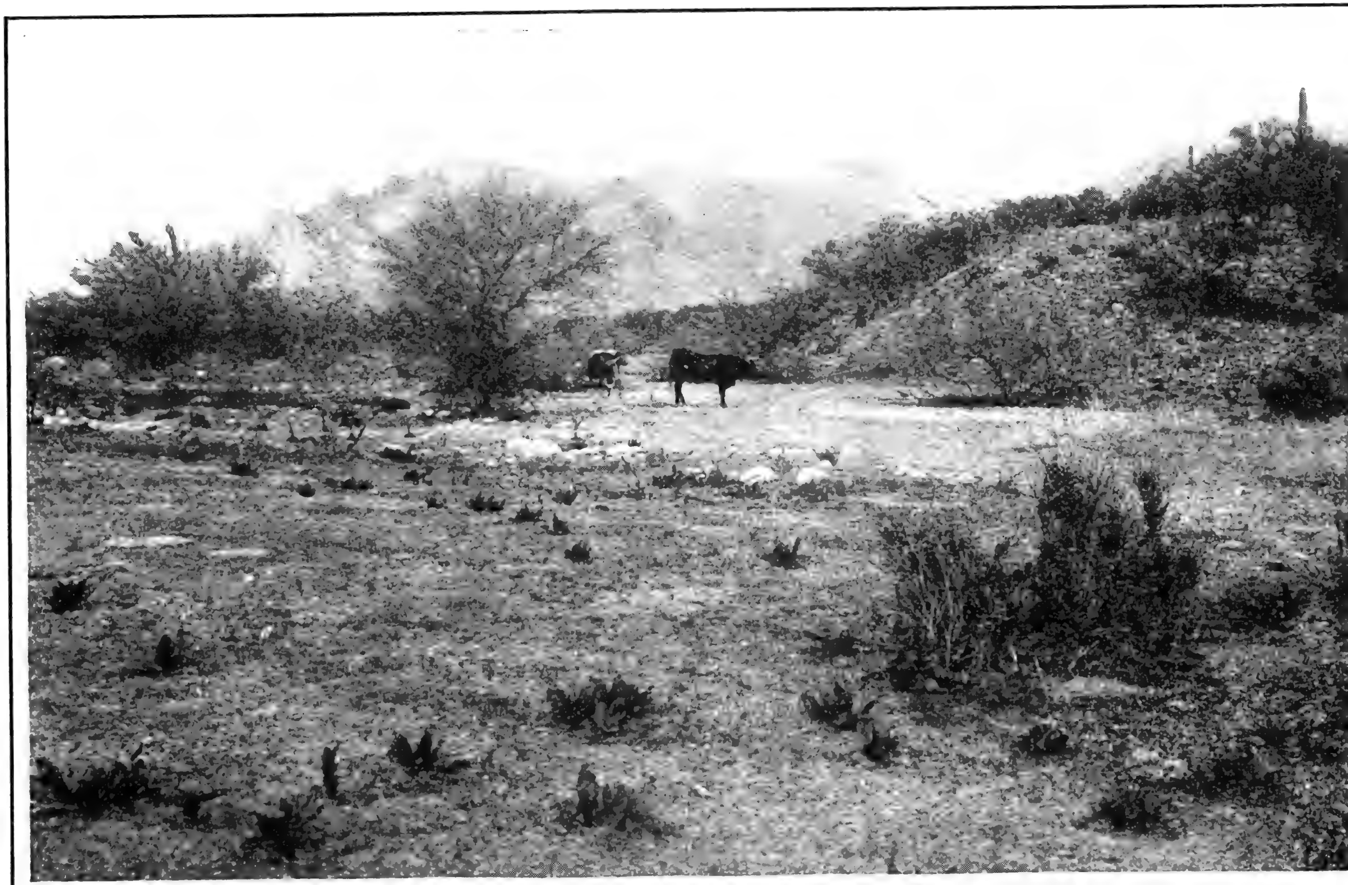
SUMMER ANNUALS.

Several euphorbias spread their small dense mats of thin stems and minute leaves on the surface of the ground, and are rich in a latex or milky juice containing resins, starch, and some caoutchouc, which is reputed by the Indians of various tribes to furnish an antidote for the venom of the rattlesnake—a supposition not confirmed by experimental evidence, however. Another group of species which forms green mats on the surface is comprised within the genus *Tribulus*. Some of these cover an area of nearly a square yard with a dense mass of green compound leaves offering a background contrasting with the bright yellow and reddish colors of the flowers, which show interesting opening and closing movements. The thin yellowish, almost leafless, stems of the parasitic *Cuscuta*, or dodder, make a rapid growth during the humid season and quickly twine round the stems and sink their haustoria deep into the bodies of many host-plants, being capable of attacking successfully some forms with an extremely indurated bark or epidermis. During all of this season the humid air, especially after the sudden rains, becomes laden with the pungent odors of the creosote-bush and of the various volatile substances produced by many of the desert forms.

THE DRY AFTER-SUMMER.

The latter part of the moist midsummer has witnessed the beginning of growth of a number of grasses of the genera *Triodia*, *Bouteloua*, and *Aristida*, which ripen their seeds and persist as tufted bunches of dry haulms and leaves during the rainless season of October and November, being eagerly eaten by grazing animals. During this season an almost total cessation of vegetative activity ensues, and continues until the double stimulation of the moisture of the winter rains and of the increasing heat of the sun after the winter solstice is received. Then the seasonal succession of forms ensues as described, with various modifications due to the wide departures from the normal or average conditions. An example of this diversity is suggested by the records of precipitation, which may vary from 5 to 25 inches per year.

Slope in Pima Canyon, Santa Catalina Mountains, bearing *Opuntia versicolor* and *Dasylirion wheeleri*.



Dry alluvial flat of Rillito wash. Canaigre (*Rumex hymenosepalus*) and *Ephedra* in foreground. Palo verde (*Parkinsonia microphylla*), mesquite, and saguaro in background.

Cats-claw tree (*Acacia greggii*) near Tucson, Arizona, affected by a mistletoe (*Phoradendron californicum*).
(Reprinted from Publication No. 6.)

TEMPERATURES OF PLANTS IN THE DESERT.

No exact determinations have been made of the intensity of insolation in American deserts with respect to its effect upon vegetation, but it may be assumed to be high, partly on account of the low relative humidity. The green chlorophyl screens of the shoots, whether in leaves or green stems, are subject to the direct action of the rays and take on a temperature only modified by the cooling action of transpiration, which, however, must be slight in many instances, particularly in the cacti, which have been found to throw off water more rapidly in their native habitats by night than by day. Then again the action of the sun's rays heats the surface layers of the soil, in which the roots of many species lie, so that in some cases at least the absorbing organs are embedded in a medium much warmer than the air. This point is illustrated by the following observations made near Flagstaff, Arizona, July 16, 1898:

The bulb of a mercurial thermometer was pushed down into the soil around the root tips of a clump of bunch-grass to a depth of 2 inches, and the glass stem of the instrument shaded from the direct rays. The soil consisted of a mixture of volcanic sand and alluvial deposit. At 2^h 20^m p. m. a temperature of 106° F. was recorded; a few minutes later 108° F., with the air ranging from 91. 4° to 93.2° F. At 3 p. m. the black volcanic sand around the roots of *Cleome serrulata* showed a temperature of 111° F., with the air at 113° F. Professor Toumey cites the fact that the temperature of the soil at the depth of 1 inch near Tucson reaches a temperature of 113° F., with a mean average of 104.9° F. for the entire month of July; also that the average for the month of July at a depth of 4 feet was 82° F. with a maximum of 84.5° F. and a minimum of 81° F. Professor Toumey states that the temperature of the soil near Tucson increases slowly during July, is stationary during August, and begins to decrease in September. These observations are of great interest, since the insolation would be practically identical with that near Flagstaff, although the altitude of the latter place is somewhat greater. The soil in which the observations at Tucson were made consisted chiefly of decomposed granite with some mica.

Mr. A. E. Douglass, of the University of Arizona, has communicated some observations indicating that the sandy soil around the roots of small herbaceous plants in the Grand Canyon, Arizona, on September 4, 1898, exhibited temperatures as high as 148° F.

A pair of Hallock soil thermographs have been in operation at the Desert Laboratory since 1905, and it is found that these extreme temperatures are met only by the roots of species spreading in the surface layers of the soil. The records taken at 6 inches below the surface during the last week in July, 1906, show a variation between 85° and 98° F., although it is to be said that this type of instrument responds somewhat slowly and it is quite possible that the maxima might have been as much as 3 or 4 degrees above that shown for a few minutes. When these instruments were first installed the bulb of one was placed with its center 3 inches below the surface, with the result that the tracing pen rose above the slip and temperatures of 102° and 105° F. were indicated. At a depth of a foot the temperature during the week indicated did not show a daily variation of over 2 degrees, but a continuous rise of 6 degrees occurred.

It is not to be taken for granted that all plants native to the region are active under such conditions, however. The winter annuals and perennials come to bloom early in February in great number, and it is to be seen that the roots are embedded in a soil that ranges from 48° to 55° F. at 6 inches from the surface, while at a foot the mean average is practically the same, with a narrower amplitude of diurnal variation. This temperature at the depth of a foot is practically the same as that recorded for midsummer in New York.

A study of the mechanism of absorption would doubtless detect by comparison some important differences between the roots of winter annuals which take up soil solutions at 50° F. and those of the summer flora which habitually function at a temperature in the neighborhood of 100° F., 50 degrees higher. Important correlations with the transpiratory activities may also be expected.

The temperatures of a number of plants were obtained by thrusting the bulbs of small mercurial thermometers into the fleshy stems and shading the exposed portion of the instrument from the sun's rays. The following data were recorded from tests of this character with an opuntia on July 17, 1898:

Temperature of—	$7^h\ 20^m$ A.M.	$8^h\ 10^m$ A.M.	$9^h\ 00^m$ A.M.	$10^h\ 30^m$ A.M.	$11^h\ 00^m$ A.M.	$11^h\ 30^m$ A.M.	$12^h\ 30^m$ P.M.
Opuntia......	79.0° F.	93.5° F.	93.8° F.	97.2° F.	111.2° F.	109.4° F.	108.0° F.
Air..........	78.5	82.4	87.8	91.4	96.8	100.4	100.4

The flattened fronds of the cactus were in an upright position, with the edges in the plane of the meridian, so that the angle of the incident rays of sunlight decreased with the altitude of the sun. As a consequence of this insolation the resulting temperatures rise until about 10 a.m., and then decrease until the sun once more comes into a position where the rays might strike the surface at or near a right angle, reaching a second maximum at 2 p.m., though observations on this point were somewhat obscured by the daily clouding at the time of the experiments.

The above data were obtained at Flagstaff, Arizona, at an altitude of about 7,000 feet, and some further measurements were made at the Desert Laboratory on April 13, 1907, on opuntias similar in form to the above and which were showing flower buds about to open. Fronds in a vertical position were selected which were facing toward the point on the horizon directly under the sun at 2 p. m., and into these were thrust the slender bulbs of thermometers the glass stems of which were shaded. Readings of 108° to 117° F. were obtained with the air at 92° F.

In the thermometry of globular, decumbent, or cylindrical forms of fleshy plants, such as *Cereus*, temperatures of 113° to 115° F. were often found with the air at a temperature of 93° to 100° F. It is to be seen that plants in this region are subject to the action of a fierce insolation and to an atmosphere of low relative humidity. As a result of such insolation the body of the plant and the surface layers of the soil are raised to very high temperatures. The increase in temperature of the shoot aided by the direct action of the light upon the transpiratory mechanism would tend to increase the amount of water given off by the shoot. At the same time, however, the temperature of the soil undergoes a corresponding increase, thereby increasing the osmotic processes of absorption, so that the two processes, absorption and transpiration, automatically equalize each other, provided the maximum temperature of protoplasmic activity is not passed.

It is not to be taken for granted that the temperatures recorded above represent the maximum limit in the matter. Algæ are found in certain springs in the Southwestern deserts which flourish at 128° F., and accredited records of air temperatures of 122° to 128° F. are available. The shoot of plants exposed to the sun under such conditions would doubtless be as warm as 135° or perhaps 140° F. It is evident therefore that the supra-maximum temperature of active protoplasm and of chlorophyl usually quoted in text-books are good for the laboratory only, and do not measure the range of endurance offered by desert forms. Capacities of this character would probably be found to depend upon the character and structure of the proteid constituents of living matter, as well as on the water content necessary for growth and for other functional and vegetative activities.

In comparison with the above, some data obtained by Messrs. Douglas and MacDougal on the summit of San Francisco Mountain, near Flagstaff, Arizona, are of interest. Observations were made at a camp at 11,500 feet during the first week in August, 1898, and some recording instruments were kept in operation for a longer period. A consultation of these records shows that the temperatures did not range so widely during the course of a day as at lower altitudes. The difference between the soil and air seems very marked, however. Kerner estimates that at an elevation of 3,000 feet the mean temperature of the soil in humid localities is 2.7° F. greater than that of the air; at 4,000 feet it is 3° F.; at 5,000 feet, 4.3° F.; at 6,000 feet it is 5.4° F., and at 7,000 feet it is 6.5° F. In an observation made at 4 p. m. August 8, on the western slope of the peak, the soil stood at 71.6° F. and the air at 57.6° F., and at 7 a. m. the next morning the minimum of 21.2° F. was obtained for the air and 48.2° F. for the soil. This increase in the difference between the temperature of the soil and the air is due to the increase in intensity of the direct sun's rays and the diminution of the intensity of the diffused radiation by reason of the attenuation of the atmosphere at such altitudes.

No records of the temperature of living plants under such conditions are available, but it is evident that the entire subject needs reinvestigation by exact methods in which the separate effects of ground radiation and direct insolation will be separately accounted for. Such studies would be carried out in a system of observations which would embrace plantations including identical forms grown at different altitudes.

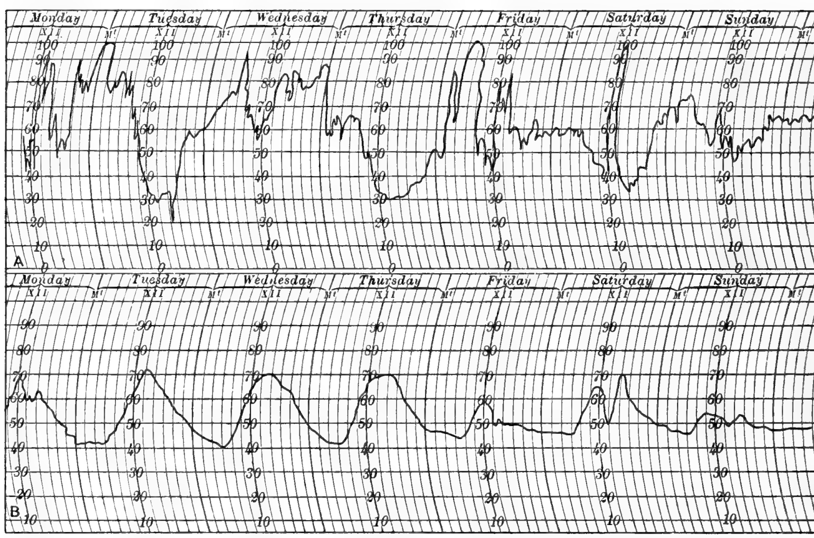


Fig. 1.—Meteorological data from San Francisco Mountain, Arizona, August 8 to August 19, 1898. The upper curve, traced from the hygroscopic record, shows variations in relative humidity. The lower curve shows the corresponding air temperature in the shade. (Reprinted from Publication No. 6.)

Some important results have already come to hand from the investigations carried on by the Committee on the Relation of Plants to Climate of the American Association for the Advancement of Science.

Dr. MacDougal, to whom the work on soil temperatures was intrusted, reported as follows on a series of observations made at a depth of 6 inches in the New York Botanical Garden (Monthly Weather Review, August, 1903):

It may be seen from these that the maximum daily temperatures occurred between 8 and 11 p. m., and the minima 12 hours later, or between 8 and 10 a. m. The optimum temperature for absorption by roots lies well above that of the soil, at the depth at which the observations were made. It follows, therefore, that the temperature of the soil approaches this optimum most nearly, and offers most favorable conditions for the taking up of watery solutions at a time of the day when the amount of water thrown off by the shoot and of mineral matter used in metabolism are nearing the minimum by reason of the absence of light, lowered air temperature, and consequent increased humidity of the air. These inharmonious conditions account almost wholly for the profusion of guttation excretions, or "dew-drops," formed on the tips and margins of grass blades and leaves of low-growing plants early in the evening.

Absorption by the root continues quite vigorously after sunset by reason of the favorable temperatures; and the augmented amount of fluid in the cortex of the roots sets up a pressure which ultimately forces the water into the central cylinder and up through the woody cells faster than it may be used and transpired by the thin-walled cells of the leaves. The vessels become filled with water which is forced out in form of drops through the excretory openings. In some species the amount of water coming away from the plant in this manner may reach quite an appreciable quantity.

On the other hand, the forenoon witnesses the rapid acceleration of transpiration by all parts of the shoot at a time when the soil temperature is decreasing to a minimum. The increase of transpiration continues until mid-afternoon, while the temperature of the soil reaches a minimum two or three hours earlier, and then begins to rise, but does not do so sufficiently to favor absorption to any great extent. It is true, of course, that the needs of the leaves may be partially met by the activity of the rootlets which lie nearer the surface.

When plants are cultivated in pots in greenhouses, the small volume of soil around the roots responds much more rapidly to changes in the temperature of the surrounding air and to the influence of streams and sprays of water than does the upper layer of soil in the open. In general, the soil in the greenhouse will show a much higher average temperature, which, with the other conditions mentioned, makes necessary special treatment on the part of the gardener. If the natural conditions of water-supply by precipitation were complied with, the needs of the plant would by no means be met under the altered conditions of temperature.

Another point of interest in the present connection is the fact that such notable differences are found between the temperatures of the subterranean and aerial portions of the bodies of plants at almost all seasons. During June, 1902, the shoots of herbaceous plants were in an atmosphere that varied between 8° C. (46.5° F.) and 34° C. (92.5° F.), while the roots were between 8° C. (46.4° F.) and 13° C. (55.4° F). As the maxima and minima were not synchronous the actual difference between the temperature of twigs and leaves on the upper part of the plant and roots on the lower amounted to as much as 22° C. (nearly 40° F.) at certain times of the day. Such conditions occur, though slightly less accentuated, during the entire summer in this locality. It is evident without further discussion that such differences in the temperature conditions of the two poles of the plant must exert a more or less important influence on the transport of fluids and solutions from one part of the plant to another. Referring to the previous discussion concerning the comparative transpiration and absorption during the day, it is to be seen that the heightened temperature of the shoot must operate, in a simple physical way, to greatly augment the amount of water thrown off, while the roots must take water at the same time to meet the loss, at a temperature as much as 40° F. lower.

During the movement of the water from the roots to the leaves of grasses and other low-growing plants a total distance of no more than 50 centimeters (20 inches) may be traversed, occupying a matter of a few minutes or an hour at most, during which time the temperature is raised the above amount. The warming of the liquid as it passes upward through the living and non-living cells is attended by alterations in its solubility of mineral and organic substances and by a decreased capacity for holding gases in solution. The downward movement of solutions of sugars, acids, and nitrogenous substances from the leaves encounters the opposite set of conditions. This movement takes place almost entirely by osmose and diffusion, and is a much more complicated process, both chemically and physically, taking place in living cells only. The cooling of the liquid would entail alterations in its power of carrying substances in solution, and would also alter its physical relations to atmospheric gases.

It may be said, in conclusion, that the facts disclosed as to the actual temperatures in the soil, the diurnal and seasonal change therein, lead to the belief that the differences in temperature of the aerial and underground portions of plants can not fail to be of very great importance in the physical and chemical processes upon which growth, cell-division, nutrition, and propagation depend. The determination of the effect of differences in temperature between the roots and aerial shoots has received but little consideration from the physiologist and the geographer. A careful analysis of the conditions and results of experimental observations, carried on with plants under artificial conditions with the roots and shoots under abnormally similar temperatures, would no doubt result in the detection of many mistaken conclusions, especially in regard to absorption, translocation, and transpiration.

That soil temperatures and their relation to those of the air must be of very great importance in the cultivation of economic plants is self-evident, especially in species in which the desired useful portion is formed underground and receives storage material formed by the activity of the aerial organs. Thus, in the case of such plants as the potato, certain mineral substances are absorbed from the soil at a comparatively low temperature, carried aloft into the heated leaves, where they participate in activities resulting in the formation of sugars, starches, and other carbohydrates, perhaps some nitrogenous substances as well, and then these complex bodies are slowly diffused downward, with many accompanying chemical and physical modifications, to underground cool-storage organs, where a condensation occurs and the products are stored in insoluble form in the tuber.

THE WATER RELATIONS OF DESERT PLANTS.

During recent years it has become increasingly apparent that data obtained by the measurement of the activities of plants under laboratory conditions are oftentimes misleading, especially when dealing with forms fitted for special conditions, as illustrated by the water relations of desert plants. One of the earliest series of experiments in the field to remedy this defect was carried on at Turkey Tanks, on the western edge of the Malpais Desert, near the Little Colorado River, east of Flagstaff, Arizona, at an elevation of 6,500 feet, in July, 1898. Attention was given to transpiration and temperatures and the results are given below.

Measurements of transpiration were made by means of a potometer of the form described in the *Botanical Gazette* (vol. 24, 110, 1897). This apparatus consists of a long calibrated tube of small internal diameter supported in a horizontal position and fitted with a Y extension at one end. The tube is filled with water and the excised shoot of a plant fitted to one end of the Y by means of a tightly wired section of rubber tubing. The other end of the Y is closed by a stopcock, which may be opened to admit water when necessary. The rate at which water is taken into the shoot is noted by the progress of an air bubble in the horizontal portion of the tube. It is to be borne in mind that the rate at which water may be absorbed by the basal portion of an excised shoot in contact with water may not, and probably does not, represent the exact rate at which transpiration actually takes place, but it offers a very valuable method of comparison of the capacities of shoots of various types to take up and throw off water under similar conditions.

Experiment 1.—Mentzelia pumila is a representative of a class of plants which, annually growing from seeds, produce flowers and seed during the season of greatest humidity, and then die, the species surviving through the resting season in the form of seeds. It is a marked example of the xerophytic species which have a weakly developed root-system consisting of a number of thin branching fibrous roots which extend chiefly laterally through the upper layers of soil and do not penetrate beyond a depth of a few inches. The aerial shoot has a roughened cylindrical stem about 16 inches long and a number of lateral branches of equal length, giving the entire leafy shoot a globoid form, a form characteristic of many desert plants. The specimen used was furnished with 18 branches and bore about 900 irregular narrow roughened leaves and 200 yellow flowers. The entire surface of the portion of the plant exposed to the air might be estimated at about 800 square inches. The plant was taken from the soil after the above facts had been ascertained, and the root-system was cut away from the base of the stem before attachment to the potometer as above. Several minutes were allowed to elapse before observations were taken to allow the plant to recover from the shock of handling, to which it had been subjected.

At the beginning of the experiment the apparatus stood in the shade of a small pinyon tree with a fitful movement of the air at a temperature of 80° F. During the first few minutes of the observations in which equalization of the negative pressure was in progress, the time in which a unit (100 milligrams) of water was taken up was as follows: 40, 45, 42, 48, 47, 50, 50, 50, 50, 50, 50 seconds, or at the rate of 2 to 2.5 milligrams per second. Half an hour later, at $10^h\ 30^m$ a.m., after the negative pressure had been equalized tests were made in the open, with the sky clouded, and the air at a temperature of 84° F. The periods in which 100 milligrams were absorbed were 75, 70, 80, 85, 85, 90, and 95 seconds, giving a rate of 1.05 to 1.4 milligrams per second. With continued cloudiness and the air at a temperature of 88° F. beginning at $10^h\ 50^m$ a. m., the periods were 75, 75, 60, 70, 70, 75 seconds or at a rate of 1.3 to 1.4 milligrams per second. The sun emerging from the clouds the readings of 400 milligrams in 150 seconds, 400 milligrams in 210 seconds, and 300 milligrams in 150 seconds were taken, giving an average rate of 1.9 to 2.2 milligrams per second. With the return of the clouds immediately afterward the readings were 400 milligrams in 210 seconds, 500 milligrams in 330 seconds, 900 milligrams in 600 seconds, or an average rate of 1.9 milligrams per second, decreasing to 1.5 per second as the effects of the cloudiness were felt. The rate again rose to 1.8 and 1.9 milligrams per second as the sun emerged from the clouds.

Experiment 2.—*Artemisia* sp. was used in this test. It is a low, densely branching shrub with an extensive root-system of the deeply penetrating type. It stands nearly inactive throughout the dry season, taking on a quickened growth, as demonstrated by the formation of new shoots and reproductive organs within a month after the beginning of the July rains.

A main branch with 30 branchlets, about 12 inches long, was fastened to the potometer at 9 a.m., July 16, with the air temperature 75° F. Readings of 700 milligrams in 17 minutes, 400 milligrams in 10 minutes were made with the sun obscured by clouds. In sunshine readings of 1,100 milligrams in 25 minutes, 900 in 19 minutes, 500 in 12 minutes, and 500 in 16 minutes were made, with an average of 0.6 to 0.7 milligram per second. The total area of the surface of the branch and leaves was about 960 square inches.

As a means of comparison similar tests were made with the same piece of apparatus on moisture-loving plants in the physiological laboratory at the University of Minnesota.

Experiment 3.—A well-grown shoot of the tomato with a total surface of 256 square inches was fastened to the potometer in a room in diffuse light with a humidity of 25 to 35 per cent, about the same as in the previous experiments, at a temperature of 79° F. Readings of 1,000 milligrams in 32 minutes and 600 milligrams in 21.2 minutes were made, giving an average rate of about 0.5 milligram per second, and subsequent observations showed no important deviation from this rate. It is to be noted that the conditions differed from those of the desert plant in the lower temperature and the much lower intensity of the light.

Experiment 4.—Eucalyptus globulus was used, being the shoot of a young plant grown from seed in the greenhouse and having a surface of 352 square inches. The test was made at the same time of day (10 to 11 a. m.), and under approximately the same conditions as experiment 3. Readings of 500 milligrams in 7.5 minutes, 9.5 minutes, 10.5 minutes, 10 minutes, and 10 minutes were made with an average rate of 0.79 to 1.11 milligrams per second.

The data furnished by the above tests afford a fair means of comparison of the relations of moisture-loving and desert plants to water if due allowance is made for dissimilar conditions. It is to be seen that a given area of surface of *Mentzelia* at similar temperatures and in a light vastly more intense and in a drier atmosphere transpires water at a rate slightly less than the tomato and at a rate about a third to a half that of *Eucalyptus*. The exposure of the two last-named species to similar temperatures, insolation, and dryness of the air would doubtless show that the moisture-loving plants would take up and lose water at a much greater rate.

The shrubby *Artemisia* was found to use water at a rate per area about one-fourth that of the tomato under the dissimilar conditions offered. An increase of the temperature, insolat ion, and dryness of the air affecting the tomato would doubtless increase the ratio many times.

Still another interesting suggestion arises from these results. *Mentzelia* is an annual that carries on its growth only during the season of maximum humidity, while *Artemisia* is an example of the perennial shrubby plant which makes no reduction of its surfaces during the dry seasons. The latter therefore must be better protected against the danger of drought and actually uses only about half the amount of water per area of surface that is needed by *Mentzelia*, and it sends its roots to enormous depths to insure a constant supply to keep up a steady but slow rate of transpiration.

The fleshy cacti are examples of wholly different types of shoots, in which the leaf-organs are reduced to a minimum. Dr. W. A. Cannon has found that a young sahuaro (*Cereus giganteus*) about 4 inches high and of cylindrical form transpired 33 milligrams of water per hour in an atmosphere with a relative humidity of 32.5 to 35.5, while a bisnaga (*Echinocactus wislizeni*) of the same height, but globular form, and hence great surface, gave off but 9.6 milligrams per hour in an atmosphere with a relative humidity of 35 to 45 per cent. It is quite possible that the specific rates correspond to the different types of root-systems with which these two forms are equipped. These fleshy forms, however, have such storage capacity that the rate of water loss does not have a direct connection with the amount available in the soil. Thus it was found that a small plant of *Opuntia versicolor* gave off water at a rate of 129 milligrams per hour in April, 27.5 milligrams in June, and 26.1 milligrams in July, after the ground around the roots had been thoroughly wetted. A renewal of growth following the summer rains brought about an acceleration, due in part to the activity of the minute leaves, which are highly functional in transpiration.

It is not to be taken for granted that the measurements given above represent absolute capacities, for not only is the rate of transpiration affected by a wide variety of conditions, but also a great individual diversity results from environmental differences. Prof. V. M. Spalding (Biological Relations of Certain Desert Shrubs, *Botanical Gazette*, vol. 38, p. 122) found that a plant of *Covillea* grown with a plentiful supply gave off water 3.7 times as rapidly as one reared under more arid conditions.

The facts brought to light by Dr. W. A. Cannon (On the Water Conducting Systems of Some Desert Plants, *Botanical Gazette*, vol. 39, p. 397, 1905) also show a lack of correlation between the amount of development of conducting tissue in stems in general, and the water-supply. It does seem probable, however, that this development is influenced largely by the water-supply available at the exact time when the conductive cells are in a formative condition.

In all of these investigations it was found possible to make use of a method of measuring transpiration available in dry climates, in which the test-plant was inclosed in a bell-jar of known capacity and the amount of water thrown off estimated from the changes in relative humidity indicated by a hair hygrometer inclosed with the plant. In test-periods of a few minutes nothing superior to this method has been found.

Further work upon the subject by Professor Lloyd has demonstrated that the rate of transpiration exhibits no close relation with the movements of stomata, and that these minute organs have but little of the adaptive capacity with which they have heretofore been accredited. In fact it is found that the variations in the daily rate of transpiration are capable of rational interpretation only by the strictest comparison with the conditions of relative humidity and when taken, as described by Dr. B. E. Livingston, as relative transpiration (Relation of Desert Plants to Soil Moisture, Carnegie Institution of Washington Publication No. 50, 1906), governed largely by purely physical factors, although subject to physiological regulation the mechanism of which is not understood. Thus it was found that this regulatory action was exerted to check water-loss at temperatures between 79° and 90° F. in the plants examined, and that checking action disappeared at temperatures ranging from 80° down to 75° F.

With regard to any possible capacity of desert shrubs to absorb moisture from the air during periods of high relative humidity, the investigations of Spalding (Biological Relations of Desert Shrubs, *Botanical Gazette*, 1906, vol. 41, p. 262) show that xerophytic types are the more unfitted for this purpose the more widely do they differ from those inhabiting moister regions. The chief specializations, then, of the plants of the desert are concerned with soil moisture, checks on loss of water, and the development of storage organs which would conserve a surplus accumulated during a period of much precipitation.

SOIL RELATIONS OF DESERT PLANTS.

The soils of deserts naturally present a wide range of physical character and chemical composition. In regard to the latter feature it is to be pointed out that such soils offer a small proportion of organic matter or humus, and that in many places certain saline compounds and alkaline salts are present in the surface layers, owing to defective drainage or lack of the leaching effect of precipitation. In such highly charged soils the specially adapted halophytic forms also characteristic of sea-beaches find a foothold.

In all other soils in which clay, loam, sand, or rocks predominate the feature which has the greatest determining influence is that of the amount and disposition of the moisture. Many striking dispositions of the root-systems are being discovered which can only be correlated with the moisture factor.

Water being so conspicuously lacking on the surface of a desert, the opinion finds favor that the roots of plants established there must have enormous penetration and reach down to a supposititious supply of water far below the surface. If such were the case these organs would in some instances need to penetrate several hundred feet, because after a depth of a few inches is reached the amount present does not increase very rapidly. Deeply penetrating roots are found for the most part in shrubs growing in loam or alluvium in bolsons or valleys where a supply of water is to be found within a reasonable distance of the surface, and the increasing amount coming with depth must act as a stimulating factor both in the growth and directive action of the plant. Thus Coville reports an observation of a main root of a *Prosopis juliflora* near the streamway of the Amargosa River in California which had a length of about 50 feet. A similar exaggerated vertical development is to be remarked especially in the seedlings of species inhabiting localities in which the supply of moisture lies deep. The date-palm makes an initial root of great length, as well as *Welwitschia* and numerous other forms.

In the analysis of the meaning of any root-system it must be borne in mind that these organs have a dual function—that of anchorage and of absorption—while in some instances storage facilities are afforded both for water and for food material or surplus starch or sugar.

A marked feature of the distribution of desert forms is the peculiarly isolated position of the separate individuals, especially in the perennials. Each shrub will occupy, to the exclusion of others of its kind, an area of many square feet or square yards. With this wide separation one is quite prepared to find a great horizontal distribution of the roots, and this does occur in many species, but is not to be taken for granted in any instance not confirmed by actual observation. Long lateral roots of *Yucca* have been recorded on page 11 of this paper and on many other species, but the character is wholly a specific one. Dr. W. A. Cannon has found that distinct types of root-systems exist among species inhabiting the arid areas in which a marked increase in the proportion of soil moisture does not occur until a great depth is reached.

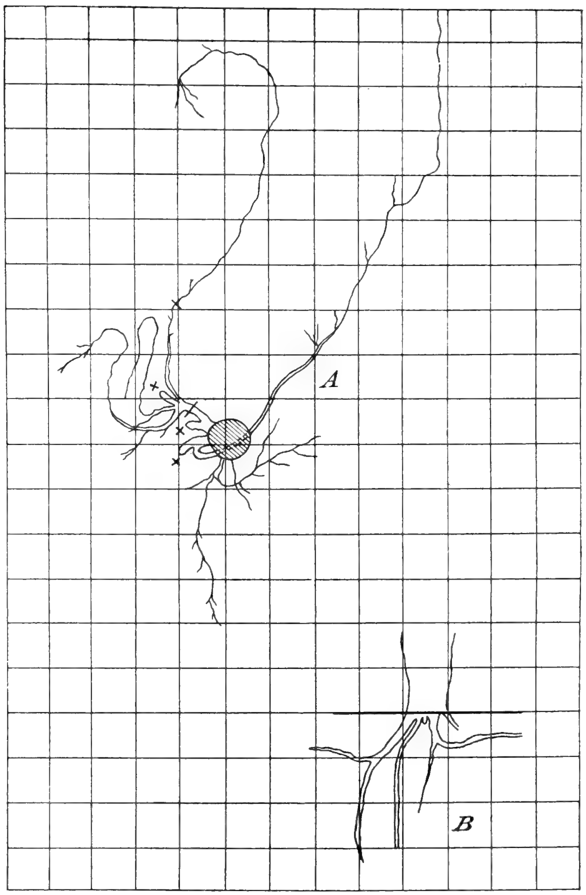


FIG. 2.—Root-system of *Cereus giganteus*. Scale: 1 unit = 4 inches.

The root-system of a specimen of *Echinocactus wislizeni* which was 60 cm. high and 35 cm. in diameter, growing about 75 meters north of the laboratory, was carefully exposed and the course of its roots mapped (fig. 3). The roots, as the figure indicates, were branched very freely. There were three main roots which arose from the base of the plant not far from 10 cm. from the surface of the ground, and which so directed their growth, and that of the branches, that the area compassed by them was about equally apportioned and well covered. As a rule, the roots were slender. At a distance of 15 cm. from the plant one of the largest of them was 7.6 mm. in diameter, and 1 meter from the plant it was 4.6 mm. in diameter. The roots ran about 6 cm. below the surface, in places which were free of stones, but when a stone was encountered the root dipped beneath it and availed itself of the better water-supply to be found there. The most deeply placed root, however, was not more than 10 cm. below the surface of the ground. There are therefore two noticeable characteristics of the root-system of *Echinocactus wislizeni*, namely, the roots are slender throughout their entire course and they are superficially placed.

The roots of *Cereus giganteus*, on the other hand, in form and position, and perhaps in extent and branching also, are very different from those of *Echinocactus*. Fig. 2 presents the root-system of a *Cereus giganteus*, about 1 meter high, which was growing 200 meters west of the *Echinocactus* just described. Four main roots were observed to arise from the base of the plant. Very soon after leaving the plant the roots branched. One branch, whose later history could not be traced, struck directly downward, and the other took a more or less horizontal course. The latter branched at intervals, although perhaps not so frequently as those of *Echinocactus*, and extended, in one instance at least, over 1 meter from the plant's base. How much farther the root reached could not be learned because of its fragility and the small size of the distal branches. The superficial portion of the root-system of *Cereus giganteus* was more deeply placed than were the roots of *Echinocactus*, and, owing to the fact that these parts were not so densely branched, the ground included by them was not so thoroughly occupied. However, in one characteristic which is of interest to note, but the significance of which I have not investigated, the superficial roots of the two forms are alike, namely, the longer roots and the greatest number of roots are situated on the uphill side of the respective plants. This peculiarity is shown in the two figures. In fig. 3 the uphill side is to the right, and in fig. 2 it is at the top of the sketch.

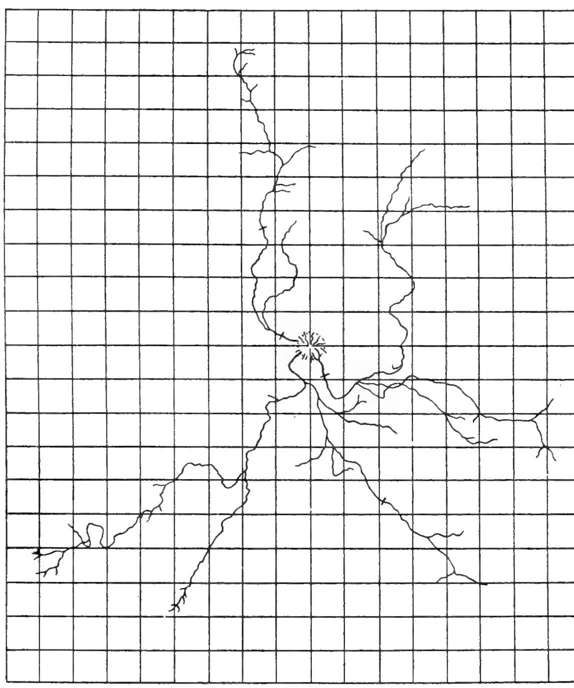


FIG. 3.—Root-system of *Echinocactus wislizeni*. Scale: 1 unit = 1 foot.

It is to be seen of course that the various types of roots also present the additional feature of varying temperature relations between the absorbing organs and the foliar or transpiratory surfaces. Roots like those of the *Echinocactus* or of the small annuals must be exposed to temperatures identical with or differing but little from those of the shoot. Deeply penetrating roots, on the other hand, may often have a temperature as much as 40° or even 60° F. from the shoots to which the stream of soil solution is sent.

In consequence of the great excess of possible evaporation over the precipitation in desert regions, the amount and condition of the moisture in the soil must be largely dependent upon the physical properties of the principal soil constituents and of the underlying geological formation. This excessive evaporation may in itself become a factor in the laying down and structure of strata near the surface, and also indirectly of formations at considerable depth. Chief among these is the "caliche" of Southwestern deserts, which is probably duplicated in the lime deposits of the deserts of southern Africa and of other parts of the world. The evaporating power of the exceedingly dry air of the desert removes the moisture from the surface layers of the soil much more rapidly than it may be supplied by movement through the films surrounding the soil particles from below; consequently the surface layers soon become "air-dry" and the hypothetical capillary columns end beneath, retreating to a depth where the evaporation hindered by the blanket of dry soil above is balanced by the supply. Such an equilibrium is generally attained at a depth less than a yard beneath the surface. The slowly moving but constant stream of water charged with lime therefore evaporates and necessarily leaves its lime content at this depth, and in the course of centuries a "caliche" formation of considerable thickness may be formed; this in itself is a factor of great influence upon the habits of the plants which root in the soil above it.

Recently methods have been developed for the intensification of the action of the air-dry layers by pulverizing it in such manner as to form a dust mulch in what is known as "dry-land farming." The retarding effect of a dry surface layer is well illustrated in the gypsum sands in New Mexico. The action of the sun heats and dries the surface of the dunes to a snowy whiteness, and this dry layer has a thickness of a few inches only. It may be removed readily and layers moist and cool to the hand uncovered in the most arid season. By reason of this supply such plants as poplars, which are able to endure the highly charged soil solutions, but which require fairly abundant moisture, grow readily.

The air-dry layer is in part responsible for the long periods of dormancy of the bulbs, tubers, and seeds of many desert species. Such structures with the protoplasm in a resting condition, protected by heavy outer cellulose coats, may lie inert for indefinite periods in the loose layers of the dust blanket of arid regions.

CONDITIONS CONTRIBUTORY TO DESERTS.

The term desert may be applied to areas of the earth's surface which support a sparse vegetation of a more or less specialized character, owing to inadequate rainfall, or to the unsuitable composition of the soil, while the two may be present in such combination that limited areas may be devoid of any but possibly microscopic forms of plants. Of these factors scanty water-supply may be regarded as of the greatest importance, and it is to this that most deserts owe their existence. The essential and resultant features include undeveloped drainage, activity of wind erosion, great diurnal variation in temperatures, low relative humidity, and nearly humus-free soils, with comparatively small vertical increase in the proportion of soil moisture. Landscapes of this character are readily recognizable by the xerophytic aspect of the vegetation inhabiting them.

Desert conditions come about in any region in which the rainfall is markedly less than the amount of water that might evaporate from a free water surface in the open air. As the amount of evaporation increases from the poles toward the tropics and is affected by winds, it follows that no arbitrarily fixed amount of rainfall may be designated as an invariable cause of aridity. Thus in certain portions of the tropics a rainfall of less than 70 inches results in aridity, while some of the most fertile agricultural districts in the north and south temperate zones receive scarcely one-third this amount.

Regions in which precipitation is less than evaporation are characterized by a lack of running streams, or of a permanent run-off, although in some instances these districts may be traversed by large rivers which have their sources in distant mountain ranges, as in the case of the Nile in Africa and of the Colorado River in America. The rainfall in a desert may be so heavy at certain seasons as to produce torrents of great volume, which, rushing downward over the slopes and mountain sides, wear distinct streamways extending out into the plains below in some instances for miles; but the flow soon ceases after the rains have passed and the stream-beds become dusty channels until the next rainy season. Striking examples of such streamways are to be seen in the great Sonoran Desert in northwestern Mexico. It is evident that districts in which the average rainfall is not much greater than the evaporation are in a very critical condition, since in seasons of minimum precipitation the amount of water received may be less than that lost, and drought may result, often with direful effects on agricultural operations and economic conditions in general.

The seasonal distribution of the rainfall is a matter of importance in regions where evaporation is nearly as great as precipitation. If the rainfall occurs within a brief period the remainder of the year must be extremely dry and the region will show distinct desert conditions, with a tendency on the part of the native plants to develop marked storage capacity for water. The distribution of the scanty rainfall throughout the year in any region will favor the development of slowly growing xerophytic forms.

METEOROLOGY.

The principal features in the distribution and total amount of rainfall in several localities which may be included within the arid regions of North America are given below. The data concerning the maximum and minimum temperatures and rate of evaporation afford a means of estimating the actual usefulness or availability of water-supply for the native vegetation. Thus, for example, evaporation is so great and humidity of the air so small, in the southernmost stations given, that the effectiveness of the rainfall in meeting the needs of plants is diminished 50 or even 60 per cent. Of the localities named below, El Paso, Fort Wingate, Chihuahua, and San Luis Potosi may be included in the Chihuahuan Desert, and the other places within the Nevada-Sonoran Desert.

METEOROLOGICAL TABLE.

The following tables give the mean rainfall and the absolute maximum and minimum temperatures for 16 stations, 13 in the United States and 3 in Mexico. All data for the United States stations are from records in the U. S. Weather Bureau. Data for two Mexican stations, San Luis Potosi and Chihuahua, are taken from the Monthly Bulletin of the Central Meteorological Bureau of Mexico for 1901. The rainfall record for Torres, Sonora, Mexico, was courteously furnished by Mr. T. Oldendorff, agent of the Sonora Railway at that point. The figures for this station were copied from the report made daily to the manager of the railway.

	El Paso, Texas.			San Luis Potosi, Mexico.			Chihuahua, Mexico.			Fort Wingate, New Mexico.		
	Max. temp.	Min. temp.	Mean rain-fall.	Max. temp.	Min. temp.	Mean rain-fall.	Max. temp.	Min. temp.	Mean rain-fall.	Max. temp.	Min. temp.	Mean rain-fall.
No. of years' observations.	23	23	18	1	1	1	1	1	1	5	5	39
	°	°	*Ins.*	°	°	*Ins.*	°	°	*Ins.*	°	°	*Ins.*
January.......	77	5	0.53	73	38	0.57	64	28	0.00	68	−10	1.06
February......	82	5	.42	79	38	.02	69	33	.17	69	− 3	1.49
March.........	89	21	.40	79	42	.97	72	37	.02	78	5	.95
April..........	98	29	.15	90	46	.00	80	39	.05	82	19	.79
May...........	105	40	.49	91	50	.46	82	56	.46	92	11	.57
June..........	113	49	.39	91	58	.08	86	62	.58	100	29	.57
July..........	112	56	2.08	91	47	.94	..	..	4.50	99	39	2.29
August........	110	52	1.80	90	43	1.64	86	68	.84	96	42	2.15
September.....	104	42	1.11	82	56	.94	84	54	1.95	92	32	1.26
October.......	94	28	.92	79	50	.15	84	55	2.29	84	15	1.08
November.....	85	11	.50	71	40	1.44	81	31	.00	81	8	.79
December	76	−5	.54	..	37	3.20	..	..	.00	69	0	1.00
Year......	113	−5	9.33	91	37	10.41	..	..	10.86	102*	−16*	14.00

	Hawthorne, Nevada.			Winnemucca, Nevada.			St. George, Utah.			Fort Duchesne, Utah.		
	Max. temp.	Min. temp.	Mean rain-fall.	Max. temp.	Min. temp.	Mean rain-fall.	Max. temp.	Min. temp.	Mean rain-fall.	Max. temp.	Min. temp.	Mean rain-fall.
No. of years' observations.	5	5	14	23	23	22	5	5	22	5	5	15
	°	°	*Ins.*	°	°	*Ins.*	°	°	*Ins.*	°	°	*Ins.*
January.......	62	− 6	0.59	57	−28	1.09	70	− 1	0.98	52	−34	0.38
February......	68	6	.40	69	−22	0.88	79	1	.92	60	−21	.47
March.........	75	14	.35	82	− 3	0.92	86	12	.53	75	0	.65
April..........	81	19	.20	83	12	0.85	98	18	.35	85	12	.65
May...........	85	31	.45	96	17	1.03	97	20	.36	91	25	.66
June..........	100	40	.29	98	29	.65	114	36	.06	101	33	.18
July..........	101	26	.27	104	35	.17	115	41	.44	104	34	.50
August........	100	46	.45	102	26	.16	110	43	.65	101	34	.57
September.....	95	30	.23	94	16	.35	103	31	.42	94	17	.99
October.......	80	25	.31	87	10	.56	93	20	.39	84	13	.61
November	78	19	.39	93	− 9	.67	81	13	.40	70	1	.25
December......	68	0	.57	65	−20	.98	71	1	.96	52	−19	.58
Year......	101	− 6	4.50	104	−28	8.31	115	− 1	6.46	104	−34	6.49

*15 years' observations.

	Fort Yuma, Ariz.			Phœnix, Ariz.			Tucson, Ariz.			Mohave, Cal.		
	Max. temp.	Min. temp.	Mean rain-fall.	Max. temp.	Min. temp.	Mean rain-fall.	Max. temp.	Min. temp.	Mean rain-fall.	Max. temp.	Min. temp.	Mean rain-fall.
No. of years' observations.	26	26	20	17	17	22	6	6	15	5	5	26
	°	°	*Ins.*	°	°	*Ins.*	°	°	*Ins.*	°	°	*Ins.*
January	81	22	0.42	87	12	0.80	80	17	0.79	70	16	0.95
February	91	25	.51	92	19	.70	83	17	.90	78	20	.92
March	100	31	.26	97	24	.58	92	22	.77	83	26	.75
April	107	38	.07	105	30	.30	95	28	.27	100	35	.17
May	112	44	.04	113	35	.13	102	32	.14	102	38	.03
June	117	52	T	119	33	.10	112	48	.26	107	48	.05
July	118	61	.14	116	46	1.03	108	59	2.40	115	64	.08
August	115	60	.35	116	49	.88	109	57	2.60	112	57	.04
September	113	50	.15	114	39	.64	107	49	1.16	104	45	.07
October	108	41	.28	105	34	.37	98	29	.64	93	40	.25
November	92	31	.29	97	24	.54	90	21	.81	84	27	.40
December	83	24	.46	95	18	.86	83	10	1.00	70	15	1.26
Year	118	22	2.84*	119	12	6.93	112	10	11.74	115	15	4.97

	Prineville, Oreg.			Lost River, Idaho.			Laramie, Wyo.			Torres, Mex.	
	Max. temp.	Min. temp.	Mean rain-fall.	Max. temp.	Min. temp.	Mean rain-fall.	Max. temp.	Min. temp.	Mean rain-fall.	Rain-fall, 1901.	Rain-fall, 1902.
No. of years' observations.	6	6	6	5	5	5	5	5	13		
	°	°	*Ins.*	°	°	*Ins.*	°	°	*Ins.*	*Ins.*	*Ins.*
January	76	−9	0.64	45	−26	1.12	52	−23	0.23	...	0.00
February	73	−17	1.09	49	−41	.26	54	−40	.35	...	.00
March	83	5	.81	62	−1	.91	63	−14	.91	...	.00
April	92	12	.64	76	14	.35	74	−10	1.19	...	.00
May	96	21	.80	90	15	1.27	78	18	1.41	...	.00
June	98	24	.77	95	23	.68	91	28	1.12	...	.00
July	119	29	.03	99	30	.61	92	33	1.30	3.99	7.26
August	111	30	.64	95	25	.64	91	32	1.09	1.31	3.01
September	98	20	.81	89	21	.44	85	17	.73	.75	4.66
October	89	20	.75	75	14	.63	72	7	.86	.21	.04
November	82	9	1.06	60	−8	.92	63	−12	.25	...	.77
December	76	−5	.97	48	−23	.82	52	−27	.37	...	1.02
Year	119	−17	9.01	99	−41	8.65	92	−40	9.81	....	16.74

*26 years' observations.

The ratio of rainfall to evaporation can not be exactly determined, as data for evaporation are meager or wholly lacking. It has been deemed worth while, nevertheless, to get an approximate notion of this ratio by estimating the evaporation and dividing by the normal rainfall. In the following table this has been done and the results appear in the last column, headed Ratio. This table also shows the maximum and minimum annual precipitation at each station during the observation period shown in column 2.

Place.	Annual precipitation.				Annual evaporation. (estim.)	Ratio.
	No. of years.	Max.	Min.	Mean.		
		Ins.	*Ins.*	*Ins.*	*Ins.*	
El Paso	24	18.30	2.22	9.23	80	8.7
San Luis Potosi	1	.....	....	10.41	...	....
Chihuahua	1	.....	....	10.86	...	....
Fort Wingate	39	25.00	6.37	14.00	80	5.7
Fort Yuma	26	5.86	0.60	2.84	100	35.2
Phœnix	18	12.83	3.77	7.06	90	12.7
Tucson	25	18.37	5.26	11.74*	90	7.7
Mohave	26	21.38	2.20	4.97	95	19.1
Hawthorne	14	8.35	1.89	4.50	80	17.5
Winnemucca	22	11.91	4.89	8.51	80	9.6
St. George	13	9.81	3.55	6.46†	90	13.9
Fort Duchesne	15	11.43	4.36	6.49	75	11.6
Prineville	6	11.64	7.49	9.01	70	7.8
Lost River	7	11.86	6.22	8.47	70	8.3
Laramie	13	31.42	5.56	9.81	70	7.1
Torres	1	.....	....	16.97	100	6.0

*From 15 years' observation. †From 22 years' observation.

Discussion.—The foregoing meteorological data are given concerning localities which very clearly lie within the true desert regions of North America. It would be impossible to outline the included areas upon a map except by means of data obtained by an accurate and extended hydrographic and biological survey. The rate of evaporation for the several localities mentioned is roughly estimated from data taken from the Report on the Climate of Arizona by Greely and Glassford in 1891. It is probable that actual measurements might show a variation of 15 per cent by way of error in these estimates, the evaporation being overestimated, but the ratios found may be regarded as fairly approximate for the regions in which the several stations are located. It is to be seen that the evaporation at Tucson, Arizona, and at Laramie, Wyoming, is about 7 times as great as the normal precipitation, while at Yuma, Arizona, it is more than 35 times as great as the average or normal amount of precipitation. The evaporation at the last-named locality amounted to 160 times as much as the precipitation in the year 1899.

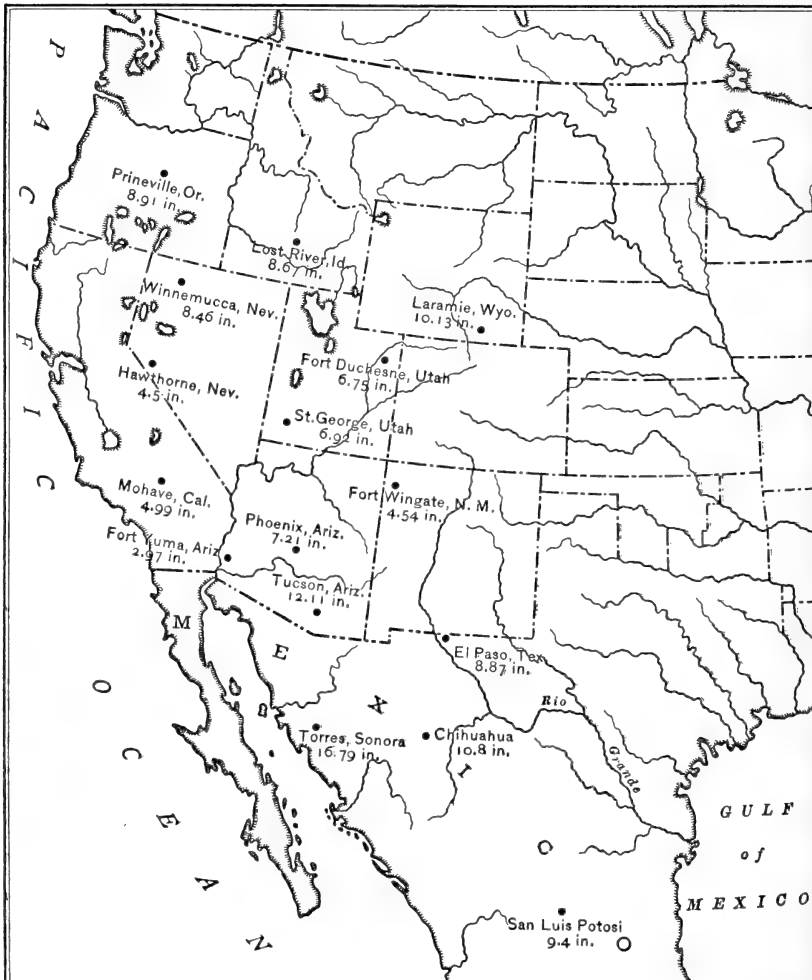


FIG. 4.—Location of and annual precipitation at certain stations in the arid region of western America. Chiefly from records of the U. S. Weather Bureau. (Reprinted from Publication No. 6.)

The arid area to the northeastward and leeward of the higher portion of the main range of peninsular California, however, can scarcely exceed this limit, although no measurements have been made. Near Bay San Felipe were seen wheel-tracks which had been made sixteen years before, while it is currently reported that the deep ruts of the gun-carriages of the

Walker Filibustering Expedition, where sheltered from the wind, are still visible in the deserts in the northern part of the peninsula after half a century.

The seasonal distribution of the rainfall in a region in which the normal precipitation bears a low ratio to evaporation may not only exert a marked influence on the character of the vegetation, but may also operate to produce desert conditions and make possible the support of xerophytic vegetation only, in districts with a large amount of rainfall. Thus, if the greater part of the precipitation should occur during a season of low temperature or in the quiescent period of the native species, the resulting dryness of the growing season would result in desert conditions. Such effects are most marked in regions in which the surface layers of the substratum consist of loose material not capable of retaining water in sufficient quantity for moisture-loving species. A striking example of this feature is offered by the area around Crater Lake, Oregon, as described by Coville. The surface layers in this locality consist of powdered pumice apparently almost devoid of humus, from which water drains with extreme rapidity. Snowfall to a depth of about 10 feet occurs in winter, but after this melts the soil becomes extremely dry and the plants capable of enduring the resulting drought show marked protective adaptations, the vegetation consisting principally of such species as *Phlox douglasii*, *Spraguea umbellata*, and *Arenaria pumicola*.*

The above factors must be taken into account in the interpretation of alpine districts in many parts of the world. The precipitation on mountain summits is very great, but in some instances it is in the form of snow, which melts and drains away very rapidly, leaving the humus-free soil extremely dry, while the air shows rapid alterations from high to extremely low relative humidity. An example of this character is offered by the summit of Agassiz Peak in the San Francisco Mountains of northern Arizona. A description of the meteorological conditions on this mountain will be found on pages 79 and 80.

SOIL.

The chief factor in the production of deserts is a lack of water as a nutrient substance for vegetation. Deserts may be produced as a result of other defective nutritive and mechanical conditions as well. Such conditions are to be found in areas in which the soil contains harmful substances in injurious concentration in the soil, of which the alkali lands are familiar examples. Sterile areas, due to lack of nutritive material and water and to the unsuitable mechanical conditions of the soil, are offered by stretches of sand-dunes and plains in many parts of the world. In

*F. V. Coville. The home of *Botrychium pumicola*. Bulletin Torrey Botanical Club, 1901, vol. 28, p. 109. The August vegetation of Mount Mazama, Oregon. Mazama, 1896, vol. 1, p. 170.

sand-dunes the substratum is in constant motion of greater or less rapidity, lacks a suitable water-supply, and may be devoid of other nutritive material. Even if the dune areas are supplied with water in proper quantities, the peculiar character and movements of the substratum result in some striking forms of vegetation.

A combination of the above mechanical and physical conditions of the soil and of the presence of harmful substances is offered by the white sands in the Otero basin in New Mexico, of which a more detailed description is given on pages 11 to 15.

The sand-dunes in this district consist chiefly of gypsum, the principal remaining constituents being silicates and calcium chloride in the proportions of 3 per cent and 1 per cent respectively. The gypsum is slowly soluble in cold water and retains the greater part of the water which falls upon it. Consequently the dunes are really moist hillocks of a granular structure, the surface layers of which are dried out by the heat of the sun to a depth of a few inches. The dried layer is constantly drifted by the wind, and the exposed layers are dried in turn, so that the progressive action of sand-dunes is manifested. The underlying layers at some depth often become solidified and stratified, but are easily broken up when exposed to the action of the sun and wind. The moisture included is sufficient for a number of species of plants, but the mineral substances in solution make it possible for only those forms which are adapted to an alkaline substratum to gain a foothold. The White Sands absorb the entire precipitation and give rise to no distinct streams, but occasional small pools or tanks of water highly charged with calcium salts are to be found in areas among the dunes. In western Australia extensive areas of gypsum desert are to be found which, it is reported, form a distinct harder surface crust instead of a granular layer, as in the instance described above, but no exact analyses of the substratum are at hand.

A number of districts in America show inclosed pockets or basins, forming the extreme lower depressions of ancient lake and river beds, in which the soil is highly charged with salts, the most of which is sodium chloride. Examples of this character are offered by the region around Great Salt Lake, Utah, and by the Salton District in the Colorado Desert of southern California. The characteristic vegetation in both instances is composed of species showing halophytic adaptations resembling those found near the seashore.

Limited areas in various regions show soils impregnated with sodium sulphate, sodium carbonate, potassium sulphate, sodium phosphate, sodium nitrate, calcium sulphate, calcium chloride, magnesium chloride, and magnesium sulphate. In agricultural operations two types of such soils are recognized, namely, *white alkali* and *black alkali*.

The nature of the mixture in the soil constituting white alkali is illustrated by the following analysis:

*Surface Crust of Soil from Kern Island, Bakersfield, California.**

	P. ct.		*P. ct.*
Potassium sulphate	0.52	Calcium phosphate	0.20
Sodium sulphate	82.96	Calcium carbonate	.10
Sodium chloride	.48	Ferric and aluminum oxides	.30
Sodium carbonate	.40	Silica	1.34
Magnesium sulphate	.50	Organic matter and water of crystallization	4.07
Magnesium carbonate	.13		

Alkali from the Valley of the Rio Grande in New Mexico.†

	No. 1.	No. 2.	No. 3.
	P. ct.	*P. ct.*	*P. ct.*
Insoluble matter	75.59	74.24	34.40
Portion soluble in water	24.41	25.76	65.60
Composition of soluble portion:			
Potassium oxide	4.71	3.57	.21
Sodium oxide	37.72	28.97	31.38
Calcium oxide	5.57	6.60	7.92
Magnesium oxide	.98	1.55	1.05
Aluminum	3.24	0.00	0.00
Sulphates	10.16	47.72	52.67
Chlorides	47.96	4.58	1.20
Carbonates	trace	trace	trace
Water of crystallization and organic matter	.44	8.04	5.84

The composition of the impregnating salts producing the black alkali is shown by the following analysis of alkali salts from soil near Fresno, California.‡

	P. ct.		*P. ct.*
Potassium chloride	1.30	Sodium carbonate	18.72
Sodium sulphate	18.23	Sodium bicarbonate	25.72
Sodium chloride	35.93	Phosphoric acid	.10

*Analysis by E. W. Hilgard: Report of Work of the Agricultural Experiment Stations for the year 1900, p. 97.

† Analysis by Goss and Griffin made from three samples from different localities. Bulletin No. 22, New Mexico Agricultural Experiment Station, p. 26, March, 1897.

‡Means, T. H., and Holmes, J. G.: Soil survey around Fresno, California. Field Operations of the Division of Soils, U. S. Department of Agriculture. Second Report, p. 373, 1900.

HISTORICAL.

The current conceptions of deserts are neither adequate nor correct, if the descriptions in the best dictionaries and cyclopedias are to be taken as an index. A work of wide circulation and use defines a desert as "A region that is wholly or approximately without vegetation. Such regions are rainless, usually sandy, and commonly not habitable." Another characterizes a desert as "A region of considerable extent which is almost if not quite destitute of vegetation, and hence uninhabited, chiefly on account of an insufficient supply of rain; as the Desert of Sahara; the Great American Desert. The presence of large quantities of movable sand on the surface adds to the desert character of a region. The word is chiefly and almost exclusively used with reference to certain regions in Arabia and northern Africa and others lying in central Asia. The only region in North America to which the term is applied is the Great American Desert, a tract of country south and west of the Great Salt Lake, once occupied by the waters of that lake when they extended over a much larger area than they now occupy. The name *Great American Desert* was originally given to the unexplored region lying beyond the Mississippi without any special designation of its limits" (fig. 6).

The insufficiency of the above descriptions obviously rests upon faulty observations and upon the failure to recognize the fact that the habitability of a region is no criterion of its arid character. The development of modern methods of transportation has made possible the maintenance of dwellings and towns with a considerable population at 100 or even 200 miles from the nearest supply of water. Also such facilities are not necessary to the sustenance of a population in deserts of the most extreme type as illustrated by the Sahara, which has a population of 2,500,000 people. So far as the vegetation is concerned, the actual number of individuals is much less than on a similar area in a moist climate; this in fact is one of the chief characteristics of a desert, but it would not be safe to estimate the total number of species much below the average number.

Lastly, be it remembered that local topography has but little influence on the desert character of a region. Sandy flats, plains, valleys, and rocky hills reaching to such altitudes as to become mountains are included in some desert tracts. It follows, as a natural consequence of the sparse vegetation as one factor, that the surface layers of the substratum, being usually dry in arid regions, are readily shifted and worn by winds.

The designation of the vast region between the Missouri River and the Rocky Mountains as the Great American Desert rested upon a lack of definite knowledge by the earlier geographers, which was shown by textbooks as recently as 1843. Later, when the more exact results of the earlier explorations and surveys became known, the more important arid regions were fairly well delimited, and the desert areas in the Bad

Lands, the Staked Plains of Texas, the Chihuahua Desert, the Great Basin, and the Colorado Desert were shown approximately within the districts which may appropriately be designated as desert at the present

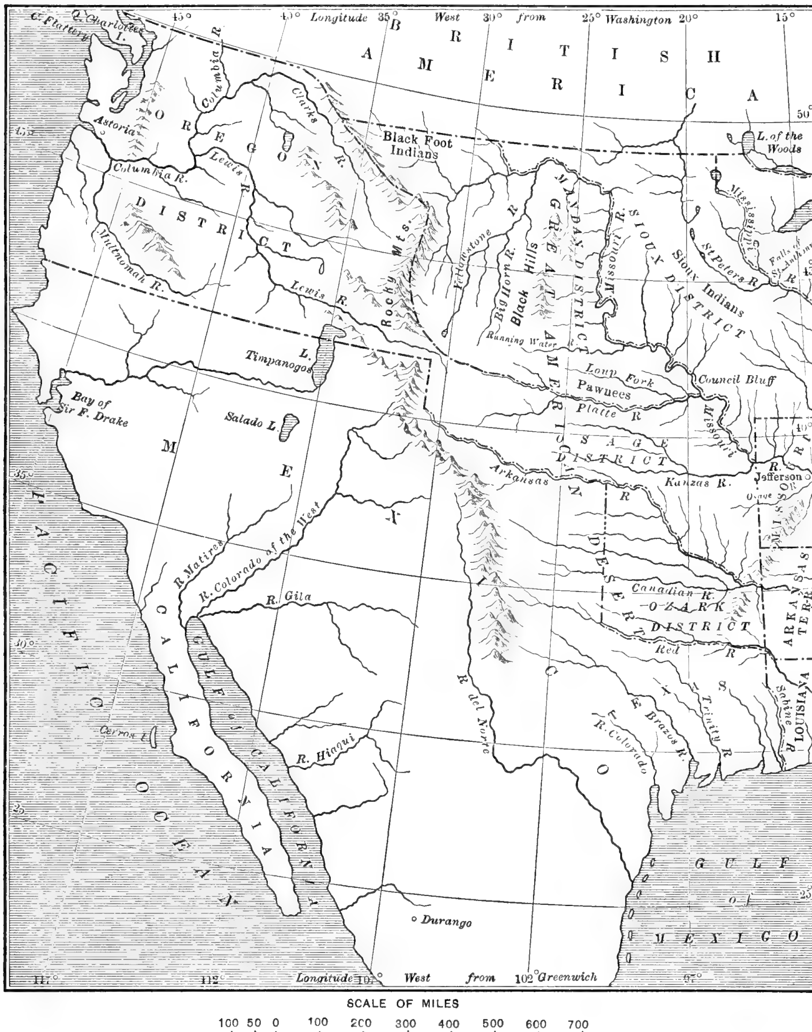


FIG. 5.—Western America, showing conceptions of American deserts current in 1835. Copied from T. G. Bradford's Comprehensive Atlas, published at Boston in 1835. (Reprinted from Publication No. 6.)

time. This conception of the matter is shown in fig. 6, being a map from a text-book on physical geography published in 1859.

A study of the physiographic, floristic, and meteorological features of western North America has resulted in delimiting two great desert areas by the geographer, botanist, and meteorologist. The outlines of these might be roughly traced by lines inclosing the stations shown in fig. 4. These regions may be designated as the Sonora-Nevada Desert and the Chihuahua Desert.

The Sonora-Nevada Desert embraces portions of Utah, Idaho, Washington, Oregon, Nevada, California, Arizona, Baja California, Sonora, and Sinaloa. The northern portion of this region is mainly comprised in the Great Basin and embraces the beds of a number of ancient lakes and the surviving Great Salt Lake. Other special physiographic features of interest in this connection are the areas which bear the names of Snake River Desert of Idaho; the Sage Plains of Washington; the Lava Beds of Oregon; the Ralston Desert in Nevada; Death Valley, Mohave Desert, Colorado Desert, Salton Desert in southern California and Arizona; the Painted Desert in Arizona and New Mexico; and the Sonora Desert in Mexico. The southern portion of the region consists of a series of extended slopes and terraces traversed by many ranges of hills and mountains with peaks of some altitude. Along the shores of the Gulf of California and of the Pacific Ocean proper the desert area includes the entire surface to within a few feet of the water's edge, and the xerophytic vegetation of the plains comes into direct contact with the mangrove and strand flora.

The Chihuahua Desert occupies the central table-land of Mexico east of the Sierra Madre, extending as far south as San Luis Potosi and including parts of the States of Coahuila, Chihuahua, and Texas and also portions of Arizona and New Mexico. The Bad Lands of the Dakotas and Montana and the Red Desert of Wyoming, both included in the "Great American Desert" (fig. 6), might be regarded as a northern arm of this region for the purposes of this paper. The arid portions of this area consist for the most part of great valleys inclosed by parallel ranges of mountains which in some instances attain such altitudes as to be timber-clad and even bear an alpine vegetation.

FORMATION AND EXTENT OF DESERTS.

The deserts of the world's surface are not easily delimited, even in North America, where some attention has been given to the geographical extent and position of the arid areas, which may be taken to cover over 500,000 square miles. The accompanying map (plate 61) indicates the general location of deserts only and not an outline of the areas to be included. So far as estimates may be based upon the data obtained from it, a very large proportion of the earth's surface receives a rainfall much less than the possible evaporation, and is therefore inhabited by plants of specialized form and of xerophytic and halophytic adaptations.

These desert areas have been subject to many conditions of change in recent geological history, as a result of which some are more arid now than ever before in their history, while in other cases the weight of evidence lies in favor of the view that the present is a state of maximum aridity, which may become still more accentuated. Small areas may become suitable to desert types of vegetation by highly localized causes, such as an accumulation of salts brought to the surface by the capillary action of introduced water.

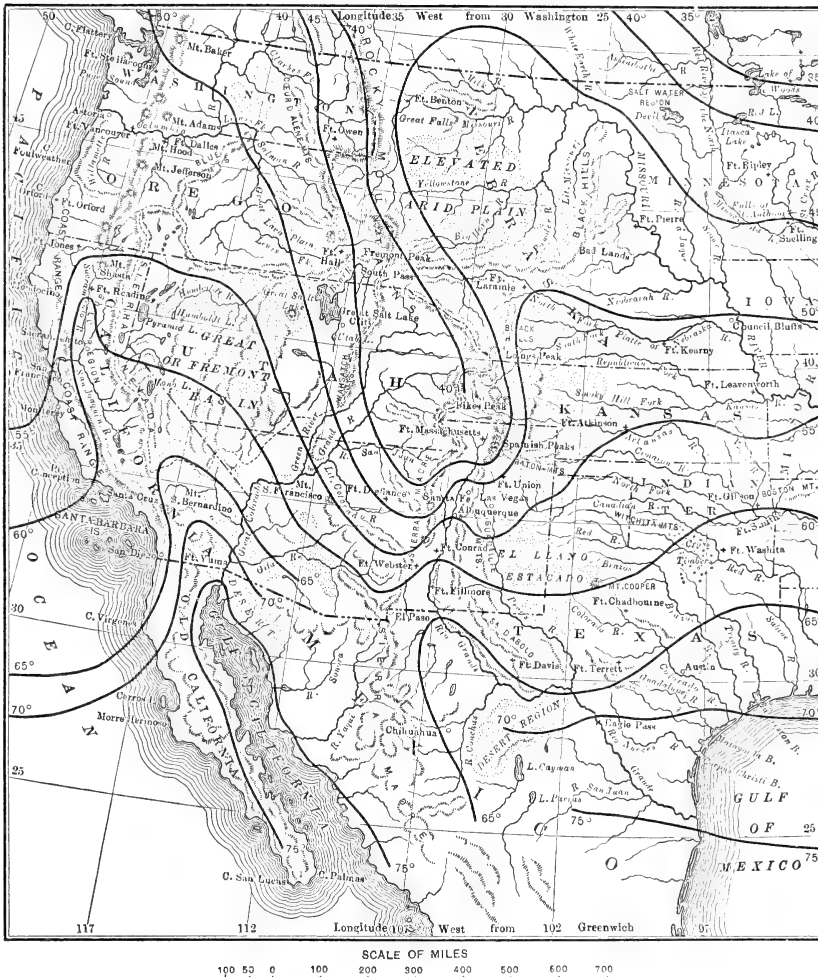


FIG. 6.—Western America, showing conceptions of American deserts current in 1859. Copied from Warren's Physical Geography, published in 1859. (Reprinted from Publication No. 6.)

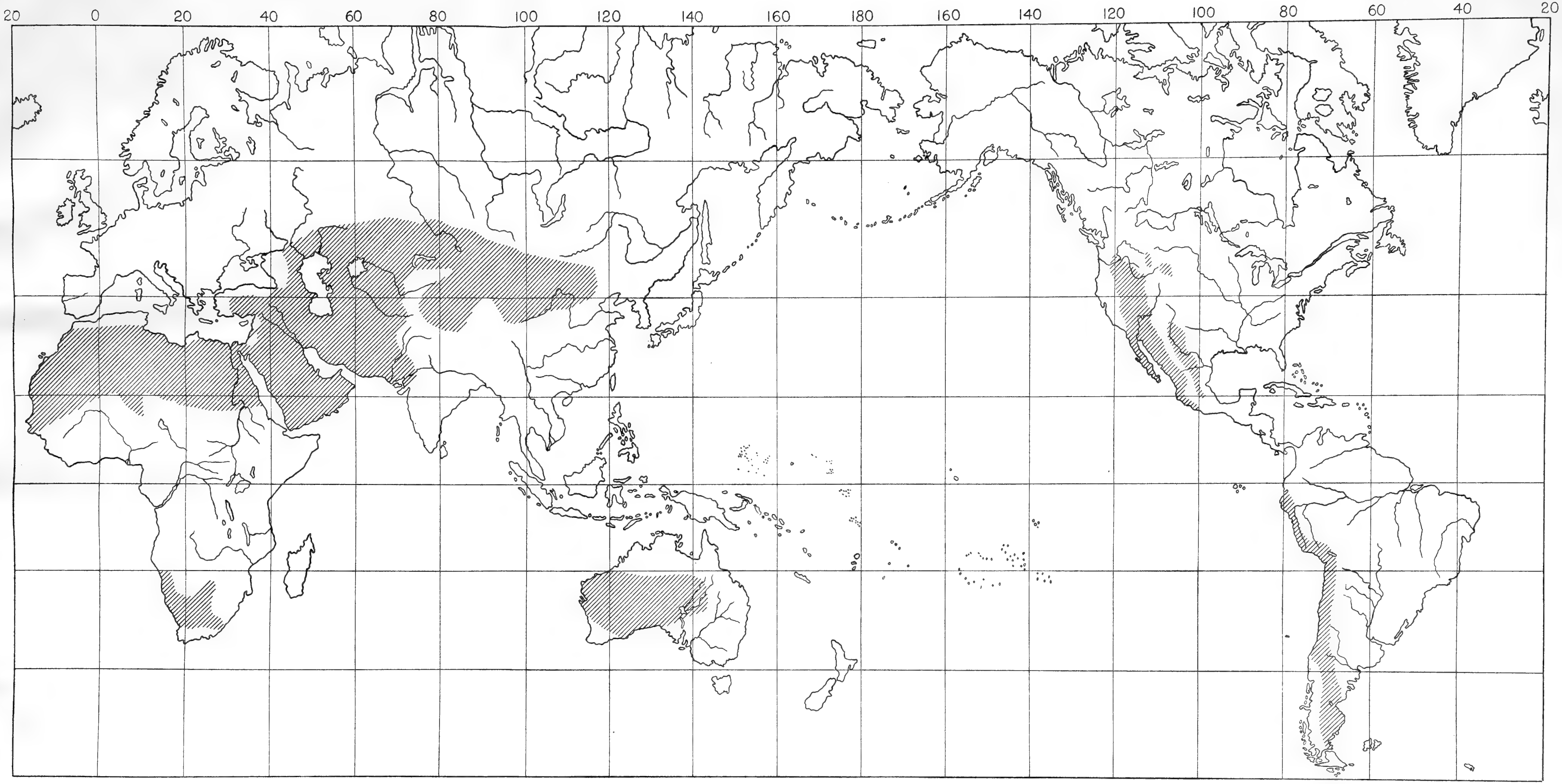
The chief cause of deserts, however, may be ascribed to the change from lower temperatures and accompanying greater supply of moisture in glacial times to the comparative aridity of the present. This change, however, may not be assumed to have been one constantly moving in the same direction. According to Russell (I. C. Russell, Geological History of Lake Lahontan, Monograph 11, U. S. Geological Survey, 1886), the Great Basin region of Nevada underwent a period of desiccation before it received the waters of Lake Lahontan, which, after reaching a maximum height without overflowing, receded to leave the region even more completely desert than at the present time. The next oscillation toward increase of the water-supply carried the lake back to a level higher than the first, and then receded to leave a desert for the third time, which, so far as weight may be given to some of the evidence, reached its greatest aridity a few hundred years ago; so that the Nevada desert is now not so dry as it has been within the period witnessing the advent of man.

Climatological and geological changes of this kind work a double effect upon a region. The decreasing rainfall results in a general aridity of the entire region affected, and the reduction of the streams is followed by a recession of lakes and other sheets of water by which basins with the soil highly charged with salts are left to specialized types of vegetation. Comparatively local causes, such as the cutting off of the head of the Gulf of California by the silt of the Colorado River, may leave a basin to become a part of the contiguous desert, as is also the case with the Pattie Basin to the southward. Changes of level by both upheaval and subsidence may also contribute to the formation and extension of deserts, as indicated in a preceding section.

The great Lake Eyre basin in southern central Australia is taken by some geologists to have had a complicated history, by which the region in which it was included was slowly depressed until flooded by the sea, then emerged to undergo the resultant changes in the muds that covered its floor. In a second subsidence the surface was carried down to a level where its floor was 39 feet below sea-level. Two rivers carried such volume of water into it that it became the bed of a fresh-water lake, with a luxuriant development of plant and animal life which found agreeable conditions for existence. The entrance from the sea appears to have become filled, the amount of river flow decreased, the annual evaporation in the basin being about 86 or 88 inches per year, and a desiccation set in probably early in the Pleistocene, which continued to the present time, although, as in all deserts, small bodies of water occasionally collect in the lower parts of the basin. (J. W. Gregory, The Dead Heart of Australia, London, 1906.)

Lastly, many writers hold to the opinion that distinct changes in climate with increasing aridity have taken place on various parts of the earth's surface long since the advent of man and well within historic time. The most pronounced of such views is held by Huntington concerning central Asia. He says:

> To sum up the history of Lop-Nor during the last 2,000 years: We have first a comparatively large lake, said to measure 75 miles each way, in spite of the fact that the populous towns of Lulan and of more remote regions diverted much more water than now. Next, during the early centuries of the Christian era, there is



MAP SHOWING THE GENERAL LOCATION OF THE PRINCIPAL DESERTS OF THE WORLD.

Compiled by G. Sykes.

a decrease in the recorded size of the lake, even though the towns of Lulan were being abandoned and their water was being set free to reinforce the lake. Then, in the Middle Ages, there was an expansion of the lake, which can not have been due to diminished use of the rivers for irrigation, for the population of the Lop Basin at that time was greater than now, though not equal to that of the flourishing Buddhist times, a thousand or more years earlier. Finally, during the last few hundred years there has been a decrease both in the size of the lake and the population about it. If Lop-Nor alone is considered, this sequence of events is not proved by compulsory evidence in all particulars; but it fits the facts better than any other theory as yet suggested. And, more than this, it agrees with all the data which I gathered from the whole of the 1,500 miles of longitude and 400 of latitude of the Lop basin and from Kashmir. All the facts are explicable on the theory of a secular change of climate from moister to drier conditions, with a rapid intensification in the early part of the Christian era and a slight reversal in the Middle Ages.*

Hedin, who has carried on extensive explorations, holds views quite different from those of Huntington and sees no evidence of climatic change in the extensive disturbances of the population and pursuits of the inhabitants which he notes.

Evidence upon a matter of this kind is not easily sifted, and a spirit of controversy prevails in most of the writings upon the subject. The short-period oscillations of climate, which swing back and forward with average amplitude; the movements of nomads and half-civilized people in response to these changes, and the abandonment of schemes for division and use of water for agricultural purposes, may in some instances give remains simulating the effects of increasing desiccation. Exact meteorological observations extend over so brief a period that they throw no light on the main question. (See R. DeC. Ward, Changes in Climate, *Popular Science Monthly*, 1906, vol. 69, p. 458.) Much has been written upon the subject by explorers and investigators of archeological remains in the deserts of northern and southern Africa. A review of these writings would be out of place in the present volume.

INFLUENCE OF THE DESERT ON LIFE.

The geological and climatic changes by which a region varies from a cool, moist, equable climate, with well-leached soils and complete drainage, to an arid basin, with saline or alkaline soils, imperfect drainage, great evaporation, and wide diurnal and annual changes in temperature, entail, of course, sweeping modifications in the composition of the flora, and consequently the fauna. Such movements would put vegetation in a state of continued high stress. Forms in existence at any given time would gradually perish as their habitats were narrowed and the limits of their power of accommodation and acclimatization were reached. New forms which arose by a supposed gradual modification and selection

*E. Huntington: The Rivers of Chinese Turkestan and the Desiccation of Asia. *Geographical Journal*, October 28, 1906, p. 352; and Lop-Nor, A Chinese Lake, Bulletin American Geographical Society, February and March, 1907; see p. 146.

would take up the succession, the process of adaptation continuing until the present succulent and spinose types were reached. On the other hand, the new conditions might be met by sports or mutants, offsprings of the existing forms, which diverged from the parental types very widely, and which occur in such manner that some would be born which would be able to survive and thrive under the modified conditions of soil and climate. Gradual modifications by which a long series of forms, each slightly different from its immediate progenitors, appear to have been found among animals, but with plants no such series has yet been brought to light. These organisms, on the contrary, exhibit sports or saltatory derivatives, which now have been seen and recognized in a number of species. Such mutants are now occurring and we may predicate with certainty that they have occurred with normal frequency during the formation of the deserts of southwestern America. That many of them have survived to become constituents of the present flora is a supposition fully in accord with the facts, and it seems reasonable to assume that the greater number of the units of the plant population have arisen in this manner.

The recession of an inland sea or the drying up of a lake might lay bare great areas in regions of relatively small precipitation, with the result that the desert would be extended. Such new desert basin would be populated with plants by invading movements from the contiguous territory. If the adjoining areas were of equal aridity, the occupation of the new desert would be a comparatively simple matter in the succession of formations which would follow the receding waters, although a series of this kind has never been actually observed. The occupation of such a desert might, however, require great departures from the types of vegetation accessible to it, and in such instances we are confronted with the choice between possible modifications as direct adaptations to the newly presented environmental conditions or to fitting mutations. The time requirement would favor the latter in most instances, and there is yet no evidence at hand to prove the direct response of plants to any given environment by structural adaptations which would be suitable to that environment. Thus the armature of desert plants is often thoughtlessly cited as an adaptation by which these forms protect themselves against the ravages of animals. The presence of spines undoubtedly operates to prevent a plant from being eaten by animals, but the action of the animals has in no wise induced their formation by the plant. As a matter of fact, the fatality among desert plants by injury from animals is greatest in the seedling stage. For every prickly-pear that survives, tens of thousands of seedlings are eaten by rodents, and these seedlings are as unarmed as those of any other type. The natural selection actually operative in such cases is one that chooses among forms offered, but does not in any sense exercise a directing or guiding action on the development of such forms.

It is not to be assumed, however, that external factors are without effect upon the evolution of living things. It has not yet been demonstrated that climatic or soil factors acting upon the somatic or vegetative part of the plant produce changes that are heritable, but on the other hand, MacDougal has shown that certain external agents, when brought to bear directly upon the germ plasm of the pollen tube or the embryo-sac of a plant, may produce profound alterations which are strictly inheritable after being tested to the third generation of the progeny. Solutions of zinc, calcium, and other substances combined were used and similar results followed the exposure to the action of radium.

If we seek a like possible intervention of external forces which would act upon the plant unaided by man, we might find such influence coming from radio-active substances, such as spring and rain-water, or from the effects of sulphurous and other gases, which are being set free in numberless localities, or the protoplasts most nearly in contact with the egg apparatus may well excrete substances which would produce the same effect without regard to the forces which originally caused the disturbances in the extra-ovular tissue. The actual technique of injection would be imitated in a measure by the action of foreign pollen which might find lodgment on the stigmatic surfaces and, sending down tubes through the style, introduce unusual substances into the vicinity of the egg-cell without participating in normal fertilization, which would ensue in the customary manner. Lastly it is to be said that it would appear that a most prolific source of such disturbances might be expected to result from the stings and lacerations of insects or the action of parasitic fungi, both sources of the most profound morphogenic alterations in somatic tissues, profusely exemplified by the well-known gall-formation of plants. (MacDougal, "Heredity and Origin of Species," reprinted in advance from the *Monist* for January, 1906, and distributed December 18, 1905; also "Discontinuous Variation in Pedigree Cultures," *Popular Science Monthly*, September, 1906.)

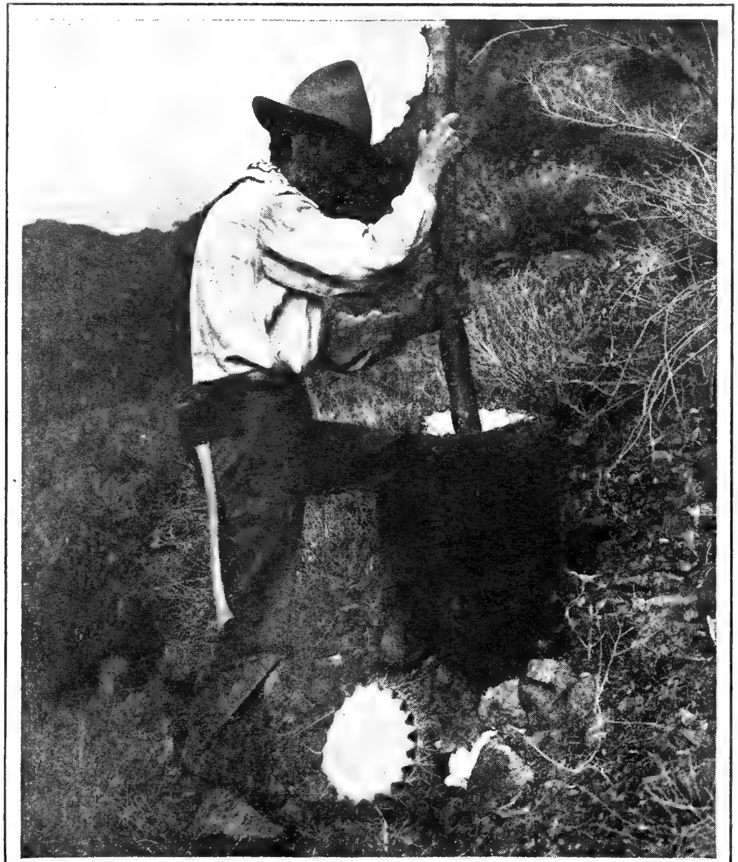
Tower (An Investigation in Evolution of Chrysomelid Beetles of the Genus Leptinotarsa, Carnegie Institution of Washington Publication 48, 1906), after eleven years of assiduous experimentation with beetles, likewise concludes that influences merely exerted upon the body are without lasting effect in the history of a race and that they are not inheritable. When such variations in moisture and temperature as would affect the germ-cells were brought to bear, however, profound changes ensued, which might be transmitted from generation to generation and which were not in the nature of adaptations.

Formerly the desert was held to be an uninhabitable place, but by the aid of the devices of modern civilization the requirements of life, comfort, and luxury may be transported to the most remote deserts, and large populations may carry on pursuits, such as mining, unconnected with the climate, regardless of aridity. One of the most important developments of modern agriculture is that of dry farming, in which forms of economic plants are sought which will produce crops under arid conditions, and constant and assiduous attention is being given to the development of cultural methods which will facilitate the growth of plants in deserts and conserve the soil moisture by checking evaporation. These and other individual adaptations of the human animal are of extreme interest, particularly when considered by the archeologist engaged in the study of the ancient civilization of desert peoples. (C. S. Scofield, Dry Farming in the Great Basin, Bulletin No. 103, Bureau of Plant Industry, U. S. Department of Agriculture, Washington, 1907.)

One of the most difficult problems to solve is that of transportation in the desert, and there are extensive areas in American deserts that have not yet been systematically explored by reason of this condition.

The camel is perhaps the most extensively used of any means of transportation, and as such he has played an important part in the history of the human race in the arid regions of Asia and Africa. This animal has also come to be of great usefulness in Australia, where it was introduced in 1846, and a later importation of these animals, brought in 1860, accompanied the Burke and Wills Expedition across the continent. In this same period efforts were made to make use of the camel in American deserts, and although the conditions were undoubtedly and still seem quite as favorable, the movement was a failure by reason of prejudice, and of the organization of transport of burros, horses, and mules already in a high state of specialization in this region. The extension of railways to tap mining regions and the usefulness of the modern motor car, as proved in the deserts of Nevada, now make any further consideration of the camel unnecessary along main lines of travel, while the solitary traveler or the small party following personal routes have available animals and supplies, so that the most economical outfit is that of horses, mules, and burros. A camel is reputed to be able to carry a load of 600 pounds with ease, but the same amount might be taken by three or four burros at a cost of original investment and maintenance only a fraction of that of the camel-train. It is to be said, however, that a small efficient camel-train would make possible the scientific exploration of the deserts of western Sonora and of the region traversed by the Camino del Diablo with some certainty of success.

A comprehension of the part that water plays in existence and travel in the desert is to be gained only by experience. Some of the native animals, such as mice and other small rodents, have been known to live on hard seeds without green food for periods of several months, or even as long as two or three years, and nothing in their behavior indicated that they ever took liquid in any form. (F. V. Coville, Desert Plants as a Source of Drinking Water, Smithsonian Reports for 1903, pp. 499–505. 1904.)



Crushing the pulp of a decapitated bisnaga (*Echinocactus*) to obtain a drink in Central Arizona.

Papago Indian drinking from a cactus (*Echinocactus emoryi*) west of Torres, Mexico.

Deer and peccary are abundant in deserts in Sonora in which the only available supply of open water is to be found in the cacti. The endurance of the camel is well known, and some of the best authenticated evidence upon the matter comes from Australia. The camels of the Tietkins party in 1891 and 1892 made a march of 537 miles in 34 days without a drink. These animals take water every day when a supply is available, but it is their capacity for accommodation that has made them such a potent factor in transportation in the deserts of Asia, Africa, and Australia. Other animals, including the common domestic sheep, are also capable of making such changes in their habits that they may go for weeks without a drink.

Man and his most constant companion on the desert in America, the horse, are comparatively poorly equipped against the rigors of the desert. A horseman may go from the morning of one day until some hour of the next in midsummer and neither he nor his horse will incur serious danger: experiences of this kind are numerous. If the traveler is afoot, abstinence from water from sunrise to sunset is a serious inconvenience to him, and if he continues his journey, the following morning his sufferings may so disturb his mental balance that he may be unable to follow a trail, and by the evening of that day, if he has not come to something drinkable, he may not recognize the friendly stream in his way; instances are not unknown in which sufferers from thirst have forded streams waist deep to wander out on the dry plain to a grisly death.

Some estimate may be made of the actual amount necessary from the fact that a worker at the Desert Laboratory during the course of an ordinary day in May, at Tucson, consumed 16 pints of water. A horse would have used 15 or 20 gallons in the same time. A walk of 3 or 4 miles was taken, but no special muscular effort beyond this was involved. A march across the desert in midsummer would increase this quantity by half. Under such circumstances, a canteen of less capacity than a gallon is a toy, and one of real usefulness should contain at least twice that amount. The most notable example of endurance of thirst is that of a Mexican prospector hunting for a "lost mine" near the old Camino del Diablo, or trail from Sonora to Yuma, who made camp safely after being out for eight days with a supply sufficient for one. This experience is not likely to be duplicated soon, although it is reported that Indians often go as long as four days without water. (W J McGee, Desert Thirst as a Disease, Interstate Medical Journal, 1906, vol. 13, No. 3, 1906.)

The experience of the field expeditions from the Desert Laboratory demonstrates that saline or alkaline waters which contain as much as one-fourth of 1 per cent of salts may be used for periods of many days without serious discomfort, but if the proportion be increased to one-third of 1 per cent only hardened travelers may use it, while water which contains as much as one-half of 1 per cent is inimical to health and comfort, although it might suffice for a few hours or save the life of a person who had been wholly without water.

All devices for allaying the discomfort arising from the dryness of the mucous membrane, such as carrying bullets or pebbles in the mouth, chewing grass or a piece of rubber, are wholly futile in meeting the serious thirst problem. The relative humidity often falls to 5 per cent in the Southwestern deserts, and in a temperature of over 100° the evaporation from a vessel of water standing in the open may be as much as an inch a day. The amount thrown off by the skin is correspondingly great, and if the loss is not made good, thirst ensues, and ten hours' lack of water may thicken the tongue so that speech is impossible.

The Indian and the desert traveler often seek relief in the juices of plants when water fails. The fruits of some of the prickly-pears are slightly juicy, the stems of the same plant or the great trunks of the sahuaro contain much sap, but for the most part it is bitter, and while it would save life, in extremity, yet it is very unpleasant to use. The barrel-cactus, or bisnaga (*Echinocactus*), however, contains within its great spiny cylinders a fair substitute for good water. To get at this easily one must be armed with a stout knife or an ax with which to decapitate the plant, which is done by cutting away a section from the top. Lacking a suitable tool the thirsty traveler may burn the spines from the outside of the bisnaga by applying a lighted match and then crush the top with a heavy stone. This or other means is taken to remove a section 6 to 8 inches in thickness and expose the older parenchyma around the small central woody cylinder. Next a green stake is obtained from some shrub or tree that is free from bitter substances, and with this or with the ax the white tissue of the interior is pounded to a pulp and a cavity that would hold two gallons is formed. Squeezing the pulp between the hands into this cavity will give from 3 to 6 pints of a drinkable liquid that is far from unpleasant and is generally a few degrees cooler than the air (plate 62). Scouting Indians have long used the bisnaga, and a drink may be obtained in this manner by a skilled operator in 5 to 10 minutes. Some travelers are inclined to look with much disfavor on the liquid obtained in this manner, but it has been used without discomfort by members of expeditions from the Desert Laboratory. That it is often preferred by Indians to fair water is evinced by the fact that the Whipple Expedition found the Mohaves near the mouth of the Bill Williams River, in 1853, cooking ducks and other birds in the juice of these plants by means of heated stones dropped into the cavity containing the pulp.

The sap of the sahuaro (*Cereus giganteus*) and of other cacti contains bitter substances that make it impossible to be used to allay thirst by man, although it may be given to burros. A supply is usually obtained by felling the heavy trunk and elevating the ends a few inches above the ground, while the middle is allowed to sag lower over a bucket or vessel that has been suitably placed in a hole in the ground below. A cut is made above the bucket to allow the liquid to exude, while the process is hastened somewhat by building a fire under the ends.

The experiences of the expeditions from the Desert Laboratory made it evident that a still or condenser by which even a small quantity of drinkable water could be obtained from the abundant sap of these plants or from alkaline waters would greatly facilitate field-work. After some experimentation the form adopted was one designed by Mr. Godfrey Sykes, in which the cactus pulp or liquid to be distilled was placed in a boiler of pressed steel. This boiler has a capacity of about 2 gallons and is built up of two pressed-steel kettles, one of which is inverted over the other and fastened by a riveted seam. An opening 4 inches in diameter in the bottom of the inverted vessel received a threaded fitting to which is attached a half-inch pipe with an elbow. Sections of pipe 30 inches long with conical friction joints are carried, and as many are fitted as may be necessary to secure condensation. This apparatus may be set up anywhere, and the cooling of the steam escaping through the condensing pipe may be effected in the air, by embedding in the earth, or by a drip from cloths. A capacity of several gallons per day has been shown by this apparatus, an amount that would enable a party to make a stay at a locality in which the untreated water would be wholly undrinkable. This apparatus has the additional advantage that the replacement of the outlet of the boiler with a screw plug makes it a suitable vessel for carrying a supply on the march.

Some experimentation has been made for the purpose of designing a solar condenser in which the vapor coming from a water surface under the influence of the sun's rays would be condensed on a cooler shaded portion of the glass top, and the collected drops conducted to a receiver. Devices of this sort constructed of non-soluble glass are used at the Desert Laboratory to secure water of a high grade of purity for use in injection experiments with plants. These work very slowly, however, and no form of this apparatus has yet been designed that would be of any practical value in life on the desert.