WILEY

North American Deserts

Author(s): D. T. MacDougal

Source: *The Geographical Journal*, Vol. 39, No. 2 (Feb., 1912), pp. 105-120

Published by: geographicalj

Stable URL: <http://www.jstor.org/stable/1778561>

Accessed: 10-06-2016 21:55 UTC

REFERENCES

Linked references are available on JSTOR for this article:

http://www.jstor.org/stable/1778561?seq=1&cid=pdf-reference#references_tab_contents

You may need to log in to JSTOR to access the linked references.

Your use of the JSTOR archive indicates your acceptance of the Terms & Conditions of Use, available at

<http://about.jstor.org/terms>

JSTOR is a not-for-profit service that helps scholars, researchers, and students discover, use, and build upon a wide range of content in a trusted digital archive. We use information technology and tools to increase productivity and facilitate new forms of scholarship. For more information about JSTOR, please contact support@jstor.org.

Wiley, The Royal Geographical Society (with the Institute of British Geographers) are collaborating with JSTOR to digitize, preserve and extend access to *The Geographical Journal*

The Geographical Journal.

No. 2.

FEBRUARY, 1912.

VOL. XXXIX.

NORTH AMERICAN DESERTS.

By Prof. D. T. MACDOUGAL; M.A., Ph.D., LL.D., Director, Department of Botanical Research, Carnegie Institution of Washington.

ONE of the most important purposes of the Desert Laboratory, which constitutes the centre of effort of the Department which I have the honour to represent, is the investigation of the water and light relations of plants in their widest aspects. The prosecution of the researches upon the main problems which have presented themselves directly has incidentally led us into fields common to nearly all of the sciences. In fact, progress in modern botanical science is much like building cantilever viaducts, the farther ends of which may come down upon foundations in chemistry, physics, geology or geography. The point of view acquired in such experiences leads one to expect similar expansion in related subjects, and particularly the botanist hopes to meet the geographer in a common interest in the forces which act in a causal or modifying manner on the surface of the globe.

It is conceivable that views might be held which would limit geography to exploration and cartography, and botany to descriptive work and laboratory experimentation, but such restriction would cause both sciences to fall far short of their possible usefulness. The geographer holding to the narrower interpretation of his subject might ignore the existence of vegetation, and decline to take into account all organic agencies; but the botanist may no longer content himself within a similarly limited choice. His problems lead him to consider a wide range of facts and phenomena which interlock with the external activities of plants, and knowing a little of the midways of science he can no longer ignore their possibilities. The botanist must perforce be something of a geologist; the intensity of the meteoric factors are of prime importance in his interpretations, and a large

* Royal Geographical Society, December 18, 1911. Map, p. 192.
No. II.—FEBRUARY, 1912.]

share of his conclusions are unintelligible except from the geographical point of view. It is in this broad domain of conjunctive science that the activities of the members of the Desert Laboratory chiefly lie, and the presentation of some of the features of the desert as viewed by those co-operating in our work is the main purpose of the present paper.

The need of a consideration of the subject from widely separated points of view is emphasized by the fact that although one-sixth of the total land surface of the globe is desert, yet when an attempt is made to ascertain upon what grounds the classification is made, considerable vagueness is met with. It is to be acknowledged at the outset that we are not ready to construct the equation of the desert at the present time. The topographical, climatic, geological, and biological features which are so obvious in any arid region, are yet not easily reducible to exact expression. The boundaries and limits of desert areas are likewise not readily definable, and it is only in a very few localities that the traveller may pass directly from the desert to naturally moist and fertile lands innocent of all phenomena of aridity. It is quite feasible, however, to point to the position of the more pronouncedly desert regions, to recognize the things which ameliorate them gradually or abruptly to moist conditions at their margins, and to cite the distinguishing characteristics of desert regions in general (see map).*

The primary condition of aridity is obviously that of a restricted precipitation, but plain as this may be, no limitation of amount may be fixed upon, which would result in the formation of a desert. Latitude and altitude, of course, modify the effect of a given amount of rainfall on any land area, but it would be quite impossible to say, for instance, what rainfall would be followed by a desert in latitude 18° or 34° N., or at elevations of 2000 or 8000 feet in any latitude; since the topographical relations and wind-flow are equally important features which are difficult to correlate. Two aspects of the water-relation are easily appreciable, however. These are the ratio of the annual precipitation to the possible evaporation and the ratio of the maximum and minimum annual precipitation.

Assuming that the possible evaporation from a free water surface in the great desert basins of Utah would be about fifty inches yearly, this amount would be nearly five times the maximum rainfall, ten times the minimum, and six times the average, although greater disproportions undoubtedly are to be found in this region. The evaporation in the Salton basin is about seventy-two inches yearly, which is a hundred and twenty times the minimum rainfall and twelve times that of the heaviest precipitation known. No accurate data from the eastern moist temperate portion of the continent are available, but the supposition is hazarded that the fertile region between the Mississippi and the Atlantic receives an amount of rainfall not far

* MacDougal, 'Botanical Features of North American Deserts.' Publ. Carnegie Inst. of Wash., No. 99, 1908.

from the possible evaporation. The biologist does not go very far into the study of the environment of plants and animals before he is brought to realize that meteorological records, especially of temperatures, as now made in the observatories of the world are not kept in such manner as to include some features of prime interest in agriculture. Maximum and minimum temperatures are highly variable in their limiting value, and averages of temperature are all but meaningless in cultural operations. It has been proposed, therefore, to integrate temperature, wind-flow, relative humidity and intensity of solar radiation in terms of evaporation from a water surface, and the invention of the porous clay cup atometer by Professor B. E. Livingston, has given us a very efficient tool for the measurement of evaporation as a factor affecting vegetation. Doctors Livingston and Shreve, by the aid of a large number of collaborators at stations widely placed over the continent, have secured data demonstrating that the relative rate of evaporation during the growing season applied to the rainfall gives results upon which the character of the dominant vegetation may be determined with fair accuracy. A map of the continent is now being compiled in which the concurrence of atmometric data and the existence of deciduous forest, grasslands, coniferous forest, cactus regions, etc., are to be illustrated.*

The second important feature of the water supply is that of the ratio of the maximum and minimum annual rainfall, first proposed as a factor in climate by Angot in 1883. A disproportion between the annual amount received, as great as one to three, has been found by Dr. Shreve in the mountains of Jamaica, and doubtless occurs in some few tropical and moist regions, yet this is a pronounced and invariable feature in deserts. It is in effect a yearly irregularity, the geological and biological effects of which are much too complicated to be discussed within the limits of the present paper. A review of the conditions in North American deserts with regard to this point reveals the fact of the great diversity to which arid areas may be subject. For example, the great sage brush regions of Utah and Nevada, formerly known as the Great American Desert, and one of the most difficult to traverse, has a maximum which is more than two and a half times as great as the minimum, and the desert character of the region is such as to make it deserve its reputation for intensity. The wide valleys and slopes of the Sonoran desert, in which the Desert Laboratory is situated, receive a rainfall which may vary from 5 to nearly 24 inches yearly, while 500 miles to the eastward across the main continental divide, in the Chihuahuan desert, the ratio may be as one to nine. The extreme conditions are to be found in the Mojave basin, in which the total precipitation may be ten times as much in one year as in another, while in the rainfall

* B. E. Livingston, 'The Relation of Desert Plants to Soil-moisture and Evaporation.' Publ. Carnegie Inst. Wash., No. 50, 1906. "Relation of Soil Moisture to Desert Vegetation," *Bot. Gaz.*, vol. 1, pp. 241-256; 1910. "A Study of the Relation between Summer Evaporation Intensity and Centers of Plant Distribution in the United States," *Plant World*, vol. 14, Oct., 1911.

in the Salton basin the disproportion is nearly as great. It is well known that the rainfall in all such sheltered basins is irregularly distributed throughout the year, and that these places are subject to highly localized storms or cloud bursts, in which a yearly total is sometimes received within the space of a few minutes. Neither the rainfall-evaporation ratio, nor the maximum-minimum ratio, alone, may be taken as a causal condition to deserts, but their concurrent existence is invariably accompanied by the phenomena of aridity as denoted by the character of the erosion and the types of the dominant vegetation. It seems probable that the development of a plan proposed by Dr. Shreve by which soil-moisture and evaporation ratios applied to the length of the dry season may furnish rational expression of the arid character of a region.

An extension of the study of the effects of the total rainfall and of variations of rainfall and evaporation leads one to a consideration of the actual amount of water necessary for the development of vegetation. Rapidly growing crop plants are said to take up and use from 300 lbs. to 600 lbs. of water to produce one of dry material.* Probably as much as a ton of water must be put on a given area to produce a pound of dry plant substance, since only a fraction of the total falling on the soil may be taken by the plant. This proportion would hold only for closely grown crops. The mode of life of the various types of desert vegetation which will be discussed later is such that it might be safely estimated that 10,000 to 25,000 lbs. of water would need be received by the soil in order to allow the formation of a pound of dry matter by the small, quickly growing annuals, massive succulents and slowly growing spinose perennials of arid regions.

Aside from the climatic effects described, the western American deserts are, of course, subject to the general alternation of the seasons, and two distinct types of climate are encountered. The regions which lie seaward of the higher ranges near the Pacific coast receive only the westerly storms, and have but a single period of precipitation, culminating in intensity in January and February, with a rainless period extending practically from March to November. The immense area between the coastal ridges and the main continental divide, and to the eastward of it, is also subject to midsummer storms of tropical violence, which result from the heating of the great land mass. It thus follows that some of our deserts have one period of precipitation annually, others lying in sheltered positions have their rainfall irregularly distributed throughout the year, and others have two well defined periods of precipitation. It is needless to say that the general appearance of the surface, and of the vegetal covering, differs widely in these regions (see diagram on map).

The deserts of North America include as a prominent feature a number of great basins, the rims of which rise high above the level of the

* McGee, "Prospective Population of the United States," *Science*, vol. 34, p. 428. 1911.

lowermost portions, such as the depressions once occupied by Lakes Bonneville and Lahontan, in Utah and Nevada, the Mojave basin, Death valley, and the Salton basin in California, the Otero basin, in New Mexico, and the shallower Bolson of Mapimi, in Chihuahua. The precipitation in these basins, together with the run-off from the rocky slopes of the mesas and mountains, drains toward the centre, and may, in some instances, reach the lowermost depression in such quantity as to form a permanent lake—as the Great Salt Lake of Utah—with a widely fluctuating level. In other cases, the drainage may reach the low places in the basin only in times of flood; and the bodies of water formed at this time soon evaporate, giving rise to many so-called “dry lakes,” of which a notable example is found in eastern Arizona, being crossed by the main line of the Southern Pacific Railway. This lake-bed lies in a region in which very perfect mirages are encountered, and the traveller, viewing it from a distance, may not say with certainty whether the lake-bed is wet or dry until his train actually runs out on the rails that cross it on an embankment raised only slightly above the general level.

The surface features of the great basins of Utah and Nevada are so well known from the writings of Gilbert and Russell, that it would be superfluous to go into any detailed description of them.* Both basins lie at some elevation in a latitude which brings low minimum temperatures. The yearly irregularity of the rainfall is as one to two and a half; the possible evaporation may be estimated as six or seven times the average precipitation. The lowermost portions are occupied by sinks, saline plains, or permanent lakes, the Great Salt Lake being the fluctuating remnant of the ancient Lake Bonneville.

Thousands of square miles of the slopes support a dense growth of *Artemisia*, and consequently the region is known as the “sagebrush plains,” while a stretch 50 by 120 miles southward and westward of the Great Salt lake still receives the appellation of the Great American desert. The maps of half a century ago spread this term to include not only all of the basins, but also the “short grass plains” to the eastward of the main continental divide.

Deserts were formerly characterized more strictly with regard to their influence on human activity. A region which did not furnish the traveller with fuel, forage, water and shelter was apt to be regarded as “uninhabitable.” “Absolutely devoid of vegetation” is still a ready phrase among explorers, although some of the areas to which this description has been applied may show hundreds of low-growing perennials per acre, as is well known with regard to certain portions of the Sahara.

“Dry farming,” in which the rainfall, amounting to 12 to 20 inches annually, of one or two seasons is conserved by special tillage and made

* I. C. Russell, “Geological History of Lake Lahontan,” ‘Misc. Doc. House of Rep., 1st Session, 49th Congress,’ vol. 2, 1885-1886. G. R. Gilbert, “Lake Bonneville,” ‘Misc. Doc. House of Rep., 1st Session, 51st Congress,’ 1889-1890.

to grow a crop every second or third year, has been practised with success in the great basins mentioned, but it may be predicted with fair certainty that this method of agriculture will not be found profitable under present economic conditions in regions in which the yearly irregularity of precipitation is greater than one to three, and the evaporation does not amount to more than five or six times the average rainfall. The possibilities of irrigation, as yet but little developed, and the other industries of the region marked as desert on the accompanying map combine, however, to give it the greatest wealth per capita of any part of the country.*

The best method of gaining a comprehension of the mechanism of the desert is by the consideration of the phenomena offered by smaller areas, and it is proposed therefore to discuss some of the features of the Salton basin of the desert of the Colorado, as this region has been the subject of considerable study during the last few years. This basin lies north-eastward of the San Jacinto mountains, and as this range reaches an altitude of about 10,000 feet, the basin is sheltered from the westerly winds, the only rainfall reaching it being principally that of fringes of the "sonoras" or mountain storms which usually come in such manner as to be regarded as cloudbursts. The yearly precipitation at any one station may, in consequence, vary in the ratio of 1 to 9 or 10, the actual minimum being as low as six-tenths of an inch, while the annual maximum of less than 6 inches may be received in less than a day. The open part of the basin has an area of about 5000 square miles, but the foothills of the limiting ranges and the drainage area back to the mountain summits raises the total to more than twice this amount. Various uncertified maximum records of temperature of 118° to 128° F., are known from the region, although our own instruments have not gone above 109° F. The possible evaporation has been estimated by the United States Weather Bureau 69 to 72 inches yearly, which is nearly thirty times the average precipitation, and a hundred and twenty times the minimum. It is to be seen, therefore, that we are dealing with a region of extreme aridity, and the instrumental results are fully borne out by one's personal impressions in the field. Furthermore, the presence of some desert deposits not later than the Tertiary shows that the place was arid at a time extremely remote. We are not prepared to say, however, that it has been dry continuously or uniformly. The lowermost part of the basin lies 284 feet below sea-level, and 40 feet above sea-level is a well-marked beach-line. Below this high beach-line and within 253 feet of it are to be seen eighty-three different strands, denoting stages in the level of the ancient lake, which at various times contributed to a deposit of travertine many inches thick on the rocks bathed by it at its upper levels. It has been customary to consider the lower part of the basin as having been once occupied by an arm of the Gulf of California, but many difficulties stand in the way of acceptance of this simple solution of the problem. The delta at the present time closes

* Widtsoe, 'Dry Farming.' New York : The Macmillan Co. 1911.

the southern end of the basin so incompletely that the full lake would communicate with the Gulf by a possible flow 20 feet deep, and the height of the lake is 40 feet above the high tide levels of the Gulf itself. Furthermore, the saline deposits occurring in the basin are of lacustrine rather than marine origin, as shown principally by their composition. It would be unsafe to assume a narrow limit of conditions under which travertine might be deposited, but it is highly suggestive that the old incrustation is heaviest immediately below the highest water level, and that the lake at the present time with a concentration only slightly more than seven-tenths of 1 per cent. has begun to unload its calcium content. It seems impossible to account for the basin without recourse to some assumptions as to upheavals, but this is a question of a purely geological character. The alluvial deposits of the delta form part of the great bowl of the Salton, and not infrequently within historic times floodwaters have found their way in great quantity across the rim and down into the basin, making a lake of small size. A few years ago a large canal was cut out from the banks of the main river channel leading water over the edge and down the slopes of the basin irrigating an area which became known as the Imperial valley. Floodwaters enlarged this canal in 1905, 1906, and 1907, in the absence of proper headworks, and the water was brought under control only after tremendous effort and at great cost. Meanwhile sufficient water has escaped into the basin to form a lake 50 miles long, 25 miles at its greatest width, and 84 feet deep in places, which probably simulated in every feature previous makings of the lake in the desert.*

The political situation is one worthy of some attention. The Mexican-American boundary crosses the delta at right angles, and part of the basin lies in the province of Baja California. The irrigation canal was planned to take water out of the Colorado river, the navigable channel of which forms a north and south section of the international boundary, and, after making a loop through the delta in Mexican territory, crosses the line to irrigate farms in California. It was necessary to extend a railroad and take an army of workmen into Mexico to bring the flood waters under control in 1906, and all operations were put in charge of the managing engineers, practically making American territory of a large area for the time being. Extensive protective operations have been continued by our engineers far down the river, and it speaks volumes for the diplomatic relations of the two countries concerned to say that no territorial questions have been allowed to interfere with engineering plans. During many months of the present year the Mexican federal government lost entire control of the region, but the insurgent army, using the canals as defensive works, did nothing to interfere with the delivery of an adequate supply of water on the American side.

The Salton basin had been an object of interest in many ways to various

* MacDougal, "The Desert Basins of the Colorado Delta," *Bull. Amer. Geog. Society*, December, 1907.

members of the staff for many years, and the writer made a visit to its lowermost part in 1902, and was so fortunate as to secure photographs of the surface and the vegetation. The making of the lake during 1906 found the Desert Laboratory fully organized, and plans for research in various problems were made at once. The opportunity secured was unparalleled for the study of the unmaking and remaking of the desert, with all its attendant phenomena of sterilization and revegetation of the area occupied by the lake. A first visit of observation was made in May, 1906, when the lake had not attained half its depth, and the Colorado still flowed into it at a rate which brought its depth from 34 feet to 84 feet by the following February. Meanwhile a small expedition had been planned, and we started from the north-western end of the lake in a sail boat on February 7, 1907, being so fortunate as to be afloat on February 10, the day of maximum level. The total area now amounted to about 450 square miles, the water was as yet unsettled, and bore on its surface all of the drift of a river in flood as well as thousands of water-worn and rounded fragments of pumice which had been lifted and shifted in previous inundations of the basin. The long tongues of water extended up the channels of the dry washes, and the loosely-packed wind-borne soil of the desert when wetted became a strip of mud below and above the actual water-line that made landings difficult. The water at this time contained about one-fourth of 1 per cent. of dissolved salts, and was consequently drinkable, and, as was seen by results obtained later, was not especially harmful to seeds of many kinds.

A group of mud-volcanoes was covered by the lake and the surface of the water has since showed no indications of their activity. Many small hills stood in the lowermost parts of the basin, and some were completely submerged, while three rose many feet above the water-level. The results which have been obtained from the observations on the island of Krakatau since its denudation by volcanic action, inspired us to watch the behaviour of these islands with the keenest expectancy. The highly alkaline soil of the Salton hills was first sterilized by the brackish water, which gradually became salter, then, later, the hills began to emerge as islands separated from the shore by miles of water. One might with but little exercise of the imagination, see in them the making and peopling of new lands, with fair hope of detecting the relative action of the various agencies which would be operative in bringing seeds or spores to them.

Our observations on the emersed islands are rich in detail of main interest to the botanist, but the more general facts may be pertinent here. It soon became evident that flotation was the chief way in which plants might win their way to unoccupied lands of this kind, and only one introduced species was found above the high-water mark. The fruit of this species being an adhesive burr, support is given to the supposition that it may have been brought by birds, which resort to the islands in great numbers. No evidence of seeds wind-borne to the islands was found,

PLATE I.—TOP OF A HILL ONCE SUBMERGED APPEARING AS AN ISLAND IN THE SALTON SEA. THE FIRST PLANTS FINDING A
FOOTHOLD ARE *PLUCHEA* AND *ALLENROLFEA*.

PLATE II.—DRY BED OF MIDDLE LAKE, OTERO BASIN, NEW MEXICO.

although many must have been brought to the lake in this manner and then cast ashore by the water (Plate I).*

Popular opinion ascribed climatic effects hundreds of miles away on the desert to the lake, but, as a matter of observable fact, the visible effect of the presence of this body of water on the surrounding slopes of the basin was very small. This was not unexpected, as arid conditions may be recognized by the character of the vegetation within a few feet of mangrove strands along the Gulf of California. The only noticeable changes above the highest level of the lake were those attributable to the damming of the underflow from the steeper slopes of the mountains on the southwestern side of the lake. It is on these steeper slopes also that the receding lake is leaving some terracing effects with sorting of the material in the strands. The separation of the coarser and finer material of a strand makes bands or lines of substratum suitable for certain plants, and the lack of erosion by wind and run-off in sheltered localities leaves such places undisturbed with the result that beach lines which one would hardly dare date within four hundred years are accurately marked by rows and bands of vegetation. The establishment of such vegetational lines has already been seen and, in a few places, with a gentle gradient, the emersed strands of 1907 have already returned more or less completely to the desert conditions prevailing previous to the recent flood. The total evaporation from the lake amounts to about 70 to 72 inches yearly, of which about 18 to 20 inches are compensated for by the underflow and run-off from the mountains, by the water from a few artesian wells, and by the waste from the great irrigation system from the canal which formerly fed the lake. Our present studies may, therefore, be continued until this inflow meets the evaporation loss, which would occur under present conditions with a lake surface of about 150 square miles.

A second region which has received some detailed attention is the Otero basin, which lies east of the main continental divide in New Mexico, in a region in which the yearly irregularity of the rainfall is as one to nine,† and the average about one-sixth or one-seventh of the possible evaporation. This basin is a long narrow dropped block between two mountain ranges. The detrital slopes fall steeply at the foot of the mountains to a flat and featureless plain, in which lie several *playas*, the whole valley being deeply filled with material worn from the mountains. The basin seems to have been occupied by a variable lake, which, after its last period of expansion, deposited beds of reddish, gypsiferous and saline clays. The intermittent rainfall and the action of the wind have resulted in covering these deposits to some depth. The *playas* of which there are five or six a few miles across become shallow lakes, which, in dry periods, are beds of gypsum and salt

* See 'Reports of Department of Botanical Research,' Carnegie Inst. of Wash., 1906, 1907, 1908, 1909, 1910, and 1911.

† MacDougal, 'Botanical Features of North American Deserts.' Publ. Carnegie Inst. of Wash., No. 99, 1908.

(Plate II.). Nowhere may more beautiful wind effects be seen, and the dry beds as well as the older deposits are subject to its erosive effects in such manner that a great series of gypsum dunes cover an area of about 15 by 40 miles (Plate III.). Still older dunes, fixed and covered with vegetation, give evidence of a period of slightly greater rainfall not farther back than a few hundred years, and the terraces and old lake strands promise some interesting evidence upon a subject to which Prof. Ellsworth Huntington in co-operation with the Desert Laboratory, is devoting much attention. The biologist looks into the life of these basins with the keenest interest as to the occurrence and distribution of the existing species. No species endemic or characteristic of either the Salton or Otero basin are found so far as available information goes, although such forms are known in the greater basins of the Death Valley and Mohave Desert. Plants of extremely localized distribution are numerous in a large part of the general region in which these basins lie. Alterations in climate would of course affect these enclosed basins most profoundly, and if new forms have originated in them they may be taken to have disseminated beyond the limits of their birthplace, with the result that their genetic connection with a locality is lost to us.

Many other large self-centred drainage areas are included in American deserts, but this brief description will serve to characterize the more important basins. The greater part of the desert, however, consists of elongated trough-like valleys, tributary to the larger rivers like the Colorado, and receiving the run-off from the mountain slopes. The mountain streams may barely emerge from the mouths of the cañons in which they are formed, or they may make their way down the slopes according to the season, the volume of water carried and the steepness of the slopes. The Santa Cruz river gathers the drainage of a dozen mountain ranges, and fills a well-defined channel near the Desert Laboratory in times of flood. A few miles away it spreads over a *playa*, miles in width, from which water has been spilled over into the Gila river but few times in the memory of living men (Plate IV.). It has been my good fortune to be in camp near the termination of the flow of a desert stream making its way down the dry channel, and I found it extremely fascinating to watch the tip of the tongue of moisture as it advanced by night and retreated by day over a distance as great as a hundred yards. Many incidents are on record of travellers camped in the dry channels of such streams being overwhelmed by walls of flood sweeping down on them from the distant mountains.

The water which sinks into the coarse sponge of the detrital matter may strike clayey layers lower down, and be forced to the surface, where a short course is run until the water evaporates or escapes over the edge of the impermeable layers to be lost again in the gravels. Such is the history of various "lost rivers," and the pools, which may be seen in clayey formations or harder rocks, are known in the south-west as "tanks" (Plate V.).

PLATE III.—GYPSUM DUNES FORMED FROM THE DEPOSIT IN LAKE-BED, OTERO BASIN, NEW MEXICO.

PLATE IV.--VIEW FROM DESERT LABORATORY. THE SANTA CRUZ RIVER IS IN THE MIDDLE DISTANCE. THE DETRITAL SLOPES MAY BE SEEN AT THE FOOT OF THE SANTA CATALINA MOUNTAINS IN THE DISTANCE.

The aborigines of this region also had the practice of making bowl-like depressions in the soil, which were tamped with clay, and thus acted as reservoirs, which are designated as "charcos." One of the earliest things to receive attention in any desert valley is that of sinking bores to test for the presence of water, and these holes must sometimes go down to as much as 400 or 500 feet before a water-bearing stratum is found.

The habits and adaptations of the aborigines and other animals with reference to arid conditions are of surpassing interest. Large mammals and birds are known which go for months without any water beyond that obtained by eating succulent cacti. Deer and peccary have been found in regions in which the nearest accessible water was 30 or 40 miles distant. Some of the smaller rodents are known to be able to live on hard grains alone, which may contain not more than 10 or 15 per cent. of water.

Man and the horse are among the animals least adapted to undergo the inevitable thirsts of the desert. The traveller afoot may consume and need as much as 16 pints of water daily, and entire deprivation of water for a period of more than 24 hours is likely to be followed by the most serious consequences. The use of such great quantities of the liquid gives special effect to dissolved salts, and the frequenter of the desert may not use for any length of time water containing more than one-fourth of one per cent. of saline material, although he is frequently compelled to make shift with stronger solutions for brief periods. The horse may endure more concentrated solutions, but its needs are truly enormous, as 15 to 30 gallons per day is the average requirement. The smaller half-wild horses of the south-west may make long traverses, and go for a second or third day without drinking, but their endurance is far surpassed by that of the Mexican donkey or burro. A serious effort was made to introduce the camel into American deserts about half a century ago, coincidently with its being taken into Australia, where it has proved so useful. The attempt was an unnecessary failure. The development of the modern motor has now made the camel unnecessary, as the horse and the donkey may be used to supplement the automobile for all the necessities of travel at the present time.

Mountains which rise to altitudes of 7000 and 8000 feet will, of course, receive a rainfall far in excess of low-lying slopes and valleys. The average rainfall at the Desert Laboratory is about 12 inches yearly, but the slopes of the Santa Catalinas, which rise over 6000 feet higher (to 9025 feet) have an annual precipitation three times as great. This supply of water makes a climate far from arid, and supports a vegetation in which mesophytic types are very abundant. The general aspect of the entire desert would therefore be that of a great region (including many rivers of size) moist on the upper portions of the mountain ranges, with the rainfall collected in streams which flow down to the arid lowlands carrying a fringe of moist soil, in some instances clear to the sea. The accompanying map, compiled by Dr. Forrest Shreve, gives the position and extent of

the arid region of North America, in which only the principal mountain ranges are indicated, and no attempt has been made to accomplish the difficult feat of tracing the non-desert strips along the river courses, or to marking the mountain ranges which attain a height of less than 7500 feet (see map). Above this the surfaces may be carpeted with vegetation, and a layer of soil of some depth may be retained. Below this, in south-western America, the arid character of the mountain slopes is unmistakable. The habit of most desert plants is such that they stand isolated from each other, and the loose material on the unprotected slopes is moved by the wind and swept down by the occasional precipitation to the base of the mountain. Nothing is so surely indicative of aridity as the disposition of the detrital material at the base of the slopes from which it came, and nothing so clearly expresses the abruptness with which the exposed base of a mountain wall rises from the loose material at its foot as to say that one may walk over the lower slope and lean against the mountain as against a wall. The character of the long arched slopes in which the detrital material from desert mountains is disposed by the torrential action of the streams coming from them is equally distinct. Our Mexican neighbours have long designated such slopes "*bajadas*," and, in accordance with the proposal of Prof. C. H. Tolman,* this term is used exclusively by the workers at the Desert Laboratory. Boulders and finer material are mingled indiscriminately in *bajadas*, but the finer material in suspension is carried until the water of the outflow comes to rest in the level places in the middle of the valleys, where the deposit of this finer material forms level flats or *playas*. The terms *bolson*, *playa*, *mesa* and *bajada* are in common use by the inhabitants of Mexico, and it is found to be a great convenience to be able to apply these common appellations in an exact and discriminating manner, particularly in the field with Mexican helpers (Plate VI.).

The vegetation of deserts presents specializations quite as marked and characteristic as the phases of erosion, evaporation and precipitation, and no adequate discussion of an arid region is possible without some presentation of the more salient biological features. It has already been pointed out that the mountain-tops within even the most arid regions are moist, and the streams flowing down from them furnish habitats for plants requiring much moisture, and presenting an aspect not much different from that of other broad-leaved forms in the temperate zone. In addition to these biological islands, the flora of many arid regions includes a large number of rapidly maturing annuals, which complete their development during the rainy season, and pass the rainless periods in the form of seeds. These, likewise, are not distinguishable from species of moister regions, so that altogether Prof. Spalding found that over forty per cent. of the total plant population of the area about the Desert

* C. H. Tolman, *Jour. of Geol.*, vol. 18, Feb. and March, 1909.

PLATE V.—A "TANK" IN THE DESERT.

PLATE VI.—A "WASH" OR DRY STREAMWAY IN AN ARIZONA.

Laboratory consisted of non-desert forms, and if the species from the mountain tops were included, the proportion would be even greater.* The results of such an analysis would seem to be of special significance to the palæontologist in the deduction of climatic conditions from fossil remains. The mechanical relations of this mesophytic element of the flora to the streamways are much more favourable for their preservation than that of the characteristic desert plants, as they would be especially liable to be covered up in *bajadas* and *playas*.

The observer may get his most correct impression of the habits and character of a desert flora by gaining the top of a small prominence from which a view may be had of near-by mountain-slopes and of the *bajadas*, which fall gently away from their bases. It is seen at once that the separate individuals do not crowd each other, making dense cultures, but that nearly every shrub and bush stands alone out. The separation of the individual plants is connected with the fact that the roots instead of being deeply penetrating are horizontally disposed very near the surface, and that the superficial layer of the soil is densely occupied for a depth of 6 or 8 inches only. Root-systems of this character are in a position to absorb water most advantageously after the rains, which do not penetrate deeply, but the sparse shoots offer but little shade which would lessen evaporation. The surface dries quickly after a rain, and is subject to wind erosion at all times, and, of course, the amount of humus present is very slight, some being found around the bases of low-growing shrubs.

Two distinct types of desert plants or *xerophytes* may be recognized : one includes the forms with reduced woody stems and branches, restricted leaves and water-proofed surfaces being in general of a spinose character. These structures are correlated with some very striking qualities. The juices of the leaves and stems of some spinose species that have been examined show a concentration which would give them an osmotic pressure of 75 to over 100 atmospheres. The roots are in constant absorbent contact with the soil, and presumably a slow diffusion of soil solutions into the plants goes on almost constantly since they quickly perish when removed from the soil, and are difficult to transplant (Plate VII.). The second type of xerophyte is a succulent which accumulates a large water-balance, the cacti being excellent illustrations. All of the reductions of the spinose plant are exhibited by these forms in an accentuated manner, and some of them show such extreme specialization that the entire shoot consists of a single thickened trunk, leaves and branches having been lost. Succulents are specially abundant in regions with the precipitation occurring within well-defined periods. The widely extended root-systems form new roots quickly under the stimulus of heightened soil moisture and temperature. Large quantities of water pass into the roots and into the thickened

* V. M. Spalding, 'Distribution and Movements of Desert Plants.' Publ. Carnegie Inst. of Wash., No. 113, 1909.

stems and other organs during the time in the rainy season in which the soil moisture is above ten per cent. The drying of the soil below this limit following the cessation of the rains, however, soon results in the death of the absorbing rootlets, and the plant then lies simply anchored in the soil by the larger roots. It is of interest to note that the juices of these plants contain so little dissolved material that their osmotic pressure is usually not over 10 atmospheres. Plants of this kind may exist for extended periods upon the large water-balance which they have accumulated (Plate VIII.). The saline and alkaline areas of deserts are characterized by still a third type of vegetation, the fleshy beach plants or salt marsh plants, which are mostly cosmopolitan, and have no direct connection with arid conditions.*

Questions as to variations in climate have received much attention in the last few years, and evidence from the most diverse sources has been examined with regard to its bearing upon the matter. Prof. Ellsworth Huntington has been especially active in this research, and has been carrying on field work in connection with the Desert Laboratory during the last two years for the purpose of comparing piedmont gravel deposits, lacustrine and fluvial terraces, ancient ruins, and traces of agriculture, tree structure, and plant remains in the American deserts with the results of similar observations in Asia. The remarkable apparent concurrences of climatic phenomena in widely separated regions brought out by this work seem worthy of the most serious consideration. An analysis of the surface geology of the region about the Desert Laboratory indicates that some fluctuations in the climatic factors have taken place in that region.† The effect of such changes is a topic worth a few minutes' consideration, and, for the sake of a clear understanding, it might be profitable to follow in imagination the consequences of the desiccation of a well-watered region, and to make a theoretical outline of the probable happenings when the climatic swing was reversed and a period of humidity followed one of aridity.

Chief interest centres, of course, in the amount of rainfall, and in the ratios described in the preceding part of this paper. The reduction of the rainfall in a region like eastern America would undoubtedly result

* MacDougal, "The Water-balance of Desert Plants," *Annals of Botany*, vol. 26, January, 1912.

† Ellsworth Huntington: 'Palestine and its Transformation' (pub. by Houghton, Mifflin & Co.), pp. 442; 1911. "Geographic Environment as a Factor in the Present Condition of Turkey," *Journal of Race Development*, vol. 1; 1911. "The Fringe of Verdure around Asia Minor," *Nat. Geo. Magazine*, vol. 21, p. 761; 1910. "The Lost Wealth of the Kings of Midas," *Nat. Geo. Magazine*, vol. 21, p. 831; 1910. "The Karst of Southern Asia Minor," *Bull. Amer. Geo. Society*, vol. 43, p. 91; 1911. "The Burial of Olympia: a Study in Climate and History," *Geographical Journal*, vol. 36, p. 657; 1911. London. "The First Americans," *Harper's Magazine*, vol. 122, February, 1911. "The Desert Laboratory," *Harper's Magazine*, vol. 122, April, 1911. "The Greenest of Deserts," *Harper's Magazine*, vol. 123, June, 1911.

PLATE VII.—SAND-DUNES AND SPINOSE SHRUBS IN OTERO BASIN, NEW MEXICO.

PLATE VIII.—PIMA CAÑON, SANTA CATALINA MOUNTAINS, WITH SPINOSE AND SUCCULENT TYPES OF VEGETATION.

from changes in the flow of the wind in a year in which the principal features would be a single wet winter season and a dry rainless summer. The total evaporating power of the air would be increased. The disproportion between the annual maximum and minimum rainfall would be heightened, and the daily and the annual range of temperature would increase, chiefly by reason of a heightened maximum.

Next would come an interlocking series of changes in soils, stream flow, erosion phenomena, and in the distribution and composition of the vegetation. Broad-leaved plants and dense formations would be restricted to the margins of streams and the higher mountain slopes. The destruction of the existing vegetation would give greater scope to erosive agencies. Detritus would pile higher at the foot of mountain slopes, the run-off coming out of the mountain gulches would carry some of this loose material out into characteristic *bajadas* and also make *playas* in the lower valleys. The humus content of the soil would be lessened, the soil-moisture content would be decreased to such extent that the capillary column to the surface would be broken, plants would no longer find a supply deep in the ground, and the types which survive would be those with horizontally disposed root-systems of the spinose or succulent forms. The saline deposits formed in the valleys would become suitable for the salt or beach plants.*

Many streamways † would show only an intermittent flow, lake-levels would be lowered or dried up, and their wind-swept bottoms become piled with dunes. The action of the wind on slopes of loose unassorted material would tend to carry away the sand and finer particles, allowing the coarser pebbles to sink in place, forming a perfect pavement with an exposed surface polished by wind-borne sand. Meanwhile the animal population, including man, would show adjustments to the slowly changing supply of water and food. Habitats and habitation sites would be abandoned, and all would become tributary to fewer centres of supply. Greater tensions and fiercer competitions would be set up, and many races would perish, while the surviving elements would necessarily be forced into new inter-relations.

Now, let us suppose the pendulum of variation were to swing slowly back toward humid conditions. The disproportions between precipitation and evaporation would decrease, and the annual rainfall become more regular. The spreading out of broad-leaved plants from the stream-margins would give a denser covering of vegetation, increase the humus in the soil, and check erosion by wind and water. Drainage lines would be connected into a living system of streams extending to the sea, cutting

* MacDougal, "Origination of Self-generating Matter, and the Influence of Aridity upon its Evolutionary Development," *Journal of Geology*, vol. 18, p. 603; 1909.

† E. F. Free, "Studies in Soil Physics," *Plant World*, vol. 14, pp. 29, 59, 110, 164, 186, 1911.

and dissecting the *bajadas* and filling up the basins to overflowing. Some plants of the desert types would survive on the drier slopes in the sunniest exposures.

The observer who examines a region for evidences of climatic variations of the kind indicated might see the upper portions of detrital slopes hanging to the mountain bases, as well as dissected *bajadas*, saline and wind deposits exposed by stream action in a humid climate. In a desert region, the terraces of lakes and streams, traces of ancient stream flow, remains of human habitations and desiccated plant remains might be taken together as indicative of conditions prevalent in times past. The structure of the great trees of California, which reach ages of twenty to thirty centuries, have been recently examined by Professor Huntington, and it seems probable that when corrections for age and locality are applied to the measurements of the annual rings, some evidence of value as to climatic fluctuations may be obtained. The completion of the computations will be awaited with much interest. A discussion of this and other phases of the problem as to climatic fluctuations lies without the scope of this paper. My present purpose has been to describe and define some of the meteoric, hydrographic and organic agencies, which interlock to make the complex and distinctive conditions of the desert.

The PRESIDENT (before the paper): The reader of the paper to-night, Dr. MacDougal, is a graduate of two American Universities, and has held various appointments. He was Assistant Director of the Botanical Gardens in New York for six years, and is now Director of the Desert Laboratory which has been established in Arizona by the Carnegie Institution of Washington. He has been engaged in exploration and other geographical work in the deserts of North America during the past twenty years, and some of the results of his work he will present to us in the paper we are to listen to to-night. He is the author of several works on his own subject, which is botany, and of various scientific papers. He is a botanist by training, but his desert researches have led him to give very close attention to the geographical conditions affecting botanical distribution. The Carnegie Institution of Washington with which he is connected was founded by Mr. Carnegie in 1902, and its purpose of research has been carried out by the organization of facilities for investigation in various fields which might not be readily occupied by members of University Faculties with the opportunities usually available to them. Many eminent scientists have been brought into connection with the Institution as research associates, while special staffs have been called together to co-operate in seeking the solution of closely related problems, such as those grouped in the programme of the Solar Observatory; the results of the extended surveys of the Department of Terrestrial Magnetism are also probably known to many members of the Society. These are the credentials of the distinguished gentleman whom I will now invite to address you.

Mr. GODFREY SYKES (after the paper): I am sure that Dr. MacDougal has left but little more to be said, but there is one point which he has touched upon which I should like to emphasize a little more. The desert regions in Western North America are a series of more or less isolated areas, extending generally in a north and south, rather than an east and west, direction. In other words, their existence depends not so much upon latitude as upon mountain slope and aspect. The

RAINFALL AT THE DESERT LABORATORY **TUCSON, ARIZONA, 1904-1910.** Compiled by Mr. Godfrey Sykes.

CLIMATIC DATA AT THE DESERT LABORATORY TUCSON, ARIZONA, 1904-1910.

Compiled by Mr Godfrey Sykes.