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Author(s): Godfrey Sykes

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Memory even now recalls the rapt way in which, in the discussion later, he spoke with enthusiasm of the plans for the second year's sledging, the purpose of which was to have been a thorough investigation of all Barrier problems during a long journey across it to the south and east. In fact, he used some such words as these in one sentence: "Ah, when we have finished this Pole business we shall really begin to do some good scientific work." For of all the local features he was most interested in that strange floating plain of wind-swept snow of which, on his return from one cold trip, he said, "Ugh, the Barrier is no place for a Christian gentleman."

The subsequent discussion turned on two principal points in the paper: the cause of the rapid movement of the Barrier, and the nature of the melting effect of the sea-water underneath it.

The suggestion by Dr. Simpson, amplified to a theory by Captain Scott, that the movement might be due to the spreading effect of such a large viscous mass of snow, came in for particular discussion, chiefly by Dr. Wilson, Simpson, Wright, and Nelson; but the general truth of the hypothesis was less in question than the details of the calculations involved, and the Scott theory bids fair to become the basis of future scientific argument on the matter.

The balance of temperature to salinity, and their combined effect on the under surface of the floating mass, was a less definite problem, depending largely on whether there was a circulation of water underneath; but Nelson's data already gathered in McMurdo Sound were called upon, and the matter threshed out to its limits. It was certainly one of the most striking of the lectures given, and the fact that these notes are written entirely from memory three years later perhaps adds weight to that statement.

F. D.

THE RECLAMATION OF A DESERT.*

By GODFREY SYKES.

THE increasing relative importance of the arid portions of the Earth's surface has been the theme of many writers of geographical papers in recent years, and for the modern student of geography the interest in deserts lies in their exploitation rather than their exploration. Desert occupation and reclamation have indeed taken place under local racial or competitive pressure from the very earliest times, but it is only in the light of the modern appraisal and stocktaking of human opportunities and resources that any just appreciation of the prospective value of such regions has been possible, or the importance of eremography as a branch of geography fully realized.

* Map, p. 492.

It has been urged with some reason that mankind will in the end be forced to utilize desert wastes as dwelling-places and industrial centres, thus releasing all more fertile areas for food production; but for the present the reclamation and development of such portions as are available is a more pertinent question, and a record of the progress which is being made in this direction is very desirable. Advances in dry-farming have made feasible the invasion of the edges of semi-arid areas, and it has become economically possible to bring more and more costly works to bear for desert development as land values in adjacent fertile districts have increased. California has furnished many excellent examples of such projects, and none perhaps more striking than the work now being carried out in the Colorado desert. The development has in this case been extremely rapid in spite of many difficulties foreseen and unforeseen; and the reclamation has afforded some interesting examples of the kind of engineering and administrative problems which may confront those who would undertake similar schemes for making two blades of grass grow where but one grew before. The geographical features of the region are somewhat unique and have in a way both helped and retarded development. Political considerations have also exerted a disturbing influence inasmuch as the Mexican boundary-line crosses the district at a critical point, and questions of great urgency have arisen which could only be satisfactorily settled by international understanding and agreement.

The surface relief of California may be broadly characterized as consisting of alternating mountain masses and included valleys or open plains whose axes coincide in general with that of the coast line; but this topographical continuity is interrupted by the transverse system of mountains and lesser ridges which mark the southern termination of the great central valley, culminate in the San Antonio and San Geronio peaks, and then extend in the form of more isolated and smaller ranges across the eastern portion of the State to the banks of the Colorado River. This lessening barrier forms the northern boundary of the great irregular triangle of the Colorado desert, of which the eastern and south-eastern sides are respectively formed by the line of the lower Colorado and the bold escarpment of the San Jacinto Mountains. The main and central portion of the area thus enclosed is in reality the north-western extension of the submarine trough of the Gulf of California, from which it has been separated by the broad alluvial plains of the Colorado delta. Its present form is that of a huge spoon, the deepest point in the bowl being some 280 feet below sea-level.

There is evidence upon every side that the geological changes responsible for the formation of this basin have been very recent ones, important modifications in the conditions therein having doubtless taken place within a period measurable by hundreds rather than thousands of years. The outline map (inset on general map, p. 492) will serve to show the general situation, and it will be seen that the Colorado river has originally emptied into the gulf at such a point and in such a direction as would cause its

heavy load of silt to be deposited as a gradually increasing barrier across the trough, until the tip reached and amalgamated with the slopes of the peninsular mass now represented by the Cocopah Mountains. The dam once formed the basin to the north-west would gradually lose its marine and assume a lacustrine character, dependent for its maintenance as a lake upon the Colorado River, but doubtless subject to great changes of level, or even complete drying up through evaporation, as the various phases of delta building took place. There is abundant collateral evidence that such fluctuations have been frequent. The delta building has progressed well beyond the stage of a mere shutting off of the sea, since the lowest point in the dam is now about 28 feet above mean sea-level and lies close to the foot of the Cocopah Mountain slope. The net result since the final exclusion of the sea has been the deposition of a great prism of rich alluvial matter upon the basin side of the dam and the final diversion of the river towards the Gulf.

As far as our present knowledge goes there is no record of a complete filling of the basin having taken place since it was first approached by the Spaniards in 1540, but the inaccessibility and great aridity of the region were such as to render the acquisition of knowledge concerning the geographical conditions therein a matter of extreme difficulty. Don Juan de Onate reached the Colorado in 1604, Father Kino in 1702, and Font, Garces, and others later in the eighteenth century; and there is good presumptive evidence that some expedition must have passed from Sonora to the Pacific coast during the last quarter of the sixteenth century, leaving traces of its work upon various contemporary maps. For all practical purposes, however, the first real information concerning the Colorado desert was that made available by the publication of the results of the Williamson expedition in 1853 in search of a practicable route for a transcontinental railway. The late Prof. William Phipps Blake accompanied this party as geologist, and his report brought out clearly the leading facts regarding the basin and the dominant part played by the Colorado in its formation.

As emigration to the Pacific coast increased during the sixties and rendered regular mail and passenger facilities necessary, an overland stage service was inaugurated which passed across the western side of the delta towards the infant settlements of San Diego and Los Angeles, and this continued in operation until superseded by the Southern Pacific Railway in 1872. The Blake report and other slowly accumulating data had made it apparent that the region, in spite of its evil reputation for intense heat, desolation, and lack of water, possessed boundless possibilities for agriculture if only the water of the Colorado could be brought into it; and so various schemes were formulated for such development. Lieut. Bergland, of the United States Army, suggested and worked out in some detail in 1875 a plan very similar to the one finally adopted; but most of these earlier schemes merely had in view the admission of water

to the basin for filling the whole portion below sea-level, and trusting to the presence of such a great lake in the midst of the desert for some amelioration of the climatic conditions.

As the modern science of irrigation was developed it was realized that immeasurably greater returns could be obtained by admitting the water under proper control, and utilizing the whole available area for the production of crops. The problems involved were however so great, and transportation and climatic difficulties still so serious, that Californian energy was for many years absorbed in smaller, simpler, and safer schemes; and this one, in spite of its evident possibilities, was allowed to lie dormant.

The Colorado River has not only created but has since their formation been a constant menace to the rich alluvial slopes of the basin. It is a great and powerful stream, with a total drainage area of over 263,000 square miles, its main sources of supply being the western slopes of the continental divide in Wyoming and Colorado. The annual rise is very regular and clearly defined, its peak reaching the delta in the latter part of June, and the water at this season carries a great amount of solid matter in suspension. The average yearly amount of this has been computed as equivalent to a layer 50 feet in thickness and one square mile in area, resulting, of course, in a very rapid up-building of banks and great variations in the level of the river-bed.

It is obvious that the diversion of any portion of a river such as this from the summit of a self-built ridge of soft alluvial matter must present some very serious problems and involve some well-planned and built diversion works if the safety of the lands below is to be adequately assured; but various other issues seem to have so obscured this point as to render the engineers who finally undertook the diversion oblivious to it; and this oversight was in the end nearly responsible for the wreck of the whole enterprise. The gradient of the river through the delta averages about $1\frac{1}{2}$ feet fall to the mile; the country towards the south-west, or diagonally down the delta-cone, has a fall of about $2\frac{1}{2}$ feet per mile, and as the basin itself is approached the fall becomes much greater, about 4 to 5 feet to the mile. Under normal conditions of direct flow into the Gulf of California breaches towards this dangerous slope repaired themselves automatically, since if through a confluence of small overflow drainage channels or other local causes a transiparian flow of any magnitude took place, drift-wood, floating roots and other vegetable matter was carried in that direction and the outlet was soon sealed by this and the muddy water. The comparatively short season of annual flood and the luxuriant growth of vegetation further combined to make such openings generally merely temporary; and for this reason perhaps the danger of a larger breach in the bank, left unclosed at a season of the year when a rising rather than a falling river was to be anticipated, was overlooked.

A chief factor affecting all plans for the basin reclamation was the limitation imposed upon the engineers by the nature and topography of the ground in their selection of a site for the diversion works. The last solid ground to be found upon the west bank is where the lower slopes of a small rocky hill, known locally as Pilot Knob, approach the river. The international boundary line also touches it close below. Pilot Knob, however, stands upon the eastern edge of a low sandy mesa or table-land, which extends some four or five miles farther south and effectually bars the direct route to the basin. Once the south-east corner of this obstruction is passed a natural high-water drainage channel which skirts its southern edge is encountered, and this forms a direct water-way to the valley. The use of the bed of this occasional stream, known as the Alamo river, had formed the basis of the Bergland plan, and was, in fact, the only feasible one. The difficulty lay in the connecting length of canal between Pilot Knob and the Alamo, restricted as it must be for a distance of nearly five miles to the narrow strip of alluvial ground between the mesa edge and the river, with only approximately the same possible fall as the latter. It was feared from the first that this portion might cause trouble through silting up, and this fear was soon amply justified.

A company having been formed, a cutting was made through the river bank in the spring of 1900, and this was furnished with a temporary wooden head-gate to serve until the proposed steel and concrete structure could be placed upon the selected site. A junction was made soon afterwards with the upper part of the Alamo channel, and the latter was dredged and straightened where necessary. The selection of the Pilot Knob gate-site brought this structure upon United States soil, and this was deemed to be important from a legal point of view, although a total distance of some 46 miles of canal and canalized channel must be traversed by the water around the base of the obstructing mesa before it again entered United States territory. Another diversion gate was placed in the Alamo near the basin rim to control and check the flow before admitting it to the distributing channels. The water reached the edge of the basin in June, 1901, and the preparation and irrigation of the adjacent land began almost at once.

A strenuous advertising campaign had been initiated by the development company for the purpose of attracting settlers, and this, together with the evident possibilities of the basin, was beginning to draw them there in large numbers. A short trial sufficed to demonstrate how potent the natural silting and sealing process of the heavily-charged water of the Colorado was likely to prove in obstructing the intake canal. The settlers were entirely dependent upon this water for their domestic as well as their farming needs, and in such an arid climate the question of keeping them supplied became an extremely serious and urgent one. Dredging had soon proved to be entirely inadequate to keep up with the

growing demand for water, and so before the summer of 1904 two successive cuts had been made between the river and the canal in efforts to reach the latter below the heaviest of the silt deposit. This was supplemented by placing a waste gate about 8 miles down the canal, in order that this length might be thoroughly flushed during the seasons of summer flood, and the deposit carried out through another natural drainage channel lower down the delta. All proved to be unavailing, however, and trouble was again caused by a partial stoppage in the almost level canal and simultaneous shifting of the river channel; so the more desperate expedient was adopted of making a direct cut 6 feet in width from the river to the head of the Alamo, and thus eliminating the intake canal entirely. This was towards the end of 1904, and under normal conditions no rise in the river was to be anticipated until the following April, by which time it was planned to have this dangerous opening properly protected by head gates. Heavy and unusual winter rains in the upper portion of the Gila basin, however, caused a tremendous quantity of flood water to strike this new opening early in 1905, and it was quickly realized that instead of the usual silting-up taking place, the balance had been turned, and the river was now deserting its own channel and entering the direct downward one of the Alamo in ever-increasing quantity.

Desperate attempts were made to conquer the new danger, which threatened to involve in absolute ruin the whole valley, with its rapidly increasing population and wealth. All agricultural development was taking place below sea-level, and if the river were allowed to flow into the basin unchecked there seemed to be no possibility of stopping the rise of the water until it overtopped the natural delta dam, and then by the slow stages of upbuilding was once more diverted towards the gulf, or until a balance was struck between the incoming flow and the loss through evaporation. Four separate attempts were, therefore, made between March and December, 1905, to check the current; but each ended in failure and the breach continued to increase in breadth and depth.

In 1906 a better-planned and more determined effort was made by opening quarries; weaving and laying an immense brush and wire mattress upon the bottom of the opening, which had now increased in width to about 600 feet; pegging this flexible structure down with piling, upon which a temporary railway was carried from shore to shore; and shooting great quantities of the ready quarried rock down upon the mat foundation to form a dam. This plan at length proved successful, and the errant river was once more diverted into its proper channel towards the gulf about the middle of October.

In the meanwhile the troublesome 4 miles of canal had been greatly deepened and enlarged and a permanent and substantial steel and concrete headgate placed at the intake. Success seemed assured. But another

"TEAVETTINE POINT," SHOWING WATER-LEVEL OF FORMER LAKE; SPUR OF SANTA ROSA MOUNTAINS IN THE DISTANCE.

(Photo by Dr. D. T. MacDougal.)

THE ALAMO RIVER NEAR HOLTVILLE DEEPENED OVER 30 FEET BY THE INBREAK
OF THE COLORADO, 1905-07.

GENERAL CHARACTER OF UNIMPROVED SANDY AREAS IN THE BASIN.

flood came down from the Gila in the beginning of December, and within twenty-four hours the embankment at the south end of the newly completed dam had been undermined and the river was again flowing towards the basin.

The population of the various prosperous settlements in the valley was now well over 10,000, and it was realized that if these communities were to be saved from total destruction by flood the efforts at closure must be made upon a truly heroic scale, far beyond the resources of the Development Company. Appeals were made to the Federal Government for aid, but it was impossible for the Washington authorities to do anything without due authorization from Congress and an arrangement with Mexico, since the cut between the river and the Alamo had been made upon Mexican territory several miles below the border, under an agreement between the Development Company and a subsidiary Mexican Company. Mexico itself was not vitally interested in making any outlay for the redirection of the river, as all the damage was being done within the United States. In the basin events were happening quickly. A great lake had already been formed in the deepest part of the Salton Sink which was growing rapidly; the channels of the generally intermittent streams down the delta slope were being deepened and enlarged; distribution canals breached and rendered useless; and over 40 miles of the main line of the Southern Pacific railroad had been invaded by the fast rising water. This company was deeply involved financially in the development and colonization scheme, and its equipment and engineering staff had already been used in the temporarily successful attempt at the closure of the breach during the previous autumn. So in consequence of the extreme urgency of the situation and at the personal request of President Roosevelt it again undertook the task, and plans and preparations were promptly made to complete the work before the arrival of the forthcoming summer flood. The proposals as outlined were truly revolutionary in character. No fascines or mats were to be used, reliance being wholly placed in the ability of the well-organized engineering force to construct lines of trestles across the new and rapidly enlarging break, and from there shoot broken stone down upon the soft and almost soluble bottom with sufficient rapidity and in large enough quantity to control and shut off the water. The fight for supremacy proved to be an arduous one. Work was begun on December 20, and the task of handling the heavy piling demanded by the contemplated loading of the trestles, and in the swiftly running water, which had attained a maximum depth of nearly 40 feet, was pushed forward as rapidly as possible.

Two independent but parallel lines were to be thrown across, each about 1100 feet in length; but before this could be accomplished three separate floods had come down the Colorado and had carried away portions of the nearly finished track aggregating over 1800 feet in length. Hundreds of car-loads of rock had been quarried in the meanwhile and

sidetracked close at hand in readiness for the final effort. One track was at length completed from shore to shore, on January 27, 1907, and at five o'clock the same evening the work of making the dam began. Before daylight the next morning 145 great car-loads of rock, totalling over 6600 cubic yards, had been thrown in and the worst was over. By February 10 the break was closed and the river again following its old channel. Over 55,000 cubic yards of rock were used in actually closing the opening, and much more, together with large quantities of gravel and clay, was deposited upon the upward face before the structure was sufficiently puddled and made water-tight.

The time had been an anxious one for the settlers and railway officials in the valley. Roads and lines of communication had been invaded and rendered impassable; thousands of men were employed in keeping the main line of the Southern Pacific above the rising water and safe from destructive wave action, in spite of numerous further track diversions or "shoo flies"; and work was being rushed in locating and grading for a still greater diversion round the whole threatened region, which would, at all events, place this important transcontinental line out of danger for several years to come. Very serious damage had been done through the cutting backward from the neighbourhood of the new lake of deep cañon-like channels for the two main streams, the Alamo and New River, through which the water was pouring into the basin.

This recessive cutting was very remarkable. The soft alluvial material of which the delta slopes are composed will break down in vertical fragments, and with a loess-like fracture, under the action of running water, when once a breast or face has been formed, and this destructive process was rendering thousands of acres of valuable land absolutely useless for any future agricultural development. The new cañons had reached an aggregate length of some 43 miles and an average breadth of 1000 and depth of 50 feet before the final closure of the great crevasse in the river bank. The town of Calxico upon the United States side of the border line had been seriously threatened, and the twin town of Mexicala upon the Mexican side virtually destroyed. The main flume line across the New River channel had been also destroyed, with the result that the whole region beyond had been deprived of water and, therefore, abandoned. Strangely enough this apparent wholesale destruction has proved to be a most valuable factor in the later development of the region, in providing an adequate drainage system for the irrigated lands; allowing the surplus alkaline matter already in the soil, or brought thereon by the water used in irrigation, to be leached out and carried forward to the natural sump offered by the deepest and salt-impregnated portion of the basin.

During the period of inflow the lake formed in this lower portion had reached a length of some 50 miles, an area of about 450 square miles, and a surface level of about -200 feet; fortunately not reaching much

improved farm land, which as yet mostly lay between sea-level and -150 feet.

The later behaviour of the Colorado in the deltaic region has served to illustrate its condition of unstable equilibrium and to render evident the fact that another serious outbreak of its water down the western side of the delta cone was already inevitable and almost due, from natural causes alone, even without the interference due to the irrigation operations. It was realized that trouble might be experienced in inducing the water to re-occupy the direct channel to the Gulf, as the fast growing vegetation had already invaded and partly obstructed the dry bed, during the time of the diversion into the basin. A careful watch was therefore kept along the western bank, and the United States Government was again asked to safeguard the valuable lands, although the immediate danger seemed to lie in the lower delta and within Mexican territory. Further works were undertaken under a somewhat unmanageable system of dual control; and though much money was spent upon the protective dams and levies there was a lack of decision and promptitude in their construction which resulted in the end in the river taking undisputed possession of the channel which it had elected to follow: that of the Abejas or Bee River, which it still occupies, reaching the Gulf through the Hardy's Colorado. Although this route for the water takes it in reality down the outward or sea slope of the delta cone, it is still so near to the crest as to constitute a menace to the basin. Constant watchfulness has, therefore, been exercised in order to avert danger from this direction, and at the present time the situation may be looked upon as being well in hand.

As soon as the immediate danger from general destruction by flood was past, the development within the basin went on at an accelerated rate, and attention was turned toward the repair and improvement of the distribution system. The circumstances of the heat and general aridity with almost total lack of underground water render the use of canal water necessary all the year round, so that the demand never falls below 25 per cent. of the absolute maximum at any time of year; and this constant but at times relatively small flow, together with the heavily silt-laden water, makes the problem of keeping the main canals and laterals clear a rather serious one. In effect a ditch has to be re-dug about once a year, and so the system has been adopted of digging two parallel and equal channels, using them either alternately or together as circumstances may render necessary; but always with the endeavour to maintain as rapid a flow as possible in one or both in furnishing any required amount of water. The twin system also makes possible any necessary closing of one channel for the purposes of cleaning or repairing, without depriving a district entirely of water.

The once troublesome intake section of the main canal has been so enlarged in cross-section as to materially lessen the speed of the water in passing through, thus forming a settling basin in which a large percentage

of the coarser and heavier solid matter sinks. A fleet of powerful dipper and suction dredges is now kept at work in this portion of the system, and seems to be fully capable of ensuring an adequate flow of water.

Experience has demonstrated that in this district an average water supply of something under three feet per acre of the land under cultivation suffices for all agricultural and urban needs, with a possible total wastage of ten per cent. due to evaporation and seepage before it reaches the consumers. At the present time (June, 1915), the total area under cultivation upon both sides of the international boundary line is about 410,000 acres, and of this total 350,000 acres lie within the United States. The quantity of water furnished in 1914 was about 1,000,000 acre-feet. The present population of the valley is nearly 50,000. The staple crops have been alfalfa (lucerne), barley, and maize, but in the past few years a large and increasing acreage has been devoted to cotton, and this seems destined to prove the most important single crop. Nearly 60,000 bales of excellent long-staple fibre were produced in 1914.

General attention has also been given to the early production of vegetables and fruit, made possible by the climate, and the development of the dairy and feeding industries have also been very important. The two deeply eroded channels of the New River and Alamo divide the region into three main irrigation districts, supplied with water through four main distribution canals: one west of New River, one between the New and Alamo rivers, and two to the east of the latter. Of these two one is a new, so-called "high-line" canal, which follows pretty nearly the sea-level contour along the north-east margin of the basin.

A branch line from the Southern Pacific Railway was carried through the centre or interfluvial district in 1904, and along this line the principal towns have grown up. El Centro, the county seat of Imperial County, has now a population of about 6500, and is the most important of these.

Political upheaval and revolution in Mexico still exist as an obstacle to any satisfactory and effective international agreement over the conservation and use of the Colorado water in the basin and delta, but at the present time a working plan is in operation whereby matters upon the Mexican side of the border are looked after by the affiliated Mexican Company, and minor Mexican officials who may be temporarily in control are placated by various means. In the meanwhile, however, a long projected, much needed, and partially built railway, which will pass through a portion of Mexican territory in reaching the port of San Diego, has been greatly hampered and delayed by the uncertainty of any adequate protection for the Mexican section and difficulty of arranging for financial support under the present chaotic conditions. This alternative route to the coast will, when completed, doubtless prove to be one of the most important factors in the future agricultural and commercial

development of the valley, since it will materially cheapen and expedite communication by way of the Panama Canal with eastern American and European markets.

A still shorter and more direct outlet by way of the Gulf of California, seems for the present to be entirely out of the question; partly on account of the Mexican troubles, but still more so from the total lack of any port facilities or even available harbour sites in the upper portion of the Gulf, which has little-known but most unpromising physical features for any such development: great tides, with accompanying strong currents, shoals, and shifting channels; and generally low alluvial shores, subject at times to heavy inundations.*

MR. STEFÁNSSON'S EXPEDITION.

IN the October number of the *Journal*, p. 316, we gave a summary of Mr. Stefánsson's doings as recorded in his despatch to the *Daily Chronicle*, from the time of his separation from the last supporting party on his northern sledge journey of 1914, down to his return to Herschel Island near the mouth of the Mackenzie towards the end of August, 1915. The narrative covered two separate undertakings—the hazardous march of 700 miles over the ice, first north, then east and south-east to the west coast of Banks Island in 1914; and the spring expedition of the present year up the west coast of Banks and Prince Patrick Islands to the new land further north, together with the return by way of Melville Island. Some further items of news have since come to hand, adding a few details to the previous accounts, and briefly outlining Mr. Stefánsson's plans for the further prosecution of his work. A letter from the explorer, written from Banks Island on the return from this year's trip, has been received at the Society, and may here be given in full though it refers only to a part of the whole undertaking, and this merely in summary.† It runs—

“ Bay of Mercy, Banks Island, July 19, 1915.

“ We are camped here for a few days near McClure's wintering place to rate our watches. It will then take us some twenty days to walk south to our base at Kellett, which will finish our spring journey. We left the home camp February 21, so the trip is already a long one in point of time. In spite of some accidents near the beginning it would also have been a pretty good one in mileage but for the strong

* The writer is greatly indebted, for data concerning this work and the engineering development in the valley, to Mr. H. T. Cory, M.A.M.SOC.C.E., who superintended the successful operations for closing the breach in the banks of the Colorado River.

† Possibly an earlier letter may have been despatched, and have failed to reach us.

Map to illustrate a paper
on the
Reclamation of the
COLORADO DESERT

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