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THE SCOTTISH GEOGRAPHICAL MAGAZINE.

SOME PHYSICAL AND BIOLOGICAL FEATURES OF NORTH AMERICAN DESERTS.¹

By DANIEL TREMBLY MACDOUGAL, Ph.D., LL.D., Director, Department
of Botanical Research, Carnegie Institution of Washington.

THE Desert Laboratory of the Carnegie Institution of Washington was established in 1903, at Tucson, Arizona, upon the recommendation of a number of botanists that facilities be provided for the study of the general problems of plant physiology, using the specialised forms of vegetation peculiar to arid regions. The earlier researches carried on at this laboratory by Dr. Cannon, Professors Livingston, Lloyd, Spalding, and myself, opened up such possibilities of advance in investigation in general botany, that the institution organised a Department of Botanical Research, which was to have its centre of activity at the Desert Laboratory,² but which would be concerned with any phase of desert work for which opportunities for new results were offered. In addition to a number of members of a regular staff, the organisation was amended later to permit the appointment of collaborators and research associates, who might act in connection with the department for limited periods.

Deserts were taken to be the expression of definite physical complexes, made up of factors or agencies affecting living organisms, and resulting in certain features of surface geology: it seemed important, therefore, to make some definite estimation of the environic factors, and to analyse their separate effects upon plants and upon the soil. In carrying out this idea a group of workers has been organised, the separate members

¹ An address delivered before the Society in Edinburgh on April 3, 1912.

² For some account of this Laboratory, with figures, see *S.G.M.*, xx. p. 605, and xxvi. p. 9.—Ed. *S.G.M.*

of which are carrying out researches on a group of related problems in phytochemistry, soil-physics, evaporation, transpiration; the composition of the sap, and the amount and variations of the water-balance of desert plants; the environic re-actions of species interchanged between maritime and alpine, desert and maritime, and desert and humid localities; the origin and fate of plant populations in well-defined regions; the distributional movements of desert plants; the re-vegetation of submerged desert areas, and various aspects of possible fluctuations in climate during recent geological time. It is unnecessary to say that such activities are not usually conducted under botanical auspices, but in this, as in all scientific effort, the results of highest value are to be obtained by the co-operative effort of workers in correlated branches.

The possible importance of investigations in the phenomena of the desert may be realised when it is considered that the arid regions of North America cover 2,000,000 square miles, that half of Africa is arid, and that if the deserts of the world were brought together, their total area would be as much as one-fifth that of the land surface of the globe, or about equal to the extent of Africa. Relative aridity has been a dominant factor in the evolutionary development of the higher plants, while the influence of deserts upon the beginnings of human civilisation, and on the shaping of cultures and moulding of religions, is a subject much too vast to be discussed in this lecture. Earlier, deserts were inhabited and used by nomads only, but now everywhere in America, Asia, Australia, and Africa, effort is being made by colonisation and occupation to convert the dry places of the world to the uses of modern civilised man.

Although the extent and location of the principal deserts are well known, yet it is not easy to state the exact conditions which operate together to make a desert. Amount of rainfall alone may not be taken as a reliable index, since the final effect of any given amount of precipitation is influenced by latitude and wind, and varies with the seasonal distribution of the rains. The possible evaporation is equally insufficient to determine the degree of aridity of a region. It was proposed by Angot, in 1886, to use the ratio between the maximum and minimum rainfall in any region as a test of its agricultural possibilities, and when the greatest amount received in any year was two and a half or three times the minimum, the limit of agricultural usefulness was presupposed. This ratio is likewise not a safe guide when taken alone, since the disproportion in annual rainfall in some places in the moist tropics is very great. Some investigations now being carried out in the Desert Laboratory by Dr. Shreve and Professor Livingston seem to indicate that the seasonal curve of evaporating power of the air and of the soil-moisture have great determinative value. While we have not yet arrived at a stage where we are prepared to write the equation of the desert, yet it may be said, with some degree of certainty, that disproportion between the annual maximum and minimum rainfall; disproportion between the total amount of rainfall and the total evaporating capacity of the air; and disproportion between the evaporating power of the air and the supply of soil-moisture, will be the important factors

in the set of conditions which result in the biological, climatic, and geological phenomena so obviously characteristic of arid regions.

It has been found that a plant needs to take up and use about 300 to 600 lbs. of water to produce 1 lb. of dry material in moist temperate latitudes, while in the agricultural operations of the warm arid parts of South-Western America, three times this amount of water is needed in even the most carefully guarded systems of irrigation. These figures apply to closely-grown crop plants, such as wheat and barley. When the isolated habit of plants native to deserts is considered, and it is known that a much greater proportion of the rainfall is evaporated from the soil, it soon becomes evident that the small amount of plant growth is a direct result of the fact that as much as 10,000 to 25,000 lbs. of the limited precipitation may be necessary to produce a single pound of dry material. The operation of "dry-farming," as practised in America, offers some points of interest in this connection. To carry out this kind of cultivation, two or three times as much land is necessary as would be sown in any one season. If a crop is to be grown without irrigation in dry soil, it is obviously necessary to increase the amount of moisture in the soil by other methods. To accomplish this, the surface is ploughed or broken up, so that the rainfall may penetrate deeply and quickly when it does come. After a rain, the surface is then finely pulverised by various special tools, so that a dry "dust mulch" covers the surface, and the capillary columns which would bring the water to the surface are broken. The process is repeated after every rainfall, until tests show that the soil contains enough water to mature a crop. This may require a year or longer. After the seeds are sown, the dust mulch must be maintained as perfectly as possible, to conserve the supply of water. After the crop is harvested, the process is repeated to make the land ready for another sowing. This method has not yet been successfully used in America in regions in which the annual rainfall is less than 15 to 18 inches, although it is reported to be practicable in Australia with a smaller amount.

North American deserts include one region, between the mountain ridges of the Californias and the Pacific ocean, in which the annual rainfall may be as much as 18 inches—but this is all received in the cooler winter season, consequently, the soil becomes very dry in midsummer, and wind erosion is very marked. It is in this region that such profitable results follow the use of the streams of the mountains for irrigation of fields and groves of citrus and pomaceous fruits. To the eastward of the Sierra Nevada lie a series of great basins, some of which are so depressed as to have their bottoms below sea-level. The rainfall is very limited, and, furthermore, is irregularly distributed throughout the year, while the amount of precipitation in some years may be not more than one-twelfth of the maximum. These basins include the famous Death Valley, Mohave Basin, and Salton Basin, while to the northward and eastward lie the great basins in Utah and Nevada, which were formerly occupied by the ancient Lakes Lahontan and Bonneville. These sunken basins include the most arid portions of the continent, and as the temperature sometimes reaches 128° F. and

the rainfall varies between half and six inches, the deserticulous effects are very marked.

The greater part of the arid area of North America, however, consists of trough-like valleys, enclosed by detrital slopes leading down from the mountains, which are so much worn in some instances as to be completely buried, although some rise as high as 6000 to 9000 feet above sea-level. Most of this region is characterised by two rainfall periods, the maximum of the one coming in the summer, and the other in winter, a fact which accounts for the complexity of the flora, which shows as many species per square mile as the densest tropical jungle, although the number of individuals is very small by comparison.

It will be of interest to examine the details of some of these deserts with greater minuteness, and we naturally begin with "The Great American Desert" lying in Utah, about which so much has been written, since it lies on the main highway across the continent, and was a very serious matter to the traveller by wagons sixty years ago, when settlers poured into California from the eastward. The principal vegetation is the sage-brush, or *Artemisia tridentata*, which grows densely over large areas. In regions occupied by the Great Salt Lake in recent time, and in other places also, the ground may support only a scanty vegetation, showing a surface of hard clay, or a loose layer of wind-carried soil, which may have a high salt content, and hence would be termed alkaline, or saline.

The Salton Basin has been the object of some special studies by the members of the staff and co-operators of the Desert Laboratory, and some of the results obtained are of great interest. This basin lies in Southern California and partly in Mexico, and has a total area of about 5000 square miles, of which 2200 square miles are below mean tide-level, the lowermost part being 284 feet below sea-level. I was so fortunate as to have visited the bottom of this basin in 1903, and made an examination of the lower part, in which a great salt deposit had been formed, and the vegetation was chiefly of the halophytic types of the sea-shore capable of existence in such places. The delta of the Colorado River forms the south-eastern wall of the basin, and the presence of many old beach and strand lines show that the waters of the river have filled the basin to varying depths on many different occasions. The faulty construction of an irrigation canal on the Mexican side of the international boundary, allowed the waters of the river to flow into the basin during 1904-1906, making a lake with an area of 500 square miles, and a maximum depth of 85 feet, which of course completely destroyed the desert vegetation of the submerged area. The break in the canal was brought under control in 1906, and as there was every prospect that the lake would again disappear, as it had many times before, plans were made for a study of the return of the desert species to the emerged area. In this work it was realised that the re-vegetation of the tops of the hills, which appeared as sterilized islands, would offer some exceptional opportunities for the study of the dissemination of plants, while it would be possible to get some facts bearing upon the fossilising effects of saline waters upon plant tissues. It should be mentioned that

the fresh waters of the river took up so much salt from the soil of the basin that the total saline content of the water of the lake was one-fourth of one per cent. at first, the chief salt being sodium chloride. Attention was also paid to the formation of beach terraces on the steeper slopes as the waters of the lake receded, since conditions had been set up in old terraces of this kind whereby bands of vegetation were formed that maintained their integrity for hundreds of years.

The islands, or emersed hill-tops, were seen to be sown with the seeds which were floated on the surface of the lake, and some living branches were also cast ashore on them. From seeds there came *Sesuvium*, *Allenrolfea*, *Sueda*, *Rumex*, *Pluchea*, and another composite, a grass and a sedge, while *Typha* and *Prosopis* arrived as floating branches, or root-clumps. In no instance could it be shown that a plant was transported to an island by the exclusive agency of the wind, although the seeds of many species were blown on to the surface of the water in this manner. Much attention was also directed to detecting the probable action of birds in the bringing of plants to the islands, and although gulls, cormorants, and ducks resorted to these places in great numbers, yet in only one instance was it allowable to suppose that a plant, with burr-like seeds, had been carried to a place slightly above the high-water line by one of these birds. It became distinctly noticeable early in the present year, that species which were floated in previous seasons to the beaches and on to the newly appearing islands, no longer appeared in the annual sowings. The only explanation offering itself is, that the saline content of the water of the lake had increased to 72 to 100 per cent., making a concentration probably fatal to the seeds—although this has not yet been tested experimentally. The total evaporation from the surface of the lake is about 80 inches yearly, yet so much fresh water from precipitation and from irrigation systems flows into it, that the actual fall is about 40 inches, and the level is now about 18 feet below that of 1906. It is proposed to continue our studies on various phenomena of the lake, including the soils of the emersed strands, for several years.

The Otero Basin in central New Mexico (United States) has also many features of interest in the present discussion. Geologically, this basin has been formed by a dropped block, and it is about eighty miles long and twenty-five miles wide. The drainage from the enclosing slopes has made a large lake in times past, the old beaches of which are still visible, but now the rainfall, which is less than 25 cm. annually, results only in temporary pools and lakes, which show a bare bed incrustated with salts during the dry seasons. The principal constituent of these is calcium sulphate, which forms coarse crystals on the playas, or lake beds; these are fractured and powdered by the action of the sun and wind, and are carried to the north-eastward into a great system of beautiful dunes of snowy whiteness. These dunes contain much moisture, and support much vegetation, which does not seem to be much affected by its growth in this unusual substratum. It is notable that neither here, nor in the Salton Basin, are more than a half-dozen species found which might be termed endemic, although the environment is highly specialised as to its edaphic characters.

There now remains to be considered the more general desert landscape, that in which the deep valleys between mountains have been filled by material eroded from the cliffs and mountain-sides. The most striking features of such regions are the wind erosion effects, and the abruptness with which the steep slopes of the mountain rise like walls from the gentler slopes of detrital material. In some instances the mountains rise to such height that their moist summits support a vegetation of a distinctly mesophytic character, in which case they form biological islands in the desert. In any case the rainfalls on the higher parts of the mountains, where the condensation is, of course, always greater than in the adjacent lowlands, collect in the canyons and rush down the steep gradients as torrential streams, carrying an immense quantity of material out into long arched slopes leading down from the mountains. These slopes may be from one to eighty miles long, and are known to our Mexican neighbours as *bajadas*, a term which has been adopted to designate them by the workers at the Desert Laboratory, after the proposal of Professor Tolman. In times of great precipitation the stream may flow down the entire length of the bajada which it has formed, and reach the bottoms of the valleys, where the water comes to rest, depositing level floors of finely divided material, in the form of *playas*. At other times the water sinks into the loose material, and may flow in considerable volume beneath the surface. If a rock or clay stratum is encountered, the flow is brought to the surface, making pools or "tanks." The agricultural development of country of this character entails bringing the underflow to the surface by wells, or by sinking concrete dikes in the *bajadas*. It is needless to say that the physical characters of the *bajadas* and *playas* exercise a very important effect on the distribution of the vegetation.

In addition to the mesophytic vegetation which may occur on the mountain tops, it is important to note that many species belonging to the well-water regions of the north temperate zone are to be found along the margins of streams and in flood-plains, constituting in the vicinity of the Desert Laboratory as much as forty or fifty per cent. of the entire flora. If the species which inhabit the dry slopes are examined, it will be found that they may be roughly divided into two classes. In one the shoots are reduced, the branches are short, or are reduced to the shape of short spines, the leaves are extremely small, and the parts exposed to the air are waterproofed in such a manner as to reduce the rate of water loss, while the root-systems are enormously developed, and occupy a mass of soil that has the general form of a hemispherical basin sunk in the ground. The most striking feature of such forms, however, is one not visible to the eye; this is the high concentration of the sap, which was beautifully demonstrated by Professor Fitting in his notable work on the plants of the Sahara at Biskra. Here he found that the sap of some of these spinose forms was capable of setting up a pressure of over a hundred atmospheres. These plants seem capable of absorbing water from soils containing very small proportions of moisture, and in this connection it may be stated that they are very difficult to transplant; the root-system seems to be very delicately adjusted to the

high-pressure absorbing organs and to the soil-particles, around which the film of hygroscopic water is very thin, and this adjustment is not easily made. With regard to the origination of these forms, it is to be pointed out that when species requiring much moisture are grown under arid conditions, shoots and leaves are formed which suggest the changes necessary to produce the spinose forms of the desert.

The second type of plant peculiar to deserts is the succulent, as exemplified by the Cactaceae. The evolutionary development of these forms may be taken to include all the changes necessary for the spinose forms, and in addition, to include still more serious departures from the normal type of land plants. In this type the branches may be entirely lacking, the leaves may appear only as rudiments quickly cast off, and the entire shoot may have the form of a simple upright, cylindrical or globular body. The root-systems of such plants lie immediately beneath the surface of the soil, and extend horizontally over a comparatively large area. By this arrangement, the wetting of the soil by rains is followed by the formation of innumerable rootlets and root-hairs, which rapidly absorb water from the moist soil, and a comparatively large quantity may be taken up in a short time. When the rains cease, the soil dries out, and then the finer absorbing rootlets die, and the succulent stands inert, its roots serving as anchors only until the beginning of the next period of humidity. The sap of such plants differs widely in its composition from that of the spinose forms, as its concentration in various succulents is such that it would not set up a pressure of more than three to twelve atmospheres. The actual amount present, however, is very large; thus, an individual of the tree cactus (*Carnegiea gigantea*, or *Cereus giganteus*) may hold as much as 500 to 1000 gallons. The juice of one of these succulents, *Echinocactus wislizeni*, in the Arizona deserts is so low in mineral content that it may be used as a substitute for water by the traveller, and it is possible to obtain a quart of the cool fluid from the crushed pulp in a few minutes, as I have often demonstrated.

Man and the horse are among the animals least capable of enduring the thirst of the desert. A man requires ten to sixteen pints per day, in the drier season, although he may use less for two or three days at a time; travellers have endured twenty-four hours in the desert without water, but a longer deprivation may produce dementia and hallucinations, ending in death. The water found in desert sources often contains much dissolved matter, and our field experience shows that while a mineral content of $\frac{1}{4}$ per cent. may be used for some time, the limit as regards human consumption is reached at 1 to 3 per cent., where the great amounts taken in with the quantity of water necessary to quench thirst become dangerous.

The horse may use more concentrated solutions, and it requires eight or ten times as much per diem as a man, although it may go two or three days without a drink. The water relations of the wild animals of the desert is a subject which has not been systematically studied. It is known, however, that such animals as deer, peccary, mountain sheep, and many rodents, thrive in localities where water is not procurable, and

their sole supply of moisture must be derived from the plants used as food. Some animals live almost wholly on dry seeds and tissues containing not more than 10 or 15 per cent. of water.

The field work of the Desert Laboratory is carried on by pack trains of horses and mules, by wagons, and recently we have been able to traverse many hundreds of miles of desert in automobiles, carrying instruments, food and water. The south-western deserts of America have been crossed by aeroplanes in 1911, and the military operators in North Africa have demonstrated that this machine is now available for reaching places otherwise inaccessible.

The chief purpose of the present paper has been to point out the extent of the desert areas of the world, and to show some of the physical and biological conditions which prevail in arid regions. A closer study of these will doubtless yield results of value in the general physiology of plants, and in the environic relations of organisms in general.

In addition to the general scientific advance made possible, the knowledge gained should be directly useful in the occupation and colonisation of arid regions now being attempted in many parts of the world.

A VISIT TO PATAGONIA.¹

By W. G. RAE SMITH.

(*With Illustrations.*)

General Character.—Patagonia may be taken as that part of South America situated south of the Rio Negro and the Chilian Province of Valdivia. Of the total area of 322,550 square miles, slightly more than a twentieth part is insular, the remainder forming part of the Continent of South America. West of the Andes lie rugged islands separated from the mainland by channels and fjords formed by the combined action of the waves, winds and glaciers. The chief groups are Chiloe, the Chonos Islands, Wellington Island, Hanover Island and the Madre de Dios and Queen Adelaide Archipelagoes, the last giving protection to steamers for miles on their way along the coast. On the south, Patagonia is bounded for almost four hundred miles by the Straits of Magellan, while on the east, the Atlantic Ocean forms the boundary. The eastern coast presents great contrasts to the west and south, for off it hardly an island is to be found, and the shores are low-lying and even, with few indentations, with the result that good ports are scarce.

¹ The following paper is the result of a visit paid by the author and a companion to the country in 1909. Ship was taken to Punta Arenas, at which town riding and pack horses were obtained for the journey northward. The route followed was *via* Laguna Blanca, the upper waters of the Gallegos, Lakes Argentino, Viedma and Tar to the Chico; thence to Lake Buenos Ayres, from which an eastward route was taken by the rivers Fenix and Deseado to Comodoro Rivadavia on the shores of the gulf of San Jorge.