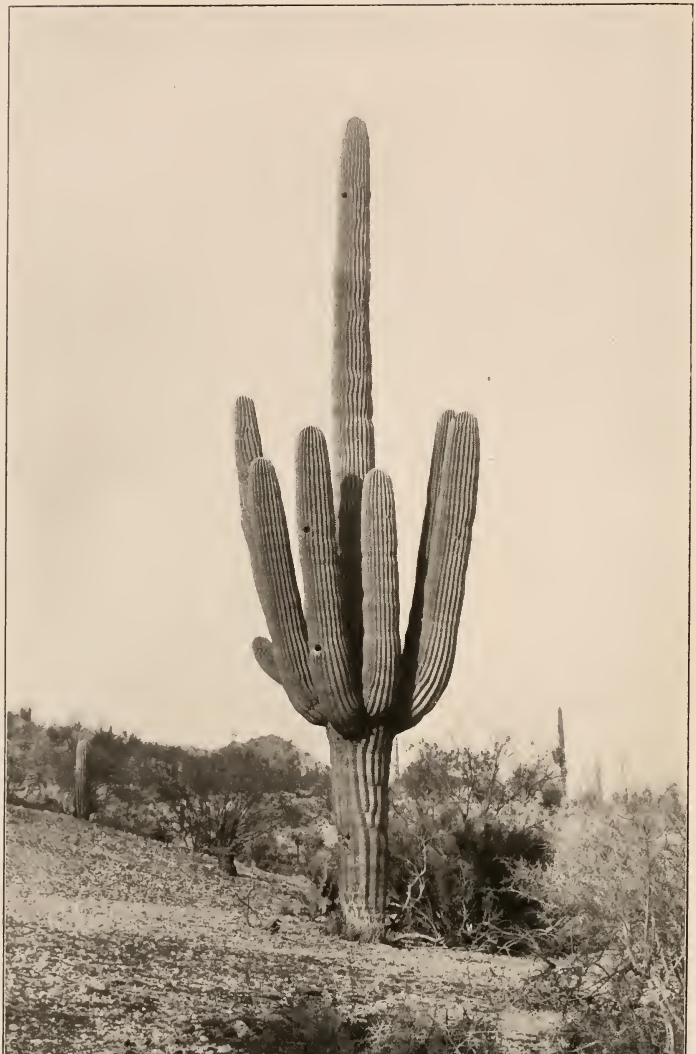

Saguaro or giant cactus (*Cereus giganteus*) near Tucson, Arizona. About 40 feet high. Birds nest in the cavities of the trunk.

Desert Botanical Laboratory

of the

Carnegie Institution

BY

FREDERICK VERNON COVILLE

AND

DANIEL TREMBLY MACDOUGAL

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ANNOUNCEMENT.

At the suggestion of Mr. Frederick V. Coville, botanist of the United States Department of Agriculture, the Advisory Committee on Botany of the Carnegie Institution, recommended the establishment of a Desert Botanical Laboratory in the arid region of the United States, the purpose of such establishment being to thoroughly study the relation of plants to an arid climate and to substrata of unusual composition. Mr. Coville and Dr. D. T. MacDougal, who were already well acquainted with the arid regions of the United States, were requested to act as a committee of inquiry on this subject. The results of their inquiry are herewith presented, from which it will appear that a site for a botanical laboratory has been selected near Tucson, Arizona. Dr. W. A. Cannon, of the New York Botanical Garden, to whom a grant had been made by the Carnegie Institution, in aid of research, has been appointed Resident Investigator in charge of the Laboratory. A suitable structure has been erected, and the investigations commence in the autumn of 1903.

Daniel C. Gilman,
President of the Carnegie Institution.

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ILLUSTRATIONS.

THE DESERT BOTANICAL LABORATORY OF THE CARNEGIE INSTITUTION.

Introduction.

Several investigators, in Experiment Stations and other branches of government inquiry, have made special studies of the relations of plants to alkaline and other soils. They have also observed the behavior of plants in arid regions under the influence of irrigation. For the most part, both of these classes of studies were concerned with special and local problems, the immediate purpose of such study being to obtain information for the use of the agriculturist and horticulturist. Despite this limitation they clearly showed the need of a broader and more thorough study of the technical and general aspects of the relation of plants to dry climates and to substrata of unusual composition. Special mention should here be made of the results obtained by Messrs. Kearney and Cameron, who have investigated the separate and the combined effect upon plants of the substances usually found in alkaline soils. Other important papers are cited in the accompanying bibliography, pages 53 to 58.

When the Carnegie Institution was established, Mr. 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 approved 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.

Furthermore, it was arranged to provide such an equipment as would enable a small number of trained investigators, should they so desire, to utilize the opportunity for studying those questions for whose solution the Laboratory and its environment are especially favorable. Not the least important part of the duties of the resident investigator will be to aid visiting botanists and others.

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 24 and February 28, 1903, they made a reconnaissance of the region along the Mexican boundary. As the outcome a site was selected on a small 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. He at once undertook the preparation of the bibliography of desert plants, which is printed in this report, pages 46 to 58.

As no publication exists, suitable to the needs of the botanist who visits our western deserts, it has seemed desirable to present a brief narrative of the trip, accompanied by illustrations of landscapes showing characteristic vegetation. The observations were necessarily interrupted by night travel, and as the time at command was short, only a mere skeleton of the desert flora can be presented. If, however, this shall serve to convey an idea of the diversity of the several lesser floras of which the whole is made up, and of the wealth of material afforded for detailed geographical and physiological study, the chief purpose of this portion of the report will have been accomplished.

ITINERARY.

The two members of the Board having met at Washington left that city January 24, 1903, and arrived at El Paso, Texas, on the morning of January 28. During the day they visited the sand dunes in the Chihuahua desert between Samalayuca and Los Medanos, Mexico, and in the evening took the train for Alamogordo, New Mexico. From January 29 to January 31 they were engaged in a wagon trip to the White Sands of the Tularosa desert, southwest of Alamogordo. On February 1 they returned to El Paso and proceeded by rail to

Tucson, Arizona. Here they remained February 2 and 3, examining the desert flora of the plain and adjacent mountain slopes. On February 4 they proceeded by rail to Nogales, on the boundary line between Arizona and Mexico, where they stayed February 5, making observations on the vegetation in that vicinity. On the morning of February 6 they arrived by rail at Torres, Sonora, Mexico. February 7 to 10 was spent on a saddle trip into the desert west of Torres, toward the Gulf of California. February 11 a journey was made by rail to Guaymas and return which afforded an opportunity to observe both the desert and the seacoast flora of Guaymas harbor. February 12 and 13 were passed on the desert in the immediate vicinity of Torres. On February 14 the Board returned to Tucson where they remained during the two following days. On the morning of February 17 they arrived by rail at Salton, in the Colorado desert of southern California, and remained during the day examining the vegetation of the salt and alkali lands. On the morning of February 18 they proceeded to Indio, also in the Colorado desert, and in the afternoon drove to Thousand Palm canyon and return. February 19 they went by rail to Los Angeles and the next morning took a train east, passing through Cajon pass and across the Mohave desert, arriving on the evening of February 21 at the Grand Canyon of the Colorado river, in Arizona. February 22 and 23 were spent in a trip to the river by the Bright Angel trail. On the morning of February 24 they left the canyon and on February 28 arrived in Washington.

THE ARID REGION OF WESTERN TEXAS.

Eastern Texas has the characteristic humid subtropical flora of the Gulf region, with longleaf pine (*Pinus palustris*), cane (*Arundinaria*), bald cypress (*Taxodium distichum*), and their associates, but this flora gradually merges into the wholly different one of arid western Texas. Beginning east of San Antonio the ground is covered with an open growth of mesquite trees (*Prosopis*), 10 to 20 feet high, resembling a vast peach orchard. Scattered through it are larger trees, some deciduous, others evergreen oaks. The mesquites themselves are nearly leafless in late winter and are much infested with a mistletoe. Scattered among them are various shrubs 4 to 8 feet high, and as the most conspicuous feature of the undergrowth a prickly pear with large flat orbicular vertical joints, the whole plant rising 1 to 3 feet from the ground. Another occasional feature of the undergrowth is a small *Yucca* with long and broad leaves, commonly without a trunk but occasionally reaching a height of 6 to 8 feet. Some of the oaks have their branches clothed with a gray epiphyte

(*Tillandsia*). Between Sabinal and Uvalde occur areas on the higher, more sterile parts of the plain, over which the mesquite and oaks are wanting, the undergrowth, however, remaining. These areas often contain a growth of an *Acacia* 2 to 3 feet high with dark yellowish-green persistent foliage, the whole plant suggesting the creosote bush of the more western desert.

Between Del Rio and Devils River a change in the flora takes place, the sotol (*Dasylirion*) becoming the most conspicuous feature of the upland vegetation, with a broad leaved *Yucca* having a trunk 1 to 6 feet high, a shorter leaved grayer plant than the one about San Antonio. The *Acacia* mentioned earlier and various shrubs, chiefly gray leaved and spinose, are also abundant, while the mesquite is small and confined chiefly to the ravines. A lechuguilla (*Agave*) occurs on rocky slopes and thin soils, and a coral bean (*Sophora secundiflora*), with its shining, bright green leaves, in the canyons.

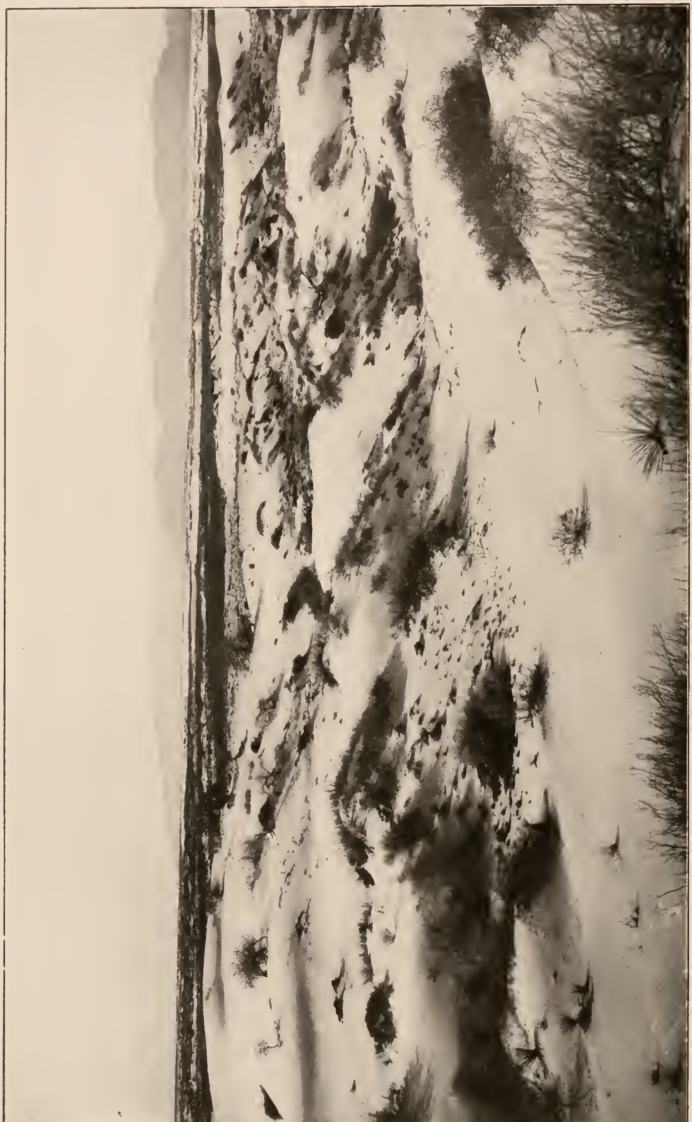
Between Shumla and Dorso the ocotillo (*Fouquieria splendens*) and the creosote bush (*Covillea tridentata*) appear, interspersed with the large yucca, the lechuguilla growing in abundance on thin rocky soils with acacia, and the mesquite and a small juniper growing in the washes. The area is characterized also by a second smaller species of *Opuntia*, in addition to the larger one earlier mentioned, and by an *Ephedra*, probably *E. antisyphilitica*. The ocotillo disappears at an elevation of about 2,000 feet as the plateau west of the Pecos is reached.

THE SAND DUNES OF CHIHUAHUA.

South of El Paso and crossed by the old traders' trail from Santa Fe to the city of Chihuahua is a long stretch of sand dunes which we had determined to examine; these were familiar to the early travelers but are almost unknown to the botanists of today. Taking a Mexican Central train at Juarez we were put off, through the courtesy of the railroad officials, among the sand dunes, about six miles south of the station of Samalayuca. This station is eighteen miles from Juarez and one mile north of Los Medanos.

The dunes where the railroad crosses them are about forty feet high, with scant winter vegetation consisting of a few woody plants, principally a labiate bush (*Poliomintha incana*), an *Artemisia*, a *Chrysothamnus*, a *Yucca* (*Yucca radiosa*), and a suffrutescent *Senecio*. Two perennial grasses, an *Andropogon* and a *Sporobolus* with a spike-like panicle (*Sporobolus cryptandrus*), 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 forty feet from the plant.

Tree yucca (*Yucca radiosa*) in the Tularosa Desert, New Mexico. The large plant, which is in fruit, has lost some of its lower leaves by the nibbling and rubbing of cattle. The two small plants are younger specimens of the same species.



The White Sands, Tularosa Desert, New Mexico. The view is southwest toward the San Andreas Mountains.
In the foreground are parallel dunes with characteristic vegetation.

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

The highest part of the dunes is not crossed by the railroad but lies east and southeast from Samalayuca about five miles and apparently rises 200 to 300 feet from the plain.

About nine pounds of the material of which the dunes were composed was collected by removing a thin surface layer and then placing 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. Dr. Gies' report is printed on pages 10 and 11 of this pamphlet.

THE TULAROSA DESERT.

Starting westward from Alamogordo, New Mexico, across the Tularosa desert, one first enters a region characterized by low mesquites, commonly 3 to 6 feet high, with an abundance of *Atriplex canescens* and *Koeberlinia spinosa*. That the soil is alkaline is indicated by a surface deposit along an irrigating ditch. The ground bears also an abundance of a suffrutescent *Suaeda*, a bunch *Sporobolus* with expanded panicles, and occasional specimens of a *Lycium*. In low spots and along the margins of clay bottomed washes, an incrustation of alkali appears, accompanied by *Allenrolfea occidentalis*. In this area water is commonly found in wells at a depth of 50 to 70 feet. Toward the middle of the valley the mesquite disappears, and the principal bush vegetation is *Atriplex canescens*, with a great deal of the *Sporobolus* and areas in which *Yucca radiosa* (Plate II), or *Opuntia arborescens*, or another *Opuntia*, conspicuous at this season by its scarlet fruit, are abundant. The wagon road in this part of the valley often strikes at the depth of a foot the so called caliche rock, a sort of hardpan. Ground water is presumably to be found only at a great depth.

Our principal object on this trip into the Tularosa desert was to examine the flora of a remarkable area of drifting sand it contains, known as the White Sands, composed not of silica but of gypsum, and estimated to cover an area of 10 by 40 square miles (Plate III). These sands are most easily reached at a point about 20 miles southwest of Alamogordo. Here there are some water holes where horses when forced by continued thirst can be watered with safety. Water for men, however, must be carried from Alamogordo.

Two principal plant formations occur in the bottoms and the dunes of the White Sands. The bottoms occur at nearly the same level as the surface of the plain surrounding the sands, the dunes are irregular heaps and ridges of white gypsum sand, rising to a maximum height estimated at 60 feet. When moist the sand is of a slightly yellowish or buff color, when dry almost pure white. When taken in the hand it has not the sparkling effect of silicious sand, but its grains are dull even in sunlight. As compared with silicious sand it may be likened to corn meal, the other to granulated sugar. The separate grains can be rubbed between the fingers to a fine white powder. Except on steep slopes the dunes of the White Sands form an excellent surface for walking, comparable in hardness with a sandy seabeach wet by an outgoing tide. These hard surfaces are covered everywhere with ripple marks caused by the wind.

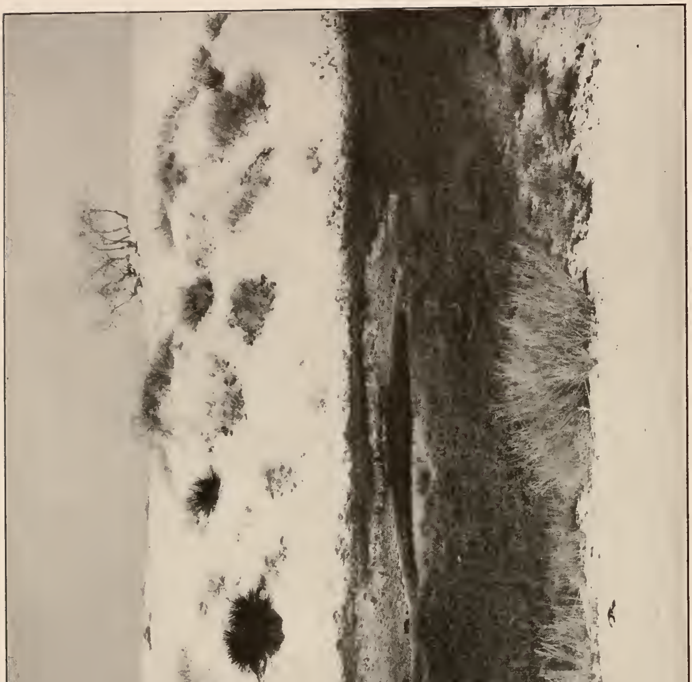
The most characteristic plant of the dunes is the threeleaf sumac (*Rhus trilobata*), which occurs in the form of single hemispherical bushes 4 to 8 feet high, the lower branches hugging the sand. The plant grows vigorously, the trunk at or beneath the surface often reaching a diameter of 3 inches. The 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 rain 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 IV). 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 three 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 four inches, those of the *Yucca* six 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 fifteen 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 lime 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

Sand column, in the White Sands, New Mexico, caused by the protection afforded by the three-leaved sumac growing over it. Distance from base to summit of column about 15 feet.

In the White Sands, Tularosa Desert, New Mexico, looking northwest. Grama grass (*Bouteloua*) flat in the foreground at base level of dunes. Remnants of a wasted dune are shown immediately beyond and to the right of the flat.



Water hole in the White Sands, Tularosa Desert, New Mexico. The water is locally known as "gyp" water. A group of cottonwoods (*Populus fremontii*) are shown in the background on the right.

Yucca radiosa growing up through a dune 30 feet high, White Sands, New Mexico.
A few of the upper circles of leaf bases can be seen in the picture.

Advancing eastern margin of the White Sands, Tularosa Desert, New Mexico. The dark area, on the left, is a part of the desert across which the dunes are advancing. Ripple marks, made by the wind, are shown in the foreground.

presence of a grama grass (*Bouteloua*) forming almost a turf, and by frequent clumps of an *Ephedra*, of a grayish purple color at this season and with 3-scaled nodes (Plate V). 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 salt grass (*Distichlis spicata*) and wire grass (*Juncus balticus*), both of them characteristic of moist alkaline soils (Plate VI).

In addition to their woody vegetation the White Sands appear to have an abundant herbaceous vegetation which would well repay careful systematic and ecological study. The area they cover is large, probably 400 square miles or more, the physical and chemical properties of the soil are very unusual, and no botanist has yet thoroughly studied the vegetation.

The relation of *Yucca radiosa* to the sand dunes is unusually interesting. A group of four small yucca plants standing about three feet high to the tip of the highest leaf, was found upon the summit ridge of a thirty-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 (Plate VII).

A gentleman, familiar with the White Sands for twenty years, told us that in that time they had advanced eastward at one point, the one of greatest activity, about half a mile. A road traversing the plain in a north-south direction close to the eastern front of the sand showed frequent changes necessitated by the advance of the dune (Plate VIII).

A section from the base of the Sacramento mountains southwest through Alamogordo into the White Sands, shows four belts: (1) the delta slopes from the mountain canyons, characterized by a nearly pure growth of creosote bush (*Covillea tridentata*), the soil usually gravelly and probably washed nearly free from alkali; (2) the mesquite area already described; (3) the *Atriplex* area also already described, and (4) the White Sands.

The Tularosa desert as traversed by the railroad from Alamogordo south to El Paso has a red and apparently mellow soil, the most characteristic plant of which is *Yucca radiosa*, sometimes associated over large areas with grass, but often associated with low mesquites, the latter in some spots gathering large hummocks of earth from drifting dust, out of which the twigs of the mesquites project. A large *Ephedra* is also a frequent associate of the mesquite and yucca. The railroad traverses only a little of the creosote bush foot slopes of the mountains.

Analyses of Sands.—The following report on the gypsum sand from the White Sands of the Tularosa desert and on sand from the Chihuahuan desert has been received from Dr. William J. Gies:

Gentlemen: 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: TULAROSA DESERT, 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 analysis 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., was 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°–35° C.:

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

(*b*) On drying to constant weight in an air bath at 50°–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 one 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°–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.
		Per cent.	Per cent.
1	One part HCl 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[1]	5.7
4	Cold H_2O (15°C.)	96.4	3.6

Some General Deductions.—The analytic results set forth in the above table and in that on the following page 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.

[1] Calcium sulphate is more soluble in cold than in hot water.

Percentage Composition. Sand dried at 30°–35°C. and at 110°–120°C.

	I.	II.	Average.	Average.
	Per cent.	Per cent.	Per cent.	Per cent.
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 lt.

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

Quantitative Analysis.

Preliminary Data.

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

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

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

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

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

(*b*) On treatment for three 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.
		Per cent.	Per cent.
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°–120° C.

	I.	II.	Average.
	Per cent.	Per cent.	Per cent.
SiO_2	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 the 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°–120° C.:

Sand dried at 110°–120° C.

	Sample I.	Sample II.
	Per cent.	Per cent.
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.

Respectfully submitted,
WILLIAM J. GIES.

West of El Paso, within the valley of the Rio Grande the characteristic vegetation, above the moist bottom, is creosote bush, with some ocotillo and lechuguilla on rocky places. The soil under the creosote bush is almost always gravelly.

As the road rises, near the station of Strauss, to the plateau and crosses it westward at an elevation of a little more than 4,000 feet, the same flora appears as that of the Tularosa desert; mesquite, *Yucca radiosa*, and grass, or either of these plants alone with the grass, and *Ephedra* a frequent accompaniment. Creosote bush occurs only occasionally and on gravelly slopes near desert hills.

TUCSON AS A LABORATORY SITE.

The woody vegetation of the desert in the vicinity of Tucson consists chiefly of creosote bush (*Covillea tridentata*) interspersed with several species of *Opuntia*, most of them with cylindrical stems (Plate IX), and occasional plants of joint pine (*Ephedra trifurca*) and barrel cactus (*Echinocactus*), with an abundance of mesquite (*Prosopis*) and cat's claw (*Acacia greggii*) (Plate X) in the lower drainage areas. Upon the foothills occur in addition the giant cereus (*Cereus giganteus*, see frontispiece), two species of palo verde (*Parkinsonia microphylla* and *P. torreyana*), ocotillo (*Fouquieria splendens*), two species of *Lycium* and many other woody plants. This is of course in addition to a great variety of annual vegetation which may spring up between the sparse shrubs after any drenching rain, particularly the repeated slow rains of winter.

In recommending a site for the Laboratory the Board kept in mind four principal requirements:

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 drouth 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, such as that about Phœnix, Arizona. 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.

Winter vegetation of the desert plain at Tucson, Arizona. Santa Catalina mountains in the background. The prevailing bush, creosote bush (*Covillea tridentata*), appears in the middle of the picture. The herbaceous vegetation of the foreground consists mainly of green rosettes of plantain (*Plantago*). The cactuses are species of *Opuntia*.

Cat's claw tree (*Acacia greggii*) near Tucson, Arizona, affected by a mistletoe (*Phoradendron californicum*).
Many trees are killed by this parasite

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 Tularosa desert 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 members of the Board are acquainted with several charming situations in the mountains of the desert, remote from civilization, rich and remarkable in their flora, furnished with an abundance of pure never failing water, and altogether delightful in their surroundings. Such situations are often chosen for army posts and they are and will always remain treasure spots for the camping naturalist. For the purpose of a laboratory, however, they are objectionable for several reasons. Such a situation involves first of all the maintenance of a hotel or its equivalent, a feature that would tend to exhaust the financial and mental resources of the management of a laboratory. Furthermore, severe isolation for long periods would doubtless have a depressing instead of an exhilarating effect on some research workers, and the solicitude of friends and relatives would doubtless in some cases be a bar to residence at such a place.

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.

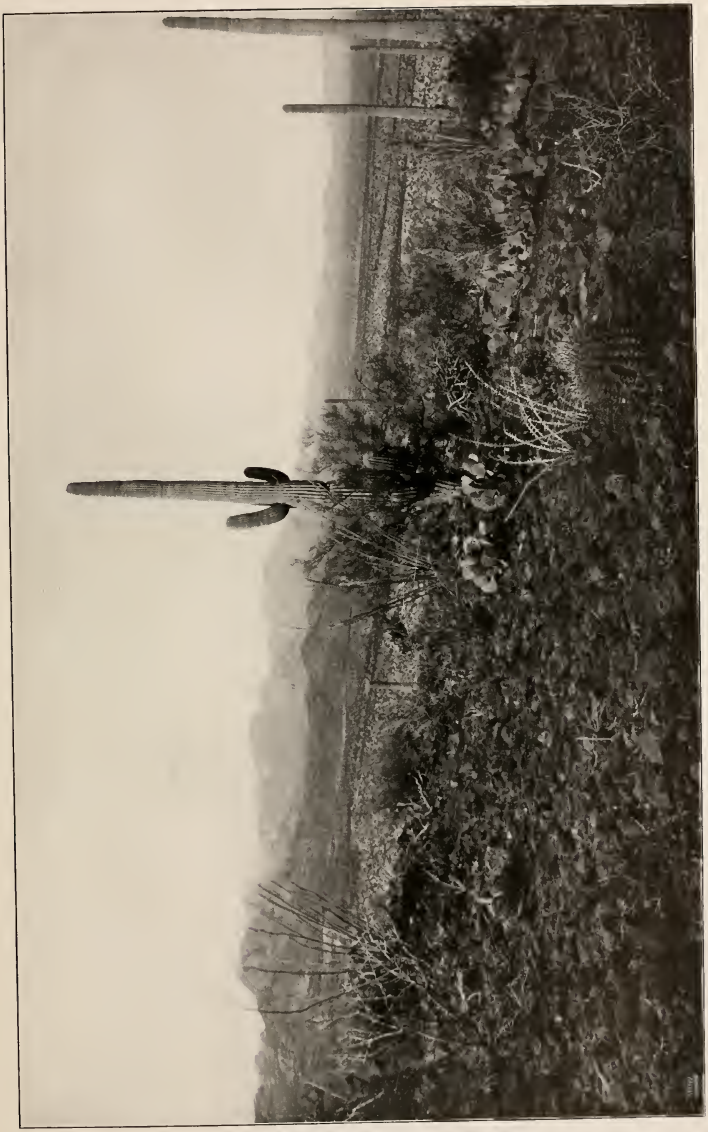
Viewed from the standpoint of these primary requirements Tucson has a climate of a thoroughly desert character, and a flora, including mountains and plain, rich in species and genera. In addition to its situation in the heart of the desert of Arizona, it is centrally located, both as to position and transportation, with reference to the deserts of Texas, Chihuahua, New Mexico, California, and Sonora. The city has a population of about 10,000. It is situated on a transcontinental railroad, the Southern Pacific, less than four days' railway travel from New York, about one and a quarter days from San Francisco, and seventeen hours from Los Angeles. The Laboratory will be connected with the city by telephone, and thence it will be in communication by telegraph and cable with as much of the world as the sender of a message may require. The business of the city and the conduct of its municipal affairs are largely in the hands of progressive Americans. The members of the Board, while outfitting at Tucson for a short trip to the Santa Catalina mountains, found a provision store that would have done credit to a metropolis. 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 6,000 feet higher. The University of Arizona, with its School of Mines, and the Arizona Agricultural Experiment Station are located at Tucson. A hospital maintained by a sisterhood and known as St. Mary's Hospital is another of the city's institutions.

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 a water system, telephone, light and power connections, and of a road to the site of the Laboratory, about two miles from Tucson (Plates XI to XIII). The monetary value of these concessions is by no means small, and is much enhanced by the generous spirit in which they were tendered. President Manning of the Chamber of Commerce and the gentlemen associated with him in a special committee to aid in the establishment of the Laboratory were quick to realize the needs of the institution and eager to meet these needs with the resources at their disposal. The members of the Advisory Board gratefully acknowledge the generous treatment accorded the Laboratory by the city of Tucson through its Chamber of Commerce, a body which has placed under lasting obligations all botanists interested in the purposes of the Laboratory.

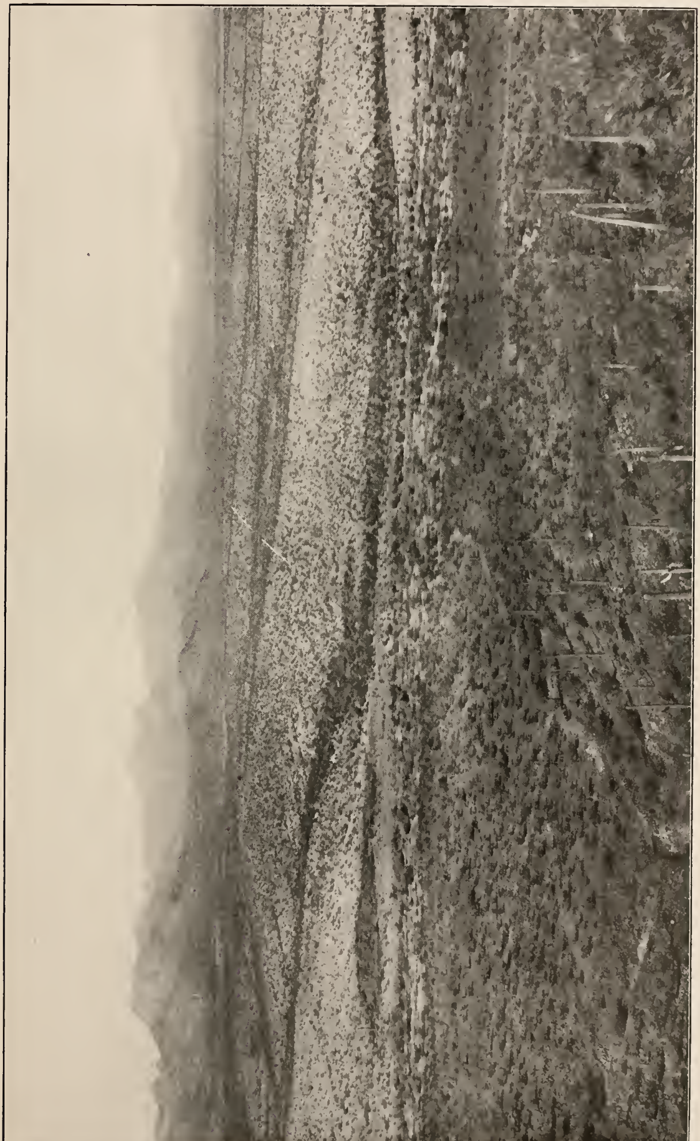
President Adams of the University of Arizona, and Professor R. H. Forbes of the Agricultural Experiment Station also rendered important service in perfecting arrangements and in offering coöperation from their institutions which will do much to increase the efficiency of the Laboratory.

History. — Historically Tucson is an interesting old town. It was acquired from Mexico as a part of the Gadsden Purchase in 1853, and

Tucson mountain, near Tucson, Arizona. The Laboratory site is on the shoulder a little to the left of the middle of the picture. Giant cactuses, 20 to 30 feet high, are scattered over the slopes.



Vegetation on Tucson mountain, near Tucson, Arizona. In the middle of the picture is a giant cactus partly surrounded by the branches of a palo verde (*Parkinsonia*). A barrel cactus (*Echinocactus*) is shown near the middle foreground.



Looking westward from Laboratory site shown in Plate XI. In the middle distance is shown a strictly desert vegetation, consisting of giant cactus, palo verde, ocotillo, creosote bush, prickly pears, chollas, etc.

at that time had of course a population almost exclusively Mexican and Papago. The beginning of its present period of social and architectural development dates from the advent of the Southern Pacific Railroad in 1880. As late as 1850 Tucson was still walled for protection against the Apache Indians. Originally it was an Indian village, at which the Mexican mission church of San Xavier del Bac, nine miles south of Tucson, is believed to have been built about 1690. Of the still earlier history of Tucson, as a Papago Indian village, the following extract from a letter written by Mr. W J McGee, the ethnologist, gives some interesting facts:

"The eastern base of the mountain lying west of Tucson, Arizona, is the site of an aboriginal settlement or village of the Papago Indians. Water was taken from the Santa Cruz sand wash; the bottom lands were in part devoted to the tribal crop, beans, as well as to corn, squashes, etc.; most of the habitations, chiefly grass houses, were on the low mesa west of the sand wash, which is still sprinkled with potsherds, and where traces of the early mission remain; while the mountain itself is a trinchera, *i. e.*, a fortified place of refuge from Apache invasions. The Papago name for the settlement was the same as their name for the mountain, *i. e.*, Tuuk-soon (all vowels having the continental sound) or Black Base. The appropriateness of this name is obvious when the mountain is viewed from the south-southeast in either morning or afternoon light, when the darker volcanic rock forming the base of the mountain shows clearly against the gray mass above. The same name is applied also by the Indians to a modern settlement some seventy five miles west-southwest of this site, *i. e.*, to the hill and Indian village commonly called Little Tucson. There are no means now of determining with any degree of certainty the aboriginal population of the site on which you are about to locate, though it is practically certain, first, that the inhabitants for some centuries before Columbus were the ancestors of the modern Papago; second, that the settlement was a part of a series extending up Santa Cruz valley to its head and beyond; third, that the prehistoric Papago, like their modern descendants, were partly migratory, moving southward in autumn to hunt in the sierras during the winter, and returning in spring to replant their crops; and, fourth, that the settlement was permanent, save for the migrational abandonments, for centuries before the arrival of the Spanish explorers and missionaries. Neither is it possible to give account of the earliest visitations of Caucasians; Cabeza de Vaca may possibly have approached the region about 1535, while Marcos de Niza in 1539 and Coronado in 1540 and 1542 passed within rumor-distance of it during their journeyings up and down the Rio San Pedro; 'A Missionary of Arizona,' the late Archbishop Salpointe, in writing his history of the old Church of San Xavier del Bac, inferred that this mission was established between 1690 and 1692, while in 1699 Padre Kino knew of the Papago village below the mission as San Agustin; certainly this village was a visita, or visiting charge, of San Xavier mission in 1763, and there was a Spanish settlement hard by in 1776 when the presidio, or capital, was removed thither from Tubac, this Spanish settlement being called San Agustin de Tuquison while the aboriginal village was known as San Agustin del Pueblito de Tuquison; and certainly Archbishop Salpointe, as well as the late Dr. Coues, the editor, and Mr.

Hodge, the annotator, of the Garcés Diary, etc., repudiated the occasional claims that a Spanish settlement was founded there in the sixteenth century. The Indian name was variously rendered, Teuson, Tueson, Tubson, Tuczon, Tulquson, Tuson being among the more reasonable variants, while Tucson has prevailed since the Gadsden Purchase. The aboriginal Papago name has, however, remained in constant use among the tribesmen, who retain definite traditions of the ancient settlement, which was still occupied by them until within a generation. It is merely a curious coincidence that the origin of the name may be traced to the Pima term *styuk-son*, meaning 'dark' or 'brown spring'; for not only has the Papago occupancy and usage been continuous since prehistoric times, but there is no 'spring' of any color there, still less at the desert settlement of Little Tucson. The Papago village on your site was apparently the northeasternmost permanent settlement of the tribe; and in 1775 Padre Garcés found it the last Christianized pueblo in this direction, though some leagues down the valley he saw the site of a Papago rancheria depopulated a few years previously by Apache hostilities.

"It is of interest to note that the prehistoric Papago was a farmer, and derives his designation from this fact. The characteristic crop plant was the native bean, called pah′, or, in the plural, papah′; and the same term was applied to the tribe by neighboring peoples. The Spaniards slightly corrupted the appellation, pronouncing it Papah′o (the final vowel feeble and obscure), and spelling it, with some emphasis of the aspirate, Papago; the Americans retained this orthography, but pretty effectually concealed the original form of the tribal name by adopting the pronunciation indicated by their own orthoëpy. The tribesmen themselves long ago accepted the name by which they were known among other tribes, adding the descriptive term *a′atam* — literally, Beansmen, *i. e.*, Bean-people. A few of the earliest Spanish visitors ascertained the meaning of the tribal designation, and translated it *Frijoleros;* but in general its signification was lost, and the name was erroneously connected with the Spanish *papa* (pope, hence catholic), the English *baptized* (referring to the supposedly acquired through really aboriginal custom), etc. I am not aware that the name was interpreted in English before my first visit to the tribe in 1874. About Tucson and on the reservation at San Xavier the Indians follow the American pronunciation of their name; toward the Mexican frontier and in Sonora they retain the Spanish (Mexican) pronunciation or their own closely similar form.

"You will be interested in noting also that the local tribesmen were among the earliest and most successful agricultural experimentalists of the western hemisphere. They are desert folk *par excellence*, and entered into the distinctive solidarity of desert life to a unique degree; they scoured the Sonoran plains for chance water holes as well as more permanent waters, carrying religiously hoarded seeds; they chased rain storms seen from commanding peaks for scores if not hundreds of miles; and wherever they found standing or running water, or even damp soil, they planted their seeds, guarded and cultivated the growing plants with infinite patience, and after carefully harvesting the crop, planted some of the finest seeds as oblations, and preserved others against the ensuing season, so that the crop plants were both distributed and improved from year to year. I have already had occasion to point out that agriculture is a necessary product of desert life, since it is only in regions of extreme aridity that plants and animals are forced into a common solidarity at last controlled and guided by the supe-

Yucca-like vegetation one half mile east of Nogales, Arizona. The monument on the sky line is one of the marks of the international boundary.

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*.

rior mentality of mankind; this I described in 'The Beginning of Agriculture' (*American Anthropologist*, Vol. VIII, pp. 350–375); and the lesson I learned from the Papago experimentalists themselves as their ancestors learned it from Nature long ago. They were prominent among the aboriginal makers of corn, as well as the bean and other native crop plants."

NOGALES.

The region immediately about Nogales, on the border between Arizona and Sonora, lies at an elevation of about 4,000 feet, just below the oak belt. The characteristic vegetation of the hills is of yucca-like plants, including species of *Yucca*, *Nolina*, *Dasylirion*, and *Agave*. Shrubs of the ordinary desert character are few and form no part of the vegetative landscape. Scattered oak trees of small dimensions appear here and there among the yuccas (Plate XIV).

TORRES.

The plain in which lies the railroad station Torres is at 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 (*Cereus thurberi* and *C. schottii*) (Plate XV), and two cylindrical stemmed species of *Opuntia*. The palo fierro, meaning ironwood, 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. 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 are known as sina. *Cereus thurberi* is called pitahaya. One of the common species of *Opuntia*, 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 drouth is an important source of refreshment to wild animals and even to man. The other common cylindrical stemmed *Opuntia*, called cholla, has several times thicker joints 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, a tree mimosa with pink flowers having 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, a tuberous rooted cereus 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 sonorae*), a cucurbitaceous tendril bearing plant whose inordinately thickened root and stem base sits white and half exposed upon the ground beneath some trellising shrub (Plate XVI).

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 macdougalii*) (Plate XVII), brasil (*Haematoxylon*), torote prieto (*Bursera*), the tree morning glory (*Ipomoea 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. Two trees pass under the name torote blanco,

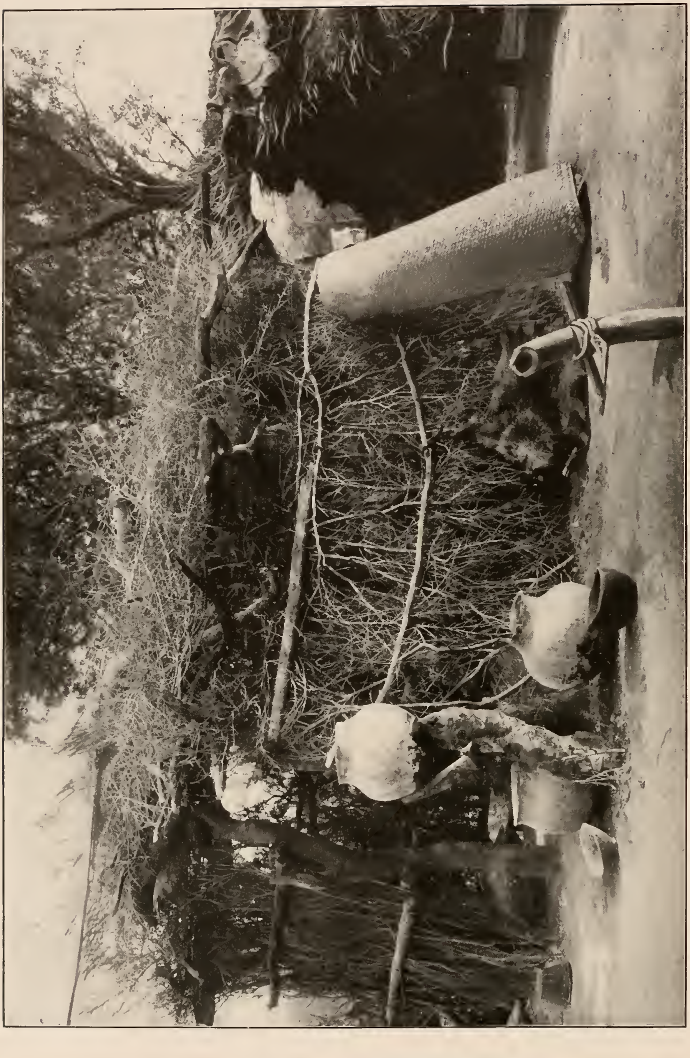
* Locally corrupted to *sangrengrado*.

Guarequi (*Ibervillea sonorae*) beneath a clump of bushes, west of Torres, Mexico. More than half of the turnip-shaped root lies above the surface of the ground.

Tree ocotillo (*Fouquieria macdougalii*) near Torres, Mexico. The tree is in full leaf and about 25 feet high.

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

Yaki Indian family and dwelling at El Rancho, west of Torres, Mexico. At the right stands a Papago Indian guide. At the left is the Yaki family, father, mother, and two daughters. Two palo fierro trees (*Olneya tesota*) are in the background.



Water jars (ollas) at a Yaki dwelling, west of Torres, Mexico. One of them is on a stump of palo verde. Under it are three spears of Indian corn, irrigated by the drippings. Near the mat is the skin of a peccary.

one a *Bursera* with papery buff colored exfoliating bark, the other a tree of very similar appearance but leafless in the winter season and suggestive of *Jatropha*.

It was among these desert hills west of Torres that we had an opportunity 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 five feet high and with a blunt stake of palo verde pounded to a pulp the upper six or eight 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 two or three quarts of clear water, 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 drouth but that they used it also to mix their meal preparatory to cooking it into bread (Plate XVIII).

About eight miles west of Torres Yaki settlements begin (Plates XIX and XX). One abandoned house had a ridgepole made of a palm trunk. This was notched in the manner followed by the aborigines in pre-Columbian times in making a ladder, and it is evident that it had been put to such a use before it was employed as a ridgepole. This palm trunk, it is believed, must have been brought from the mountains westward toward the Gulf of California, and very likely it indicates the occurrence there of groves of *Neowashingtonia*. This together with the presence of *Guaiacum* and *Haematoxylon* shows why this part of the Sonoran desert is treated by some American students as belonging to the tropics, although the desert character of the region is not at all suggestive of the vegetation we are inclined to regard as representing a tropical environment.

GUAYMAS.

The flora in the harbor of Guaymas is a desert flora 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 in the vicinity of Torres, but of smaller growth. The hecho (*Cereus pecten-aboriginum*), whose bur-like fruits are often 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*, *Cereus pringlei*, and other characteristic desert plants (Plates XXI and XXII).

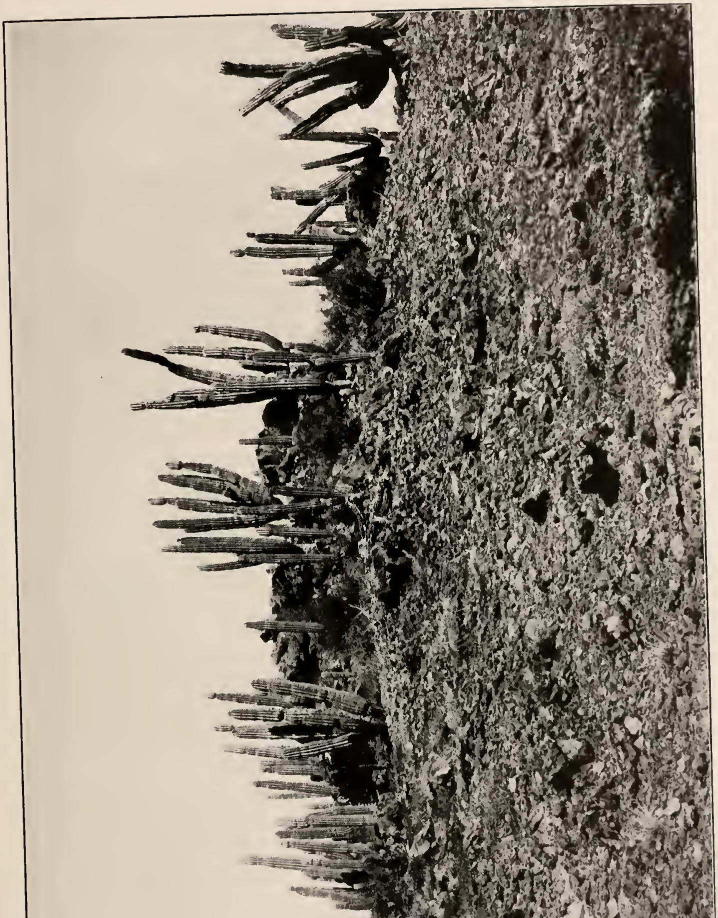
THE COLORADO DESERT.

The Colorado desert of California offers, along the line of the Southern Pacific, several types of vegetative areas, the result of soil differences. West of the Colorado river bottom, in the gravel hills, the creosote bush (*Covillea tridentata*) is the principal woody species, the tops of the ridges being so exceedingly arid as to be devoid even of that most drouth resistant plant. Associated with the creosote bush are the ocotillo (*Fouquieria splendens*) and the ironwood (*Olneya tesota*), and occasionally the mesquite (*Prosopis*), a joint pine (*Ephedra*), and a palo verde (*Parkinsonia torreyana*). Within sight of the railroad, to the southward, extends a line of sand dunes from the Colorado river northwestward for about fifty miles, nearly to Flowing Well. These extensive dunes we were not able to examine, but from the fact that they lie in what is probably the most arid of all the deserts of North America, it is believed that their flora is well worth critical geographical examination.

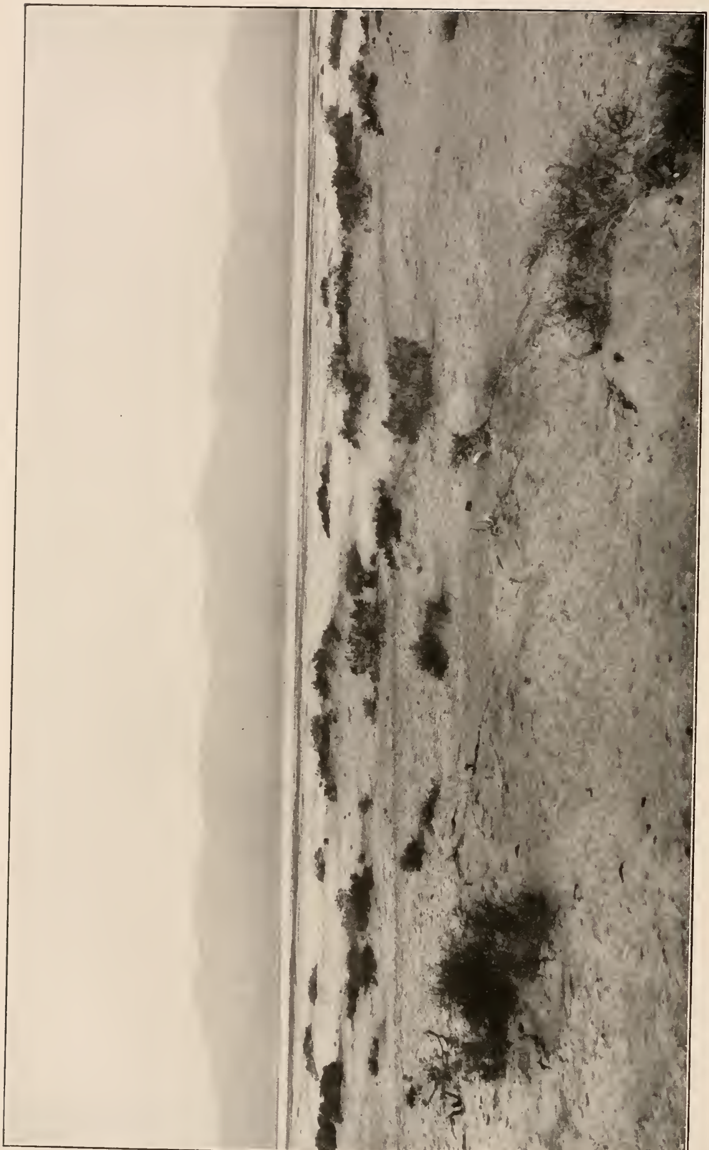
At the station Volcano the alkali flats begin. At first these have little white incrustations and are devoid of vegetation except for a few saline plants along the arroyos, such as the chenopodiaceous shrubs *Allenrolfea* and *Suaeda*. At the station Frink, 16 miles east of Salton, white incrustations begin. Here in occasional areas the only plant growth consists of clumps of *Allenrolfea* growing upon hummocks of earth rising above the general level of the alkali incrusted soil.

At Salton, which lies on the edge of the salt flat and near which are several saline or alkaline springs, is afforded an excellent opportunity for securing material of alkali resistant plants. On the sandy hummocks desertward from the alkali incrusted soil were two salt bushes (*Atriplex canescens* and *A. polycarpa*), a composite bush with burlike fruits (*Gaertneria dumosa*), a *Parosela*, a *Suaeda*, the mesquite (*Prosopis*), and an occasional *Lycium* and ironwood tree (*Olneya tesota*). The springs are sluggish and have built up about themselves low mounds of earth. The soil, except where the water is actually emerging, had an incrustation of salt and alkali. Four plants make up most

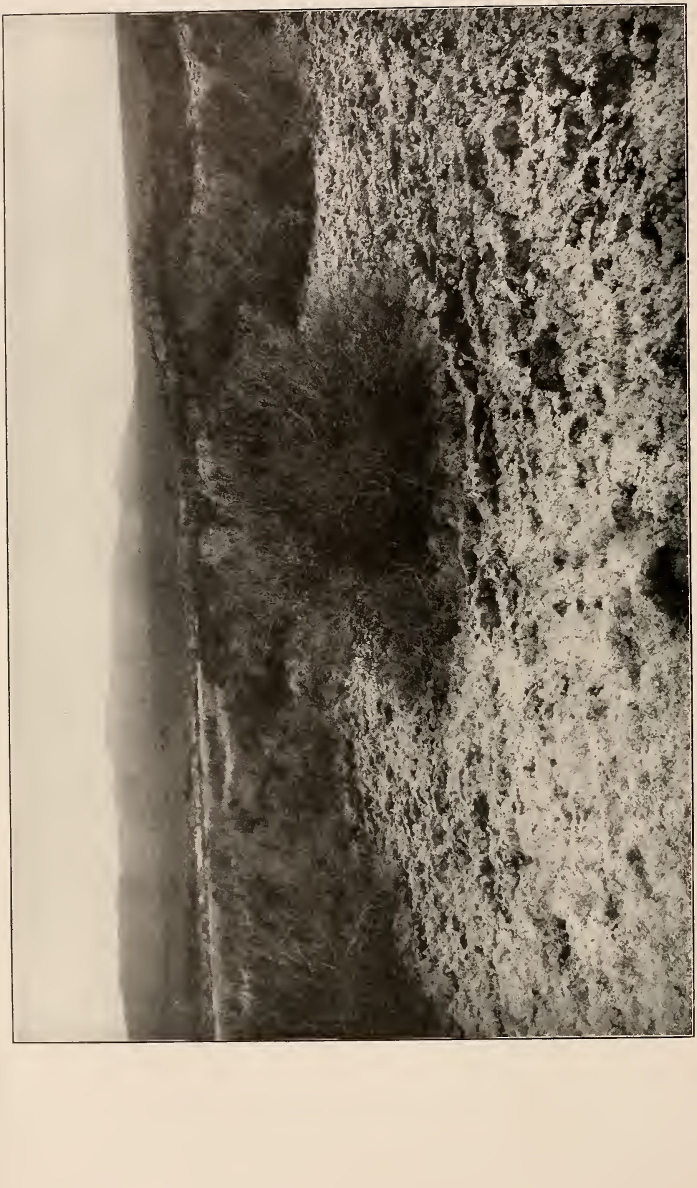
Desert island in Guaymas bay, Mexico. The large cactus is *Cereus pringlei*. There is a fringe of mangrove (*Avicennia* and *Rhizophora*) along the beach.



Cereus pringlei on summit of island shown on Plate XXI. Among the large plants (10 to 15 feet high) are a number of young ones.



Salt valley, Colorado desert, California. Looking westward from Salton over region sometimes called the Salton desert.



Salt encrusted ground near Salton, California. The principal plant is *Allenrolfea occidentalis*, growing to a height of about three feet.

Group of palms (*Neowashingtonia filifera*) in the Colorado desert, California. Old, discarded leaves are lying under the trees.

Belt of palms (*Neowashingtonia filifera*) in the Colorado desert, California. The whitish soil about the palms is encrusted with alkali. Mesquite bushes grow among the palms.

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 (*Tessaria borealis*) (Plates XXIII and XXIV).

The visitor to Salton should bring his own supplies and camp outfit as no accomodations or supplies are available.

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 filifera*). The groves visited by us were not those nearest the town, about five miles, but those to which we were guided under the name Thousand Palms canyon, about nine miles from Indio.

The ordinary diameter of the trunk is about two feet and the trees at full maturity are about fifty 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 eight feet through and sometimes eighteen 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 (Plate XXV).

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 (Plate XXVI). 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 *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 the product of 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.

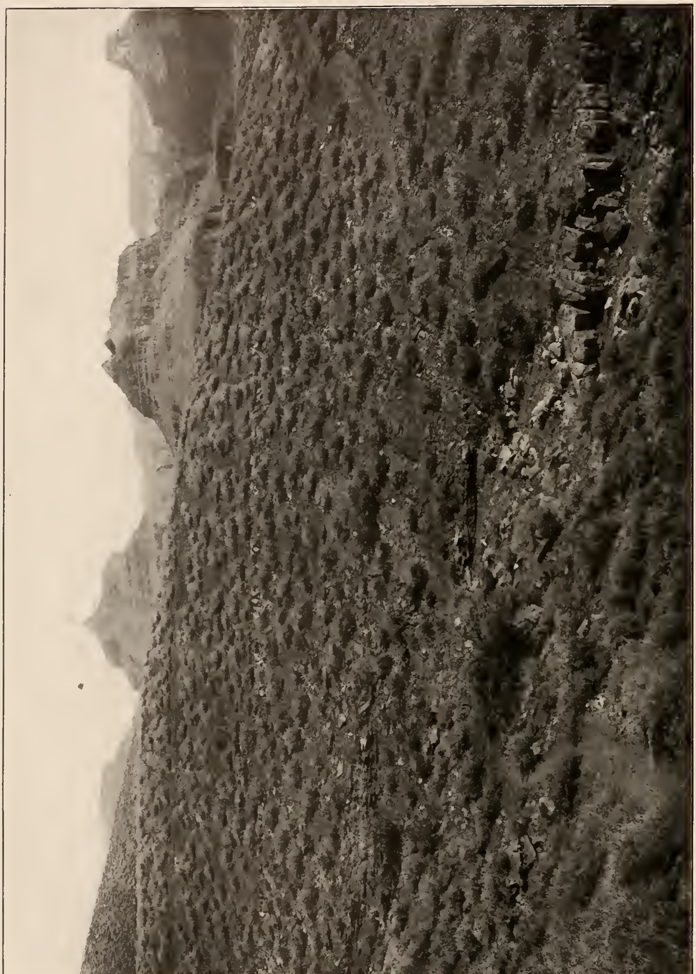
Between Rimlon and Palm Springs is an area in which the vegetation is subjected to strong sand laden winds, a veritable sand blast. The western faces of the wooden telegraph poles are deeply cut within two feet of the ground by the sharp, driving sand, and the railroad employees have found it necessary 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 moulded 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 projected 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 a foot and a half high and wide, and extending about four feet from the rock.

Clumps of *Ephedra* and plants of *Yucca mohavensis*, the cylindrical stemmed *Opuntia bigelovii* and *O. echinocarpa*, and the flat stemmed 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.

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 four 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 two 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

Vegetation in the Grand Canyon of the Colorado, Arizona. The cactus is an *Echinocereus* and the shrub behind it *Ephedra nevadensis*.



Along the Bright Angel trail, Grand Canyon of the Colorado, Arizona. The prevailing plant is a rosaceous shrub (*Coleogyne ramosissima*).

in the washes, the prevailing bush, and continues throughout the long waste of desert to the Colorado river. A fuller description of the vegetation of the Mohave desert and the areas to the north is given in Coville's Botany of the Death Valley Expedition, cited in the bibliography.

THE GRAND CANYON OF THE COLORADO.

A visit was made to the Grand Canyon of the Colorado with the expectation that its lower elevations would afford lodgment for many desert plants, and that a descent from the timbered rim, at 6,866 feet, to the river at 2,436 feet, would permit the traveler to see in a brief trip a wide range of desert vegetation. Although the descent is full of botanical interest, and does carry one down through several different belts of vegetation, the comparatively limited number of woody desert plants rendered the journey somewhat disappointing from the standpoint of the main object of our trip. 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 (Plate XXVII). One of the most striking features is extensive fields of a rosaceous shrub, *Coleogyne ramosissima*, which extends in an almost pure growth over the canyon terraces at an elevation of about 3,600 feet in a soil seemingly well supplied with lime (Plate XXVIII). There is a notable absence of many shrubs which would be present in the open desert at the elevations 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 precipitate 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.

Plant Life in North American 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 or lack of soil. Of these conditions, scanty water supply may be regarded as of the greatest importance, and it is to this factor that most deserts owe their existence. Desert conditions arise in any region in which the rainfall is markedly less than the amount of water that evaporates from the surface of this liquid in the open air. As the amount of evaporation naturally increases from the polar regions toward the tropics and is affected by winds and elevation it follows that no arbitrary amount of rainfall may be designated as an invariable cause or accompaniment of arid or desert conditions. 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. These factors are further considered on page 28.

Arid deserts occur in all of the great land divisions and reach an enormous extent in Africa, Asia, and Australia. The most pronounced desert conditions of South America are found on the western slopes and benches of the Andes, one locality, that of Copiapo, having an average precipitation of 0.4 inch per year, and, so far as known, is the driest spot on the earth's surface. The deserts of North America are confined to the Cordilleran region and occupy plateaus and plains east and west of the main ranges to an extent of more than a million square miles.

METEOROLOGY.

The principal features in the distribution and total amount of rainfall in several localities which may be included within the arid regions 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 fifty or even sixty 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 TABLES.

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
	°	°	Inches.	°	°	Inches.	°	°	Inches.	°	°	Inches.
Jan.	77	5	0.53	73	38	0.57	64	28	0.00	68	—10	1.06
Feb.	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
Sept.	104	42	1.11	82	56	.94	84	54	1.95	92	32	1.26
Oct.	94	28	.92	79	50	.15	84	55	2.29	84	15	1.08
Nov.	85	11	.50	71	40	1.44	81	31	.00	81	8	.79
Dec.	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

* 15 years' observations.

	Hawthorne, Nev.			Winnemucca, Nev.			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
	°	°	Inches.	°	°	Inches.	°	°	Inches.	°	°	Inches.
Jan.	62	— 6	0.59	57	—28	1.09	70	— 1	0.98	52	—34	0.38
Feb.	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
Sept.	95	30	.23	94	16	.35	103	31	.42	94	17	.99
Oct.	80	25	.31	87	10	.56	93	20	.39	84	13	.61
Nov.	78	19	.39	73	— 9	.67	81	13	.40	70	1	.25
Dec.	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

	Fort Yuma, Ariz.			Phœnix, Ariz.			Tucson, Ariz.			Mohave, Cal.		
No. of Years' Observations	26	26	20	17	17	22	6	6	15	5	5	26
	°	°	Inches.	°	°	Inches.	°	°	Inches.	°	°	Inches.
Jan.	81	22	0.42	87	12	0.80	80	17	0.79	70	16	0.95
Feb.	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
Sept.	113	50	.15	114	39	.64	107	49	1.16	104	45	.07
Oct.	108	41	.28	105	34	.37	98	29	.64	93	40	.25
Nov.	92	31	.29	97	24	.54	90	21	.81	84	27	.40
Dec.	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

*26 years' observations.

	Prineville, Oreg.			Lost River, Idaho.			Laramie, Wyo.			Torres, Mex.	
No. of Years' Observations.	6	6	6	5	5	5	5	5	13	Rainfall. 1901	Rainfall. 1902
	°	°	Inches.	°	°	Inches.	°	°	Inches.	Inches.	Inches.
Jan.	76	— 9	0.64	45	—26	1.12	52	—23	0.23	......	0.00
Feb.	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
Sept.	98	20	.81	89	21	.44	85	17	.73	.75	4.69
Oct.	89	20	.75	75	14	.63	72	7	.86	.21	.04
Nov.	82	9	1.06	60	— 8	.92	63	—12	.25	......	.77
Dec.	76	— 5	.97	48	—23	.82	52	—27	.37	......	1.02
Year.	119	—17	9.01	99	—41	8.65	92	—40	9.81	......	16.79

The ratio of rainfall to evaporation cannot 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.		
		Inches.	Inches.	Inches.	Inches.	
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	8.31	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	....	......	16.79	100	6.0

* From 15 years observations. † From 22 years observations.

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 ten per cent by way of error in these estimates, but the amount given 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 seven times as great as the normal precipitation, while the evaporation at Yuma, Arizona, is more than thirty-five times as great as the average or normal amount of precipitation. The evaporation at the last named locality amounted to one hundred and sixty times as much as the precipitation in the year 1899.

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 sup-

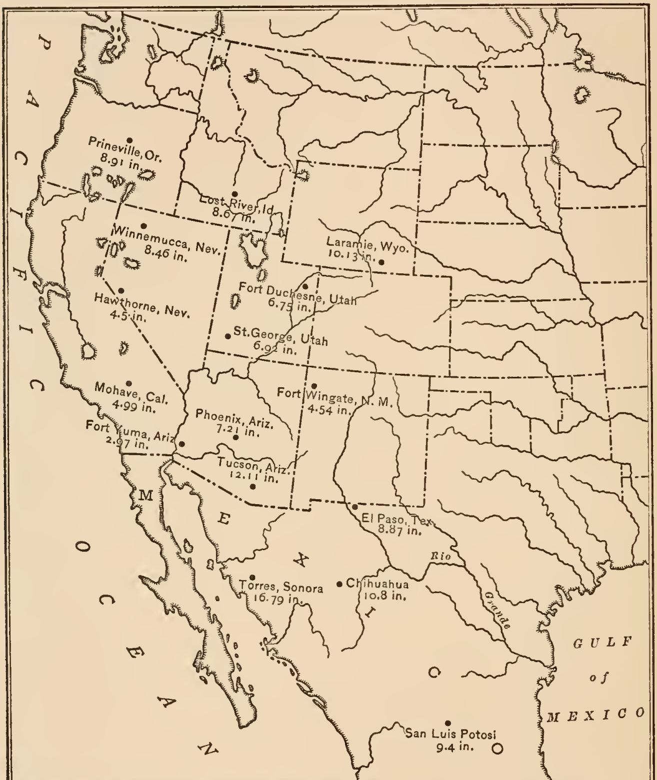


FIG. 1. Location of and annual precipitation at certain stations in the arid region of Western America. Chiefly from records of the U. S. Weather Bureau.

port 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 Mr. 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 drouth show marked protective adaptations, the vegetation consisting chiefly of such species as *Phlox douglasii*, *Spraguea umbellata*, and *Arenaria pumicola*.[1]

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 alternations 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, an illustration of which is shown in Plate XXIX, facing page 43. A further description of the meteorological conditions on this mountain will be found on pages 38 to 45.

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 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, yet the peculiar character and movements of the substratum result in some striking forms of vegetation.

[1] Coville, F. V. The home of *Botrychium pumicola*. Bull .Torr. Bot. Club, **28**: 109. 1901. The August vegetation of Mount Mazama, Oregon. Mazama, **1**: 170. 1896.

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 district in the Tularosa desert in New Mexico, of which a more detailed description is given on pages 5 to 10. The sand dunes in this distinct 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 amount 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 makes 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 enclosed 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 analyses:

SURFACE CRUST OF SOIL FROM KERN ISLAND, BAKERSFIELD, CALIFORNIA. ANALYSIS BY HILGARD.[1]

	Per Cent.
Potassium sulphate,	.52
Sodium sulphate,	82.96
Sodium chloride,	.48
Sodium carbonate,	.40
Magnesium sulphate,	.50
Magnesium carbonate,	.13
Calcium phosphate,	.20
Calcium sulphate,	.10
Ferric and aluminum oxides,	.30
Silica,	1.34
Organic matter and water of crystallization,	4.07

ALKALI FROM THE VALLEY OF THE RIO GRANDE IN NEW MEXICO: ANALYSIS BY GOSS AND GRIFFIN[2] MADE FROM THREE SAMPLES FROM DIFFERENT LOCALITIES.

	No. 1.	No. 2.	No. 3.
	Per cent.	Per cent.	Per cent.
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.[3]

	Per cent.
Potassium chloride,	1.30
Sodium sulphate,	18.23
Sodium chloride,	35.93
Sodium carbonate,	18.72
Sodium bicarbonate,	25.72
Phosphoric acid,	.10

[1] Hilgard, E. W. Report of Work of the Agricultural Experiment Stations for the year 1900, p. 97.

[2] Goss and Griffin. Bull. No. 22, New Mexico Agric. Exp. Station, p. 26, March, 1897.

[3] Means T. H. and Holmes, J. G. Soil survey around Fresno, Calif. Field Operations of the Division of Soils, U. S. Dept. 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

FIG. 2. Western America showing conceptions of American deserts current in 1835. Copied from T. G. Bradford's Comprehensive Atlas, published at Boston in 1835.

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 word 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. 2).

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 one or even two hundred miles from the nearest supply of water. Even 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 two and a half million 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 text books 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 time. This conception of the matter is shown in *Fig. 3*, being a map from a text book on physical geography published in 1859.

Further exploration and utilization of desert areas in agricultural and mining operations led to the abandonment of the term desert as applied to all the regions shown in *Fig. 3* except those about the lower Colorado river and near Great Salt lake. 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 connecting the stations shown in *Fig. 1*. 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. 2), 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 enclosed by parallel ranges of mountains which in some instances attain such altitudes as to be timber clad and even bear an alpine vegetation.

One of the striking features of the Chihuahua desert consists of the great sand dunes, or "medanos," more than a hundred feet high, in some instances forming great ridges that have almost the imposing appearance of mountain ranges; these move across the floor of the desert

FIG. 3. Western America showing conceptions of American deserts current in 1859. Copied from Warren's Physical Geography, published in 1859.

plains with a sweep that obliterates minor features of topography. These moving dunes bear a characteristic vegetation adapted to the unusual physical conditions offered by the sand and lack of water and nutrient material. The gypsum deposits forming the White Sands in the Tularosa desert north of the Rio Grande have already been mentioned. The Jornada del Muerto (Journey of Death) of the ancient Spanish explorers lies in the western portion of the Chihuahua desert in New Mexico separated from the Tularosa desert by the Organ mountains. Further northward the great stretches of *malpais*, or black volcanic rock, form a desert district of the extreme type, while numerous areas are impregnated with alkali, and are either almost wholly free from vegetation or support only halophytic species. The Bad Lands of Dakota owe their desert character to the peculiar composition of the soil which is clayey, poor in nutrient substances, and subject to great erosion so that extensive areas are destitute of vegetation of any kind.

Observations upon the striking forms of xerophytic vegetation characteristic of arid regions have been made by occasional explorers in various parts of the world; among these are to be noted the writings of Philippi on the desert of Atacama on the west coast of South America, published in 1860. The accounts of the earlier surveys of western America also contain some interesting information concerning some of the features of the flora of the desert regions. The first general studies of the flora of arid regions were made by Volkens and by Maury, whose results were published in 1887 and 1888.

Volkens made some examination of the physiographic and climatic conditions in the deserts of Arabia and Egypt and also of the relation to habitat of some of the characteristic species. His treatment of the functional performances of xerophytic plants indigenous to this region is based upon anatomical characters almost wholly, and no effort appears to have been made to measure the actual work acccomplished by the plant under any of the conditions described. The detailed study made of the general structure and vegetative habit of a large number of species resulted in the acquisition of a rich mass of anatomical facts, upon which our present knowledge of the properties of desert plants chiefly rests.

Maury also made an examination of the general features of the minute anatomy of xerophytic plants from the Sahara region, and sets forth the principal adaptations which these species have undergone in response to their arid environment.

The work of Warming upon the flora of the dry savannas at Lagoa Santa in Brazil is also to be regarded as an important contribution to the general subject of desert vegetation. A fairly complete bibliography of the entire subject forms the concluding section of this report.

In 1891 Mr. Frederick V. Coville made a botanical investigation of the Death Valley region 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 deemed 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° 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 adaptations were found for storage of water. 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.

TRANSPIRATION AND TEMPERATURES.

Mr. D. T. MacDougal, in 1898, made a series of experiments at Turkey Tanks on the western edge of the malpais or lava desert near the Little Colorado river east of Flagstaff, Arizona. In these attention was chiefly given to the amount of transpiration and to the temperatures of the soil, of the air, and of the bodies of succulent plants, the results of which are now given for the first time.

Measurements of transpiration were made by means of a potometer of the form described in the *Botanical Gazette* (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 aërial 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 outline, 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 10.30 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 10.50 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 .6 to .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 .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 .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 rate even much greater than the *Mentzelia*.

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, insolation and dryness of the air affecting the tomato would doubtless increase the ratio many times. The *Eucalyptus* would offer even greater disproportion.

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 dangers 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 ensure a constant supply to keep up a steady but slow rate of transpiration.

No measurements were made of the intensity of the insolation, but a comparison of the conditions with those prevalent in other localities in which photometric work has been carried out would tend to the conclusion that it is higher than that of 1.6 units recorded in the East Indian tropics, an effect due to the low relative humidity of the desert atmosphere. The intensity of the insolation may affect plants in three ways of interest in connection with the purpose of this paper. The action of the blue-violet rays may exercise a disintegrating effect upon the protoplasmic constituents of the organism. The attainment of the higher temperatures as a result of the conversion of light rays into heat may reach the maximum limit of the activity of protoplasm; also the critical point at which chlorophyl begins to undergo chemical deterioration, and the action of the sunlight upon the soil would result in the attainment of temperatures affecting the development and absorptive activities of the root system. In order to obtain data bearing upon these points the following observations were made:

July 16. 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 2.20 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* Pursh 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 one 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. The writers are indebted to Professor Toumey for the statement that the temperature of the soil near Tucson increases slowly during July, remains 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 Lowell Astronomical Observatory at Flagstaff, 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.

The temperatures of a number of plants were obtained by Mr. MacDougal 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* (probably *O. engelmannii*) on July 17, 1898.

	Temperature of Opuntia.	Temperature of Air.
7.20 A. M.	79.0° F.	78.5° F.
8.10 A. M.	93.5	82.4
9 A. M.	93.8	87.8
10.30 A. M.	97.2	91.4
11 A. M.	111.2	96.8
11.30 A. M.	109.4	100.4
12.30 P. M.	108.0	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 Mr. MacDougal's observations on this point were somewhat obscured by the daily clouding at the time of the experiments. 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 to be noted that the amount of evaporation or transpiration of water from a leaf must be sufficient to keep the temperature of the leaves and other green organs below the critical point of chlorophyl, or the temperature at which it begins to suffer chemical decomposition as a result of heat. This critical temperature is usually given as 113° F.,

Alpine desert on summit of San Francisco mountain, Arizona, with meteorological instruments in position.

while the writers have observed numbers of bodies of plants in which the midday temperature reached 115° and 116° F. without injury, and from their location must have undergone similar conditions repeatedly. This gives rise to two suggestions. The protoplasm of plants which have become adapted to this region must have undergone certain variations in composition, as its maximum point of activity is beyond that of other plants, and these forms must also be furnished with specially adapted chloroplasts by which the chlorophyl would be kept from injury at temperatures beyond the critical point at which it suffers damage in other plants. The existence and growth of certain algæ in the waters of hot springs lends favor to this supposition. It is however probable that the death of plants which have found foothold in such regions may result from the intense insolation quite as much as from a lack of a proper supply of water.

In connection with the above observations it was deemed important to make some comparative observations upon the climatic features encountered by alpine plants, and Mr. MacDougal in company with Mr. A. E. Douglass and his assistants made an ascent of San Francisco mountain north of Flagstaff, and about fifteen miles due west from the station at which the observations on desert plants were made but at an elevation about a mile higher. Camp was made and maintained during the first week in August, 1898, at an elevation of 11,500 feet and in addition to the astronomical equipment a battery of instruments including a thermograph, a hygrograph, and mercurial thermometers were allowed to remain on the summit at 12,500 feet for fifteen days (Plate XXIX). The records obtained of the temperature and relative humidity of the air are given in the accompanying diagram (Fig. 4).

It is to be seen that the temperature of the air does not undergo such great diurnal variation as that at lower altitudes. A greater difference is to be found between the temperature of the soil and air, however, than at lower elevations. 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 sun's rays and the attenuation of the atmosphere at such altitudes. It is estimated that the intensity of the sun's rays at an altitude of 9,000 feet is

11 per cent greater than at the sea level in a humid atmosphere, and that the intensity is 26 per cent greater at an altitude of 15,600 feet, on the summit of Mont Blanc, than at sea level. It is to be seen by reference to the curve of humidity that the amount of moisture in the air in the locality under discussion is at times extremely small, which would further intensify the insolation. It would be entirely safe therefore in a comparison of this summit with that of Mont Blanc to say that the

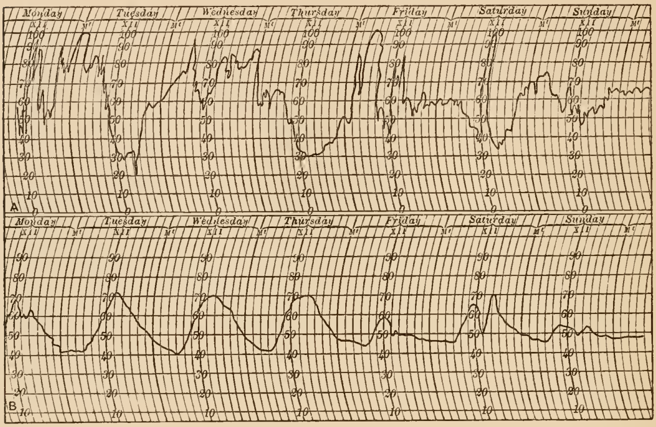


FIG. 4. Meteorological data from San Francisco mountain, Arizona, Aug. 8 to Aug. 19, 1898. The upper curve, traced from the hygroscopic record shows variations in relative humidlty. The lower curve shows the corresponding air temperature in the shade. The instruments were in the shelter shown in Plate XXIX.

intensity of the sun's rays is at least 25 per cent. greater than at sea level and about 12 per cent. more than on the plain below, which by its altitude and other conditions would in turn be about 12 or 13 per cent. greater than at sea level.

The species of plants inhabiting this and all alpine situations are almost altogether perennials, passing the unfavorable season in the form of a fleshy or woody rootstock. The aërial shoots are generally prostrate and lie close to the ground, a device generally conceded to be due to the thermotropism of the plant whereby it receives all possible advantage of the higher average temperature of the soil than of the air. So far as the structural features of alpine plants are concerned it is to be seen that a general similarity to that of desert forms is exhibited. The outer integument of the plant is developed in such manner and furnished with devices for the prevention of damage from the effects of the intense insolation, and for preventing rapid radiation. Either cause would result in an excessive transpiration and damage to the chlorophyl apparatus and protoplasmic mechanism. No important anatomical features of plants at high altitudes or high latitudes have yet been discovered which might unquestionably be interpreted as adaptations to an alpine or polar climate.

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Note: This list of publications is arranged in four groups. In the first, pages 46 to 52, are included *general* treatises; in the second, pages 52 to 53, those relating to *climate;* in the third, pages 53 to 57, those relating to *soil* and in the fourth, pages 57 to 58, those relating to *water*.

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