miting factor for assimilation. On the other hand, owing to the specialised character of the typical shade species in respect to this process by which assimilation attains its optimum in low intensities of light (cf. SALISBURY, E. J. The effects of coppicing as illustrated by the woods of Hertfordshire. Trans. Herts Nat. His. Soc. Vol. XVIII, pages 1 to 21, 1924 and literature there cited) when the shade is removed, as when a wood is felled or the undergrowth coppiced, the photophilous marginal species will alone be able to take full advantage of the high CO_2 output from the soil and these flourish at the expense of the specialised shade flora. Thus in exploited woods there is a constant natural change in the structure of the herbaceous vegetation consequent upon the artificial change imposed by man on the upper layers. In natural conditions the same ebb and flow takes place in relation to light gaps caused by the death of the dominant trees.

VI.

A cycle of the salton sea

By D. T. MAC DOUGAL, Tucson (Arizona)

Mit einer Kartenskizze und einer Tafel

Eingegangen 14. Februar 1925

Twenty-one years ago (February 1904) a party, including Mr. GODFREY SYKES, Professor R. H. FORBES, now Chief Agricultural Engineer for the Compagnie Générale des Colonies (France), who since 1922 has been engaged in a study of the agricultural possibilities of the Niger in the region near Timbuktu, and myself, left Yuma in a specially constructed open boat for the purpose of learning something of the course of the Colorado River in the lower part of the delta and to determine the general character of the vegetation of the alluvial land and of the desert shores of the Gulf of California.

We eventually reached Bay San Felipe on the western shore of the Gulf and were rewarded by many things of interest to the botanist and the geographer.

The expedition left Yuma at midday and camp for the night was made on the right (western) bank a short distance beyond the point where the international boundary line starts toward the Pacific.

By a brief scramble through a jungle of arrowweed and mesquite we were able to inspect the intake of a canal leading a small amount of water out of the river to the westward. The headworks of an irrigation canal to carry water to a tract of land 50 or 60 miles to the westward north of the boundary in the United States had been left high and dry by the low river, and this short cut had been made to lead water into the conduit lower down. This emergency measure carried out in the previous autumn was the source and beginning of some vivid history in engineering and agricultural development during the following decade.

A tract of land, which became known as "Imperial Valley," near the southern end of the spoon-shaped depression, known as Cahuilla basin, 185 miles in length, the bottom of which is variously given as 265 to 312 feet below sea-level according to the reference used, was designed to be irrigated by the water brought from the river.

The basin was originally a trough opening into the Gulf, but the delta deposits, rising to about 30 feet above sea-level, had cut it off. At this time the Salton (from Saltern) sink occupied a few square miles of the bottom of the basin and the remainder of the area (2200 square miles) bore a sparse xerophytic and halophytic vegetation.

A situation such as that suggested would imply that this bowl may have been dried up and variously and partially filled with water from the sea and the river as the blocking off progressed. In the last few hundred years, however, such filling of the basin must have been almost wholly from the river as the salt deposit approximates that of condensed river water rather than sea-water.

From my own work it has been shown that the depression may have been entirely filled about four centuries ago. Numerous records of partial flooding of the basin since 1840 are available.

As our party sat about the campfire near the emergency intake the hazards entailed in leading the water of a river through an uncontrolled cut in an alluvial bank were vividly recalled, as among us we had seen something of the great deltas of the world. The history of the region since that time has amply justified our doubts as to the wisdom of the engineering practice noted.

A second party, including Mr. SYKES and myself of the first company, passed down the river in flood in 1905 and saw a great turbid flood rolling away to the southwestward through a wide channel, and this flow continued and increased until a lake with an area of 450 square miles and a maximum depth of over 80 feet was formed.

At this time the inflow was stopped, February 1907, and the first exploring party from the Desert Laboratory was afloat on the surface in a wooden boat, and a circumnavigation of the flooded area was made, chiefly for the purpose of tracing the shores and to obtain information upon which systematic observations on the history of the lake and its effect on the surrounding desert vegetation might be made.

The lake at its maximum level contained about 0.3 p. ct. of dissolved solids. Seepage and evaporation reduced the level about 42 inches in 1907, so that a beach more than a mile wide was bared on the gentler slopes, while it was but a few feet wide on the steeper shores. There thus gradually emerged during the year a vast oval strip of moist beach, with a total length of over a hundred miles, on the desert slopes of the basin. The pioneer species on the beach came down the desert streamways on the accasional run-off, were stranded from the lake to which they had been brought by the incoming water of the Colorado River, or were wind-borne from various sources.[1]

At the beginning of the second year the salts in the water amounted to 460 parts in 100,000, as compared with 330 at the highest level. The beach laid bare in this second year was moisten-

[1] MAC DOUGAL, D. T. and collaborators, The Salton Sea. Publ. 193. CARNEGIE Inst. of Washington. 1914. The Salton Sea. Amer. Journ. of Science. 4th Series, Vol. 39. 1915. pp. 231—250. A Decade of the Salton Sea. Geogr. Rev. *3*. 457—473. 1917.

ed with a more saline solution, and consequently some of the plants appearing on the uppermost beach were missing. The increasing salinity was such that by 1916 but 5 species of halophytes appeared on the beaches, the water at this time carrying 1,647 parts of salt per 100,000.

Following the stabilization of agricultural conditions, the area irrigated was gradually increased to nearly 400,000 acres by 1922, supporting a population of about 60,000 people.

In my earlier publication the possible evaporation at a rate of 110—116 inches yearly, and seepage balanced against the wastage from the irrigation system, was calculated to bring the lake down to an area of 150 square miles. Increase in irrigation led to a revised estimate in 1916 of 200 miles, but the use of water was greater than anticipated so the lake came down to a condition in which it fluctuates about a level of nearly 250 feet below sea-level, with an area of about 250 square miles, which is more than half of its recent maximum.

The evaporation, however, amounts to a layer which may be as much as one-fourth of the total depth of the lake each year, with a resultant increase in the salt content. A recent analysis (June 18, 1923) by Prof. E. B. Working show dissolved salts as follows:

Total solids (at 110°) per 100,000	3,893.81
Ignited at dull red heat	3,765.44
Organic matter and water of hydration	128.37
Sodium, Na	1,239.7
Potassium, K	13.665
Calcium, Ca	68.371
Magnesium, Mg	65.933
Aluminium, Al	0.625
Iron, Fe	0.0363
Chlorine, Cl	1,832.0
Sulphate radicle, SO_4	537.85
Carbonate radicle (total CO_3)	16.86
Fixed CO_3 (not removed by boiling 60 minutes)	12.87
Silicate radicle, SiO_4	2.69
Phosphate radicle, PO_4	0.067
Nitrate radicle, NO_3	0.173

Borate	Present
Lithium	Present
Copper	Trace

The samples from which these results were obtained were taken at the northwestern end of the lake at places farthest away from inflowing fresh water.

Sixty species were included in the plants appearing on the beaches from the beginning of the recession of the lake in 1907 and including the strands laid bare in 1912. The number appearing on the successive beaches decreased with the increasing salinity of the water so that only 12 species were seen on the beach laid bare in 1912. Naturally the halophytes were most persistent. Further decreases were such that only five species — *Atriplex canescens*, *Heliotropium curassavicum*, *Sesuvium sessile*, *Suaeda torreyana*, and *Spirostachys occidentalis* — appeared on the beach laid bare in 1916, when the water held 1672 parts of salts per 100,000 in solution.

Increasing salinity by which the water held 3,400 to 4,200 parts per 100,000 in solution in 1924 had the effect of reducing the strand vegetation to *Spirostachys*, which did not occur within several feet of the water's edge.

The second feature of interest was the fate of the invaders on each successive beach as the water receded and soil moisture lessened. So rapidly did the changes take place that the uppermost beaches had passed completely back to desert conditions within 8 years after being laid bare by the recession of the lake.

The fresh water from the irrigated area flowed down through two channels, the Alamo and New rivers, and a very large amount of silt was brought in by these streams. The alluvial along these streams and their small deltas offer non-saline conditions which supports a rich vegetation similar to that along the Colorado River, including *Salix*, *Populus*, *Typha*, *Prosopis*, etc. (See map).

The International Phytogeographical Excursion spent a day in the basin in September 1913 and were taken to Travertine point, where some of the members inspected the ancient beach lines 42 feet above sea-level and walked down across the recent strands of 1907 to 1913. Professor SCHROETER

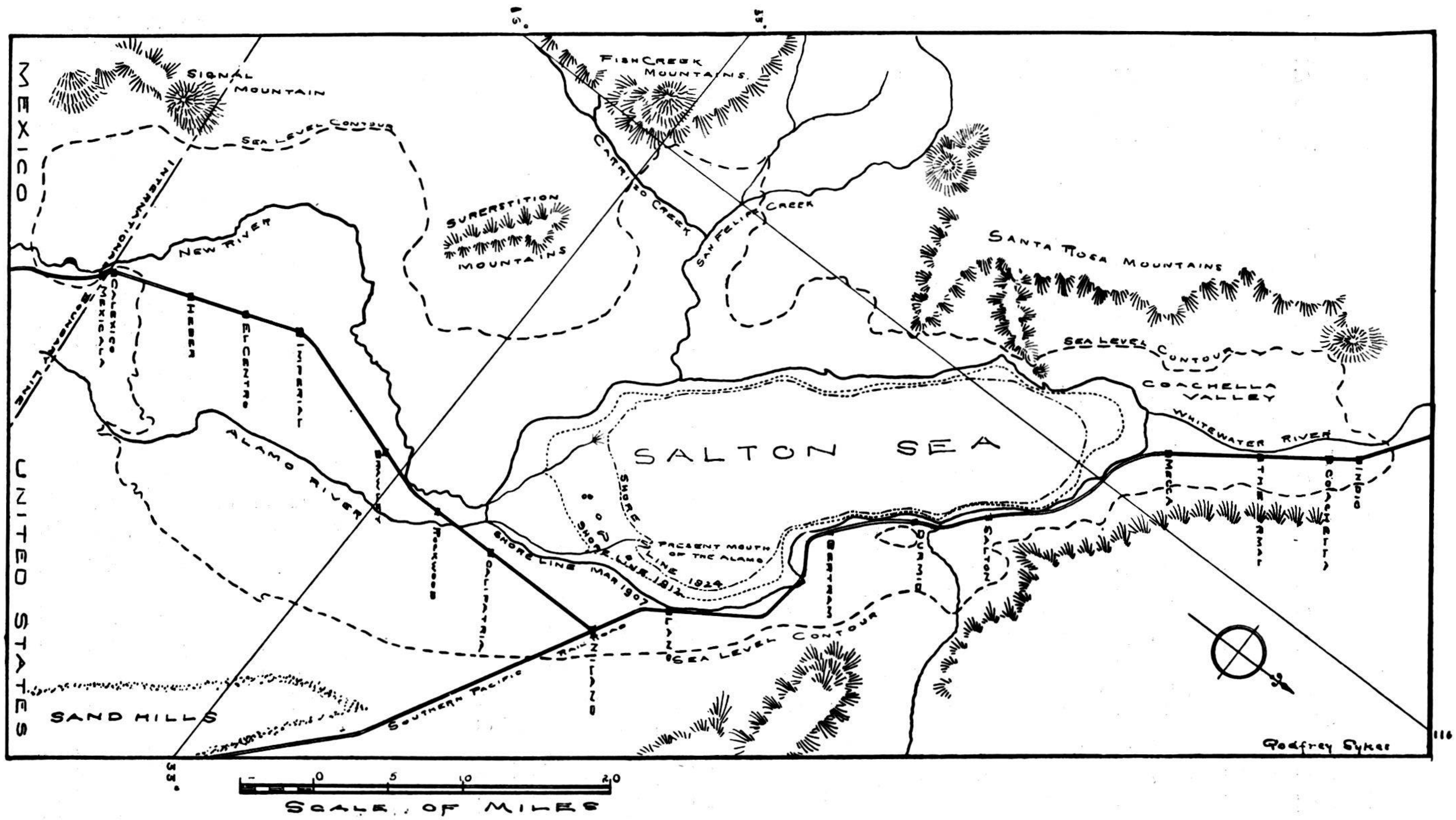


Fig. 1. Sketch map of Salton Sea region, November 1924. Sea-level denoted by heavy broken line. Level of lake March 1907, and rivers, denoted by heavy lines. Levels of lake 1912 and 1924 denoted by broken lines. Original area of lake estimated at 450 to 500 square miles. Present area 250 square miles. Compiled by GODFREY SYKES.

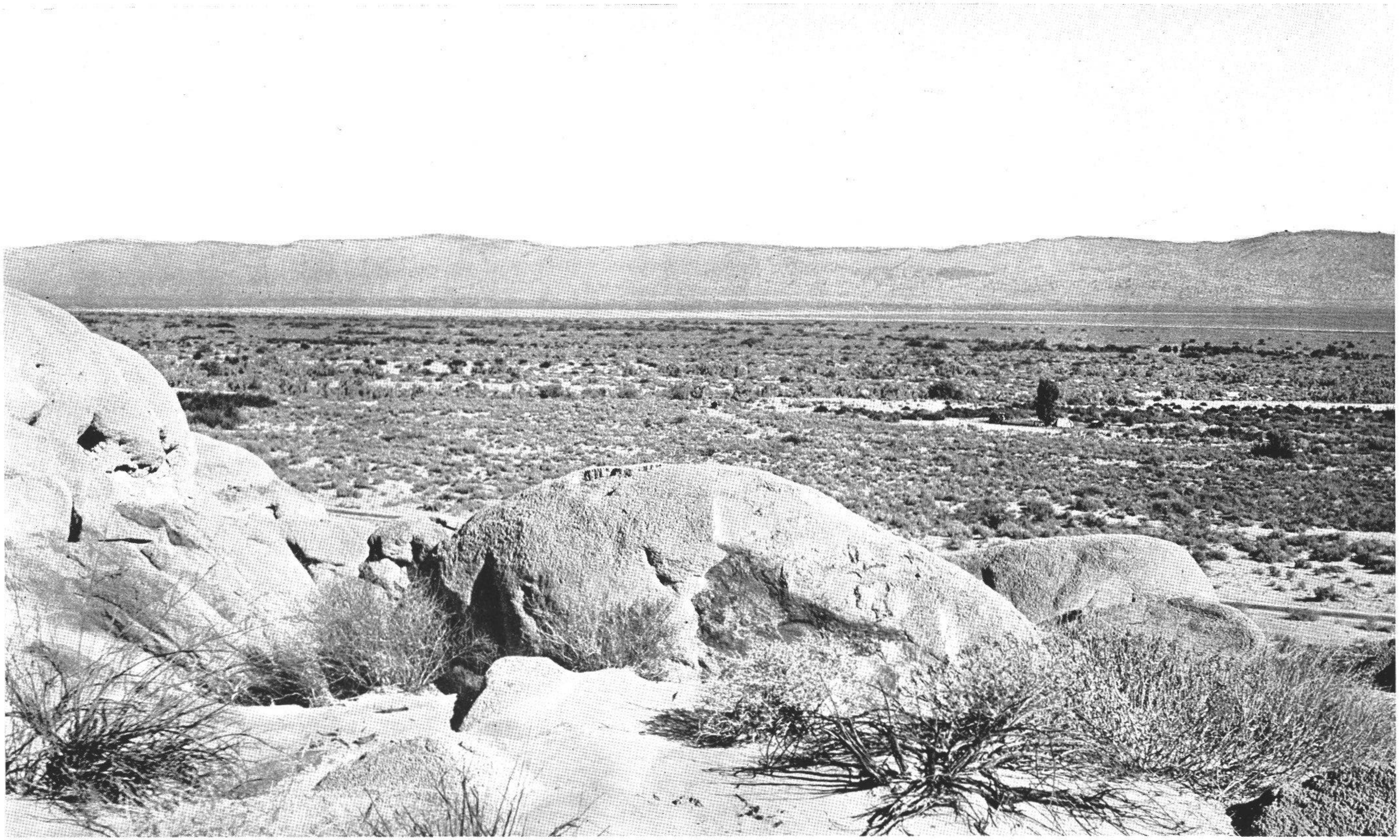
was among those who made this traverse and was a member of a swimming party in the lake. (See Fig. 1).

A number of small hills were covered by the lake at its maximum level, others were only partially submerged. The reoccupation of the isolated sterilized areas offered some phenomena not less interesting than the revegetation of Krakatau, about which so much has been written. The history of the hill which became Cormorant Island may be taken as an example. Its top was repeatedly washed by waves at the maximum level of the lake and all of the xerophytes which comprised the whole of its vegetation were killed. A year after being laid bare one plant each of *Baccharis glutinosa* and *Pluchea sericea* were found, both having plumed seeds and probably were carried across the two miles of water from the mainland by the wind. The further history of the increasing area of the island is shown by the following table:

Revegetation of Cormorant Island

	Number of individuals		
	1908	1913	1916
Atriplex lentiformis	—	5	35
Baccharis glutinosa	1	2	—
Cryptanthe barbigera	—	—	1
Distichlis spicata	—	—	1
Erigeron canadensis	—	—	2
Heliotropium curassavicum	—	2	15
Lactuca aspera	—	2	15
Pluchea sericea	1	2	4
Rumex berlandieri	—	—	1
Sesuvium sessile	—	2	5
Spirostachys occidentalis	—	20	404
Total — 2 species	2	—	—
Total — 6 species	—	33	—
Total — 11 species	—	—	470

It is to be seen that on the last-named date 460 of the 470 individuals present were halophytes, that *Baccharis* had disappeared, and that *Cryptanthe*, *Distichlis* and *Rumex* were represented by but one individual each; *Erigeron* and *Lactuca* by but two. The hill soon returned to its previous desert state.



View from ancient high beach across Salton Basin. Shore line of northwestern end of lake faintly visible in middle of picture. Rendez-vous of International Phytogeographical excursion, September 1913, at trees to right of center in middle distance. Bare strands of lake at right of picture. Granite rocks heavily coated with travertine in foreground; also *Atriplex canescens, Franseria dumosa,* and *Coldenia* growing in the sand. November 1924.

The occurence of plants with seeds not ordinarily wind-borne roused curiosity as to other methods of dissemination and led to some experiments. Seeds so small as those of *Sesuvium*, *Heliotropium* and *Spirostachys* might be lifted by the winds in such manner as to be carried across to the island. *Sesuvium* and *Spirostachys* may float about in saline water for some time without injury. A hitherto unknown possibility in dissemination was found in a number of plants, including *Atriplex lentiformis*, *Baccharis glutinosa*, *Oligomeris glaucescens*, *Juncus cooperi*, *Leptochloa imbricata*, *Prosopis pubescens*, *Pluchea sericea*, *Rumex berlandieri*, *Scirpus paludosus*, *Sesuvium sessile*, *Spirostachys occidentalis*, and *Suaeda torreyana*, the seeds of which, being cast into the water by any agency, sink at first, then sprout and rise to the surface where they may float from five to forty days before deterioration begins. If these seedlings are cast ashore the dependent roots soon penetrate the mud and secure anchorage for the young plants. Observations on material in the lake was confirmed by experiments at the Desert Laboratory. Seeds and water were brought from the lake for the experimental germination, flotation and stranding.

No well-proved case of transportation of seeds by birds was found. The cormorants, pelicans, gulls, and ducks which resorted to the lake in immense numbers came to the lake from other saline shores and hence might have brought only the halophytes which were already around the lake. It is probable that the burr-like fruits of *Cryptanthe* were carried to the mergent Cormorant Island as noted above, and to other beaches, but flotation might be responsible.

Another feature of geological and botanical interest is the formation of travertine, the dissolved calcium being withdrawn from the water by the combined action of a group of algae and bacteria which occupy fixed positions on rocks, stems and other solid objects.

That such deposition takes place at low concentrations of the dissolved salts is indicated by the fact that the travertine formation on the rocks at Travertine Point is several feet in thickness near the ancient high beach level, and that it thins to a few inches forty and fifty feet below this level. (See Fig. 1).

When the analyses of the waters of the lake were followed year by year it was seen that in 1908, when the total dissolved solids amounted to 437 parts per 100,000, the calcium and magnesium had not undergone the same relative concentration as other bases and this material was found as a deposit on submerged stems of *Prosopis*, stones and other objects. Deposition culminated in 1910 when the water contained 846 parts per 100,000, after which it slowed down. Precipitation of calcium and magnesium after this time was at a lessened rate and probably by the reactions which ensue in ocean waters.

It is to be seen that our observations on vegetation around the Salton during the last 21 years are principally concerned with the invasions and successions on emersed beaches, with a total area of 200 square miles. Secondary effects on the slopes above the beaches due chiefly to hemming of drainage were observed. Contrary to common opinion no meteoric or climatic effects were discernible.

The tensions and stresses set up by the continuously changing soil conditions on this great area of strand might be expected to be accompanied by some deviations in the invading plants. Such departures were exhibited by *Aster exilis*, *Prosopis glandulosa*, *Atriplex canescens*, and *Scirpus paludosus*. It has not been possible to test the genetical value of these environic reactions which took the form of altered leaf-structures in the first three species, and of variations in the fruits of *Scirpus*.

These departures serve to focus attention on the endemic species of the basin. *Atriplex saltonensis* Parish, *Sphaeralcea orcutti* Vasey and Rose, *Cryptanthe costata* Brandegee, *Astragalus limatus* Sheldon, *A. aridus* Gray, and *Chamaesyce saltonensis* Millspaugh occur only in the area enclosed by the high beach line, 42 feet above sea-level. *Calandrina ambigua* Howell extends a short distance beyond the ancient beach line.

Two main suppositions as to origin present themselves. These endemic species may have originated outside the basin and having reached the basin, perished on all areas outside its limits; or they may have originated in the basin and not spread beyond it, except in the case of *Calandrina*. The probabilities obviously lie with the last interpretation, and it seems reasonable to conclude that the species in question originated in the basin. This conclusion takes on greater interest when the time element is evaluated.

Some well-marked ranks of plants were found on the ancient strands near the high beach line twenty years ago. (See plate 30, MAC MOUGAL, D. T. The Salton Sea. Publ. 193. CARNEGIE Inst. of Wash. 1914.) These striking and well-marked ranks included *Atriplex canescens*, *Coldenia palmeri*, *Franseri dumosa*, *Hymenochloa salsola*, *Parosela emoryi*, and *Petalonyx thurberi* at that time. When these formations were examined in November 1924, only *Hymenochloa*, *Atriplex* and *Coldenia* remained. The eliminations in these old beach ranks can not be taken to have gone on at a uniform rate. Yet from our recent experience with the lake we are well assured that the six species named above, and other xerophytes, could have been found on the strands on this steeply sloping beach within ten years after being left by the receding waters. The fact that three out of a possible twenty or thirty species have disappeared from the formation within our observational period supports the inference that these beaches were the strands of a full lake within three or four centuries. The traditions of the Indian tribes of the region justify such a conclusion as to the occurrence of a full lake. There is no evidence to support the assumption that the endemic species inhabited or could endure the higher slopes. It is not unreasonable to conclude that the members of this small list originated in the basin and within the comparatively brief time which has elapsed since the lake, then the ancient Blake Sea, or Lake Cahuilla with an area of 2,200 square miles, occupied the basin to the 42-foot level above the sea.

The recent making of the lake coinciding with the establishment of the Desert Laboratory has given its members an opportunity to follow one of the most dramatic and impressing happenings in phytogeography.
