Plant Ecology of Death Valley, California

GEOLOGICAL SURVEY PROFESSIONAL PAPER 509

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By CHARLES B. HUNT

With a section on

DISTRIBUTION OF FUNGI AND ALGAE

By CHARLES B. HUNT *and* L. W. DURRELL

GEOLOGICAL SURVEY PROFESSIONAL PAPER 509

A description of the composition and environment of plants in Death Valley. The plants were mapped in connection with the general geologic mapping; their distribution is closely related to the distribution of the geologic formations. The geology is described more fully in two companion reports

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PLANT ECOLOGY OF DEATH VALLEY, CALIFORNIA

By CHARLES B. HUNT

ABSTRACT

Life zones in Death Valley and on the adjoining mountains range from Lower Sonoran to Boreal. This report describes the composition and environment of stands of Lower Sonoran plants on and along the foot of gravel fans rising from the edge of the bare saltpan in the interior of Death Valley and below sea level, to the top of the gravel fans and base of the adjoining mountains, at altitudes of 1,000 to 1,500 feet.

Death Valley is at the southern edge of the Great Basin and is between it and the Mojave Desert. Altitudes range from about 280 feet below sea level on the bare saltpan to more than 11,000 feet on the summits of adjoining mountains. The floor of the valley is the warmest and driest part of the United States; it receives an average of only 1.65 inches of rain per year. Average temperatures in July exceed 100°F; minimum winter temperatures rarely are low enough to cause freezing. Ground-surface temperatures in summer reach 190°.

Three quite different kinds of soil conditions are represented in the valley. In the central part is the saltpan, an area covering more than 200 square miles where salts are excessive for flowering plants. Around the edge of the saltpan is a belt about a mile wide where the ground is sandy and where ground water is shallow; in general this sandy belt is where the phreatophytes grow. Between this sandy ground and the foot of the mountains are gravel fans which are the habitat for xerophytes.

Perennial surface water in Death Valley is restricted to a few springs on the gravel fans, to some irrigation ditches, and to marshes and a few seeps at the edge of the saltpan. This hydrologic regimen and the kinds of plants resulting from it are the product of the past 2,000 years; during a pluvial period immediately prior to the Christian era, Death Valley was the site of a lake about 30 feet deep. Much more water discharged into Death Valley at that time than now, and the present location of the phreatophytes was wholly submerged.

Nine kinds of phreatophyte plants can be distinguished around the edge of the saltpan, and these are distributed in an orderly way with respect to the salinity of the ground water. Arranged in order of increasing tolerance to the salinity of the ground water these plants are:

Least salt-tolerant:

1. Honey mesquite,
2. Arrowweed and 3. Four-wing saltbush
4. Alkali sacaton grass and 5. Tamarisk
6. Inkweed
7. Saltgrass
8. Rush

Most salt-tolerant:

9. Pickleweed

Total dissolved solids in the ground water in these belts ranges from a minimum of 0.5 percent or less where there is honey mesquite to a maximum of 6 percent where there is pickleweed. Although each species can tolerate substantial ranges in salinity of ground water, nevertheless the belts are distinct from one another.

In addition to these plants around the edge of the saltpan, other less salt-tolerant phreatophytes, characterized by screwbean mesquite and desert baccharis, grow at springs on the gravel fans.

Five groups of xerophytic plants are distinguished on the gravel fans. On the lower part of the fans, in the north part of the area, is a nearly pure stand of dessertholly (*Atriplex hymenelytra*); at the south end of Death Valley, where the lower parts of the fans are sandy, this "holly" is replaced by cattle spinach (*Atriplex polycarpa*).

Above these pure stands of desertholly and cattle spinach is creosotebush (*Larrea tridentata*). On the upper parts of the fans, in the north, is burroweed (*Franseria dumosa*) but southward in Death Valley this is replaced by incienso (*Encelia farinosa*).

Also on the gravel fans, especially along washes where the supply of vadose water is greatest, are less xerophytic plants such as *Bebbia junca*, *Tidestromia oblongifolia*, *Eriogonum inflatum*, and *Boerhaavia annulata*.

None of the plant stands (communities?) is complex and several, for practical purposes, consist of a single species. Among the xerophytes these are the cattle spinach and desertholly. In the saliferous part of the belt of phreatophytes, the pickelweed generally forms pure stands.

These pure stands include the most xeric of the xerophytes and the most salt-tolerant of the phreatophytes. The less xeric and less salt-tolerant plants usually form mixed stands which as a general rule include the more xeric or more salt-tolerant species.

The altitudinal distribution of the life zones undoubtedly reflects the differences in climate at the different altitudes, but the distribution of species within a single life zone, such as the Lower Sonoran, seems to be due to geological controls, especially those affecting the quantity and quality of the water supply.

The phreatophytes are controlled first by the occurrence of shallow ground water, and second by differences in the salinity of that ground water. The xerophytes are controlled first by the absence of a shallow water table and second by the quantity of vadose water in the ground. In Death Valley the occurrence of vadose water is dependent on permeability of the ground, slope of the ground surface, and extent of the catchment area for surface water and for ephemeral ground water.

Although flowering plants extend to the 6 percent brine line, algae extend to about the 8 percent brine line, and fungi extend to the 10 or 12 percent brine line. Bacteria capable of growing in nutrient broth have been obtained to the 15 percent brine line.

The more concentrated brines probably contain chiefly autotrophic bacteria.

Fungi are most abundant in species and in numbers of spores in the zone of xerophytes, that is, on the gravel fans surrounding the saltpan. The numbers, both of spores and of species, are less in the sandy but salty zone—that is, the zone of phreatophytes where ground water is shallow, around the edge of the saltpan. Panward, beyond the limit of flowering plants, the numbers are still less. Although the algae extend beyond the flowering plants and not as far as the fungi, no systematic decrease in population was found across the salinity zones.

INTRODUCTION

In 1893 there was published in the "Contributions from the U.S. National Herbarium" "a report on the botany of the expedition sent out in 1891 by the U.S. Department of Agriculture to make a biological survey of the region of Death Valley, California." The report is by Frederick Vernon Coville (1867–1937), botanist of the expedition, and it is one of the classics in scientific literature—one that contributed greatly to the foundation for the field of study that later came to be known as plant ecology.

Coville not only reported on the systematic botany of the area, but he also considered the problems of why individual species of plants are restricted to certain kinds of habitats. His approach considered both the differences in kind of habitat and the differences in kinds of physiological adaptations to those habitats. His report is a statement of principles and of the reasons behind them.

Coville provided both the basis and the inspiration for my attempt to extend his observations. Not being a botanist, I consider the problem as a study of habitat. But it was feasible to map the plant species in Death Valley (pl. 1) because they so faithfully reflect the geology. To a degree that may surprise many, the local distribution of species in such an arid region corresponds to the distribution of the different geological formations, especially the upper Pleistocene and Recent ones.

The most useful plants for indicating environment, whether of the ground or climate, as Coville pointed out (1893, p. 18), are the woody trees and shrubs, because their root systems and their upper parts are retained throughout the year. He pointed out that although perennial herbs keep their roots, their upper parts die back each winter, and the plants therefore do not experience the aerial environment of the winter season. Annuals record only a single season of growth. My study of the flowering plants has been concerned only with the woody trees and shrubs.

Other growth forms represented in the Death Valley flora though include aquatic forms, lichens and other thallophytic forms, saprophytes, parasites, climbing plants, annual herbs, and perennial herbs. Aquatic plants seem to be restricted to a single species, ditchgrass (*Ruppia maritima*) in the pools at Badwater. Bacteria, algae, and fungi grow even in highly saline ground in the flood plains on the saltpan. As brought out in the section on distribution of the fungi, algae extend to about the 8 percent brine line, fungi to the 10 or 12 percent brine line, and bacteria capable of growing in ordinary nutrient broth to at least the 16 percent brine line. Lichens and mosses extend to below sea level on the shaded north foot of some of the mountains, and lichenoid forms are found on the underside of cobbles and pebbles forming the desert pavements on the gravel fans. A colorful parasite, dodder (*Cuscuta californica*), grows on shrubs north and east of Cottonball Basin. Climbing plants are represented by the desert gourds.

Many persons contributed both ideas and encouragement in connection with this study. Botanists who provided guidance in the form of criticisms and suggestions, both in the field and during the manuscript stage, include John C. Goodlett, of The Johns Hopkins University; Edwin A. Phillips, of Pomona College; Jean Langenheim, then with the University of California; and Farrel A. Branson and Helen Cannon, of the U.S. Geological Survey.

Thomas S. Lovering, of the U.S. Geological Survey, was in the field with me on several occasions and gave valuable encouragement and suggestions, especially in connection with the geochemical aspect of the study. I had assistance too from several chemists of the U.S. Geological Survey: Hubert W. Lakin, Frederick N. Ward, Albert P. Marranzino, and Howard J. McCarthy, in addition to the analysts whose names appear in connection with the tables of chemical analyses. T. W. Robinson, of the U.S. Geological Survey, helped in connection with the hydrological aspects of the study.

Grateful acknowledgment also is made to the staff of the Park Service at Death Valley for their many favors and cooperation during the field work.

FIELD AND LABORATORY METHODS

The plants were mapped in connection with the general geologic mapping. The geological formations were plotted on one set of air photographs, and the plants were plotted on the overlapping set. The boundaries were transferred in the field to the topographic quadrangle maps by using a desk projector; one map was compiled to show the geology and a second was compiled to show the plant communities.

The saltpan was mapped during the winter of 1955–56. Most of the saltpan, of course, is without flowering plants, but the edges of the saltpan provide the habitat for the phreatophytes (fig. 5), and these were mapped in the course of mapping the edges of the saltpan. The gravel fans, the habitat of the xerophytes, were mapped during the winter of 1956–57.

Most of the data on depth to water table, availability of vadose water, chemical composition of the waters and of the soils, and the physical characteristics of the soils and surfaces were obtained in the course of the geological mapping. In the winter of 1957–58 some additional data specifically related to the plants were obtained, such as chemical analyses of plant ashes for comparisons with the geochemistry of the habitats, plant-density estimates, and observations pertaining to plant sequences in different kinds of habitats. Plant-density estimates were made by crude transect methods by making plant counts along paced traverses. Shrubs were counted in a belt estimated to be 20 feet wide and paced for 200 feet. This count multiplied by 10 gave a measure of the density per acre. The method, of course, is suitable only in areas like Death Valley where vegetation is sparse. The advantage of the method is the ease by which large numbers of counts can be made; dependency is on a large number of such estimates rather than on a small number of precise counts.

In March 1958 John R. Stacy, of the U.S. Geological Survey, visited the project for a week to gather background material for illustrating this report. He took photographs of the individual plants, of the stands, and of the ground conditions to be illustrated and made these into a useful and attractive reference volume. Selected pictures then were used by him for making most of the illustrations that accompany this report.

The chemical analyses of plant ash, soil salts, and ground water given in this report (tables 5–23) are semiquantitative and were made in the laboratories of the U.S. Geological Survey. The analyses of the plant ashes are revealing and useful even though this study did not investigate such factors as differences in salt content of the roots, stems, and leaves in a species during resting season and during growing season, or differences in the same species growing on different kinds of ground. I use the term "ash" to include all residue from combustion. This includes inorganic matter incorporated in the plant, any minerals precipitated by the plant, as well as incombustible matter that is strictly organic.

Because the chemical analyses of the soil salts were made primarily in connection with the geochemical study of the saltpan, they represent the acid-soluble rather than the water-soluble fraction. This, of course, greatly limits their usefulness, but they are supplemented by a large number of determinations of total water-soluble salts in the soils. These were made by washing soil samples with an equal volume of water, evaporating the residue, weighing, and reporting results as percentages of soluble salt per volume of liquid extract. A large number of analyses of the ground water were made in connection with the study of the saltpan, and these are given again in this report wherever the analyses could be related to the plants.

The following description of the analytical methods was supplied by H. W. Lakin.

Calcium and magnesium determination. — In the plant-ash and soil-salt samples determination was by the Schwarzenbock method, as follows: sample was added to 1 to 3 hydrochloric acid and the mixture was heated. The cool solution was filtered if necessary, then diluted with water. The determinations were made by a modification of the versene titration of Schwarzenbock. Cal red was used as an indicator for calcium and EBT for magnesium. The soil-salt determinations were by H. M. Nakagawa; plant-ash determinations were by H. E. Crowe and C. E. Thompson. In all water samples (tables 12, 19, 20, 22) except some from springs in Furnace Creek Wash area (table 24) semiquantitative spectrographic methods were used; these determinations were by U. Oda.

Sodium and potassium determination.—Sample was added to 1 to 1 hydrochloric acid; the mixture was digested on a steam bath and diluted with water. The estimation was made with a flame photometer, using a wave length of 594 millimicrons for sodium and 778 millimicrons for potassium. These determinations were by W. A. Bowles.

Chloride determination.—In the 1957 ground-water analyses chloride was determined by turbidimetric method. All other ground-water, soil-salt, and plant-ash samples were analyzed for chloride by the Mohr method, as follows: Sample was added to 5 percent nitric acid. The mixture was heated to the boiling point, cooled, and diluted with water. The solution was then titrated with silver nitrate in the presence of potassium chromate. At the end point the excess silver reacts with the chromate to provide a color indicator when viewed under yellow light. Chloride determinations on the soil-salt samples were by H. M. Nakagawa. Chloride determinations on the 1956 ground-water samples were by H. E. Crowe; determinations on the 1957 samples were by E. F. Cooley. Chloride determinations on plant ash were by H. E. Crowe and C. E. Thompson.

Sulfate determination.—Sample was fused with sodium carbonate, sodium chloride, and potassium nitrate flux and digested with water. The sulfate was estimated by the method of Fritz and Yamamura, in which the cations were removed by an ion-exchange column and the sulfate determined by titration with barium perchlorate, using thorin as an indicator. Sulfate determinations on soil salts and on the ground water were by E. F. Cooley. The determinations made on the soil-salt samples include total sulfate, not just the acid-soluble fraction. Sulfate determinations on plant ash were H. E. Crowe and C. E. Thompson.

Carbonate determination.—Carbonate and bicarbonate were determined only in soil-salt samples. Carbon dioxide was liberated from 0.2 gram sample with 6*N* hydrochloric acid and measured in an apparatus for the gasometric determination of carbon dioxide similar to that described in "Official Methods of Analysis of the Association of Official Agricultural Chemists," 7th ed., 1950, page 118. These determinations were by C. E. Thompson and H. E. Crowe.

Other constituents, listed on the tables as minor constituents, were determined by semiquantitative spectrographic methods, and the determinations were by U. Oda. A. Tennyson Myers, of the U.S. Geological Survey, furnished the following description of this method.

In the semiquantitative spectrographic method 10 mg of the sample is mixed with 20 mg of graphite powder and then burned in a controlled direct-current arc. The spectrum is recorded on film in a 1.5 meter grating spectograph. Selected lines on the film are visually compared with those of standard spectra by means of an enlarging comparator. The standard films are prepared in a similar manner to the sample films, using standard mixtures of materials containing about 33 elements but resembling the unknowns in gross composition. The concentrations of these elements were chosen so that they increase from 1 to 10,000 ppm (1 percent) by a factor of the cube root of 10, or about 1, 2.2, 4.6, 10 ppm and so on. The standards thus form a series having three subdivisions for each order of magnitude. According to whether a spectral line of one element in the sample matches the intensity of a corresponding line of a standard or falls between the intensities of two standards, the estimated concentration is reported using approximate figures from the series: 1, 1.5, 2, 3, 5, 7, 10 ppm and so on.

In addition to the minor constituents reported in the soil-salt samples other elements looked for but not found—except as noted otherwise on the tables—with limits of detection (in ppm) in parentheses are as follows: As (1000), Ag (1), Bi (10), Cd (50), Co (10), Cb (20), In (20), Mo (10), Pb (10), Sb (500), Sc (20), Se (2), Sn (20), and Zn (500).

Whereas the major constituents of the soil salts were determined on an acid-soluble fraction, the minor constituents were determined on the total sample. The analyses of the two groups of constituents therefore are not directly comparable.

In the water analyses the boron and strontium were determined by semiquantitative spectrographic methods, U. Oda, analyst. A maximum of 10 ppm of Ba, Ti, Mn, and Mo was determined in the water samples.

Total dissolved solids and pH of the 1956 water samples were determined in the field by C. B. Hunt; determinations of the 1957 samples were by E. F. Cooley.

GENERAL ECOLOGICAL SETTING OF DEATH VALLEY

Death Valley lies at the southwest edge of the Great Basin adjacent to the Mojave Desert (fig. 1). It is 75 miles east of the highest part of the Sierra Nevada, and about 125 miles west of the Colorado River. The valley is a closed basin, and about 500 square miles of it is below sea level. The central part of the valley is a smooth playa, the saltpan, and is without flowering plants. West of the valley is the Panamint Range which culminates in Telescope Peak at an altitude of 11,049 feet. Broad alluvial fans slope 4 to 6 miles from the foot of the Panamint Range to the edge of the saltpan.

Along the east side of the valley are the Black Mountains and Funeral Mountains. Their summits are about 6,000 feet. At the foot of the Black Mountains the fans are short, but at the foot of the Funeral Mountains the fans are as long as those at the foot of the Panamints (pl. 1).

Upper Sonoran and higher altitude plant zones are represented on the mountains above an altitude of about 4,000 feet, but the plant mapping was extended only to the upper ends of the gravel fans, mostly less than 1,200 feet in altitude. The area mapped is in the Lower Sonoran zone (Jepson, 1951, p. 4), sometimes referred to as Southern Desert shrub (Shantz and Zon, 1924, p. 4–5); the belt of phreatophytes (see fig. 5) is classed as Salt Desert shrub (Shantz and Zon, 1924, p. 24–26).

Death Valley is near the north edge of the Lower Sonoran zone. The Great Basin, north of Death Valley, is mostly higher than 4,000 feet, and its vegetation, as described by Shreve and Wiggins (1951, p. 24),

> * * * is dominated by a small number of species of low shrubs, most of which are either wholly or partly deciduous. It is almost devoid of trees and also of shrubs with large evergreen leaves, and is poor in succulents and semisucculents.

As in Death Valley, the stands of vegetation are very simple in composition or have as much as 95 percent of their stand made up of a single species, chiefly *Atriplex confertifolia*, *Artemisia tridentata*, *A. nova*, *Chrysothamnus puberulus*, and *Eurotia lanata* (Shreve and Wiggins, 1951, p. 24).

In the Mojave Desert, on the other hand, again quoting Shreve and Wiggins (1951, p. 24),

> The . . . vegetation . . . is a very open stand of *Larrea tridentata* and *Franseria dumosa*. On the western edge these

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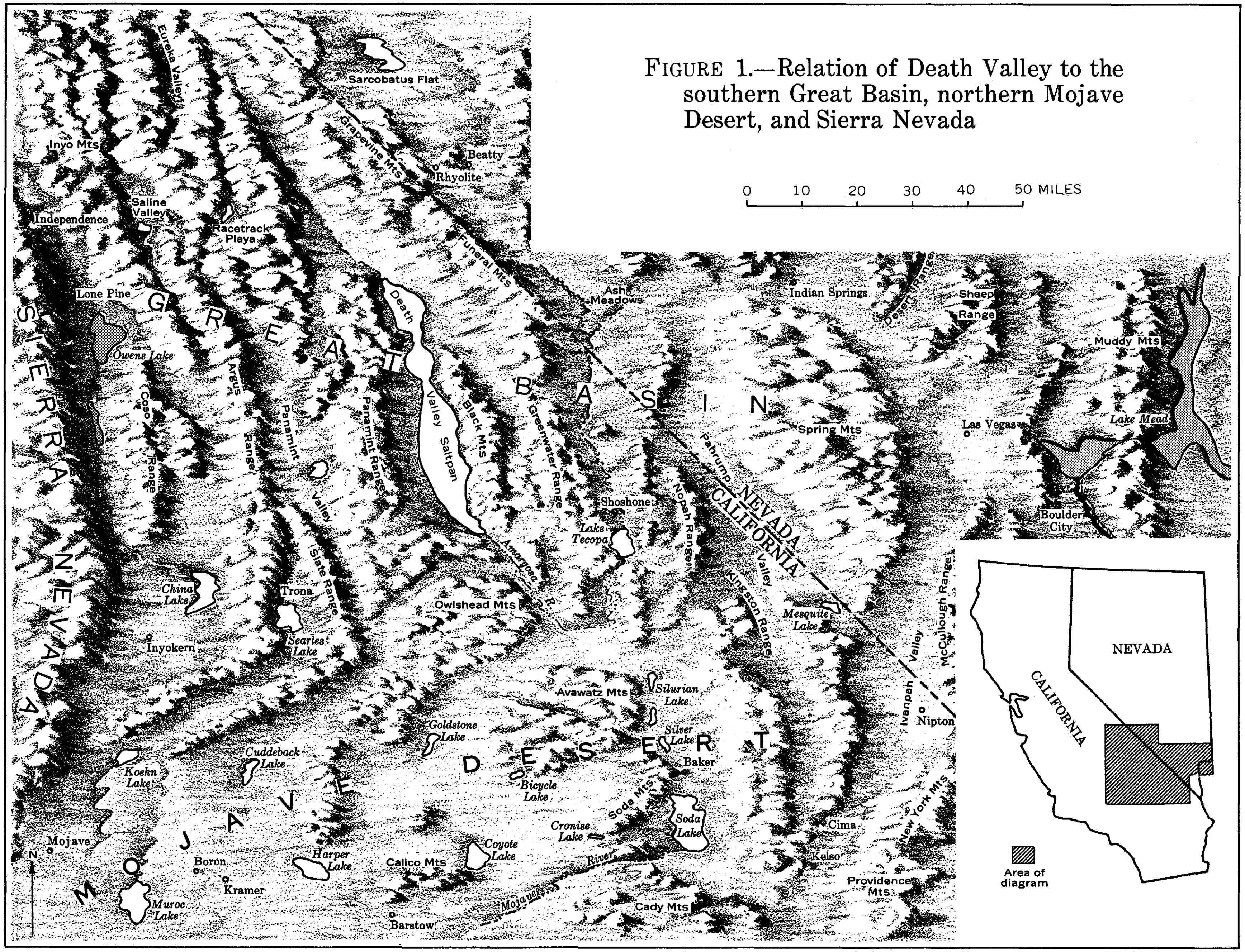

FIGURE 1.—Relation of Death Valley to the southern Great Basin, northern Mojave Desert, and Sierra Nevada

plants are joined, and to some extent replaced, by *Artemisia*, *Chryothamnus*, *Grayia*, *Tetradymia*, *Haplopappus*, and other suffrutescent perennials, and at higher elevations on the north *Coleogyne ramosissima* and *Grayia spinosa* are dominant. The only plants which rise above the low and open shrubbery are *Yucca schidigera* and *Y. brevifolia*, both of which are limited to the higher marginal elevations. Most of the Mojave Desert is very poor in succulents, and only on coarse detrital slopes along the southern and western edges will *Opuntia echinocarpa*, *O. basiliaris*, and *Ferocactus acanthodes* be found in great enough abundance to affect the aspect of the vegetation.

The Sonoran Desert southeast of the Mojave, according to Shreve and Wiggins (1951, p. 25), has a greater number and variety of life forms and more diverse plant communities than does the Great Basin or Mojave Desert or the Chihuahuan Desert east of the continental divide. The Sonoran Desert has, for example, a high percentage of trees which are favored as much by the biseasonal occurrence of rain as by its amount (Shreve and Wiggins, 1951, p. 26). The Mojave and Great Basin Deserts, including Death Valley, are dry except during the winter, and the only arboreal form growing here is *Yucca brevifolia;* even this is lacking in the area shown on plate 1. In this part of Death Valley the principal plants are those that characterize the Mojave Desert. Xerophytes grow on the gravel fans and phreatophytes grow along the foot of the fans at the edge of the saltpan (fig. 5).

The general situation of Death Valley with respect to the rest of the Lower Sonoran zone can perhaps be judged by the general range of the creosotebush (*Larrea tridentata*), the characteristic shrub of the Lower Sonoran zone. According to Shreve (1940) creosotebush ranges from below sea level where the annual rainfall is about 1.65 inches (in Death Valley), to 8,600 feet on the Picacho de las Bocas, in Zacatecas, where the rainfall is about 20 inches. Its upper limit in Death Valley (average, about 4,000 feet) coincides approximately with the lower limit of snow. The northern limit and presumably the upper altitudinal limit of the creosotebush almost coincides with the isoclimatic line for a maximum of 6 consecutive days of freezing temperature. The shrub is absent on the Colorado Plateau and in all except the southernmost part of the Great Basin; in these areas the rainfall is comparable to that in the Lower Sonoran zone, but temperatures average very much lower.

CLIMATE

Death Valley is the warmest and driest part of the United States. In the part of the valley where the vegetation has been mapped (pl. 1) summers are very hot, with air temperatures as high as 134°F. Winters are mild. On the high parts of the gravel fans frost may occur a few times each year, but at lower altitudes freezing temperatures are rare; even in the coldest month (January) the average minimum temperature is only 37°F, and temperatures as high as 85°F have been recorded. Average temperature in July is more than 100°F (U.S. Weather Bureau, 1932, 1935). Death Valley plants must be adapted to withstand very high temperatures.

As a factor affecting distribution of plants, temperature of the soil is as important as the temperature of the air. To obtain an estimate of the order of magnitude of ground temperatures, maximum recording thermometers were set at various places on the gravel fans and at the edge of the saltpan. The results obtained in 1957 are given in table 1. The observations were repeated during the summer of 1958 but on different kinds of ground. Temperature ranges comparable to those observed in 1957 were found, but a higher maximum, 190°F, was obtained on the surface of massive gypsum at Tule Spring. The thermometers were laid horizontally and empressed into the surface to a depth equal to the thickness of the thermometers. They were then covered with a layer of fine sediment approximately 0.1 millimeter thick.

TABLE 1.—*Maximum ground temperatures on some different kinds of ground, April to November 1957*

Description of locality	*Range of maximum temperature (°F)*
1. On north slope on gravel ridge above National Park Service residential area; altitude 325 feet above sea level; ground bare	110–164
2. Flat ground in saliferous sandy silt in saltgrass at mouth of Cow Creek; altitude 250 ft below sea level	144–180
3. Flat ground in smooth sandy silt about 500 ft west of the mouth of Cow Creek; altitude 260 ft below sea level; ground bare	126–174

The lower ground temperature at locality 1 may be due primarily to higher altitude or to a difference in ground texture or exposure. Minor differences in ground texture and exposure can greatly affect the microclimate, as is illustrated by the fact that locality 2 was consistently hotter than locality 3. At locality 3 the thermometer was on bare open ground; at locality 2, the thermometer was placed on open ground 3 inches south of a clump of saltgrass (*Distichlis stricta*). Evidently the saltgrass reflected much heat, as brought out on figure 2.

One thermometer was maintained at locality 2, a second was placed on ground with similar texture but in the open and about a foot from the saltgrass, and a third thermometer was placed in the shade behind the saltgrass. The differences in temperature between the position with, and the position without, reflection is about the same order of magnitude as the difference observed between localities 2 and 3.

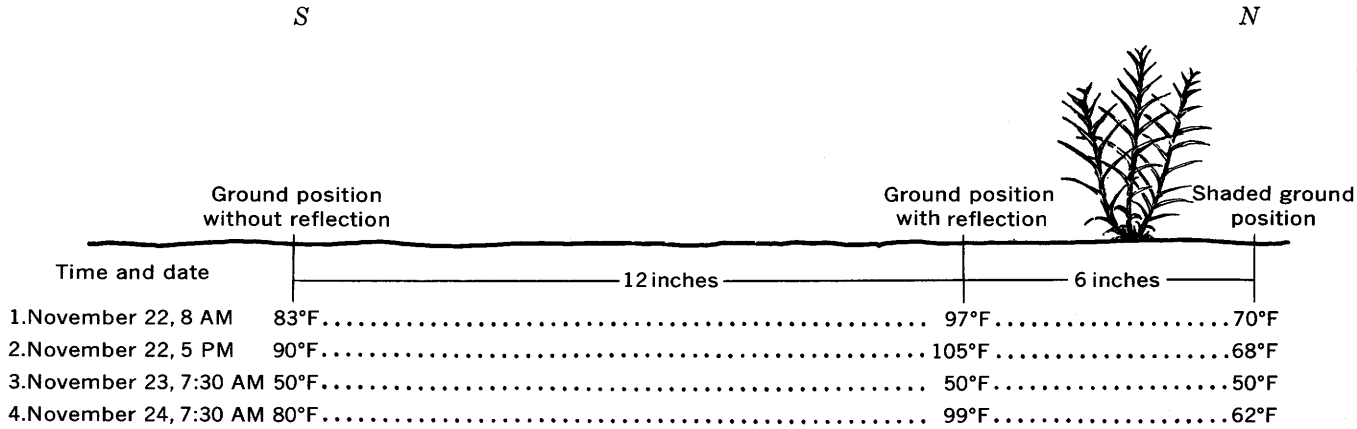

FIGURE 2.—Ground temperatures around a clump of saltgrass. Readings were made November 1957.

But despite the very high ground-surface temperatures, the temperature gradient in the upper layers of the ground is steep, and temperatures equal to the seasonal average are encountered at shallow depths. The gradient is steepest in phreatophytic environments where the capillary fringe is near the surface; there, temperatures equal to the seasonal average may be encountered in a few inches. Table 2 illustrates some random measurements of temperatures at various depths in different kinds of ground.

These data are consistent with the results obtained at Tuscon, Ariz., by Sinclair (1922) who measured the daily and annual temperature range at different depths.

TABLE 2.—*Some differences in temperature during 1956, at various depths in different kinds of ground*

	Date and time	Kind of ground	Temperature (°F)			
			Air at 3 ft altitude	Surface	Subsurface	
					°F	Depth (in.)
1	Noon, Jan. 11	Sandy ground in stand of mesquite (*Prosopis juliflora*).	------	73	70 68 54	3 6 9
2	Noon, Feb. 23	Silty sand in stand of pickleweed (*Allenrolfea occidentalis*).	82	98	63	12
3	10 a.m., Feb. 27	Damp sandy ground in saltgrass (*Distichlis stricta*).	------	84	60	10
4	1 p.m., Feb. 28	Damp sandy ground in stand of mesquite.	77	115	65	6
5	Noon, Feb. 29	Silty ground in stand of arrowweed (*Pluchea sericea*).	74	95	68	4
6	2 p.m., Feb. 29	Bare silty ground in chloride zone.	77	105	70	5
7	1 p.m., March 1	Silty ground in stand of pickleweed.	80	100	68	6
8	Noon, March 6	Bare wet silty ground in flood plains.	77	93	77	2
9	2 p.m., March 20	Bare silty ground in chloride zone.	------	122	72	6
10	11 a.m., March 21	Saliferous sandy ground in saltgrass.	91	129	73	6
11	1:30 p.m., March 21.	Fine pebble pavement in stand of desertholly (*Atriplex hymenelytra*).	95	127	90	4
12	11 a.m., March 30	Bare silty ground in flood plain.	86	122	80	5
13	1 p.m., March 30	Bare silty ground in flood plain.	93	127	77	8
14	1 p.m., April 9	Sandy ground in stand of mesquite.	96	140	86	6

He found the daily range in temperature of the surface layer of soil to be about twice that of the air. He also found that at a depth of about 2 feet there was little daily change in temperature, but there was a few degrees change between winter and summer, and that at about 6 feet in depth the temperature was nearly constant throughout the year.

These data indicate steeper thermal gradients than have been found at some other places. T.S. Lovering (oral communication), at Tintic, Utah, found constant temperatures through the year at a depth of 15 feet. Some measurements in Germany (Geiger, 1957, p. 142–143) indicate that in sand, loam, and humus there is an annual temperature range of 14°C (25°F) at a depth of 3 feet. Thermal gradients on the gravel fans in Death Valley, where ground water is deep, probably approximate the gradient reported by Lovering.

In general, temperatures decrease with increasing altitude. Observations along Furnace Creek indicate that in that topographic situation the decrease is about 5°F for each 1,000 feet of rise in altitude. However, the saltpan provides an exception to the general rule, for temperatures there commonly are 10°F lower than temperatures on the upper parts of the gravel fans—1,000 to 1,500 feet higher. The layer of cold air is about 300 feet thick. It is due partly to cold air draining from the mountains, but also to the natural refrigeration caused by evaporation of water from the saltpan. This layer of cold air extends across the phreatophyte zone and across the lower stands of xerophytes on the gravel fans.

Annual precipitation in Death Valley averages only 1.65 inches at the Weather Bureau stations which are about 175 feet below sea level at National Park Service Headquarters and at Furnace Creek Ranch. To estimate the precipitation gradient between the valley floor and the adjoining mountains, a series of rain gages was set between the valley and Auguerreberry Point in the Panamint Range, west of the area shown on plate 1. Figure 3 illustrates graphically increased precipitation at the higher altitude stations. The data suggest that annual precipitation even in the high part of the Panamint Range (above 10,000 feet) is only about 12–15 inches.

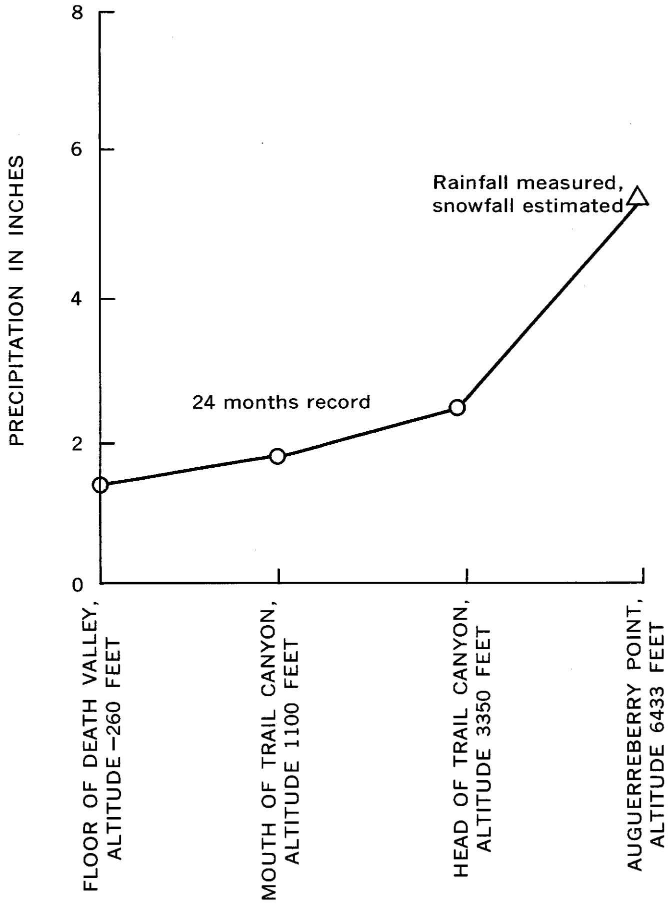

Figure 3.—Differences in precipitation at different altitudes between the floor of Death Valley and Auguerreberry Point as estimated from nonstandard rain gages 1958–60.

Winter rains are likely to be general, the result of regional storms, and they may last a few days. Summer rains are mostly showers or thunderstorms which may develop into cloudbursts. Relative humidity, especially in summer, is low—frequently 5–15 percent.

It has been found (Went and Westergaard, 1949) that the degree of development of spring annuals in Death Valley is a direct function of the amount of precipitation during the winter season. There is a good crop of annuals only when the precipitation is 2 or 3 times the average (fig. 4). (See also Went, 1949.)

Winds in Death Valley are not different from the winds in the surrounding deserts. Much of the year,

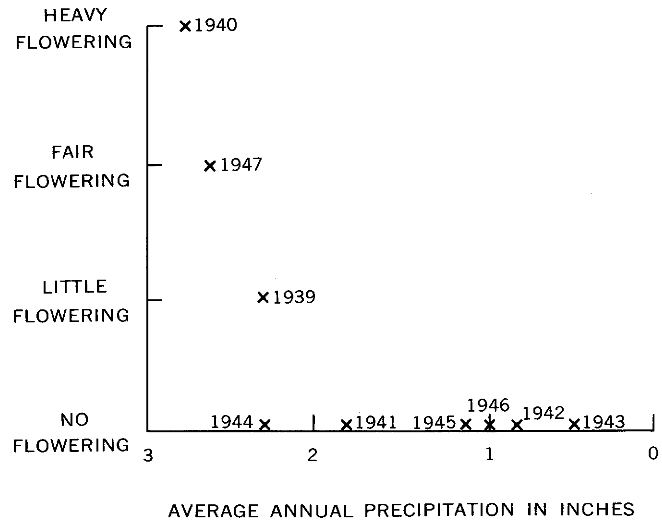

Figure 4.—Relationship between amount of precipitation during winter season (September through February) and degree of development of spring annuals in Death Valley. (Adapted from Went and Westergaard, 1949.)

especially the fall, there are periods of calm when smoke rises vertically, but part of the year, especially late in winter and in spring, strong winds are frequent and may reach gale force (39–46 miles per hour), judging by the breaking of twigs on trees and the difficulty of moving against the wind. The principal effect of air movement on plant growth in Death Valley probably is an increase in rate of evaporation and transpiration.

Random tests to show transpiration by various Death Valley shrubs, using paper stained with cobalt blue, suggest that all the phreatophytes around the edge of the saltpan transpire actively in daytime at temperatures ranging from 50° to 90°F. No tests were made at lower or higher temperatures. Desertholly, after a prolonged dry period when the leaves were pale greenish yellow, gave no indication of transpiration, but after a rain, when the leaves were freshened to a yellowish green, positive tests were obtained. Also, evidence of transpiration was obtained from a desertholly growing in a wash below one of the springs, whereas negative results were obtained from another desertholly nearby, but on the drier bank. At the same location, pygmy cedar *Peucephyllum schotti* showed signs of transpiration on the shady side of the plant but not on the sunny side.

SOILS

Soil conditions in the area shown on plate 1 are of three very different kinds. In the central part of Death Valley is the saltpan, where the salts are excessive for flowering plants (fig. 5). Around the edge of the saltpan is a belt about a mile wide where the ground is sandy, and in general this corresponds to the belt of

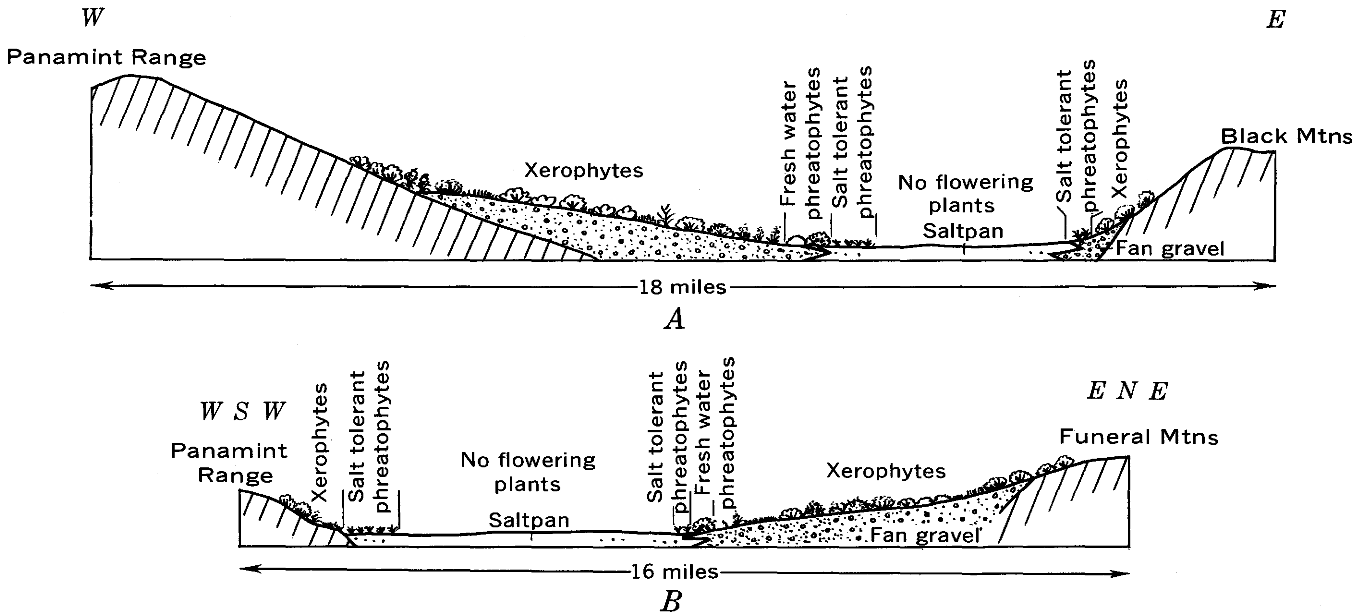

FIGURE 5.—Generalized transects across Death Valley showing distribution of the different kinds of woody plants in Badwater Basin (*A*) and Cottonball Basin (*B*). Xerophytes grow on the gravel fans and extend onto the mountains. Phreatophytes grow at the foot of the fans, where ground water is shallow. Fresh-water phreatophytes grow only on the west side of Badwater Basin and east side of Cottonball Basin, where the gravel fans are long and high. Only salt-tolerant phreatophytes grow where the saltpan is crowded against the foot of the adjoining mountains, as on the east side of Badwater Basin and west side of Cottonball Basin. There are no flowering plants on the saltpan.

shallow ground water where the phreatophytes grow. Between this sandy ground and the foot of the mountains are the highly permeable gravel fans where the water table is deep—the habitat for the xerophytes. Above the fans are the mountains, but mapping of the vegetation was not extended into those parts of the quadrangles.

The sandy soils in the preatophyte zone contain a high percentage of salts which occur as hard layers on or just below the surface and as interstitial salts that produce a porous honeycomblike structure. The soil salts and the salts in the soil water and ground water increase panward. Size analyses of such saliferous soils are of little significance except to document the obvious fact that the clastic sediments become finer panward, that is, from the belt of mesquite to that of the pickleweed. A size analysis of salt-free dune sand in the zone of mesquite is given in table 3. The zoning of the preatophytes parallels both the zoning of the salts and changes in texture of the ground and assuredly reflects the differences in quality of the ground water available for plant growth.

In the belt of xerophytes, on the gravel fans, the soils are stony and coarse textured (table 3). In a general way the gravels become less coarse and the proportion of sand and silt increases down the fans away from the mountains. This difference though is not striking and can hardly be an important factor in the zoning of the xerophytes on the fans because the difference in texture of the gravels under the different species of plants is

TABLE 3.—*Size analyses of soils (upper 3 inches only) in different plant stands*

[Values given in percent]

Plant stand and location	Percent occurrence of particles for indicated sieve size (microns)					
	>4,000	<4,000 >1,000	<1,000 >420	<420 >125	<125 >62	<62
	Gravel	Very coarse sand	Coarse sand	Fine to medium sand	Very fine sand	Silt
Phreatophyte						
Honey mesquite (*Prosopis juliflora*), dune at mouth of Salt Creek	<1	15	30	50	5	<1
Xerophytes on gravel fans						
Cattle spinach (*Atriplex polycarpa*) near mouth of Salt Creek	20	20	13	35	10	2
Do	20	20	15	40	5	<1
Desertholly (*Atriplex hymenelytra*), 0.5 mile south of Beatty Junction	22	18	12	33	10	5
Desertholly, North Side Borax Camp	25	25	15	29	5	1
Creosotebush (*Larrea tridentata*), 1 mile southeast of Beatty Junction	40	23	15	15	5	2
Creosotebush, 2 miles southeast of Beatty Junction	35	15	9	35	5	1
Creosotebush, 0.75 mile south of Salt Springs	30	25	20	20	3	<2
Burroweed (*Franseria dumosa*), south side of wash from Echo Canyon	25	25	20	20	10	<1

little if any greater than the differences that may be found under different individuals of a single species.

Water-soluble salts in the gravels range from about 0.25 percent (by volume of liquid extract (see p. 3)) to about 4.0 percent. The quantity of salt decreases up the fans. The highly saliferous areas are bare. The maximum salts in the gravels supporting vegetation are where there are pure stands of desertholly. At these stands the salt content may be as high as 1 percent (by volume); where the burroweed and incienso grow, the salts are less than 0.25 percent.

The gravel fans represent three quite different kinds of ground. The oldest gravels form elevated surfaces that are covered with smooth desert pavement. These surfaces have small catchment areas and a high rate of runoff, and they generally are bare. Gravels of intermediate age are lower and have a rough stony surface that impedes runoff. The catchment areas for these surfaces are moderately extensive and rate of runoff is slowed; these surfaces almost invariably have stands of widely spaced xerophytes. The youngest gravels, including those along the present washes, have the largest catchment areas and least rate of runoff; these areas have the greatest variety and densest growth of xerophytes, including the less xeric kinds. The distribution of the xerophytes evidently reflects the differences in the quantity of vadose water in the different kinds of ground.

Attempts to estimate the organic matter in the soils were only partly successful, because the presence of hygroscopic salts introduced difficulties in drying samples properly. A large number of samples, however, were tested by heating a gram of the soil for 3 hours at 100°C and then igniting for 1 hour. None of the samples from the xerophyte stands lost as much as 1 percent of weight, and probably some of the loss of weight that was observed can be attributed to loss of hygroscopic water from salts.

When similarly tested for organic matter, samples of soil from under phreatophytes lost somewhat more than 1 percent of their weight. One sample, from near the base of an arrowweed plant (*Pluchea sericea*), lost 1.4 percent weight after drying. This was the maximum weight loss observed, but although the soil tested was brown, apparently because of organic matter, the sample also contained about 2 percent of water-soluble salt. Probably some of the loss of weight is attributable to moisture driven from the salt.

Whatever the correct values, it is clear that the soils in Death Valley have a low content of organic matter. Inasmuch as this valley is a closed basin, one wonders what has become of the carbon that annually is contributed to the ground by the vegetation, sparse as it is. The slight amount of water that falls on the ground or runs across it would seem inadequate to leach the organic matter, but perhaps leaching is facilitated by the extreme desiccation and resulting comminution of the organic fragments. The carbon may be represented in large part by the caliche that cements thick layers of gravel. It would be of interest to investigate the carbon economy of Death Valley.

The very striking relationships between the distribution of the woody plants and the geology led to an attempt to determine if there might be a similar relationship between the geology and the distribution of the microflora. The results of that effort, given in the section on distribution of fungi, (p. 55) show that the microflora does decrease in numbers of individuals and numbers of species as the ground salinity increases. The microflora is sparse in ground containing more than 4 percent of water-soluble salts. It is intermediate in the less saline parts of the phreatophyte zone, and greatest on the salt-free parts of the gravel fans.

HYDROLOGY

Perennial surface water in Death Valley is restricted to a few springs on the gravel fans (Nevares, Travertine, and Texas Springs), to irrigation or water supply ditches at Park Service Headquarters and at Furnace Creek Inn and Ranch, and to marshes and a few seeps in the phreatophyte zone around the edge of the saltpan.

Both the Amargosa River, which discharges into the south end of Death Valley, and Salt Creek which discharges into the north end of the saltpan, are intermittent streams, although the stretch of Salt Creek through the Salt Creek Hills is perennial.

As a consequence of the scarcity of perennial surface water, the only true aquatic plant (hydrophyte) is a species of *Ruppia* which grows in the pools at Badwater.

Marshes are numerous around the edge of the saltpan, and many of them support a growth of plants whose lower parts are submerged but which have stems and upper parts in the air (helophytes). At most of the marshes the water rarely if ever becomes agitated by wind, for the water surface is protected by the plants or by the hummocks of salts that rise above the water surface. At all the marshes the water is shallow—generally less than 6 inches deep although a few small pools in Cottonball Marsh are 3 feet deep. Few marshes have ponds with sufficiently exposed surfaces for the water to become agitated and aerated during windstorms. This may contribute to the scarcity of aquatic plants.

In all the marshes, ponds, and streams the water is clear, and light penetrates to the bottom.

Between the marshes and forming a nearly continuous belt around the edge of the saltpan is a sandy zone where the water table is shallow enough to be reached by plant roots. Here grow the phreatophytes (fig. 5), plants that live on dry ground but whose roots extend to the permanent water table (fig. 6).

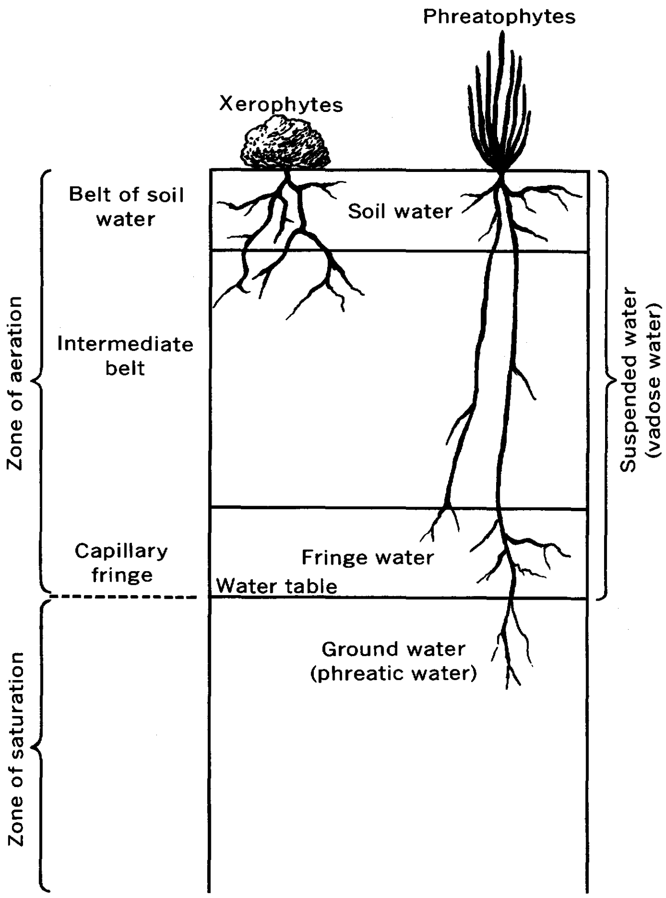

Figure 6.—Diagram illustrating occurrence and nomenclature of subsurface water (adapted from Meinzer, 1923, p. 23) available for plant growth. Phreatophytes have their roots in the phreatic water or fringe water; xerophyte roots do not reach to the top of the capillary fringe.

From the edge of the saltpan to the foot of the mountains rise the gravel fans, which is the belt of xerophytes (fig. 5). Although the xerophyte roots may be extensive, they do not extend to the water table, which is scores or hundreds of feet deep. The only water available for plant growth is that supplied directly by the infrequent rains, by dew, and by vadose water in the ground (fig. 6). Possibly some is obtained directly from water vapor in the atmosphere or in the ground. The dependence of the xerophytes on the uncertain rainfall is emphasized by the fact that some of these plants flower after warm rains regardless of time of year.

The recharge of this vadose water in part may be due to surface water seeping into the ground, but with so little rainfall it is doubtful if this is the sole or even principal mechanism of recharge, for after all, even if the entire 1½ or 2 inches of annual rain fell during one storm, there would not be enough water to wet the ground as deeply as the roots penetrate. Perhaps most moisture enters the zone of aeration as vapor, either as vapor rising from the water table, or perhaps drawn down from the surface (p. 50).

The availability of water for plant growth on the gravel fans is greatly affected by the topographic situation and by the permeability of the ground. The topographic situation concerns not only slope but also the extent of catchment area from which surface-water runoff may be collected (fig. 7). On the gravel fans, though, there is little difference between north and south slopes; in this environment direction of exposure has not been an important factor in the distribution of perennial xerophytic shrubs.

Ground permeability affects the rates of infiltration or runoff, and inhomogeneities in the ground and on the ground surface affect the recharge of vadose water. Figure 8 illustrates some examples of this.

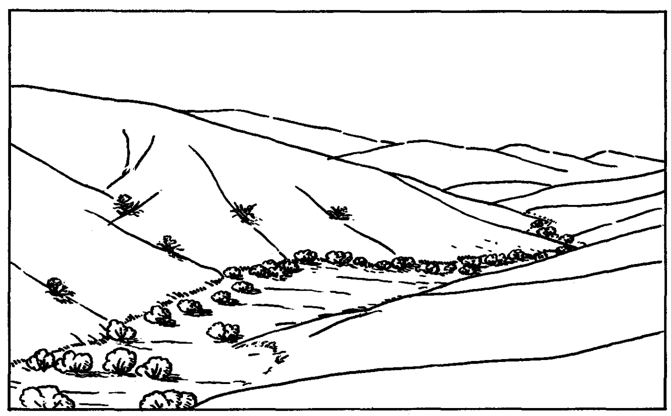

Figure 7.—Example of the control of vegetation due primarily to the topographic situation. Locality is in the lava hills on Artists Drive. Ground permeabilities differ but little between the wash and hillsides, but the hillsides have an excessive rate of runoff and are without vegetation. Small washes on the hillsides have a sparse growth of shrubs (desertholly at this locality) that are dying, probably because the last few years have been dry and the runoff collected in the washes has not been sufficient to maintain the stand. The stand in the main wash (also desertholly) has been maintained, probably because greater runoff is collected there.

GEOLOGIC HISTORY

The geologic history of Death Valley that has directly affected the composition and local distribution of the plants can be considered in four main stages.

The earliest stage we need consider is in late Pleistocene time when Death Valley contained Lake Manly,

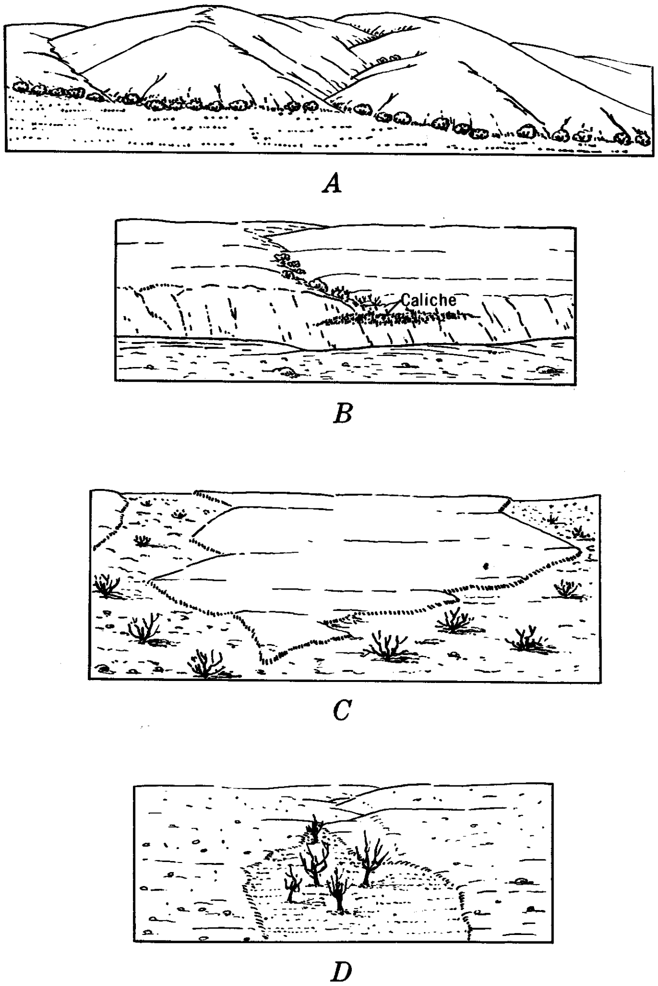

FIGURE 8.—Four common kinds of inhomogeneous ground conditions affecting occurrence of vadose water and plants on gravel fans in Death Valley. *A*, Hills of Tertiary rocks surrounded by fan gravels are mantled by a shallow layer of loose detritus. Runoff is high, partly because of the slope and partly because the ground is impermeable. At the foot of the hills, detritus collected at the break in slope forms permeable ground that receives and holds runoff from the hills. A row of shrubs—desertholly in the example—grow in this detritus. *B*, Old gravel fans have caliche layers firmly cemented with calcium carbonate or other salts, shown as a black pattern. These layers are impermeable and serve to perch an ephemeral water table. *C*, Old gravel fans are mantled by smooth desert pavement, which has a high rate of runoff. The supply of vadose water in such ground is low. The younger gravels lack the smooth pavement and have a low rate of runoff and high rate of infiltration. In these gravels the vadose water is recharged by runoff from the areas of desert pavement as well as by water originating on the young gravel surface. The permeable gravels have stands of perennial shrubs; the pavement areas are bare or have stands of a different and drier type of shrub than do the young gravels. *D*, Some fans that are mantled by desert pavement have shallow depressed areas, a few feet wide and a few inches deep, containing a high percentage of fine-grained sediments, as in this view on Johnson Canyon fan. These depressions are at the lower end of shallow washes. The depressions collect runoff from the pavement areas and, because of their permeability, hold the water better than the surrounding gravels. In the example sketched, the depression has a stand of deserttrumpet (***Eriogonum inflatum***).

which had a maximum depth of about 600 feet. We can safely assume that all vegetation below that level has invaded Death Valley since the lake was there. Moreover, this late Pleistocene lake assuredly was in existence during one of the cold stages of the Pleistocene when high-altitude species extended to lower altitudes than they do today. In humid regions pollen studies have indicated that the alpine timberline was 1,500–2,000 feet lower than it is now (see, for example, Deevey and Flint, 1957); at Gypsum Cave, 150 miles east of Death Valley, plant remains in sloth dung have suggested that the vegetation zones there were 3,000 feet lower than they are now (Laudermilk and Munz, 1934). We may infer from this that the vegetation around the shore of the late Pleistocene lakes was like that now growing at altitudes of about 3,000 feet in Death Valley. There probably was only a narrow belt of plants of the Lower Sonoran zone; the lower edge of the Upper Sonoran zone, now about 4,000 feet in altitude, would have extended down to an altitude of 1,000 feet, that is, to the upper edges of the gravel fans. Higher zones in the mountains would be comparably lower.

The second stage in Death Valley history that is important to the present plant ecology is the interval of time represented by the first half of the Recent, a period that has been referred to as the altithermal (Antevs, 1948). During this time Death Valley was drier than it is now and perhaps warmer, and the Lower Sonoran zone may have extended upward to an altitude of 6,000 feet.

Belts of xerophytes and phreatophytes, in about the position of those shown on figure 5, presumably developed during the altithermal, and much or most of the vegetation comprising those belts may have started then too. Probably the lower altitude xerophytes extended a few hundred feet farther up the fans than they do now.

After the altithermal came an interval when Death Valley was more moist, and perhaps cooler, than at present. This period I refer to as the Recent pluvial. At one time during the Recent pluvial, Death Valley was flooded by a shallow lake about 30 feet deep, and any phreatophytes that had taken their stand below the level of that shallow lake must have been destroyed because of flooding by the saline water. As the lake dried, this lower ground became reseeded. However, after the Recent pluvial the composition of the stands of phreatophytes may have changed, because the ground became impregnated with sodium chloride.

This would favor invasion by the salt-tolerant species and would retard invasion by the less salt-tolerant ones.

During the past 2,000 years the plant species developed the local distribution patterns they have today. The changes in distribution are continuing. At several places salt tolerant phreatophytes are spreading at the expense of the less tolerant ones, xerophytes are spreading at the expense of the phreatophytes and on some marginal kinds of ground the xerophytes are receding.

PLANT DISTRIBUTION

The accompanying map (pl. 1) shows the distribution of the principal woody plants in Death Valley. The botanical names of the plants and the common names as used in the following text are given in table 4. Generalized transects across the valley are given on figure 5. According to their water supply, the plants mapped can be placed in two major groups: xerophytes are those dependent on vadose water; phreatophytes are those dependent on a permanent water table (fig. 6). The xerophytes are of the Lower Sonoran zone; they grow on the gravel fans and extend into the mountains. The phreatophytes, sometimes referred to as the Salt Desert shrub (Shantz and Zon, 1924, p. 24–26), grow around the edge of the saltpan and at springs on the fans and in the mountains. The relationships of the plants to their environments is such as to lead to the conclusion that distribution of the species of xerophytes correlates with availability of vadose water, and that the distribution of the species of phreatophytes correlates with the quality of ground water.

The boundaries indicated on the map (pl. 1), in most places, are surprisingly sharp—locally as sharp as the boundary between two geological deposits and clearly reflecting geologic factors. The boundary between the xerophytes and phretophytes, for example, is where the gravel of the fans grades into sand at the edge of the saltpan. Few xerophytes extend into the belt of phreatophytes although the climate above the ground in the two environments is alike. The xerophytes can survive the dryness of the gravel fans. That they cannot survive in the phreatophyte zone, where ground water is shallow, may be due to the salinity of the soil water or simply to drowning of their roots at times of high ground water.

Only a few cacti grow in the part of Death Valley represented by plate 1, and most of these are restricted to the middle and upper parts of the gravel fans sloping from the Funeral Mountains. Cacti grow on the summit of the Panamint Range, as at Arcane Meadows, altitude 9,600 feet.

TABLE 4.—*Trees and shrubs referred to in text*[1]

Common name as used in this report	*Botanical name*
alkali sacaton grass	*Sporobolus airoides*
arrowweed	*Pluchea sericea*
athel tree (see tamarisk).	
baccharis (see desert baccharis).	
beavertail cactus	*Opuntia basilaris*
bebbia	*Bebbia juncea*
blackbrush	*Coleogyne ramosissima*
bulrush	*Scirpus* sp.
burroweed	*Franseria dumosa*
cactus (see beavertail, cottontop).	
cattail	*Typha angustifolia*
cattle spinach	*Atriplex polycarpa*
cedar (see pygmy cedar, saltcedar).	
cheesebush	*Hymenoclea salsola*
cottontop cactus	*Echinocactus polycephalus*
creosotebush	*Larrea tridentata*
desert baccharis	*Baccharis sergiloides*
desertholly	*Atriplex hymenelytra*
deserttrumpet	*Eriogonum inflatum*
ditchgrass	*Ruppia maritima*
dodder	*Cuscuta californica*
four-wing saltbush	*Atriplex canescens*
gourd	*Cucurbita palmata*
greasewood	*Sarcobatus vermiculatus*
honey mesquite	*Prosopis juliflora*
honeysweet	*Tidestromia oblongifolia*
incienso	*Encelia farinosa*
inkweed	*Suaeda suffrutescens*
Joshuatree	*Yucca brevifolia*
mesquite (see honey mesquite).	
palm (see Washingtonpalm).	
pickleweed	*Allenrolfea occidentalis*
pygmy cedar	*Peucephyllum schotti*
rabbitbrush	*Chrysothamnus* sp.
reed grass	*Phragmites communis*
rush	*Juncus Cooperi*
sacaton grass (see alkali sacaton).	
salicornia	*Salicornia* sp.
saltbush (see four-wing saltbush).	
saltcedar (see tamarisk).	
saltgrass	*Distichlis stricta*
screwbean mesquite	*Prosopis pubescens*
sedge	*Carex* sp.
shadscale	*Atriplex confertifolia*
spurge	*Euphorbia* sp.
stephanomeria	*Stephanomeria* sp.
sticky-ring	*Boerhaavia annulata*
stingbush	*Eucnide urens*
tamarisk (athel tree)	*Tamarix aphylla*
tamarisk (saltcedar)	*Tamarix gallica* (or *pentandra*?)
Washingtonpalm	*Washingtonia filifera*
willow	*Salix* sp.

[1] For a more complete list of plants in Death Valley, see Putnam (1947, p. 13–66). Useful botanical references are by Abrams (1940, 1944, 1951), Jepson (1951), Jaeger (1950), and Tidestrom (1925). Coville (1893) gives a list of plants in the region.

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XEROPHYTES

On the lower part of the gravel fans, in the nothern part of the area, are pure stands of desertholly; at the south end of the valley these are replaced by pure stands of cattle spinach. Creosotebush, which extends nearly to the base of the fans, commonly has desertholly and cattle spinach associated with it. Burroweed grows on the upper third of the fans in the north; incienso grows on the upper third of the fans in the southern part of the valley. These shrubs on the upper parts of the fans are accompanied by creosotebush and, locally, by desertholly and cattle spinach. Cheesebush grows along some washes at the foot of the fans on the west side of the valley; washes higher on the gravel fans have mixed growths of several xerophytes.

The distribution of these plants is shown on the general map, plate 1, and on several local maps and transects (pl. 2, *A* through *I*.).

Several of the xerophyte stands, for all practical purposes, consist of a single species, and none is complex. Desertholly and cattle spinach form pure stands at the foot of many of the fans, and above this level there are some pure stands of creosotebush.

The less xeric plants generally form mixed stands. Burroweed and incienso, which grow on the upper parts of the fans, for example, commonly have creosotebush and desertholly growing with them. Other species too are more numerous here than at lower levels. Creosotebush extends farther down the fans; generally it is mixed only with desertholly or cattle spinach and in places forms essentially pure stands. In general, the more xeric species extend upward into environments of the less xeric species.

The xerophytes that grow on the gravel fans extend into the mountains too, but the mountain habitats are notably less dry than the gravel fans, and the composition of the plant stands is very different. The variety of species and density of plant growth in the mountain habitats are very much greater than on the drier gravel fans, and I leave those areas to the botanists.

The greater moisture of the mountain environments is partly because the rainfall is greater, partly because evaporation is less, and partly because the geology there favors shallow perched water tables even though they be ephemeral. Vadose water is recharged more frequently than on the gravel fans, and underground reservoirs for storing the water, even temporarily, commonly are within the depths reached by plant roots.

DESERTHOLLY (Atriplex hymenelytra)

The desertholly (*Atriplex hymenelytra*) forms nearly pure stands at the foot of the fans in the north half of the valley (pls. 1, 2). Most of these fans contain a high percentage of carbonate rocks; all of them are highly saliferous. Plant density in these stands ranges from about 5 shrubs per acre to a maximum of about 250 per acre; the average probably is somewhat less than 50 per acre (fig. 9). These stands occupy the lowest, smoothest, saltiest, and hottest parts of the gravel fans.

Desertholly grows also on the higher parts of the gravel fans, even extending to where there is burroweed

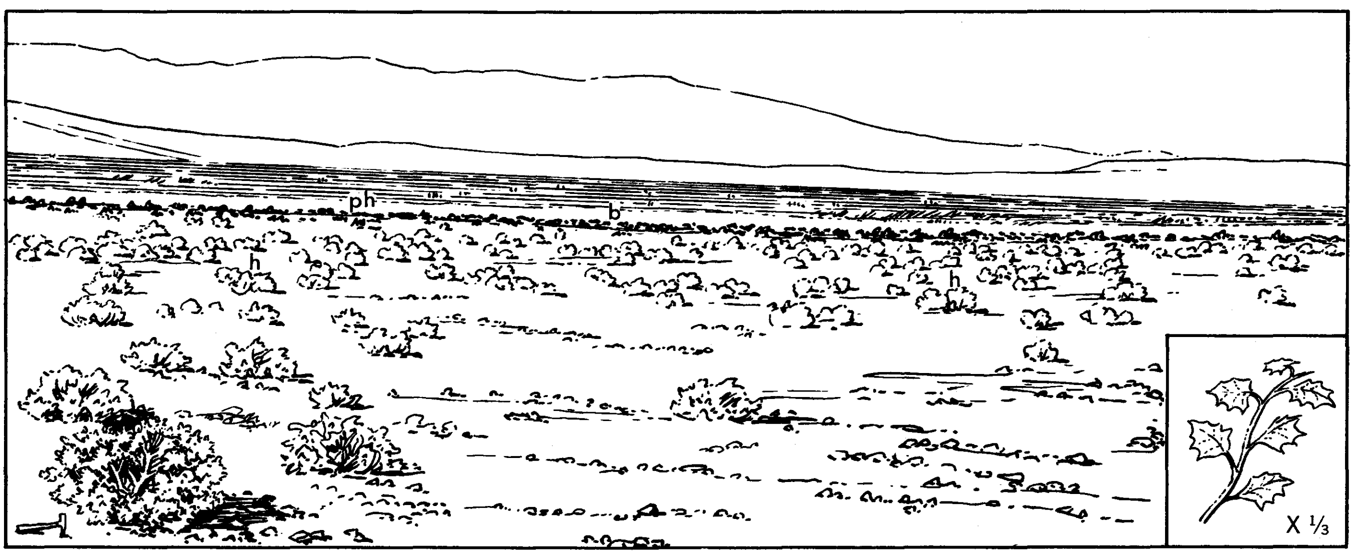

FIGURE 9.—Desertholly (insert) and view northwest across a pure stand of desertholly a mile northwest of National Park Service Headquarters. Density of shrubs in this view about 50 per acre. The desertholly (*h*) ends northwestward at the edge of the phreatophytes (*ph*) which in turn end against the bare ground (*b*) of the saltpan. (See transect, pl. 2 *C*.) Sketch by John R. Stacy, from photograph.

and incienso. The boundary between the pure stands of desertholly and the lower limit of creosotebush is drawn where the plant population includes more than one or two creosotebushes per acre. At the lower limit of the creosotebush, desertholly commonly outnumbers the creosotebush; this mapping device of course minimizes the extent of the desertholly.

The lower boundary of the desertholly is the boundary between the xerophytes and phreatophytes. This boundary is sharp, and there is surprisingly little mingling of xerophyte and phreatophyte plants. (See p. 13.) At many places the boundary is definite within the spacing of the shrubs—that is, within 25 to 30 feet. Because the gravel of the fans is being washed onto the saltpan, this boundary between the xerophytes and phreatophytes is advancing panward, and the desertholly extends short distances into the phreatophyte zone along washes containing gravel. At a few places the gravels have advanced panward far enough to isolate dunes with mesquite, which now are surrounded by the xerophytic desertholly. Best example of this is half a mile north of the mouth of Cow Creek, where the feature is on a scale sufficient to show even on the map (pl. 1).

The only other perennial shrubs that commonly grow in the nearly pure stands of desertholly are the honeysweet (*Tidestromia oblongifolia*) and a spurge (*Euphorbia sp.*), and these shrubs are abundant only along the east side of Death Valley north of Badwater. There they are mostly along washes and road shoulders. They are curiously scarce south of Badwater to Copper Canyon and along the west side of Death Valley. Locally there is sparse inkweed (*Suaeda suffrutescens*) growing with the desertholly on the lowest parts of the fans, especially where the ground is saline. In a few places the inkweed is sufficiently abundant to be shown separately on plate 1.

Desertholly is much more extensive on the east side of Death Valley than on the west side (pl. 1). South of Badwater the gravel in the fans is saline, and north of Badwater, the fans are fine grained and have excessive runoff; both conditions are highly xeric, more so than those on the gravel fans on the west side of the valley.

But although the desertholly is adapted to highly xeric conditions, it is absent and the ground is bare where the surface layers contain more than about 2 percent (by volume) of water-soluble salts (fig. 10), perhaps because the ground is not suitable for seedlings or perhaps because the soil moisture is too saline. Desertholly also is absent where runoff is excessive and the supply of vadose water deficient. This is the situation where the gravel fans contain a high proportion of fine-grained sediments, as do the fans immediately south of Furnace Creek fan. In such environments desertholly is restricted to the washes between the fans where considerable runoff is collected; the rest of the fans are bare (fig. 11).

The limits to even the desertholly, therefore, become exceeded in at least three ways—by excessive salinity (fig. 10), by excessive rate of runoff (fig. 11), and by prolonged drought (fig. 7).

Not much is known about the root habits of the desertholly. Exposures of the upper parts of the roots (fig. 12) suggest that in homogeneous gravel the length of the tap roots is at least twice the height of the shrub, and the length of the laterals is at least twice the diameter of the foliage. Probably the length of the tap roots and of the laterals is many times greater than these minimums.

FIGURE 10.—Where fan gravels contain more than about 2 percent (by volume) of water-soluble salts, they support no vegetation. The gravel bench at the left in this view, about a quarter of a mile west of the North Side Borax Camp, contains more than 4 percent of water-soluble salts and is bare; younger gravel beside it contains only half a percent of salts and supports a considerable stand of desertholly (*h*).

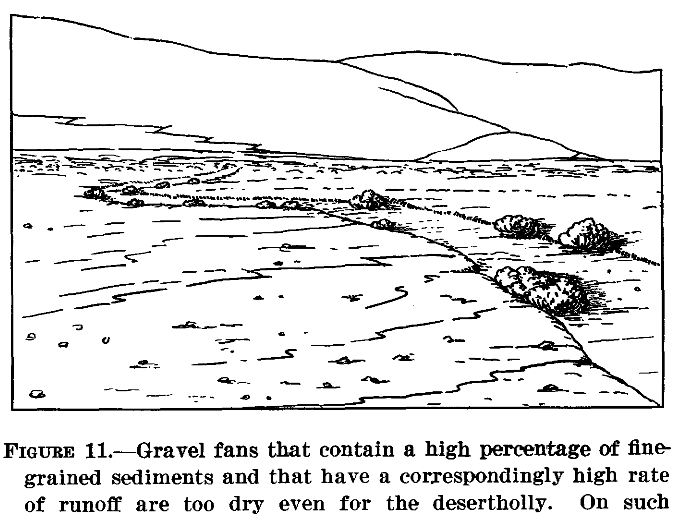

FIGURE 11.—Gravel fans that contain a high percentage of fine-grained sediments and that have a correspondingly high rate of runoff are too dry even for the desertholly. On such fans the shrubs grow only along washes where the runoff is collected. This example is sketched from a photograph looking west along the wash at the north foot of the Desolation Canyon fan.

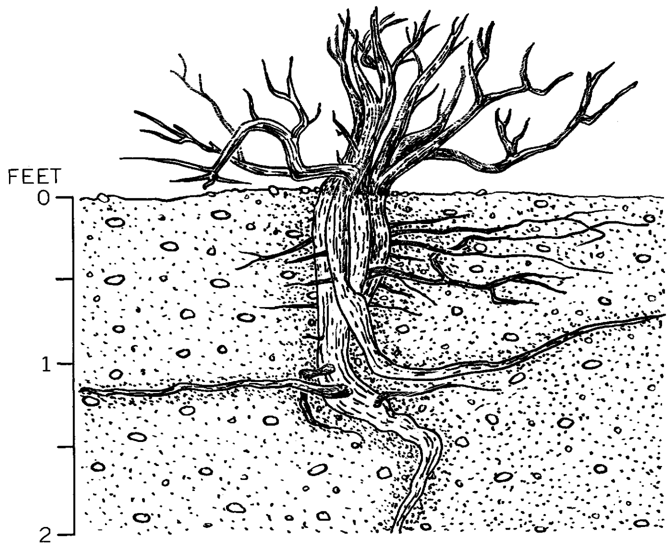

Figure 12.—Roots of desertholly exposed in gravel bank near Salt Springs.

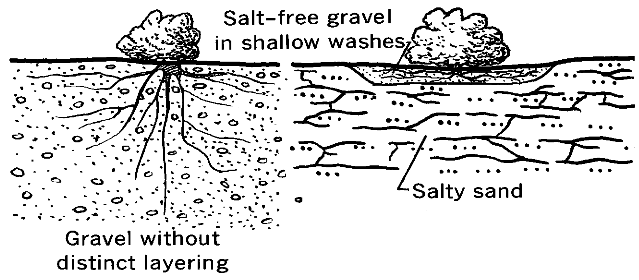

Figure 13.—Two root habits of the desertholly. Where the plants grow on gravel that is without distinct layering (left), the roots spread deeply and widely. Where the plants grow in thin layers of salt-free gravel in shallow washes in salty sand (right), the roots may stay confined to the thin salt-free layer.

Where the ground is not homogeneous, root systems are irregular and adapt themselves to the inhomogeneities (fig. 39). In places they are very limited as, for example, where gravel has been washed onto the saltpan along shallow narrow washes. Desertholly extends down these washes into the pan. This gravel contains less salt than does the sand on which it rests, and the washes collect runoff. Roots of some desertholly in such environments were excavated and it was found that their roots were confined to the gravel layer and did not extend into the underlying salty sand (fig. 13).

The ground that supports stands of desertholly is dissected very little. The washes crossing it are no more than indistinct anastomosing rills, mostly only 2 or 3 feet wide and 3 to 6 inches deep. The rills are closely spaced and their area is nearly as great as that of the ground between them, yet the majority of the desertholly plants are located along the edges of the washes and little rills. Perhaps desertholly is found in these locations because of seed distribution by running water rather than because of environmental differences affecting plants that have matured.

At the pure stands of desertholly the water table is shallow and within the reach of the plant roots; at many places the water table is within 10 feet of the surface and the water is not highly saline. (See W7g, table 19; and W19g, table 22.) The desertholly, though, extends onto the high parts of the gravel fans, where the water table is hundreds of feet deep; the plant, the most xeric of the xerophytes, may use the sweet ground water where it is available, but it can survive without it. The phreatophytes cannot.

Protracted dry periods may cause permanent wilting of desertholly in stands that developed during wet periods. Figure 7 is an example. At many places around Death Valley desertholly has invaded ground and developed stands that did not survive the several dry years that ended in 1957.

As might be expected from the environment of the pure stands of desertholly, the plant is high in sodium chloride, especially the leaves (table 5). One collection of roots (P5, table 5) contained little chloride but much calcium. The sodium chloride content is high even in the sample from high on the fan below Hell Gate (P116, table 5). Also, desertholly contains nearly as much ash as does pickleweed, and two to four times as much ash as do the other xerophytes that were tested: cattle spinach (table 7), creosotebush (table 9), and burroweed (table 11). Samples from along the northeast side of Cottonball Basin (P4, 5, 13, 106, 108, and 116) contain more zirconium than do the samples from other areas. Samples of creosotebush in this area also are relatively high in zirconium (table 9). The specimen of desertholly collected at Cow Creek fan (P17, table 5) is high in molybdenum, as is the ground water in that part of the valley. Arrowweed in this area also is high in molybdenum (p. 40).

Carbonate and silica were not determined in the ash. Together they must total more than 30 percent; most of it probably is carbonate (table 15).

Table 6 gives some analyses of acid-soluble salts in soils around the roots of desertholly. The composition of this ground is not significantly different from that around the other xerophytes (compare with tables 8 and 10) but is much higher in carbonates and lower in sulfates and chlorides than the soils around the phreatophytes (tables 14, 18, and 23).

TABLE 5.—*Semiquantitative and partial analyses, in percent, of ash from desertholly*

[Analysts and analytical methods given on p. 3–4]

	P4	P5	P13	P17	P20	P29	P40	P43	P45	P46	P106	P108	P116
Ca	6.9	21	6.2	3.5	8.2	7	5.4	8	8.2	5.9	12	9.2	10
Mg	2	.96	2.6	1.7	2	3.3	1.5	2.1	2	1.6	2.6	2.2	2.9
K	6.5	1.6	7.6	6.4	8.2	7.2	6.2	9.6	6.8	9	7.2	7.0	12
Na	26	1	28	32	24	24	31	23	26	24	20	22	17
SO_4	2.5	3.5	3	2.5	2	5	4	4	7	6	4.6	5.5	6.4
Cl	25	2.4	16	12	28	25	32	28	27	30	11	14	10
Cu	.002	.004	.002	.002	.001	<.001	.003	.002	.002	.001	.002	.0015	.003
Pb	.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	.0015	.0015	.001
Zn	.002	.005	.002	.002	.002	<.002	.008	.01	.005	.005	<.02	<.02	<.02
Ni	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.0005	<.0005	.0005
Mo	<.001	<.001	.001	.003	<.001	.001	<.001	.001	<.001	<.001	.0005	<.0005	.0005
Zr	.002	.015	.003	<.001	<.001	<.001	<.001	<.001	<.001	<.001	.003	.003	.002
Fe	.2	1	.05	.15	.15	.15	.07	.1	.05	.2	----	----	----
Mn	.03	.1	.1	.01	.01	.07	.15	.1	.05	.05	.1	.07	.07
Cr	<.002	.003	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	.001	.001	.001
V	<.001	.003	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001
Y	.001	.002	.001	.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001
Ti	.03	.15	.03	.02	.02	.02	.01	.02	.005	.03	.007	.007	.01
B	.1	.02	.03	.1	.05	.05	.05	.03	.05	.05	.1	.15	.02
Ba	.007	.03	.005	.015	.007	.005	.003	.007	.01	.005	.015	.005	.007
Sr	.2	.5	.5	>1	>1	.5	.5	.7	.7	.3	.7	.3	.1
Total ash	31.0	18.0	34.0	33.0	32.0	36.0	35.0	30.0	32.0	33.0	31	29	33

P4. Tops; Indian Pass Wash at toe of fan; 200 ft east of old road; in Recent gravel. (See R8, table 6.) SW¼SE¼ sec. 17, T. 28 N., R. 1 E. Compare with P6, table 9.
P5. Roots of no. 4. Compare with P7, table 9.
P13. Tops; Echo Mountian Wash at toe of fan; 150 ft east of old road; in Recent gravel. SW¼SW¼ sec. 21, T. 28 N., R. 1 E.
P17. Tops; at toe of Cow Creek fan; NW¼NW¼ sec. 4, T. 27 N., R. 1 E.
P20. Tops; in wash with pickleweed (see P22, table 9 and P21, table 13); NW¼ sec. 20, T. 16 S., R. 46 E. Compare with R14, table 6.
P29. Tops; by West Side Highway west of Tule Spring. Compare with P30, table 9.
P40. Tops; at toe of third fan south of Badwater. Compare with P39, table 13.
P43. Tops; Copper Canyon fan, west side 500 ft east of highway.
P45. Tops; Mormon Point, 500 ft from highway. Compare with P44, table 9.
P46. Tops; Willow Creek fan, 2 miles east-northeast of Mormon Point. Compare with P47, table 7; P48, table 9.
P106. Tops, southwest base of the middle butte of the Three Bares.
P108. Tops, south base of the west butte of the Three Bares, by State Route 190.
P116. On upper part of fan, with burroweed, altitude 2,000 ft; 0.5 mile below Hell's Gate.

TABLE 6.—*Semiquantitative and partial analyses in percent, of acid-soluble salts in soil around the roots of desertholly*

[Analysts and analytical methods given on p. 3–4]

	R8	R14
Ca	3.5	10.
Mg	.7	3.5
K	.3	.3
Na	.6	.1
CO_3	4.6	20.
SO_4	1.9	3.7
Cl	1.6	3.3
B	.01	.007
Ti	.3	.1
V	.003	.0035
Mn	.07	.03
Ni	.0005	.0005
Sr	.03	.05
Ba	.05	.03
Total acid-soluble salts	13.7	41.2

R8 At toe of Indian Pass fan, 200 ft east of old road; soil around roots of desertholly. Compare with cf P4 and P5, table 5.
R14 West side of Cottonball Basin; desertholly and pickleweed growing on same mound in bottom of a dry wash; soil around their roots; NW1/4 sec. 20, T. 16 S., R. 46 E. (See P20, table 5, and P21, 57, table 13.)

CATTLE SPINACH (Atriplex polycarpa)

In the southern part of Death Valley and in a small area north of Salt Creek, essentially pure stands of cattle spinach (*Atriplex polycarpa*) grow on the lower parts of the gravel fans, a position that in the rest of Death Valley is occupied by the desertholly (fig. 14). The fans on which the cattle spinach grows are chiefly those that are not saline and that are without high percentages of carbonate rocks—that is, fans derived from Precambrian and Lower Cambrian formations and windward from the saltpan.

Average density of cattle spinach in the pure stands is about the same as in the stands of desertholly, probably about 50 per acre, but the shrubs are larger and seem to be spaced more uniformly.

Cattle spinach, like desertholly, extends up the fans into the belt of creosotebush but is absent, or at least uncommon, on the high parts of the fans. However, either cattle spinach or a saltbush much like it reappears in the lower parts of the mountains.

The boundary between cattle spinach and the lower limit of creosotebush is drawn where the number of creosotebushes exceeds one or two per acre. The extent of the cattle spinach thus is minimized about the same way as is the extent of the desertholly. Cattle spinach is abundant in the lower part of the belt of creosotebush, but as brought out in the transects to Galena Canyon and Johnson Canyon (pl. 2, *E*, *F*,), it gives way upward to desertholly in the higher altitude stands of creosotebush.

The boundary between the cattle spinach and phreatophytes is as sharp as the boundary limiting the desertholly. The cattle spinach commonly ends against a stand of four-wing saltbush, which is lacking, or at least rare, along the edge of the phreatophyte zone adjoining the desertholly.

The ground in the areas of cattle spinach is sandier and seems to be less salty than that in the areas of desertholly. Mounds of sand 1 foot, rarely 2 feet, high have accumulated around the shrubs.

Depth to the water table in the pure stands of cattle spinach is about the same as in the pure stands of

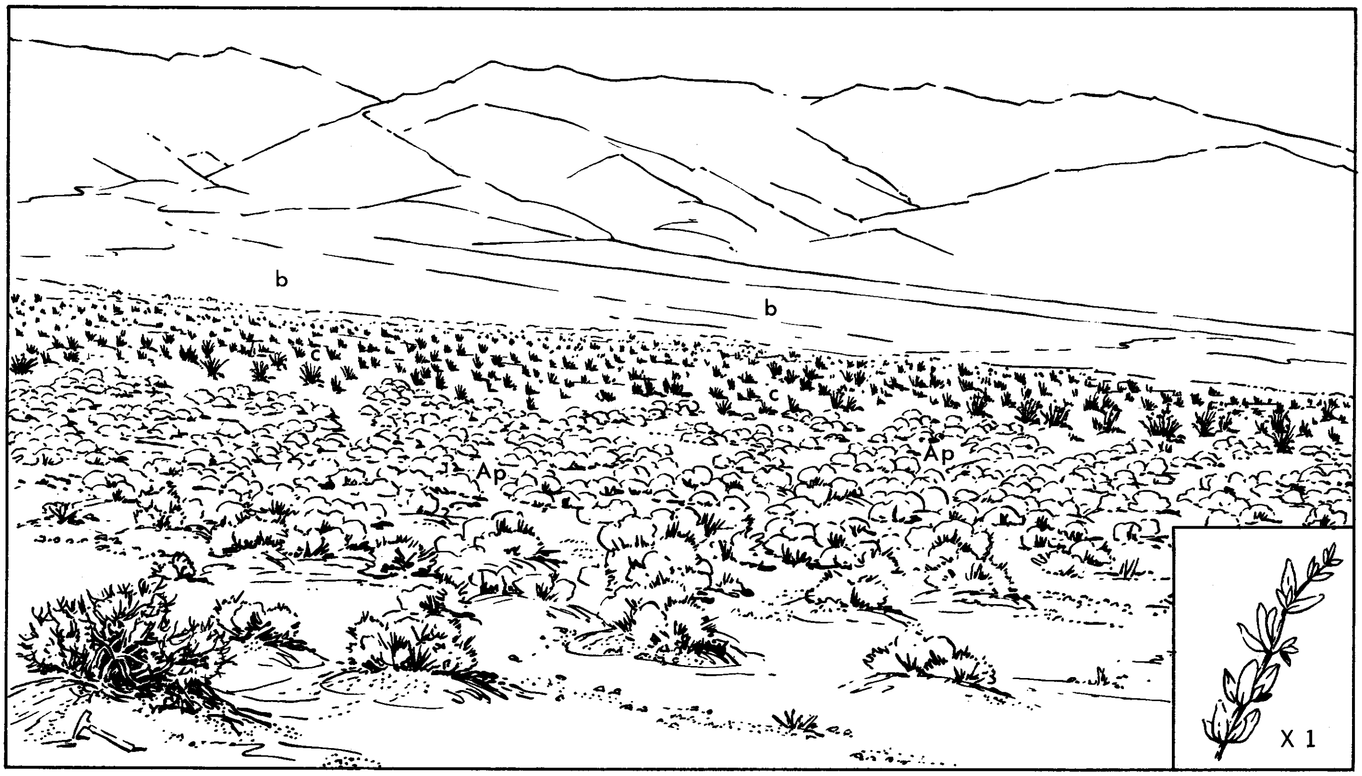

FIGURE 14.—Cattle spinach (inset) and view west across a pure stand of cattle spinach (*Ap*) to creosotebush (*c*) and bare gravel (*b*) at foot of Johnson Canyon fan. Density of shrubs in foreground is about 200 per acre. (For transect, see pl. 2, *H*.) Sketch by John R. Stacy, from photograph.

desertholly, and the salinity of the ground water is about the same. At Gravel Well, where the water table is 15 feet deep, the water contains only 1,300 parts per million of dissolved solids. But while the cattle spinach, like the desertholly, grows where ground water of good quality is available, the plant clearly can survive without it.

The ground in the areas of cattle spinach is as smooth as that in the areas of desertholly. The washes are broader and more widely spaced, but they are only a few inches deep. The shrubs are mostly along the washes, as is the desertholly, although less strikingly so.

South of Gravel Well, gravel and sand are being washed onto the saltpan, and there the cattle spinach is advancing panward into the phreatophyte zone. Along the washes, tongues of cattle spinach extend hundreds of feet into the phreatophyte zone. Some of these are extensive enough to show on the general map (pl. 1)—for example, a half mile southeast of Shortys Well and a mile north and a mile south of Bennetts Well.

Chemical analyses of the ash of some samples of cattle spinach are given in table 7. The total ash is only about half as much as in the desertholly and the proportion of sulfate to chloride is more variable. The proportion of magnesium and of manganese is much greater. In one pair of samples (P36 and P37) the roots contain more sodium chloride than do the tops. Carbonate and silica were not determined in these samples. Together

TABLE 7.—*Semiquantitative and partial analyses, in percent, of ash of cattle spinach*

[Analysts and analytical methods given on p. 3–4]

	P 32	P 36	P 37	P 47	P 49
Ca	14.0	14.0	16.0	9.6	7.8
Mg	6.1	3.5	7.4	6.3	5.5
K	9.6	3.0	7.0	11.	5.0
Na	7.6	12	10	14	22
SO_4	6.0	5.0	5.0	2.0	4.0
Cl	7.6	15.0	8.0	16.0	24.0
Cu	.003	.004	.003	.003	.004
Pb	<.002	<.002	.012	<.002	<.002
Zn	.005	.002	.005	.01	.005
Ni	<.002	<.002	<.002	.002	.008
Mo	.001	.001	.001	≤.001	<.001
Zr	.002	.01	.001	<.001	.003
Fe	1.0	1.5	.3	.15	.7
Mn	.3	.02	.3	.2	.3
Cr	.002	.005	.002	≤.002	.002
V	.001	<.001	<.001	<.001	.001
Y	.001	.002	.001	.001	.001
Ti	.07	.15	.03	.02	.05
B	.03	.05	.02	.05	.05
Ba	.01	.03	.015	.005	.015
Sr	.5	.7	.3	.5	.7
Total ash	15.0	17.0	13.0	11.0	9.7

P 32. Tops; 590 ft east of West Side Highway, 2½ miles south of Bennetts Well. Compare with P 33, table 9; P 34, table 15.
P 36. Roots; in dune sand by West Side Highway, ½ mile north of Tule Springs.
P 37. Tops at P 36.
P 47. Tops; Willow Creek fan 2 miles east-northeast of Mormon Point. Compare with P 46, table 5; P 48, table 9.
P 49. Tops; 3 miles southeast of Salt Well, SE¼NE¼ sec. 20, T. 22 N., R. 2 E. Compare with P 50, table 9.

they must total, on the average, nearly 50 percent, probably mostly carbonate (table 25). This is a somewhat higher proportion than in the desertholly. An analysis of acid-soluble salts from around the roots of cattle spinach is given in table 8.

TABLE 8.—*Semiquantitative and partial analysis, in percent, of acid-soluble salts in soil around roots of cattle spinach*

[Analysts and analytical methods given on p. 3-4]

	S141		*S141*
Ca	1.5	Ti	0.1
Mg	.5	V	.003
K	.5	Mn	.05
Na	.3	Ni	.0005
CO_3	3.8	Sr	.02
SO_4	5.	Ba	.03
Cl	.1		
B	.005	Total soluble salts	12

S141. Surface layer, reddish, 3 in. thick.

CREOSOTEBUSH (Larrea tridentata)

Creosotebush, the characteristic xerophyte in Death Valley (fig. 15, pl. 1), extends from near the foot of the fans, about 240 feet below sea level, to an altitude of about 4,000 feet in the mountains. Creosotebush, alone or with desertholly and cattle spinach, covers most of the lower half or two-thirds of the gravel fans, up to about 500 feet above sea level. Above this it is accompanied by burroweed (*Franseria dumosa*) or incienso (*Encelia farinosa*). The map (pl. 1) shows the lower limit of the burroweed and incienso and so emphasizes the extent of the upper and less xeric species at the expense of the lower and more xeric ones.

The lower boundary of the creosotebush is drawn where the density of the shrub becomes less than 1 or 2 per acre. Few creosotebushes grow in the more xeric environments occupied by the nearly pure stands of desertholly and cattle spinach. At many places this boundary is distinct within a few hundred feet.

Four floras dominated by creosotebush can be distinguished below the belt of burroweed and incienso. At the lower edge, where creosotebush adjoins pure stands of desertholly, the two shrubs are mixed and commonly the desertholly is more abundant than is the creosotebush. On gravel fans where creosotebush adjoins pure stands of cattle spinach, those two shrubs are mixed, but at somewhat higher positions on these fans the combination of creosotebush and cattle spinach is replaced by a combination of creosotebush and desertholly. A third flora, which commonly is a pure stand of creosotebush without other shrubs, extends upward on the fans to the lower limit of the burroweed and

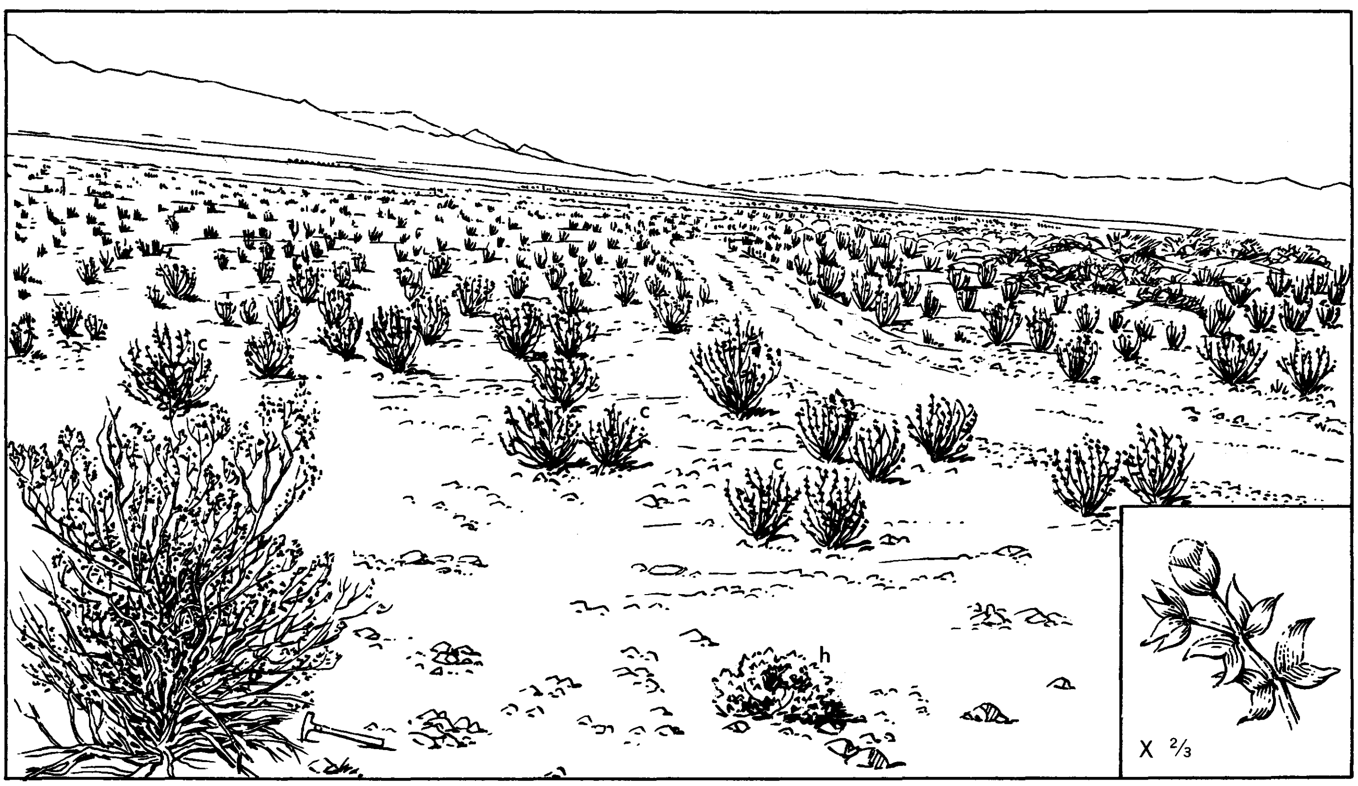

FIGURE 15.—Creosotebush (inset) and view north along a stand on Recent gravel by West Side Highway at Shortys Well. In this view there are about 150 creosotebush (*c*) and 50 desertholly (*h*) plants per acre. (For transect, see pl. 2, *F*.) Sketch by John R. Stacy, from photograph.

incienso. A fourth flora occurs along the washes and consists of creosotebush with or without desertholly and cattle spinach but mixed with such varied shrubs as deserttrumpet (*Eriogonum inflatum*), stingbush (*Eucnide urens*), sticky-ring (*Boerhaavia annulata*), and honeysweet (*Tidestromia oblongifolia*).

The density of creosotebush ranges from very few to about 125 plants per acre; the average probably is about 40.

The distribution and density of creosotebush on the gravel fans correlates directly with the suitability of the ground for recharge of vadose water. The stands are most dense where the surface layers favor seepage into the ground and where there is a catchment area to augment the supply of surface water discharging onto that ground. Such environments are provided by the Recent gravel. Less dense stands extend across upper Pleistocene gravels which have an infiltration rate intermediate between that of the older and younger gravels. At only a few places does creosotebush extend onto the older gravel deposits that have smooth desert pavement, for these pavement areas have a very high rate of runoff and low rate of infiltration. Even after protracted rains the ground on the desert pavement is wet only to a depth of an inch or two. Too, these bare pavement areas are without annuals except in unusually wet years.

Healthy stands of creosotebush grow on the fans tributary to Cottonball Basin, but southward along the east side of Death Valley, from the middle of the Cow Creek fan to the south side of the Copper Canyon fan, there is no creosotebush except for a small number along the irrigation ditch at Furnace Creek Ranch and a half dozen scattered individuals on the fans south of Badwater. The south limit of the creosotebush on the Cow Creek fan is a sharp line, as is the north limit on the Copper Canyon fan. The absence of creosotebush along this east side of Death Valley probably is due to the high rate of runoff on the fans of fine-grained sediments north of Badwater and to the high salinity of the fan gravels south of Badwater. These situations are marginal even for the more xeric desertholly. The dryness of these fans without creosotebush would be accented by their exposure—they not only face west, they are at the foot of a high steep scarp that must reflect much heat from the afternoon sun.

The ground surface in areas with creosotebush is rougher than that in the pure stands of desertholly or cattle spinach. The ground is more cobbly and the washes are deeper and wider; many are sufficiently wide and deep to appear in the topographic contours. The quantity of water-soluble salts is less than in the drier environments.

Some stands of the creosotebush are composed of large individuals having numerous and thick stems but are bordered by belts of smaller bushes having fewer and thinner stems. This difference in stature may reflect difference in healthiness of the stands, but probably reflects difference in age. If so, the creosotebush at some places is advancing down the fans into the pure stands of the desertholly and cattle spinach. Such shift in position of the lower edge of the creosotebush is local and not general. If the boundary is shifting the cause probably is the same as that causing the shift in position of the lower boundaries of the desertholly and cattle spinach (p. 15, 18), which are advancing onto ground formerly occupied by phreatophytes where gravel has been washed onto the edge of the saltpan. Similarly, the less saline and more gravelly deposits suitable for the creosotebush are being washed onto the more saline or sandier ground where only the desertholly and cattle spinach grow.

The apparently younger plants at the edge of these stands of creosotebush commonly are all about the same stature, as if they had germinated and matured together. This might suggest that creosotebush invades these more xeric areas only when conditions are optimum, as for example a series of wet years. (See p. 15).

Exposures of the upper parts of the roots of creosotebush (figs. 16, 17) suggest a root system even more extensive that that of the desertholly (p. 15). In the two situations illustrated neither the laterals nor the tap roots showed much taper.

Although the creosotebush has some shallow lateral roots, the taproots extend to depths where the daily and annual temperature is constant or nearly so. It would be of interest to know if desertholly associated with the creosotebush roots less deeply, because it is more adapted to more xeric conditions.

Animal population in the creosotebush community is small, both in numbers and species. Neither rodent burrows nor ant nests are abundant and there are few signs of larger animals. Grazing animals visit the mixed stands in the washes, but stay off the benches that have only the creosotebush and its more xeric associates.

Chemical analyses of ash from creosotebush (table 9) indicate only half as much ash as in cattle spinach and only a quarter as much as in desertholly. Sulfate and chlorides are almost equal in creosotebush. Carbonates and silica were not determined, but, judging by the apparent excess of cations, the proportion of carbonates and silica must be greater than in either desertholly or cattle spinach (table 25).

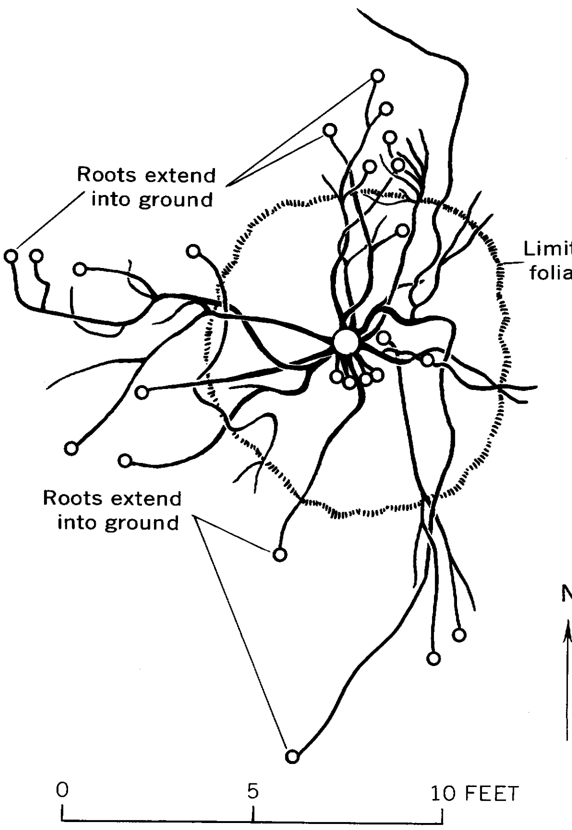

FIGURE 16.—Ground plan of shallow lateral roots of creosotebush, exposed by wind erosion in sandy ground between Bennetts Well and Eagle Borax.

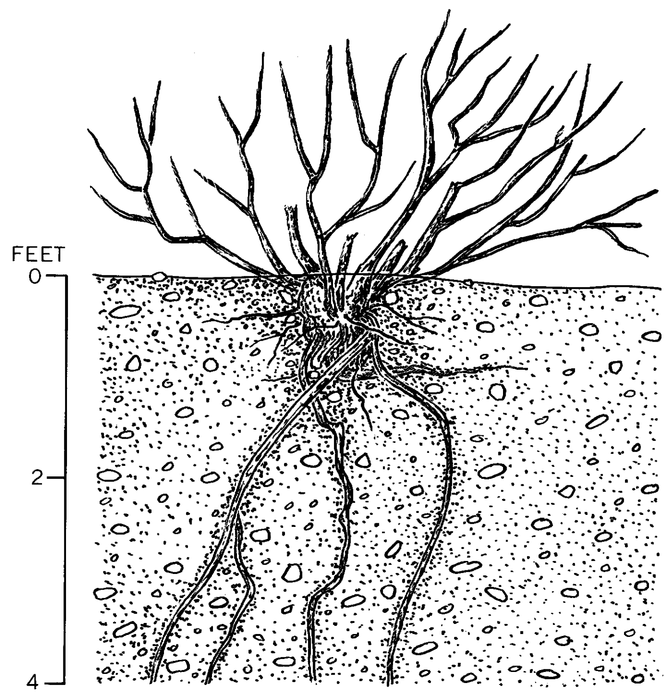

FIGURE 17.—Creosotebush roots exposed in gravel bank in Wingate Wash.

Throughout the valley, creosotebush is high in calcium. Specimens from the northeast side of Cottonball Basin are high in zirconium as are those of deserthollv in that area.

TABLE 9.—*Semiquantitative and partial analyses, in percent, of ash from creosotebush*

[Analysts and analytical methods given on p. 3–4]

	P6	P7	P8	P14	P22	P30	P33	P44	P48	P50	P105	P107	P115
Ca	21	19	26	21	17	20	19	16	20	19	21	20	22
Mg	2.9	3.8	2.9	4.2	2.7	4.2	4.6	3.7	3.7	3.7	3.7	4.5	3.2
K	16	6.1	9.6	16	14	12	12	13	8.6	8.6	15	17	17
Na	3.6	.60	5.4	1.8	5.4	3.0	1.5	6.2	4.4	3.6	2.9	.60	.50
SO^4	3.0	<1.0	<1.0	4.5	7	7.5	7.5	8	10	7	13	15	13
Cl	6.4	2.8	2.4	8.4	9.6	7.2	4.0	16	11	8.4	4.5	5	4.3
Cu	.004	.02	.01	.004	.004	.002	.004	.003	.008	.003	.01	.01	.007
Pb	.002	<.002	.005	.005	.002	.002	<.002	.005	.002	<.002	.005	.003	.005
Zn	.005	.005	.012	.008	.005	.005	.012	.008	.008	.005	.02	.02	.02
Ni	<.002	.004	.015	.01	<.002	<.002	<.002	.002	.008	.015	.003	.003	.002
Mo	<.001	<.001	<.001	<.001	<.001	<.001	.001	<.001	.015	<.001	.0005	.0005	.0007
Zr	.003	.03	<.002	.002	.001	.001	.001	.001	.001	.003	.007	.007	.003
Fe	.5	1.5	.2	1.0	.5	.7	1.0	.7	.5	1.0	------	------	------
Mn	.15	.07	.07	.07	.03	.07	.05	.07	.07	.2	.07	.07	.07
Cr	<.002	.003	.002	.002	.002	.002	.002	.002	<.002	.002	.005	.005	.003
V	.001	.003	<.001	.001	.001	.001	.001	<.001	.001	.001	.0015	.0010	.0010
Y	<.001	.002	<.001	<.001	<.001	<.001	<.001	<.001	.001	.001	.0010	.0010	.0010
Ti	.07	.1	.03	.07	.05	.05	.07	.07	.03	.1	.03	.03	.03
B	.1	.05	.05	.07	.2	.1	.03	.1	.1	.1	.3	.2	.05
Ba	.02	.05	.03	.05	.03	.015	.01	.03	.01	.02	.03	.03	.03
Sr	1.0	.7	1.0	1.0	>1.0	.7	.5	>1.0	>1.0	>1.0	1.	1	.5
Total ash	8.4	6.5	2.8	6.5	9.7	8.5	8.8	8.0	7.5	8.3	7.9	8.2	8.2

P6. Leaves; toe of Indian Pass Wash fan; in Recent gravel; SW¼SE¼ sec. 17, T. 28 N., R. 1E. (See R9, table 10.) Compare with P4, table 5.
P7. Roots of No. 6. Compare with P5, table 5.
P8. Stems of No. 6.
P14. Leaves; Echo Mountain Wash; 500 ft east of State Route 190; NE¼SW¼ sec. 21, T. 28 N., R. 1 E.
P22. Leaves; in wash with desert holly and pickleweed, NE¼ sec. 20, T. 16 S., R. 46 E. Compare with P20, table 5; P21, table 13.
P39. Leaves; by West Side Highway west of Tule Spring. Compare with P29, table 5.
P33. Leaves; 500 ft east of West Side Highway 2½ miles south of Bennetts Well. Compare with P32, table 7 and P34, table 15.
P44. Leaves, at Morman Point. Compare with P45, table 5.
P48. Leaves and stem tips; Willow Creek fan, 2 miles east-northeast of Mormon Point; Recent gravel. (See R83, table 10.) Compare with P46, table 5 and P47, table 7.
P50. Leaves and stem tips; 3 miles southeast of Salt Well in Recent gravel; SE¼NE¼ sec. 20, T. 22 N., R. 2 E. Compare with P49, table 7.
P105. Tops, from wash 1,000 feet east of State Route 190 between the eastern and western buttes of the Three Bares.
P107. Tops, at south corner of west butte of the Three Bares.
P115. On upper part of gravel fan, with burroweed, altitude 2,000 feet, 0.5 mile below Hells Gate.

Table 10 gives some analyses of acid-soluble salts from around the roots of creosotebush.

TABLE 10.—*Semiquantitative and partial analyses, in percent, of acid-soluble salts in soils around roots of creosotebush*

[Analysts and analytical methods given on p. 3–4]

	R9	R15	R83
Ca	5	7.5	2
Mg	.7	1.5	1
K	.22	.28	.66
Na	<.1	.2	.3
CO_3	4.6	20	1.4
SO_4	2.5	2.5	1.9
Cl	.6	7.5	2.7
B	.01	.005	.015
Ti	.5	.07	.3
V	.005	.002	.01
Mn	.07	.02	.07
Ni	.001	<.0005	.002
Sr	.03	.02	.05
Ba	.05	.02	.07
Total acid-soluble salts	14.45	39.62	10.58

R9. Toe of Indian Pass fan; Recent gravel around root of creosotebush. (See P6, 7, 8, table 9.)
R15. West side Cottonball Basin; soil around roots of creosotebush in gravelly soil.
R83. Cove east of Mormon Point; soil around roots of creosotebush; Recent gravel. (See P48, table 9.)

BURROWEED (FRANSERIA DUMOSA) AND INCIENSO (ENCELIA FARINOSA)

The burroweed (*Franseria dumosa*) and incienso (*Encelia farinosa*) cover the high parts of the gravel fans in Death Valley, mostly above 500 feet in altitude, and they extend upward into the mountains. Burroweed is in the north part of the valley; in the south its place is taken by incienso. In general, burroweed occurs on the upper parts of those fans that have the pure stands of desertholly at their base whereas the incienso community occurs on those fans that have cattle spinach at their base. This distribution strongly suggests a geologic control, but what that control is, if any, has not been identified.

Areas shown as burroweed (pl. 1) include some incienso, and vice versa. The density of the shrubs may be as great as a few hundred per acre, but generally is less and the shrubs commonly are confined along washes (figs. 18, 19). With them grow creosotebush and desertholly; various cacti are associated with the burroweed but are uncommon where there is much incienso.

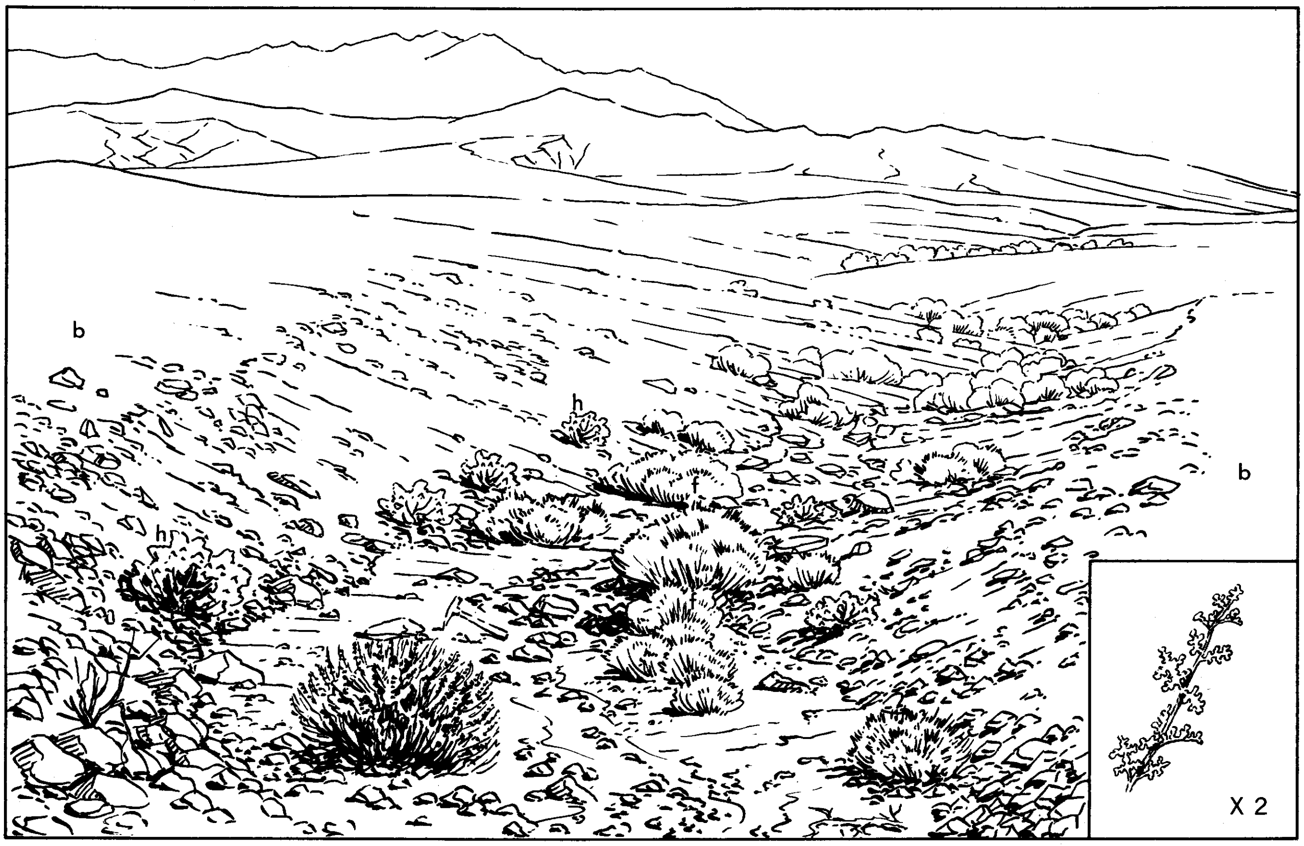

FIGURE 18.—Burroweed (inset) and view east along a stand of burroweed on gravel fan by Furnace Creek near Corkscrew Canyon. The burroweed (*f*) grows in washes between bare surfaces (*b*) on the gravel fans. Commonly there is a row of desertholly (*h*) along each side of the wash. Sketch by John R. Stacy, from photograph.

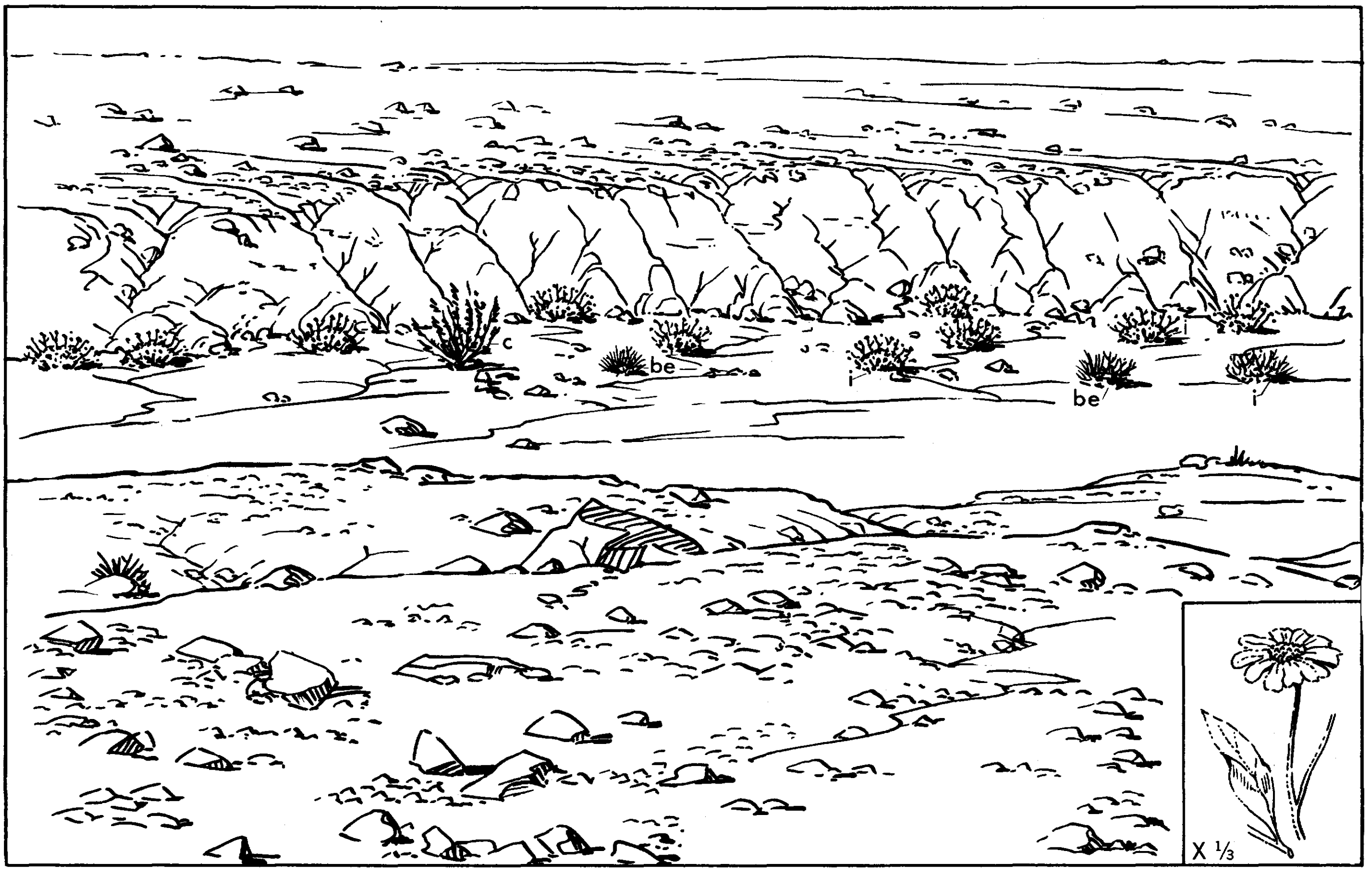

FIGURE 19.—Incienso (inset) and view across a wash with incienso on upper part of the Trail Canyon fan. Growing with the incienso (*i*) is creosotebush (*c*) and bebbia (*be*). Sketch by John R. Stacy, from photograph.

The map (pl. 1) shows the lower limit of burroweed and incienso, which emphasizes the extent of these plants and minimizes the extent of the creosotebush. The upper boundary of these plants has not been mapped; the scratch boundary shown on plate 1 is the foot of the mountains, but the plants extend onto the mountains to the top of the Lower Sonoran zone.

Topographic relief in the areas of burroweed and incienso is considerable. Main washes are hundreds of feet wide and some are entrenched as deep as 100 feet into the gravel fans. The surfaces of the benches are smooth except for shallow washes having gently sloping sides. Along such washes the burroweed and incienso (figs. 18 and 19) commonly are spaced so closely their crowns touch. A 100-foot stretch of such a wash may have 40 shrubs, by far the densest growth of perennial xerophytes in Death Valley, yet the total plant population of the burroweed and incienso areas is not large because extensive areas between the washes are bare.

The root systems both of the burroweed and incienso seem to be much more limited than the root systems of the more xeric shrubs like creosotebush and desertholly. Roots of the burroweed and incienso growing along washes probably do not extend far beyond the ground where the vadose water is recharged by the collected runoff. The roots favor the Recent fill in the washes, and probably do not penetrate far into the dry older gravels under the bare pavement on each side of the wash.

The stands of burroweed or incienso along the bottoms of many of the washes commonly are flanked by desertholly growing on the drier ground at the edge of the wash (fig. 20).

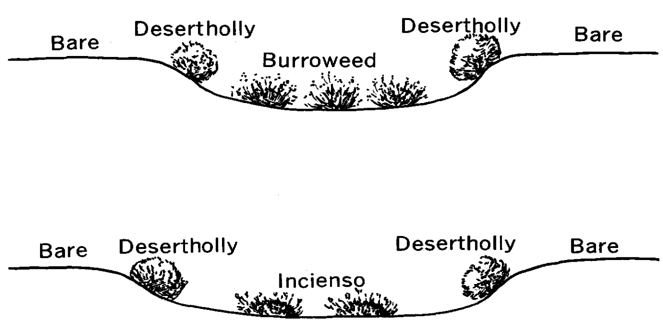

FIGURE 20.—Burroweed and incienso commonly grow along the bottoms of shallow washes flanked by a row of desertholly on the drier banks. Ground each side of the wash is bare desert pavement.

At the lower levels, these plants are restricted to the washes; the benches between the washes are bare (pl. 1). On the higher parts of the fans, however, the belts of shrubs in the washes widen and on the highest parts of the fans the shrubs spread across the smooth pavement covered benches between the washes.

The analysis of a single specimen of burroweed (P114, table 11) suggests a composition more like that of the creosotebush than like the desertholly. Calcium and potassium are accumulated in preference to sodium and magnesium, and sulfates exceed the chlorides in the ash.

TABLE 11.—*Semiquantitative and partial analyses, in percent, of ash from burroweed and cheesebush*

[Analysts and analytical methods given on p. 3–4]

	P51	P114
Ca	16	19
Mg	5.8	4.3
K	16	20
Na	.56	1.3
SO_4	6.	7.3
Cl	6.8	3
Cu	.01	.007
Pb	<.002	.005
Zn	.01	<.02
Ni	.002	.0007
Mo	.001	.0005
Zr	.001	.003
Fe	.2	----------
Mn	.07	.1
Cr	.002	.005
V	.001	.001
Y	.001	<.001
Ti	.02	.03
B	.1	.05
Ba	.01	.03
Sr	.5	.3
Total ash	6.4	11

P 51. Cheesebush, 700 ft southwest of Bennetts Well.
P144. Burroweed, 0.5 mile south of Hells Gate, alt 2,000 ft.

Both the burroweed and incienso are browsed by mountain sheep and by burros. In general, the areas of incienso shown on plate 1 are in the range of the burros whereas the areas of burroweed are in the range of the mountain sheep.

CHEESEBUSH (Hymenoclea salsola)

Some nearly pure stands of cheesebush (*Hymenoclea salsola*) grow along washes at the foot of some of the gravel fans on the west side of Death Valley (pl. 1, fig. 21). In the area mapped the shrub is restricted to these washes, but it grows at higher altitudes beyond the limits of the map.

Table 11 gives a chemical analysis of ash from cheesebush. This plant and rush (table 16) contain little ash. The proportion of calcium, magnesium, and potassium is high, or, stated otherwise, the proportion of sodium is very low. Sulfate about equals the chloride and both are low. Carbonate and silica were not determined, but they, especially the carbonate, must be high (table 25).

MIXED STANDS

Mixed stands of xerophytes occur along washes and where there is perched ephemeral ground water. Washes on most of the fans have shrubs characteristic of the neighboring benches and some or all of the following species (fig. 31):

Honeysweet (*Tidestromia oblongifolia*)
Spurge (*Euphorbia sp.*)
Pygmy cedar (*Peucephyllum schottii*)
Deserttrumpet (*Eriogonum inflatum*)
Bebbia (*Bebbia juncea*)
Stephanomeria (*Stephanomeria parryi*)
Stingbush (*Eucnide urens*)
Sticky-ring (*Boerhaavia annulata*)
Cheesebush (*Hymenoclea salsola*)

Few such mixed stands extend to the foot of the gravel fans, and generally they stay above 500 feet. The north side of Trail Canyon fan and the fans at Blackwater Wash and Tucki Wash are exceptions. The density of shrubs in the mixed stands exceeds that in the other xerophyte environments; many crowns touch, and average spacing in the areas mapped probably is about the diameter of the crowns.

The limits of these stands are sharp, for they coincide with the edges of the bottoms of the washes. Even low-level terraces in the washes are occupied by the more xeric types. Some of these stands are shown on transects on plate 2*B*, *D*, *E*, *G*. The depth to the water table is scores or hundreds of feet.

On the fans along the east and north sides of Cottonball Basin these mixed stands along the washes are altitudinally zoned. Honeysweet and spurge grow in the washes on the lower parts of the fans; the other plants listed grow in the washes at higher altitude.

Although the typical habitat of these shrubs is along washes (fig. 21), they also occur where an ephemeral water table is perched above impermeable layers in the ground.

PHREATOPHYTES

Phreatophytes are those plants that have their roots in perennial ground water or in the capillary fringe above the water table. Nine kinds are distributed around the edge of the saltpan, and others grow at the springs on the gravel fans, and at other places where the water table is shallow (fig. 22). Distribution of these plants is controlled not only by the availability of the ground water but also by its quality. Arranged in order of increasing tolerance to salinity of the ground water, the principal phreatophytes in Death Valley are:

At the springs on the gravel fans:

Desert baccharis (*Baccharis sergiloides*); willow (*Salix* sp.); screwbean mesquite (*Prosopis pubescens*); common reed grass (*Phragmites communis*).

The nine kinds around the edge of the saltpan:

1. Honey mesquite (*Prosopis juliflora*),
2. Arrowweed (*Pluchea sericea*) and 3. Four-wing saltbush (*Atriplex canescens*),
4. Alkali sacaton grass (*Sporobolus airoides*) and 5. Tamarisk (*Tamarix gallica* and *T. aphylla*),
6. Inkweed (*Suaeda* sp.),
7. Saltgrass (*Distichlis stricta*)
8. Rush (*Juncus cooperi*)
9. Pickleweed (*Allenrolfea occidentalis*)

Salinity of the ground water under the phreatophytes ranges from a few hundred parts per million under the mesquite, the least salt tolerant, to a maximum of about 6 percent along the saltpan edge of the pickleweed. The general zoning of these phreatophytes and their relationship to each other and to the geology

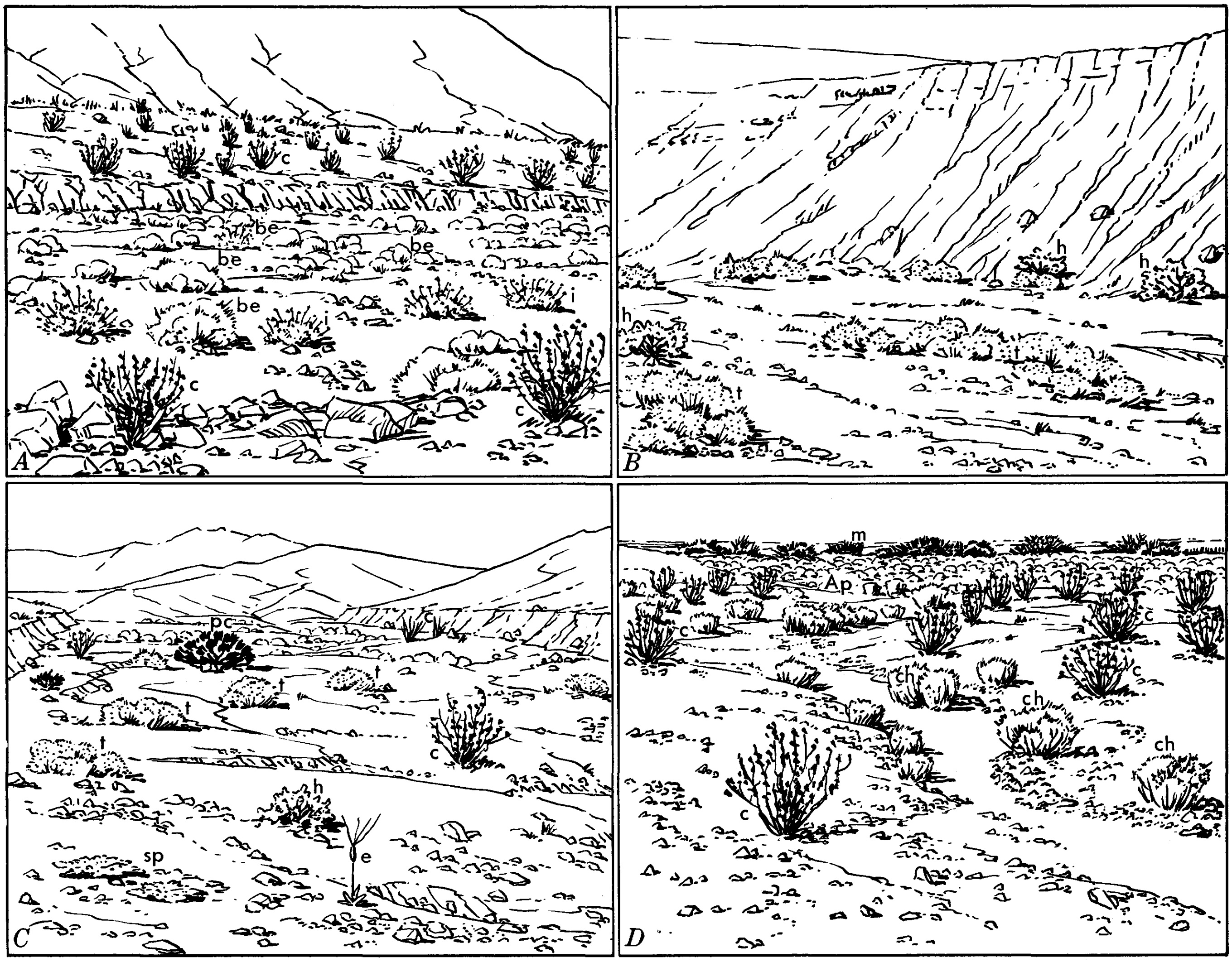

FIGURE 21.—Four mixed stands of xerophytes along washes. *A*, Bebbia (*be*) associated with incienso (*i*) and creosotebush (*c*) at mouth of Trail Canyon. *B*, Honeysweet (*t*) and desertholly (*h*) in Mud Canyon in west part of Kit Fox Hills. These plants extend down Mud Canyon to below sea level; upstream, they end at the head of the canyon and are replaced by bebbia (*be*). *C*, Wash tributary to Furnace Creek at Zabriskie Point. The plants here include honeysweet (*t*), spurge (*sp*), pygmy cedar (*pc*), deserttrumpet (*e*), desertholly (*h*), and creosotebush (*c*). *D*, Cheesebush in a wash a mile south of Bennetts Well. On each side of the wash with cheesebush (*ch*) is creosotebush (*c*). In distance is cattle spinach (*Ap*) and honey mesquite (*m*).

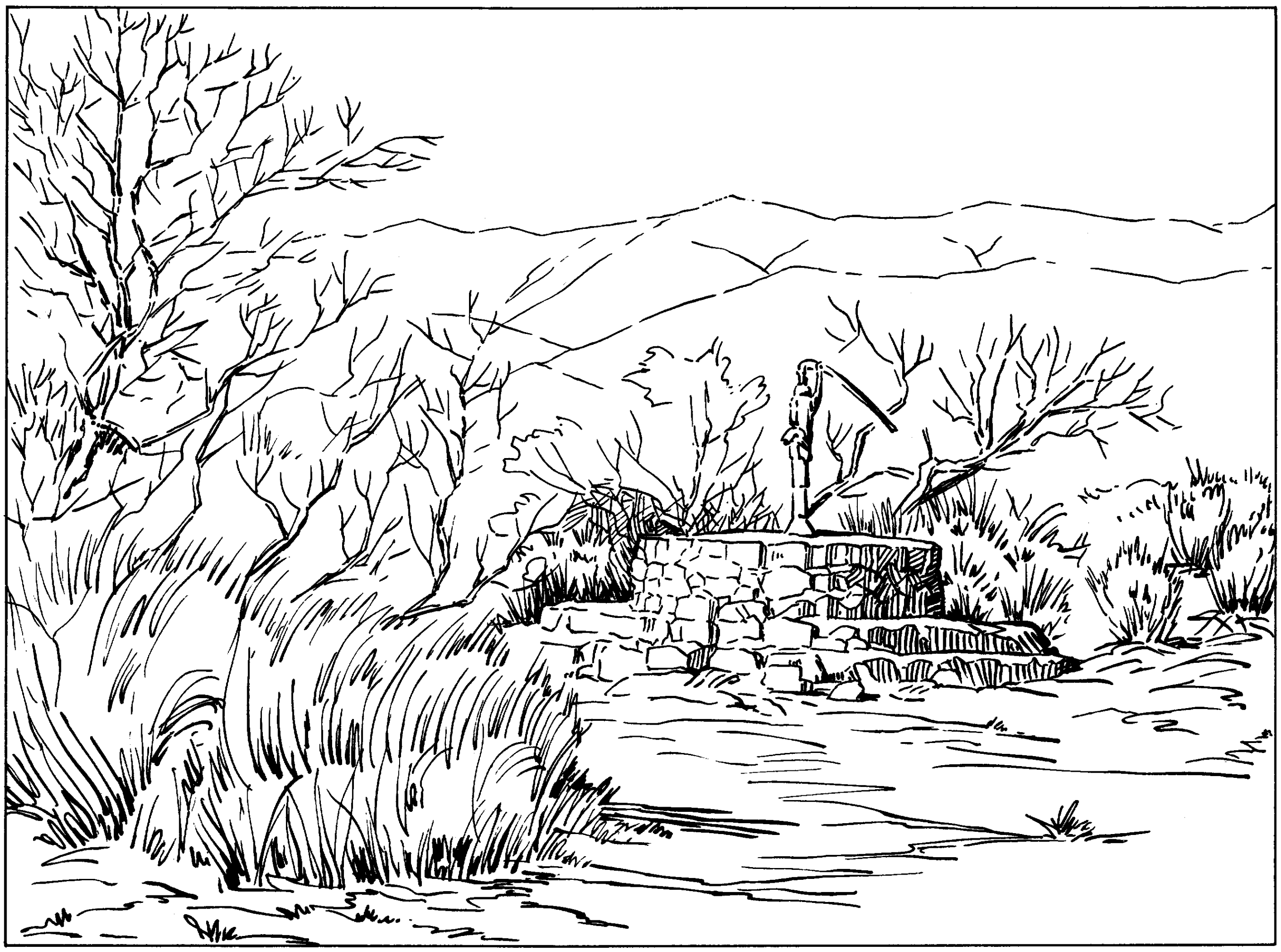

FIGURE 22.—Phreatophytes grow where the ground water is shallow. This is view of Bennetts Well where ground water is 7 feet deep; it contains 0.03 percent (300 ppm) dissolved solids. At left is clump of sacaton grass; back of the well is honey mesquite. Sketch by John R. Stacy, from photograph.

is illustrated on plate 1 and in 17 transects on figures 23 to 26. The belts of less salt-tolerant phreatophytes usually include some species that are more solt-tolerant. For example, pickleweed usually extends into the belt of arrowweed (*Pluchea sericea*), and arrowweed usually extends into the belt of honey mesquite (*Prosopis juliflora*). The most salt-tolerant plant, pickleweed, forms extensive pure stands.

This zoning of the phreatophytes around the edge of the Death Valley saltpan is duplicated by similar zoning around the edges of other saline or alkaline lakes and playas. At Great Salt Lake, for example, in the Upper Sonoran zone, the most salt-tolerant plants are *Salicornia* and *Allenrolfea*. There is an intermediate belt of inkweed (*Suaeda* sp.) and saltgrass (*Distichlis* sp.), and the least salt-tolerant plants are sacaton grass (*Sporobolus* sp.), saltbush (*Atriplex* sp.), greasewood (*Sarcobatus* sp.), and rabbitbrush (*Chrysothamnus* sp.). (See Flowers, 1934). Zoning of plants with respect to their salt tolerance also occurs along the coasts. (See for example, Kurz and Wagner, 1957.)

But, although the plants are distributed in an orderly way with respect to average differences in salinity, each species is capable of surviving substantial variations in salinity (fig. 40). Of particular interest in this connection is the early study by Hill (1908) of the way root hairs adapt themselves to changes in salinity. In a saltpan along the coast of England, Hill found that the salinity of the water around plant roots at high tide was that of sea water, about 3.5 percent, but after a rain the salinity dropped to less than 1 percent. In investigating how the plants accommodate themselves to the change, he found the osmotic balance of the cell sap of the root hairs of both *Salicornia* and *Suaeda* to be about 6.5 percent NaCl. Root hairs of *Salicornia* seedlings could stand a 5.8 percent solution of common salt, but after

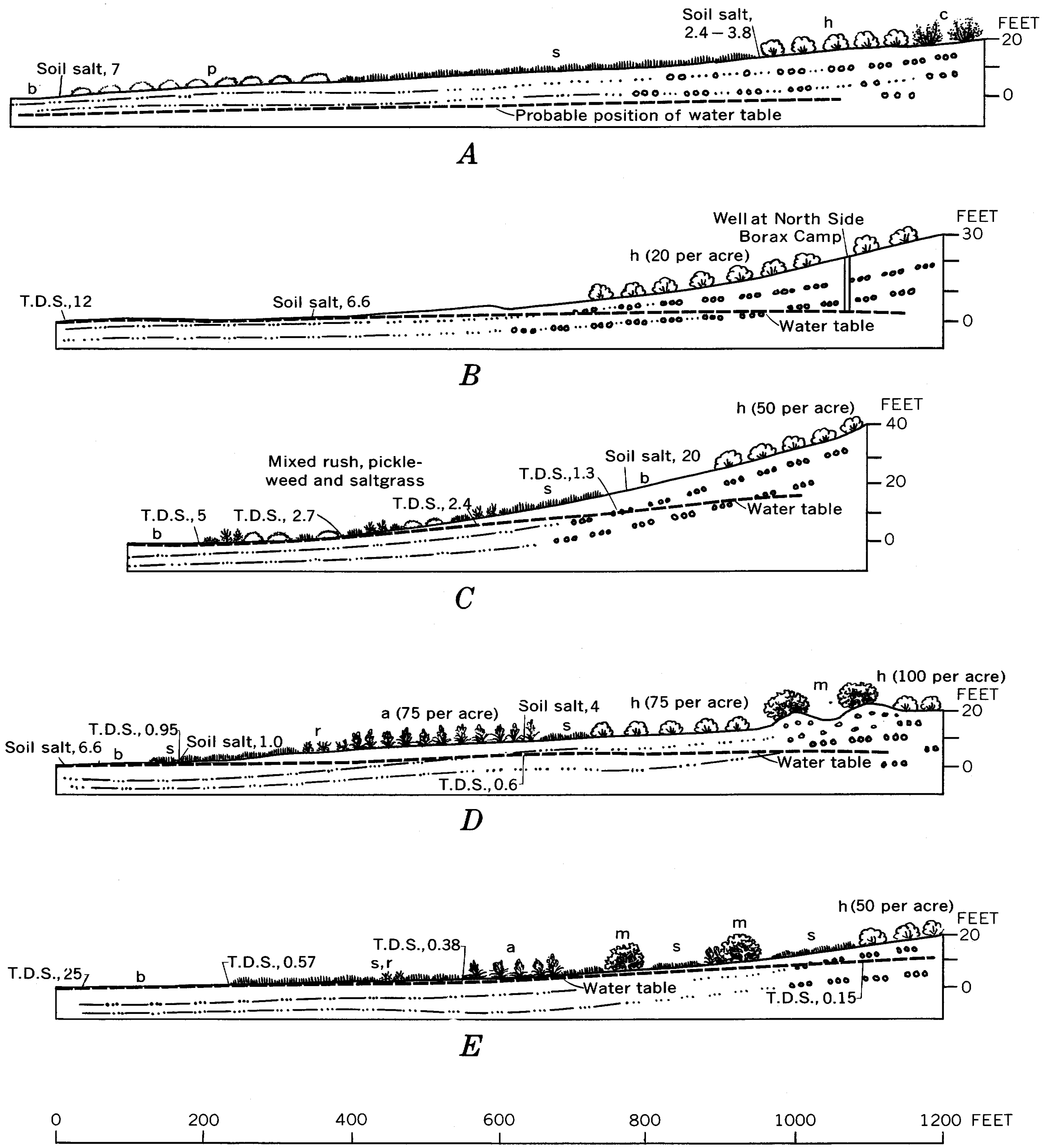

FIGURE 23.—Transects showing relationship of phreatophytes to quality of water on the north and east sides of Cottonball Basin. *A*, a mile southeast of Beatty Junction; *B*, at North Side Borax Camp; *C*, at Salt Springs; *D*, at dunes a mile northwest of National Park Service headquarters; *E*, at mouth of Cow Creek. Creosotebush (*c*) and desertholly (*h*) occupy xerophyte environments on gravelly ground at toe of the fans. *m*, honey mesquite; *a*, arrowweed; *s*, saltgrass; *r*, rush; *p*, pickleweed; *b*, bare ground. TDS refers to total dissolved solids in ground water, in percent. Water-soluble soil salts are given in percent by volume.

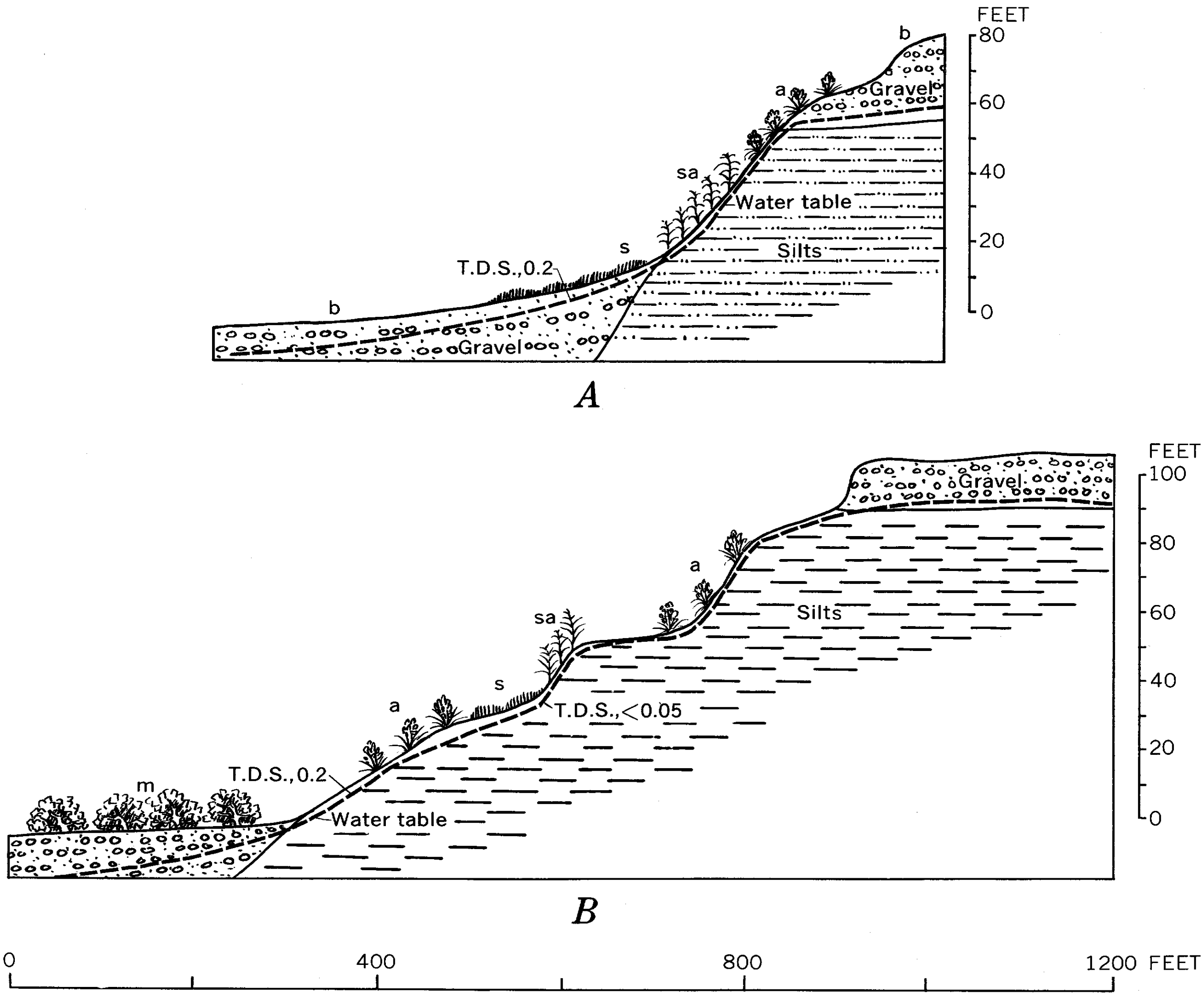

Figure 24.—Transects showing relationship of phreatophytes to quality of water at (*A*) spring zone 1,500 feet northeast of National Park Service headquarters and (*B*) spring zone 1,500 feet east of the headquarters. *b*, bare ground; *m*, honey mesquite; *s*, saltgrass; *a*, arrowweed; *sa*, sacaton grass. TDS refers to total dissolved solids in ground water, in percent.

being washed and soaked with a 1.0 percent solution for 2 hours they became plasmolysed when placed in the 5.8 solution, that is, they shrank from exosmosis. The root hairs survived variations of salinity between less than 1.0 and nearly 6.0 percent. The protoplasm shrank from the tip of the root hairs and pulled in from the sides when the salinity was increased, whereas the root hairs swelled, assumed curious shapes, or even branched when the salinity was lowered.

I attempted, without success, to duplicate Hill's experiments by using saltgrass from Death Valley. Although the roots were immersed in solutions ranging from 0.05 to 10.0 percent salts, I could detect no changes in the root hairs. Perhaps the experiment was conducted at the wrong season; in any case one may conclude that such experiments had best be left to plant physiologists!

Other, more successful, studies of the adaptations of plants to changes in salinity confirm Hill's observations that plants can tolerate substantial variations in the salinity of the ground in which they grow and in the salinity of their cell sap. (See, for example, Shakhov and Kachinskaya, 1947, p. 1817–1820; Kurz and Wagner, 1957, p. 83; Beadle, Whalley, and Gibson, 1957; Ashby and Beadle, 1957; Van't Hoff, 1903.)

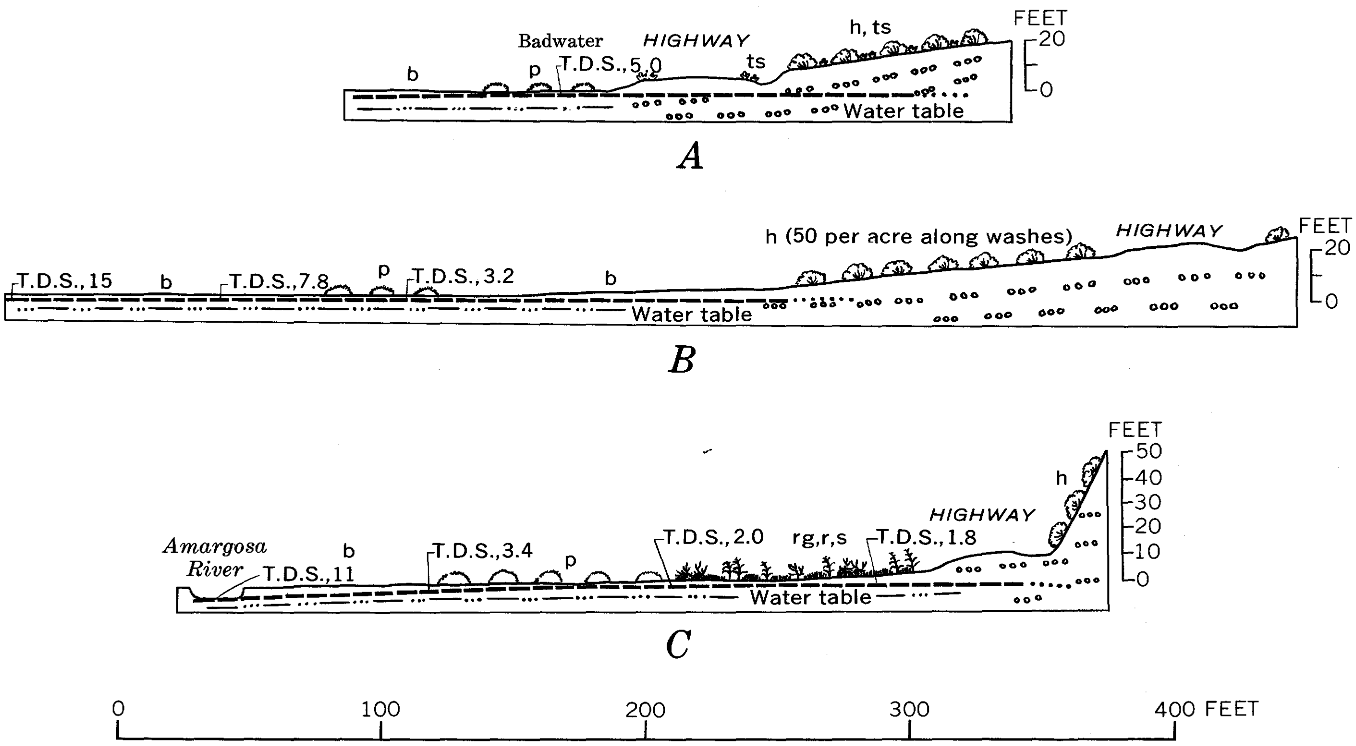

Figure 25.—Transects showing relationship of phreatophytes to quality of water on the east side of Badwater Basin. *A*, at Badwater; *B*, in second cove south of Badwater; *C*, at Coyote Hole 4 miles southeast of Mormon Point. *h*, desert-holly; *ts*, honeysweet and spurge; *rg*, giant reed grass; *r*, rush; *s*, saltgrass; *p*, pickleweed; *b*, bare. TDS refers to total dissolved solids in ground water, in percent.

In Death Valley the phreatophytes are in the sandy and silty ground at the foot of the gravel fans and at the edge of the saltpan. Toward the mountains are the xerophytes on the fans; in the other direction are bare salt flats (fig. 5). The vegetation ends panward where the salinity of the ground water becomes as high as 6 percent.

In Death Valley no annuals grow in the highly saline areas where there is pickleweed or saltgrass (Went and Westergaard, 1949, p. 35). I have seen no annuals, either, where there is arrowweed, for the ground there also is highly saline. (Transect *D*, fig. 23; transect *F*, fig. 26.) Some annuals appear in the areas of the less salt-tolerant phreatophytes but commonly these annuals are dwarfed or have black tips on their leaves, indicating injury (Went and Westergaard, 1949, p. 35).

Whereas xerophytes characteristics of the driest habitats bloom and flower after warm rains regardless of the season, the phreatophytes flower in the spring season regardless of abundance of rain at other times of the year. Although most of the phreatophytes grow at lower altitudes than most of the xerophytes, they have a dependable water supply, are independent of the rains, and respond to the seasonal changes in temperature. This response must be triggered in the epigeous parts because the roots are in the capillary fringe, or water table, where there is little annual variation in temperature.

PICKLEWEED (Allenrolfea occidentalis)

Pickleweed, the most salt-tolerant plant in our deserts, forms nearly pure stands in a belt ranging from a quarter of a mile to 2 miles wide along the whole length of the west side of the saltpan and it occurs in isolated patches along the east side (fig. 27). The area covered by it is about 20 square miles. The main stand of pickleweed practically coincides with the salt-crusted silty facies of the carbonate zone. This ground is nearly flat and is crossed by few washes, none of which is more than a few feet wide and a few inches deep. Stands of pickleweed also grow in many of the sulfate marshes.

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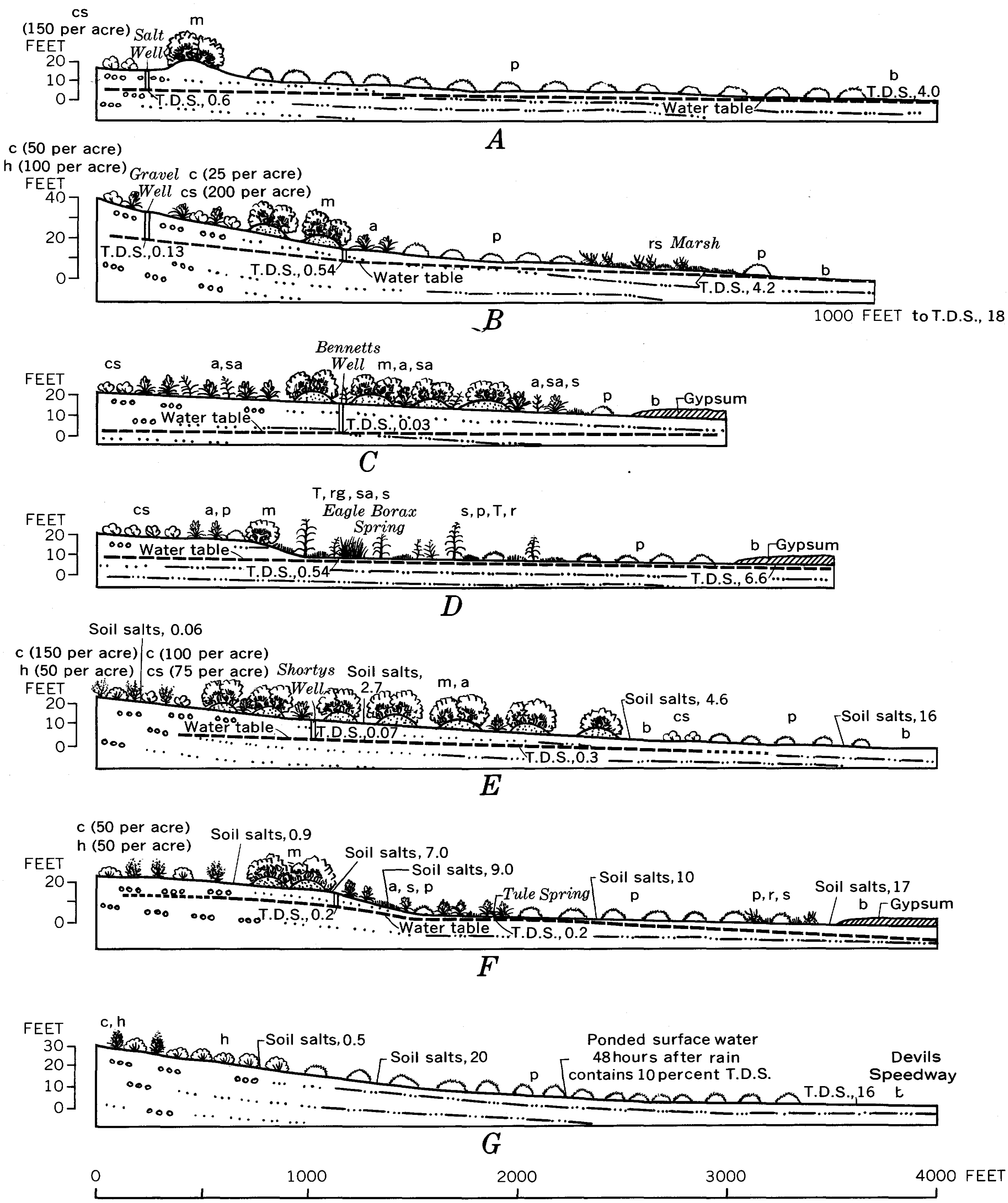

FIGURE 26.—Transects showing relationship of phreatophytes to quality of water on the west side of Death Valley. *A*, at Salt Well; *B*, at Gravel Well; *C*, at Bennetts Well; *D*, at Eagle Borax; *E*, at Shortys Well; *F*, at Tule Spring; *G*, at Devils Speedway, *c*. creosotebush; *h*, desertholly; *cs*, cattle spinach; *m*, honey mesquite; *a*, arrowweed; *T*, tamarisk; *rg*, giant reed grass; *sa*, sacaton grass; *s*, saltgrass; *r*, rush; *p*, pickleweed; *b*, bare ground. TDS refers to total dissolved solids in ground water, in percent (except in *G* the water is ponded surface water). Soil salts, water-soluble, given in percent by volume.

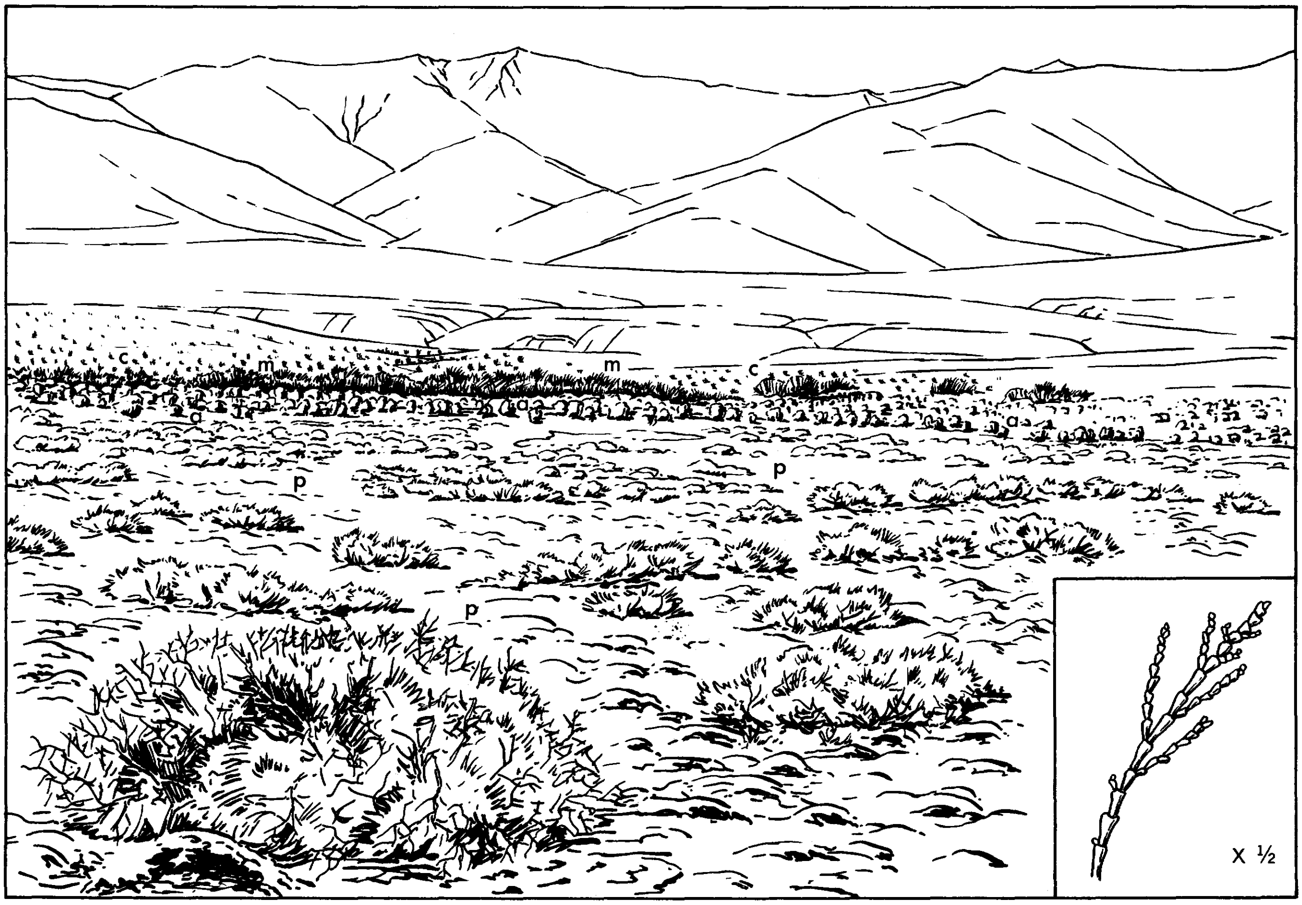

FIGURE 27.—Pickleweed (inset) and view west at Tule Spring showing successive zones of pickleweed (*p*), arrowweed (*a*), mesquite (*m*), and creosotebush (*c*). Sketch by John R. Stacy, from photograph.

Pickleweed is a sprawling shrub that seems to spread partly by runners a few inches below the surface and partly by branches lying on the ground (fig. 28). Individual plants are mostly less than a foot high but spread over many square feet. The plant is a curious succulent with jointed stems; the succulent greens and the root hairs have a density greater than water, probably because of mineral salts and dissolved salts. Depending on the season and availability of water the colors are grass green, yellow, brown, or red. Pickleweed (*Allenrolfea occidentalis*) resembles species of *Salicornia*. The latter, typically a seaside shrub, is not known in Death Valley, although it has been reported in other inland basins including Panamint Valley (Jepson, 1951, p. 331) 30 miles west of Death Valley.

Between the mounds of pickleweed the silty ground is covered by a crust of salt in blisterlike growths 1 or 2 inches high and 6 to 12 inches wide. This salt crust

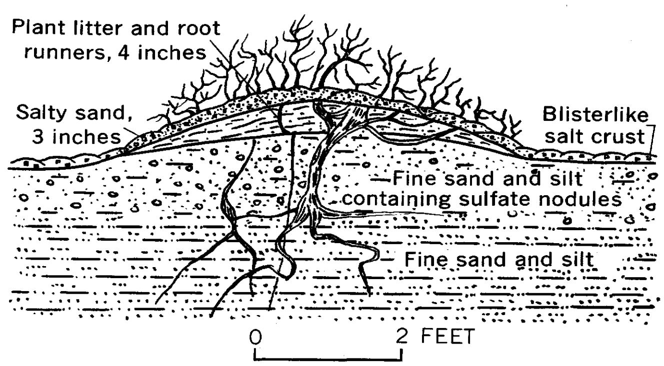

FIGURE 28.—Cross section of pickleweed mound showing the main root system.

contains as much as 20 percent of water-soluble salts (by volume). The upper limit of salinity in the silt around the roots of the pickleweed was not determined, but quantities as much as 3 percent (by volume) were obtained in spot tests. Ground water near the roots contains as much as 6 percent of salts, and salinities of nearly 10 percent have been obtained from water in these areas (table 12, W73g). These salinities are greater than those recorded in the Colorado Desert, where pickleweed also occurs on heavy-textured soils having an average salinity just under 2 percent (Marks, 1950, p. 184).

The silty ground retains moisture for long periods following rains. The water table is shallow and in most places the capillary fringe extends to the surface, at least seasonally. But the moisture, though abundant, most of the time probably is too saline for use even by the pickleweed. At least, the plant does not become green even when the ground moisture becomes as high as 10 percent.

At many places the plants grow on mounds 2 feet or more high. These are due to the accumulation of salt around the base of the plant. In part this salt may be due to the accumulation of salt-rich organic matter fallen from the shrub; in part it may be due to the wick effect of the root system causing water to rise and salts to be deposited along the roots. Some mounds are 4 or 5 feet in diameter and 2 or 3 feet high. The edge of Death Valley is dotted with eroded salt mounds marking the site of pickleweed plants; the mounds look like eolian accumulation but they are salt.

Southward from a point about a mile north of Salt Well the ground in the areas of pickleweed is sandy, and the pickleweed grows on saliferous sand dunes 1 or 2 feet high and 10 feet wide.

Analyses of ash from pickleweed plants in Death Valley are given in table 13. Total ash in the tops is as high as 40 percent and averages as high as in desertholly. This ash is mostly chloride. Carbonates and silica were not determined, but a moderate content of carbonates is needed for the anions to balance the cations (table 25). Evidently pickleweed contains little silica. Analyses of acid-soluble salts in soils around the roots of pickleweed are given in table 14.

A specimen of pickleweed, from the warm spring near West Side Borax Camp, was tested for iodine; it contained 80 parts per million.

Pickleweed seeds itself and grows readily. At Gravel Well, it has advanced westward away from the saltpan and has invaded some old dunes that once supported mesquite. It is common in the furrows of the old borax workings near Shoveltown and at Eagle Borax; it has overgrown an old trail just west of the West Side Highway half a mile south of the Trail Canyon road; and it grows on the road shoulders along the paved highway in the cove south of Copper Canyon.

On the other hand, some evidence of retreat of the panward edge of the pickleweed was noted at four localities: at the northeast foot of the Trail Canyon fan, the foot of Johnson Canyon fan, the cove south of Copper Canyon, and locally along the west edge of Cottonball Marsh. In these areas are many salt mounds which probably once were pickleweed mounds.

TAMARISK (Tamarix gallica and T. aphylla)

Two species of tamarisk grow in Death Valley. One, probably the athel tree (*Tamarix aphylla*), is evergreen. The other species is deciduous and probably is *T. gallica*. These so-called saltcedars form dense stands at five localities: Eagle Borax; a marsh northeast of Tule Spring; along Furnace Creek from Travertine Springs to Furnace Creek Ranch; Nevares Springs; and the National Park Service utility and residential areas. New stands are developing east of Gravel Well and at

TABLE 12.—*Semiquantitative and partial analyses, in percent, of water in areas of pickleweed*

[Analysts and analytical methods given on p. 3–4. Samples marked with suffix -56 collected January–February 1956, a dry year; others collected January–February 195 a wet year]

	W2–56s	W8g	W53s	W20–56g	W56g	W59g	W66g	W67s	W71s	W73g	W75s	W26–56g	W93g
Ca	>0.01	0.003	0.13	>0.05	0.09	0.11	0.03	0.05	0.07	0.01	0.13	0.025	0.15
Mg	.03	.003	.003	.03	.002	.01	.015	.025	.04	.02	.02	.025	.03
K	.07	.09	.03	.08	.06	.08	.02	.04	.1	.1	.04	.021	.05
Na	1.4	.8	.48	1.6	1.5	.96	.6	1.1	2.3	3.5	.8	.88	1.1
SO^4	.5	.4	.1	.6	.9	.2	.2	.6	1.2	1.0	.1	.14	.2
Cl	2.0	.02	1.2	2.2	1.4	1.6	1.0	1.6	1.6	3.2	1.2	1.4	2.8
B	.002	.03	.001	.03	.001	.001	.001	.001	.003	.001	.001	.0005	<.001
Sr	.004	<.001	.006	.01	.004	.01	.007	.002	.005	.004	.007	.012	.015
Total dissolved solids	4.0	2.4	1.7	5.0	4.5	3.2	2.0	3.4	7.1	9.8	3.7	2.5	4.2
pH	----------	8.2	6.8	----------	6.5	7.0	7.6	7.8	7.4	6.8	6.7	7.0	6.8

W2–56s. Surface water in Salt Creek in pickleweed at edge of the saltpan; N½ sec. 10, T. 16 S., R. 46 E.
W8g. Ground water in gravel under pickleweed; 1 ft below surface; 100 ft west of old road in SE¼ sec. 20, T. 28 N., R. 1 E.
W53s. Surface water ponded in channel near east edge of pickleweed. NW¼ sec. 28, T. 16 S., R. 46 E.
W20–56g. Ground water from spring at Badwater; pickleweed and seepweed in the marsh.
W56g. 1957 duplicate of W20–56g. Wet year.
W59g. Ground water, 15 in. below surface; in marsh at toe of fan, second cove south of Badwater.
W66g. Ground water, west edge of marsh at Coyote Hole, 4 miles southeast of Mormon Point; pickleweed. Compare with W65g, table 19.
W67s. Surface water, draining west from Coyote Hole; pickleweed.
W71s. Surface water ponded in Amaragosa River, East Distributary. SE¼ sec. 22, T. 22 N., R. 2 E. Pickleweed with saltgrass.
W73g. Ground water, underflow in Amaragosa River channel about 1 ft below surface. SE¼ sec. 27, T. 22 N., R. 2 E. Pickleweed grows along the banks.
W75s. Surface water in channel at northeast edge of pickleweed northeast of Salt Well.
W26–56g. Ground water in marsh ½ mile east of Gravel Well. Mixed pickleweed, saltgrass and rush.
W93g. 1957 duplicate of W26–56g. This marsh was drier in 1957 than in 1956.

TABLE 13.—*Semiquantitative and partial analyses, in percent, of ash from pickleweed*

[Analysts and analytical methods given on p. 3–4]

	P1	P2	P3	P11	P21	P24	P26	P27	P38	P39	P41	P102
Ca	1.6	2.7	4.5	1.4	1.8	1.6	2.6	1.4	5.6	2.7	1.9	4.8
Mg	3.6	1.8	4.4	2.0	2.8	1.7	3.3	1.1	3.7	3.7	2.7	3.6
K	3.4	.96	6.0	5.7	5.7	6.9	5.9	2.4	6.4	7.0	6.4	2.2
Na	33	30	22	35	32	32	29	33	25	32	33	18
SO_4	8.0	3.0	6.0	5.0	12.0	9.0	10.0	4.0	6.0	4.0	6.0	13
Cl	24.0	49.0	28.0	26.0	27.0	19.0	30.0	31.0	30.0	26.0	30.0	18
Cu	.002	.003	.01	.001	.001	.002	.002	<.001	.003	.002	.003	.003
Pb	<.002	.002	<.002	<.002	.002	.002	<.002	<.002	.002	<.002	<.002	.0015
Zn	.005	.002	.01	<.002	.002	.002	.002	<.002	.005	.005	.005	<.02
Ni	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	.0005
Mo	<.001	<.001	.001	<.001	<.001	<.001	.003	<.001	.001	.001	<.001	.0015
Zr	<.001	.01	.005	<.001	<.001	<.001	<.001	<.001	.001	<.001	<.001	.007
Co	<.001	<.001	>.001									<.0005
Fe	.07	.15	.7	.07	.15	.1	.05	.1	.3	.03	.05	
Mn	.02	.02	.15	.01	.01	.01	.02	.01	.02	.01	.03	.03
Cr	<.002	<.002	.003	<.002	<.002	<.002	<.002	<.002	<.002	<.002	<.002	.0015
V	<.001	<.001	.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001	.0015
Y	<.001	.001	<.001	.001	.001	.001	.001	.0015	.001	<.001	<.001	.001
Ti	.015	.07	.07	.02	.02	.015	.007	.015	.05	.005	.005	.07
B	.07	.1	.05	.07	.2	.1	.15	.02	.07	.05	.10	.05
Ba	<.002	.007	.015	.003	.005	.005	<.002	.005	.015	<.002	<.002	.02
Sr	.1	.2	.3	.3	.3	.3	.15	.15	.7	.5	.5	.15
Total ash	41.0	41.0	9.5	28.0	38.0	26.0	39.0	44.0	30.0	36.0	34.0	15

P1. Tops; at mound 1 mile north of highway at Devils Speedway. Compare with P2 and P3. See also R1 to R4, table 14.
P2. Roots; upper level laterals 6–10 in. below surface; same plant as No. 1.
P3. Roots; lower level laterals; 14 in. below surface; same plant as No. 1.
P11. Tops; toe of Echo Mountain Wash.
P21. Tops; growing with desertholly (P20, table 5). NW¼ sec. 20, T. 16 S., R 46 E. See also R14, table 14.
P24. Tops; east edge of saline facies of carbonate zone at north end of west-side marsh.
P26. Tops; east edge of marsh at Eagle Borax.
P27. Tops; at Tule Spring.
P38. Tops; in wash in flood plain a mile north of Salt Well.
P39. Tops; toe of third fan south of Badwater. Compare with P40, table 5.
P41. Tops; in marsh in cove north of Coffin Canyon.
P102. Roots and tops. Flood plain of Salt Creek 1 mile northwest of McLean Spring. Compare P101, table 21.

TABLE 14.—*Semiquantitative and partial analyses, in percent, of acid-soluble salts in soils around the roots of pickleweed*

[Analyst and analytical methods given on p. 3–4]

	R1	R2	R3	R4	R14	S106	S–51	S136a	S132b	S137a	S137b	S137c	S115c	S115d
Major constituents														
Ca	7.5	7.5	5.0	7.5	10	0.5	5.0	2.0	2.0	>10	>10	5	7.5	7.5
Mg	.8	1.0	1.0	1.0	3.5	.5	1.5	1.5	.7	.3	.2	2.0	.7	.7
K	.2	.3	.3	.2	.3	1.4	.4	.5	.7	.1	<.1	.3	.7	.3
Na	.4	.9	7	1.4	.1	28	2.3	.3	2.8	4.9	1.2	.7	.7	1.3
CO_3	16	12	8.4	13	20	8.1	2.8	4.0	.4	<.2	.2	8.2	16	1.8
SO_4	1.2	1.2	1.2	1.2	3.7	12	17	2.5	17	30	37	17	10	14
Cl	1.8	1.8	6.7	2.6	3.3	20	3.0	.6	2.2	3.4	2.4	1.0	.8	.8
Total	27.9	24.7	29.6	26.9	40.9	70.5	32.0	11.4	25.8	48.9	51.1	34.2	36.4	26.4
Minor constituents														
B	0.02	0.01	0.02	0.03	0.007	0.3	0.5	0.01	0.13	0.03	0.005	0.02	0.01	0.02
Ti	.1	.2	.1	.1	.1	.05	.15	.1	.1	.01	.007	.05	.15	.07
V	.003	.003	.002	.003	.003	.002	.003	.003	.002	.002	<.002	.003	.003	.002
Mn	.05	.07	.03	.05	.03	.001	.03	.05	.07	.001	.001	.001	.07	.03
Ni	.0005	.0005	<.0005	.0005	.0005	<.0005	.0005	.0005	<.0005	<.0005	<.0005	<.0005	<.0005	<.0005
Sr	.02	.02	.3	.03	.05	.03	.07	.03	.1	.5	.15	.05	3.5	.3
Ba	.03	.03	.03	.03	.03	.007	.03	.03	.03	.002	.002	.05	.15	.02

R1. Section of sand about roots of pickleweed in carbonate zone; by jeep trail on west side, 1 mile north of Devils Speedway. Gravel, underlying the sand, 2 ft 8 in. below surface. Tap root extends to top of this unit and spreads horizontally at the contact. (see P2 and P3, table 13.)
R2. Damp sand overlying R1; grit layer 1 in. thick 11 in. above base.
R3. Horizontally bedded sand and salt overlying R2; 4–5 in. thick; this is main level of horizontally spreading roots.
R4. Loose sand overlying R3; horizontally bedded, eolian?; 4 in. thick.
R14. West side Cottonball Basin; pickleweed and desertholly (P20, table 5 and P21, table 13) growing on same mound in bottom of a dry wash; soil from around their roots. NW1/4 sec. 20, T. 16 S., R. 46 E.
S106. Pickleweed mound, at roots, 1 ft below top of mound 2 ft high; 2 miles north of Salt Pools.
S–51. Salt-heaved sulfate zone under pickleweed, SW1/4 sec. 28, T. 16 S., R. 46 E.
S136a. Sample of 3 ft of damp sand and silt underlying the salt crust, in pickleweed ½ mile east of Gravel Well.
S132b. Silty sand on flood plain of Amargosa River, with pickleweed, SE1/4 sec. 22, T. 22 N., R. 2 E.
S137a. Sulfate marsh, with pickleweed, saltgrass, and rush; ½ mile east of Gravel Well. Crust on sulfate salts.
S137b. Same; interior of lump of sulfate salts.
S137c. Same; mud underlying the marsh salts.
S115c. Sulfate marsh in cove 2 miles south of Badwater; mud underlying the lumpy crust.
S115d. Same as 115c; lump of sulfate salts.

the marsh at the mouth of Cow Creek. At the Cow Creek marsh in January 1959 I counted 12 young tamarisk; the largest was 5½ feet high, 6 others were 3 feet high, and 5 were 6 inches high. In 1957 I noted only one tamarisk at this marsh.

Tamarisk is an introduced tree, brought to the United States from the Mediterranean and advertised in seed and nursery catalogues in California as early as 1856 (Bowser, 1957). Perhaps the trees were introduced into Death Valley after 1891 because they are not listed by Coville (1893). In the Colorado Desert, tamarisk grows in all kinds of soils—in clean sand, silty clay loam, and gravel overlain by silt, and where the salinity of the ground within about 4 feet of the surface averages 0.14 percent (Marks, 1950, p. 181).

Growing with the tamarisk at the Park Service areas and at Furnace Creek Rance and Inn are date palms, also introduced. Here and there in Death Valley in washes near these groves is a stray palm tree, evidently seeded by birds or by coyotes, who also eat the dates.

Prior to the introduction of the tamarisk trees the chief plant in these habitats evidently was honey mesquite. However, the tamarisk is well suited to this environment; it is a salt-tolerant phreatophyte that can be expected to spread to most or all the marshes around the saltpan.

INKWEED (Suaeda suffrutescens)

Inkweed (*Suaeda suffrutescens*) occurs in mixed stands spottily distributed along the boundary between the xerophytes and phreatophytes. There are stands along the foot of the fans along the west side of the valley from Hanaupah Canyon to Blackwater Wash and along the foot of the fans on the east side of the valley from Desolation Canyon northward to Cow Creek.

Inkweed has been regarded as a phreatophyte (Robinson, 1958, p. 40), but there is some question whether the Death Valley plants send their roots as deep as the water table. At many of the inkweed stands the depth to the water table is 25 feet. Many of the stands are on the gravel-fan sides of the honey mesquite where the ground water generally contains less than half a percent of dissolved solids; other stands grow where the xerophytic desertholly ends against the salt-tolerant pickleweed. In these places the ground water contains as much as 5 percent dissolved solids. At all the stands the soil is saliferous and contains 1 or 2 percent (by volume) of water-soluble salts. In the Colorado Desert inkweed grows on ground where the surface layers have an average salinity of about 0.9 percent (Marks, 1950, p. 181, 184).

The stands of inkweed are open—the space between shrubs is several times the width of the crowns. Desertholly generally is present with the inkweed except where the inkweed has spread far into the honey mesquite community.

Inkweed is high in sodium and chloride, like desertholly and picklewood, and has a higher proportion of iron than any other of the plants tested (table 15). The amount of ash is about the same as in cattle spinach. A single specimen tested for iodine contained less than 20 parts per million.

TABLE 15.—*Semiquantitative and partial analyses, in percent, of ash from inkweed* (Suaeda suffrutescens)

[Analysts and analytical methods given on p. 3–4]

	P34		*P34*
Ca	3.0	Zr	.003
Mg	4.5	Fe	1
K	9.0	Mn	.15
Na	20	Cr	.002
SO_4	7.5	V	.001
Cl	20	Y	.001
Cu	.004	Ti	.07
Pb	.002	B	.05
Zn	.005	Ba	.015
Ni	.002	Sr	.2
Mo	.001	Total ash	14.0

P34. Inkweed tops, including twig ends; more woody material than leaf; 500 ft east of West Side Highway, 2½ miles south of Bennetts Well; compare with P33, table 9 and P32, table 7.

RUSH (Juncus Cooperi)

Many marshes at the edge of the saltpan have small stands of rush, *Juncus Cooperi*. These stands are dense but are generally only 1 or 2 acres in extent and too small to be mapped. Saltgrass and (or) pickleweed commonly are associated with the rush. The general setting of these stands is illustrated on transects at Gravel Well and Tule Spring (fig. 26*B* and *F*), at Coyote Hole (fig. 25*C*), and along the east side of Cottonball Basin (transects *C*, *D*, and *E*, fig. 23). Figure 29 shows some rush bordered by saltgrass.

Judging by the position of the rush, its salinity tolerance is greater than that of saltgrass but less than that of pickleweed. Analyses of water at or near stands of rush are given in table 19. A single chemical analysis of ash from rush tops at Salt Springs (table 16) suggests that it contains a higher percentage of carbonates and lower percentage of silica than does the saltgrass (table 25). This ash contains as much manganese as does the cattle spinach (p. 18) and more boron than any other plants that were analyzed. Saltgrass at this same location contains only a tenth as much boron. (Compare with P9 and P10, table 17.) Evidently the chemical composition of the roots and tops of the rush are quite different because the analysis of the mixed parts (P103) is not like the analysis of the tops (P12).

TABLE 16.—*Semiquantitative and partial analyses, in percent, of ash from rush* (Juncus Cooperi)

[Analyses and analytical methods given on p. 3–4]

	P12	*P103*		*P12*	*P103*
Ca	4.5	4.0	Zr	.001	.015
Mg	2.3	3.5	Fe	.1	---------
K	19	2.2	Mn	.3	.07
Na	8	13	Cr	.002	.002
SO^4	13	5.9	V	.001	.0015
Cl	8.8	16	Y	.001	.0015
Cu	.004	.005	Ti	.03	.15
Pb	.002	.002	B	1	.2
Zn	.005	<.02	Ba	.007	.003
Ni	.002	.0005	Sr	.15	>1
Mo	.001	.0007	Total ash	6.1	24

P12. Rush tops, at Salt Springs in SE¼ sec. 20, T. 28 N., R. 1 E.
P103. Roots and tops; marsh 1 mile northwest of National Park Service Headquarters.

Although rush and saltgrass commonly grow together their root habits are quite different (fig. 30). Saltgrass is characterized by spreading laterals whereas the rush roots extend downward.

SALTGRASS (Distichlis stricta)

Saltgrass (*Distichlis stricta*) grows with most of the other phreatophytes. However, pure stands sufficiently extensive to be mapped separately are around the foot of Furnace Creek fan and around parts of the east and north sides of Cottonball Basin (fig. 29).

The ground in the saltgrass areas is that of the sand facies of the carbonate zone. The grass grows on the sand and in the washes containing fine gravel that cross it. The ground between the washes is level, but in detail the surface is hummocky with a microrelief of 2 to 4 inches.

The soil is sandy but contains a good deal of silt and salt and retains moisture moderately well. It contains less than a percent of organic matter. Much of the time, especially around Cottonball Basin, the surface is coated with a white efflorescence of sodium salts, including the carbonate and sulfate of sodium as well as the chloride.

At the surface is a layer 3 to 6 inches thick of limy sand with some salt and below this is a layer of caliche 3 to 6 inches thick composed very largely of sulfate salts, mostly sodium sulfate (thenardite) in Cottonball Basin and mostly calcium sulfate (gypsum) in Badwater Basin. Under this is limy sand. The saltgrass spreads by "runners" (rhizomes) (fig. 30) that commonly spread at the base of this sulfate caliche layer. From these "runners" rise stems that penetrate the caliche to reach the surface. As a result, small clumps of saltgrass tend to be arranged linearly (fig. 29).

Saltgrass in Death Valley grows in ground where the surface layer contains as much as 3.8 percent (by volume) of water-soluble salts, and with its roots in ground

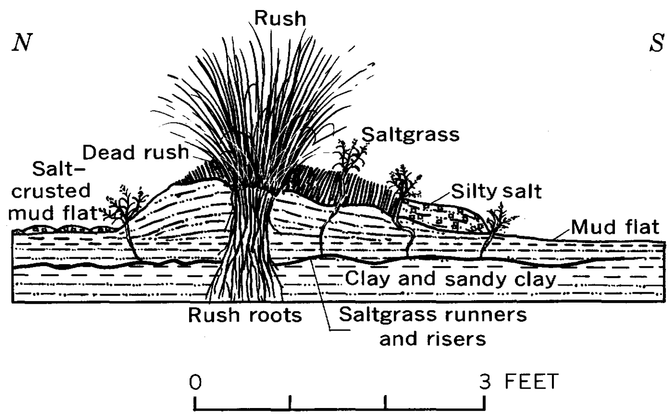

FIGURE 30.—Sketch illustrating difference in root habits of a rush and saltgrass.

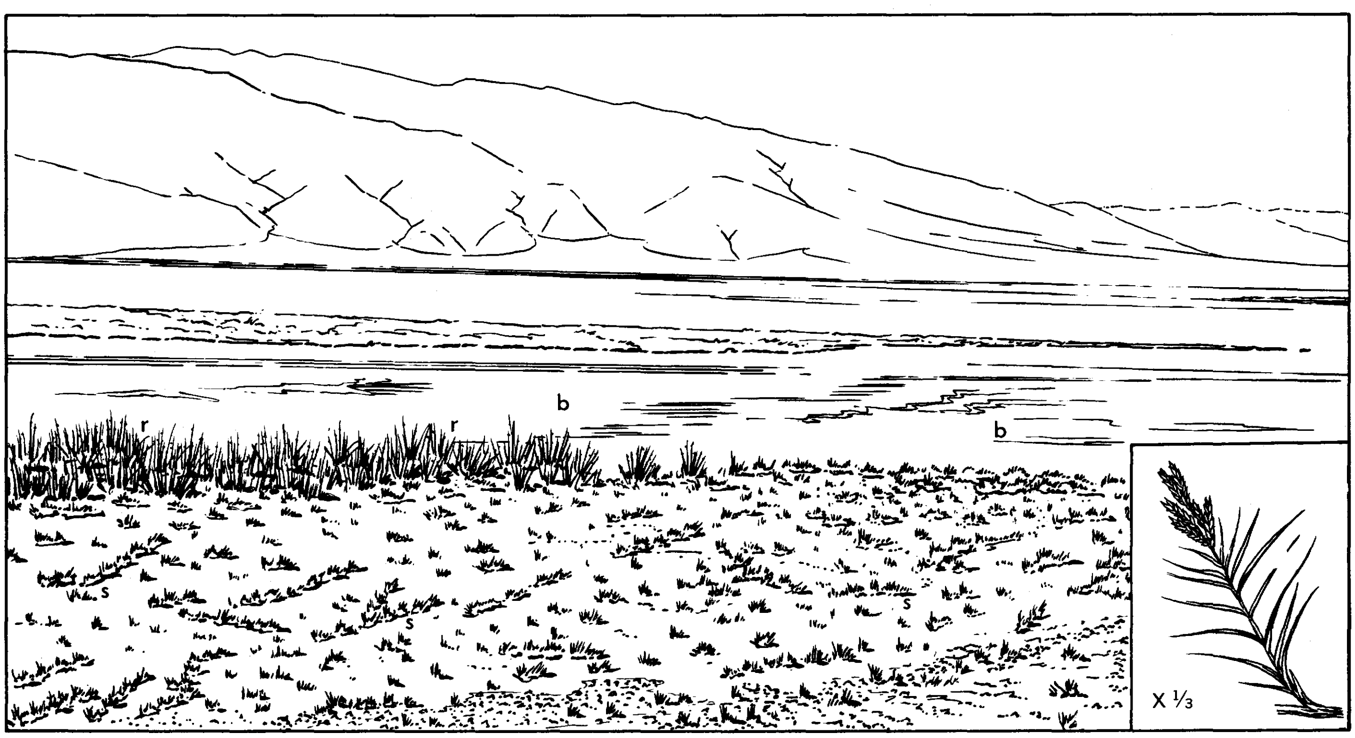

FIGURE 29.—Saltgrass (inset) and view west across saltgrass (*s*) to rush (*r*) on the east side of Cottonball Basin. Ground water under this saltgrass has about 3 percent total dissolved solid; the surface water beyond the rush contains about 6 percent total dissolved solids and ground there is bare (*b*). Sketch by John R. Stacy, from photograph.

water that contains as much as 4.8 percent (by weight) total dissolved solids. (See W60g table 19; transects *C*, *D*, *E*, fig. 23; and transect *B*, fig. 26.) Saltgrass also grows along stretches of the Amargosa River where, in dry seasons, ponded surface water contains 7 percent of salts. (See W71s, table 19.) These tolerances are somewhat higher than reported in other areas. (See, for example, Meinzer, 1927, and Robinson, 1958, p. 56–57.)

The depth of the water table in most of the stands of saltgrass is only 1 or 2 feet, but locally, as on the north side of Cottonball Basin, it may exceed 10 feet. This range in depth to the water table under saltgrass in Death Valley accords with observations elsewhere (Robinson, 1958, p. 57–58). The roots, at many places, do not reach the water table but are in the capillary fringe above it.

Along the east side of Cottonball Basin gravel is being washed from the fans onto the sand of the carbonate zone, and desertholly there is spreading panward at the expense of the saltgrass.

Total ash from saltgrass (table 17) is comparable to that from arrowweed and much less than that from pickleweed. Although carbonates and silica were not determined, the analyses suggest the presence of a moderate proportion of carbonates and a very high proportion of silica, especially in the tops. Only a small amount of carbonate is needed with the sulfate and chloride to balance the cations, and the remainder of the ash, more than 50 percent in the tops, probably is largely silica (table 25).

Saltgrass roots have a high ratio of alkalis to calcium in the areas east of Cottonball Basin, a sodium carbonate and sodium sulfate area (sample P10, table 17), whereas the ratio is reversed in roots on the west side of Badwater Basin (sample P35, table 17) where the carbonates and sulfates in the soil are those of calcium (table 17).

Table 17.—*Semiquantitative and partial analyses, in percent, of ash of saltgrass*

[Analysts and analytical methods given on p. 3–4]

	P9	P10	P15	P18	P35	P42
Ca	1.1	2.1	1.1	3.4	14.0	2.2
Mg	.9	1.2	1.1	1.2	6.8	1.5
K	2.8	17	.68	3.1	2.0	2.8
Na	5.3	5.6	2.8	9.2	4.0	6.4
SO_4	3.5	3.5	2.0	5.5	6.0	7.0
Cl	5.2	9.2	3.2	11	6.8	14
Cu	.006	.003	.002	.006	.002	.003
Pb	<.002	<.002	<.002	<.002	<.002	<.002
Zn	.002	.002	.002	.002	.005	.008
Ni	<.002	<.002	≤.002	≤.002	≤.002	≤.002
Mo	.001	.001	<.001	<.001	<.001	<.001
Zr	.003	.03	.003	.005	.015	.002
Fe	.7	5.0	.5	1.0	2.0	.5
Mr	.07	.05	.05	.07	.03	.2
Cr	.002	.005	<.002	.002	.005	.002
V	.001	.007	.001	.001	.007	<.001
Y	.001	.005	.0015	.001	.002	.001
T	.07	.3	.07	.1	.15	.05
B	.07	.1	.07	.2	.07	.07
Ba	.02	.07	.01	.03	.07	.01
Sr	.1	.07	.05	.07	.2	.3
Total ash	7.7	40.0	15.0	11.0	16.0	11.0

P9. Tops; at Salt Springs; SE¼SE¼ sec. 20, T. 28 N., R. 1 E. Compare with R10, table 18.
P10. Roots at No. 9.
P15. Tops, very dry; toe of Cow Creek fan; NW¼NW¼ sec. 4, T. 27 N., R. 1 E.
P18. Tops; at spring at west edge of hill at Harmony Borax Mill; NW¼NW¼ sec. 9, T. 27 N., R. 1 E.
P35. Roots (rinsed); marsh east of Gravel Well.
P42. Tops; in marsh in cove next north of Coffin Canyon. Compare with pickleweed P41, table 13.

Some analyses of soils from around the roots of saltgrass are given in table 18; analyses of water at some stands of saltgrass are given in table 19.

SACATON GRASS (Sporobolus airoides)

At a few places in the phreatophyte belt around the edge of the saltpan, especially near Eagle Borax and Bennetts Well (fig. 31), stands of sacaton grass are sufficiently extensive to be shown on the map (pl. 1).

Table 18.—*Semiquantitative and partial analyses of acid-soluble salts, in percent, in soils around the roots of saltgrass*

[Analysts and analytical methods given on p. 3–4]

	R10	R11	S1	S2	S3	S4	S6	S8	S137a	S137b	S137c
Ca	5	7.5	2.2	1.1	0.5	2.1	0.3	1.1	>10	10	5
Mg	.7	2.0	1	.8	.4	1.3	.1	.5	.3	.2	2
K	.5	.5	.3	.3	.2	.2	4.5	.8	.13	<.1	.3
Na	.6	.5	1	17	28	1.3	33	26.0	4.9	1.2	.7
CO_3	5.0	13	2.2	1.6	.6	2.8	5.8	5.8	<.2	.2	8.2
SO_4	1.2	.6	2.4	25	34	6.7	16	10	30	37	17
Cl	2.0	2.2	5.8	4.4	3.8	2.4	33	24	3.4	2.4	1.0
B	.03	.02	.1	.1	.75	.05	.3	.7	.03	.005	.02
Ti	.2	.1	.3	.15	.03	.3	.01	.3	.01	.007	.05
V	.003	.003	.007	.005	.001	.01	<.001	.01	.002	<.002	.003
Mn	.07	.05	.07	.05	.005	.07	.001	.01	.001	.001	.01
Ni	.001	.0005	.003	.001	<.0005	.002	<.0005	<.0005	<.0005	<.0005	<.0005
Sr	.07	.3	.02	.03	.01	.1	.01	.02	.5	.15	.05
Ba	.05	.05	.03	.02	.007	.05	.001	.01	.002	.002	.05
Total soluble salts	15.45	27.00	15.4	50.5	67.6	17.5	97.8	68.7	49.5	51.3	34.3

R10 By old road, at inner edge of saltgrass at Salt Springs, 2 miles north of National Park Service Headquarters; water in gravel 3 ft below surface. (See W9g, table 19.) Soil below the caliche layer and around the roots of saltgrass at P9, table 17.
R11 Sand and silt channel sample, 24 in. deep; in saltgrass area at mouth of Cow Creek. W20g, table 20, is ground water sample from this sand and silt.
S1 Carbonate zone; damp sand under the calichelike layer. 750 ft southeast of bench mark 241, E½ sec. 11, T. 16 S., R. 46 E. (Compare with S2.)
S2 Calichelike layer in carbonate zone at S1.
S3 Calichelike layer in carbonate zone, 6 in. thick. SE¼ sec. 11, T. 16 S., R. 46 E.
S4 Sand in carbonate zone, underlies the calichelike layer. SW¼ sec. 12, T. 16 S., R. 46 E.
S6 Efflorescence on flood plain at Salt Springs. SE¼ sec. 20, T. 28 N., R. 1 E.
S8 Sand. NE¼ sec. 29, T. 28 N., R. 1 E.
S137a Marsh, with pickleweed, saltgrass, and rush; crust on lumpy salt structure. ½ mile east of Gravel Well.
S137b Interior of lumpy salt structure at S137a.
S137c Mud underlying the marsh salts at S137a.

Table 19.—*Semiquantitative and partial analyses, in percent, of ground water and surface water at some stands of saltgrass*

[Analysts and analytical methods given on p. 3–4. Samples collected January–February 1957, a wet year]

	W7g	W9g	W17g	W23s	W60g	W65g	W71s	W93g
Ca	0.003	0.002	<0.001	0.001	0.04	0.03	0.07	0.15
Mg	.001	<.001	<.001	.001	.04	.01	.04	.03
K	.04	.11	.06	.03	.10	.02	.10	.05
Na	.4	.86	.84	.42	1.5	.54	2.3	1.1
SO_4	.5	1.2	.2	.7	.2	.3	1.2	.2
Cl	.02	.01	1.2	.2	1.6	1.1	1.6	2.8
B	.001	.001	.004	.003	.001	<.001	.003	<.001
Sr	<.001	<.001	<.001	<.001	.01	.007	.005	.02
Total dissolved solids	1.3	2.7	2.4	1.3	4.8	1.8	7.1	4.2
pH	8.1	8.0	8.5	8.5	7.0	7.0	7.4	6.8

W7g. Ground water in gravel 3 ft below surface at boundary between xerophyte and phreatophyte zones; 200 ft east of W9g.
W9g. Ground water 10 in. below surface; mixed saltgrass and rush. SE¼ sec. 20, T. 28 N., R. 1 E.
W17g. Ground water 1 ft below surface; saltgrass. NE¼ sec. 32, T. 28 N., R. 1 E.
W23s. Surface water, saltgrass growing in it. NE¼ sec. 4, T. 27 N., R. 1 E.
W60g. Marsh in cove north of Coffin Canyon; mixed saltgrass, pickleweed, and rush.
W65g. Marsh at Coyote Hole 4 miles southeast of Monmon Point; mixed saltgrass, giant reed grass, rush, and pickleweed. Compare with W66g and W67s, table 12.
W71s. Surface water ponded in Amargosa River; mixed saltgrass and pickleweed. SE¼ sec. 22, T. 22 N., R. 2 E.
W93g. Marsh ½ mile east of Gravel Well; mixed saltgrass, rush, and pickleweed.

Sacaton grass occurs locally with other phreatophytes near Shortys Well and at the mouth of Cow Creek, but it is not abundant.

The sacaton grass grows in dense clumps 1½ feet wide; the grass is 4 feet high. No analyses of the grass or of the ground in which it grows were obtained, but the location of the stands is like that of arrowweed, and the ground and ground-water probably are as saline as in the areas of arrowweed. If so, the amounts are somewhat greater than have been reported elsewhere (Robinson, 1958, p. 39).

There is some question whether the sacaton grass in Death Valley is native or was introduced by Indians. Yuma Indians who frequented Death Valley raised sacaton grass (Forde, 1931, p. 114; Hunt, A. P., 1960, p. 15–16), and a reason for suspecting that they may have introduced the grass in Death Valley is the fact that the grass is restricted to those places most frequented by the Indians. The grass was used for its seed, and the long stalks were used to line pits for storing mesquite beans (Hunt, A. P., 1960, p. 177–188).

ARROWWEED (*Pluchea sericea*) AND FOUR-WING SALTBUSH (*Atriplex canescens*)

Arrowweed (*Pluchea sericea*) (fig. 32) and four-wing saltbush (*Atriplex canescens*) (fig. 33) grow on the saltpan side of the honey mesquite. Both the ground and the ground water are more saline than where there is mesquite. The ground under four-wing saltbush is much sandier than that under arrowweed; in Death Valley the ground under arrowweed contains a good deal of silt, and the surface is roughened and

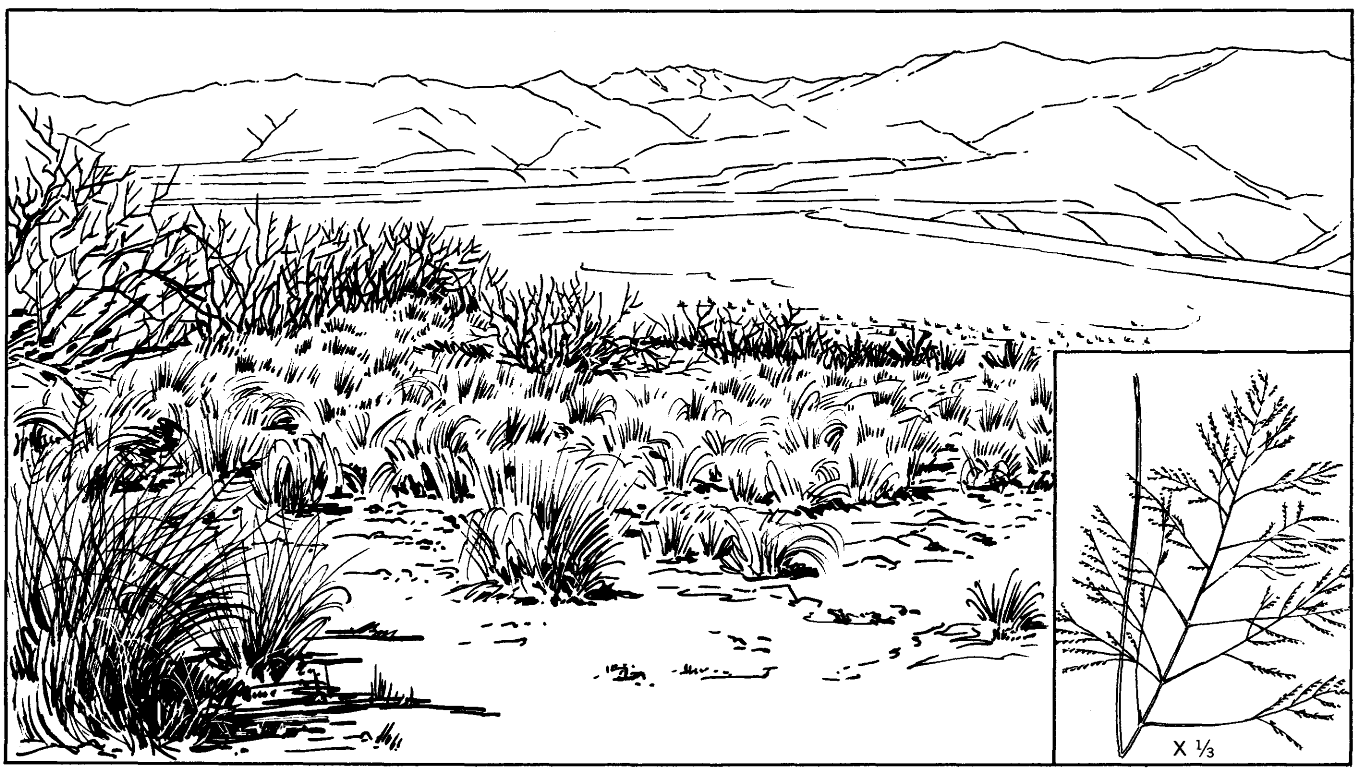

Figure 31.—Alkali sacaton grass (inset) and view southwest across a pure stand of the grass in front of honey mesquite near Bennetts Well. Salinity of the ground water at this place probably is more than 0.03 percent and less than 0.5 percent. Sketch by John R. Stacy, from photograph.

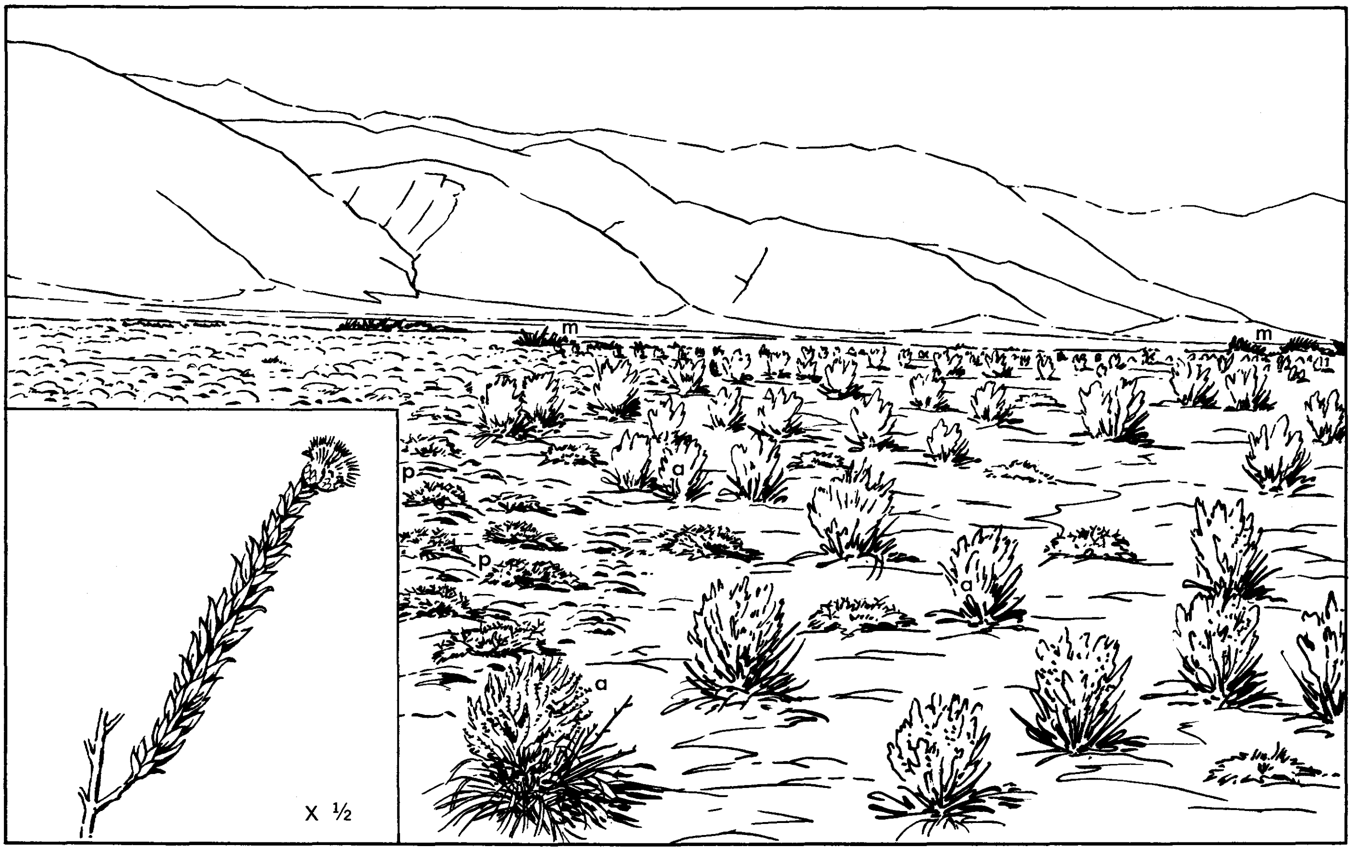

FIGURE 32.—Arrowweed (inset) and view southeast across arrowweed (*a*) stand (right) north of Tule Spring. Pickleweed (*p*) at left extend eastward to the edge of the saltpan. Mesquite trees (*m*) are at Tule Spring. Sketch by John R. Stacy from photograph.

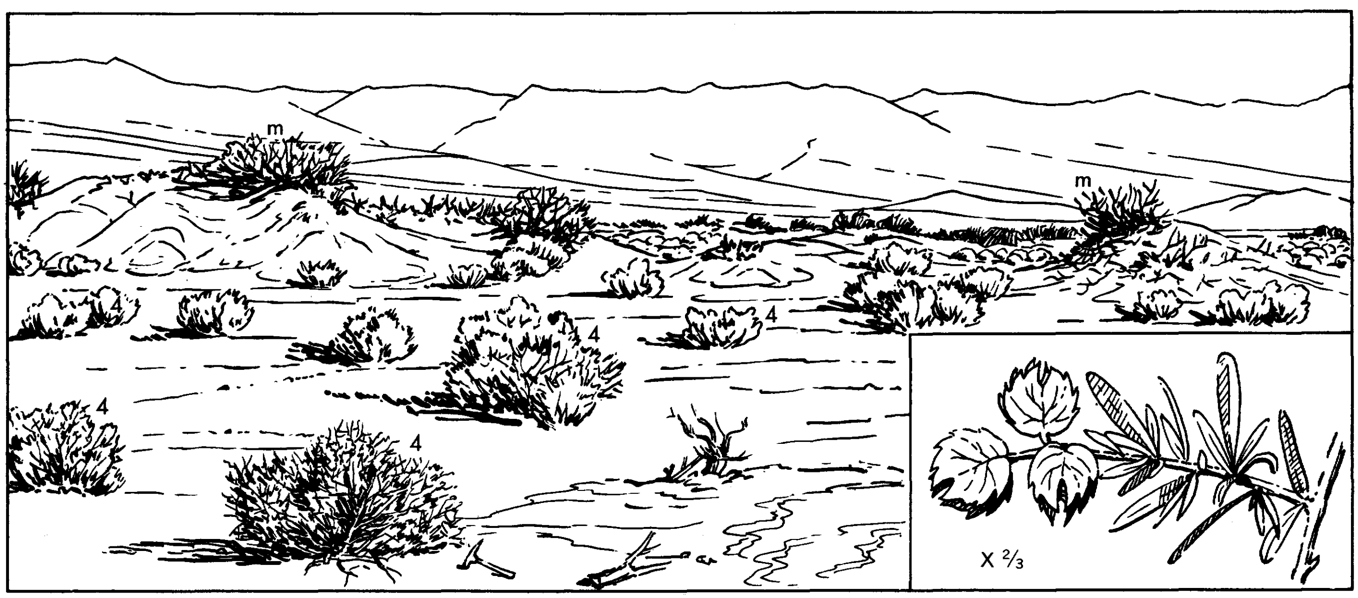

FIGURE 33.—Four-wing saltbush (inset) and view of mixed four-wing saltbush (4) and honey mesquite (*m*) along Salt Creek between the Salt Creek Hills and saltpan. Sketch by John R. Stacy, from photograph.

covered by a crumbly crust of salty silt. In Death Valley, four-wing saltbush is most common in those parts of the phreatophyte zone that adjoin stands of cattle spinach. Four-wing saltbush grows in substantial stands at four places: at the mouth of Salt Creek, on part of Furnace Creek fan, between the cattle spinach and pickleweed southeastward from Salt Well, and along the Amargosa River.

The ground surface in these areas is smooth and slopes gently panward. Microrelief usually is no more than a few inches except where sand is heaped around the plants. The area known as the Devils Cornfield, located by State Route 190 where it crosses Salt Creek a few miles west of the area shown on plate 1, is an extreme example of this. The mounds there are several feet high. In the area shown on plate 1 the mounds at the shrubs are only a foot or so high.

Except on Furnace Creek fan, well-defined washes in these areas are few. The slight wrinkling of the surface because of salt heaving in the surface layer is sufficient to disintegrate drainage that collects on the ground, and probably there is little surface runoff; most of the water seeps into the ground.

Total dissolved solids in ground water under arrowweed ranges from 0.2 to 1.8 percent. (See table 20; also transects *D* and *E*, fig. 23; transects *A* and *B*, fig. 24; and transect *F*, fig. 26.) The general quality of the ground water also can be estimated from the analyses of samples from neighboring locations. (See table 22 for analyses of water under the honey mesquite and table 12 for analyses of water under pickleweed.)

TABLE 20.—*Semiquantitative and partial analyses, in percent, of surface and near-surface brines in stands of arrowweed*

[Analysts and analytical methods given on p. 3-4. Samples collected January-February 1957, a wet year]

	W1s	W20g	W102g
Ca	--------	0.001	0.001
Mg	--------	.004	.001
K	0.06	.01	--------
Na	.5	.12	--------
SO_4	.4	.05	.04
Cl	.7	.02	.10
Total dissolved solids	1.8	.38	.20
pH	7.8	8.2	6.8

W1s. Surface water, Salt Creek at bridge 1,000 ft southeast of McLean Spring at west edge of Salt Creek Hills; arrowweed, pickleweed, and saltgrass on the flood plain here.
W20g. Ground water 10 in. below surface at boundary between arrowweed and saltgrass; near mouth of Cow Creek NW¼ sec. 4, T. 27 N., R. 1 E.
W102g. Tule Spring.

Water-soluble salts in the surface layer of the soil around arrowweed are as high as 9 percent (by volume) and generally exceed 3 or 4 percent. Where the ground is very saliferous the arrowweed may be accompanied by some saltgrass and pickleweed. These salts however are concentrated in the top one-half inch; the amount decreases rapidly downward. A few inches below the surface the quantity of soil salts (by volume) is less than 1 percent and at the water table is less than half a percent.

Chemical composition of the soils around arrowweed is intermediate between that around honey mesquite (table 23) and that around pickleweed (table 14).

Stands of arrowweed are open; the crowns rarely touch. A good stand includes 75 to 100 shrubs per acre. Saltgrass is common both with arrowweed and four-wing saltbush; inkweed is not uncommon with arrowweed. Pickleweed also grows with these plants, which end panward in a sharp boundary at the edge of pure stands of picklewood. This boundary represents the panward limit of the arrowweed or four-wing saltbush and not the limit of the pickleweed.

The boundary between the arrowweed and pickleweed is definite within a width of about 100 feet, and it appears to be stable. No evidence was found indicating a shift of its position either towards the saltpan or away from it. The boundary between the arrowweed and mesquite is equally definite. Where mesquite has died and where the dunes have become reduced in height and stabilized, arrowweed has moved onto the ground formerly occupied by honey mesquite.

On the east side of Cottonball Basin, below the dunes with honey mesquite, Recent gravels are being washed onto the sandy, arrowweed ground. At this place the arrowweed has retreated panward and has been replaced by desertholly (fig. 23*D*), a plant succession determined by geologic causes.

Generally the arrowweed ends panward at pure stands of pickleweed, but on the east side of Cottonball Basin it is bordered by rush and saltgrass (fig. 23*D* and *E*). The three plants may grow on the same mound, and the rush and saltgrass survive even after the arrowweed has died.

The animal population in arrowweed stands is small, probably because the ground is more saline than in the nearby areas where there is honey mesquite.

Arrowweed has moderate ash content (table 21). Sulfate is high; the chloride content is low. Carbonates and silica were not determined but they too must be low (table 25). Apparently the high sulfate content affects palatability because the plants are little browsed even though there is little other green food in the area. The Indians preferred the salt-rich alkali sacaton or desertholly for lining mesquite pits (Hunt, 1960, p. 177–188); perhaps the sulfate-rich arrowweed imparts an undesirable flavor to the mesquite beans.

The proportion of the different cations in the ash is of interest, for the alkalis greatly exceed calcium in the specimen from the Cow Creek Marsh (sample P16, table

TABLE 21.—*Semiquantitative and partial analyses, in percent, of ash from arrowweed and four-wing saltbush*

[Analysts and analytical methods given on p. 3–4]

	Arrowweed						Four-wing saltbush
	P16	P25	P28	P31	P101	P117	P109
Ca	7	18	18	13	4.4	10	9.2
Mg	4.8	4.1	4.2	5.3	2.8	5.1	3.8
K	11	7.2	6.4	11	2.0	4.2	13
Na	15	6.2	8	9.2	4.6	14	17
SO_4	20	40	37	48	9.1	45	5.5
Cl	6.4	9.6	8	6.8	7	4.3	12
Cu	.006	.02	.015	.02	.005	----------	.003
Pb	.002	.002	.002	.002	.002	----------	.0015
Zn	.015	.01	.018	.008	.02	----------	.02
Ni	.002	.004	.002	.004	.001	----------	.0005
Mo	.006	.001	.001	.001	.0015	----------	.0005
Zr	.001	.001	.001	.001	.015	----------	.003
Fe	.7	.5	.5	.5	----------	----------	----------
Mn	.05	.05	.03	.03	.05	----------	.05
Cr	.002	.002	.002	.002	.003	----------	.002
V	.001	.001	.001	.001	.002	----------	.001
Y	.001	.001	.001	.001	.001	----------	.001
Ti	.05	.05	.03	.03	.15	----------	.02
B	.07	.1	.7	.1	.02	----------	.1
Ba	.015	.02	.015	.01	.03	----------	.003
Sr	1	.5	.7	.5	.2	----------	.7
Total ash	8	11	10	12	45	12	17

P16. Tops; edge of carbonate marsh at mouth of Cow Creek; NW¼ sec. 4, T. 27 N., R. 1 E.
P25. Tops; 100 feet south of Shortys Well.
P28. Tops; at Tule Spring.
P31. Tops; at west edge of mesquite west of Tule Spring.
P101. Roots; flood plain of Salt Creek 1 mile northwest of McLean Spring.
P117. Tops; from travertine mound at Nevares Spring.
P109. Tops; of four-wing saltbush, by Salt Creek 1 mile east of the Salt Creek Hills.

21), whereas calcium exceeds the alkalis in the specimens from the west side of Badwater Basin (samples P25, 28, and 31, table 21; see also table 25). The Cow Creek Marsh is a sodium carbonate and sodium sulfate marsh whereas the west side of Badwater Basin is an area high in calcium carbonate and calcium sulfate. The uptake of sulfate by arrowweed is high and about the same in both areas; at Cow Creek, however, it is alkali sulfate whereas on the west side of Badwater Basin the sulfate is that of calcium. If the soil moisture in both areas is saturated with sulfate, as seems likely, the sulfate content must be very much greater in the Cow Creek area than along the west side of Badwater Basin, because of the greater solubility of sodium sulfate. Since the sulfate content of the plants in both areas is the same, the plants in the Cow Creek area would appear to be rejecting considerable sulfate in the soil solution.

A similar difference in proportion of calcium to sodium has been noted in analyses of roots of saltgrass from the two areas (p. 36).

The specimen from Cow Creek, like the desertholly in that area (p. 16), is high in molybdenum, as is the ground water there.

Arrowweed contains more copper and zinc than do the other plants tested. The single specimen of roots that were analyzed (table 21, sample P101) contains a much higher proportion of chloride to sulfate than do the tops.

Only one specimen of four-wing saltbush was analyzed (table 21, sample P109). It contains about the same amount of ash as do the tops of arrowweed but contains more chlorides than sulfates.

HONEY MESQUITE (Prosopis juliflora)

Honey mesquite (*Prosopis juliflora*) grows around the edge of the saltpan where ground water is shallow and not too saline (fig. 22). Mesquite roots may extend as deep as 50 feet (Meinzer, 1927; Robinson, 1958), but at the honey mesquite stands around the edge of the Death Valley saltpan the water table is much nearer the surface than this. Nevertheless the roots grow to enormous lengths. Coville (1893, p. 47) found one 51.8 feet long and ½ inch thick at the small end. I have measured runners 30 feet long and ¼ inch thick.

Honey mesquite is the least salt tolerant of the phreatophytes growing at the edge of the saltpan. Table 22 gives some analyses of ground water from these stands in general the water contains less than half a percent of dissolved solids.

Several of the different kinds of environments that support mesquite are illustrated in the transects across the east edge of Cottonball Basin and across the west edge of Badwater Basin (figs. 23, 24, 26). Most of the

TABLE 22.—*Semiquantitative and partial analyses, in percent, of ground water under honey mesquite*

[Analysts and analytical methods given on p. 3–4. Samples collected January-February 1957, a wet year]

	Salt Well (W74g)	Bennetts Well	Eagle Borax	Shortys Well	Mouth of Cow Creek (W19g)
Ca	0.04	0.003	0.01	0.007	0.001
Mg	.008	.001	.003	.003	.001
K	.01	------	.01	.01	------
Na	.14	------	.09	.01	------
SO_4	.10	.20	.20	.06	.20
Cl	.20	.01	.01	.02	.02
Total dissolved solids	.6	.03	.54	.07	.15
pH	6.8	7.9	6.9	6.9	7.5

Salt Well; water 9 ft below surface.
Bennetts Well; water 6.6 ft below surface.
Eagle Borax; spring water.
Shortys Well; water 6 ft below surface.
Mouth of Cow Creek.

mesquite is on stabilized sand dunes 10 to 20 feet high and 50 to 75 feet wide (fig. 34). At the foot of the Johnson, Starvation, and Hanaupah Canyon fans, the ground water is in sandy and silty playa beds underlying the dunes (fig. 26); near National Park Service Headquarters (fig. 24) the ground water is perched on top of the playa beds and at the base of gravel. Still a different type of environment is represented by the stands of honey mesquite between Gravel Well and Bennetts Well and those north of Tule Spring. At these places the trees are on silty ground covered with a salt crust, but evidently the mesquite roots are in buried gravel or sand—channellike aquifers containing water without much salt—for the trees are alined as if along buried channels (fig. 35).

Although the dune sand is even-textured clean sand, it contains much organic matter in layers of leaf litter that have become buried by the shifting sand. The organic matter is dry and decays slowly. The dunes are largely stabilized and do not provide good examples of plants adapted to active sand dune. (See Cowles, 1899; Kurz, 1942.)

The honey mesquite that grows on salt-crusted ground is accompanied by few other shrubs, mostly pickleweed, but locally arrowweed. The mesquite in the dunes however has a considerable variety of associated shrubs including arrowweed, four-wing saltbush, inkweed, sacaton grass, saltgrass, and the xerophytes desertholly, creosotebush, and cattle spinach. These shrubs and grasses are mostly in the depressions between the dunes and are not, strictly speaking, an understory beneath the mesquite. If the scale of the map (pl. 1) were larger many of these areas between the dunes could be shown separately.

Some of the highest ground temperatures in Death Valley are on dunes. No measurements have been made in summertime on this kind of ground, but ground-surface temperatures on the sand in February are as high as 170°F.

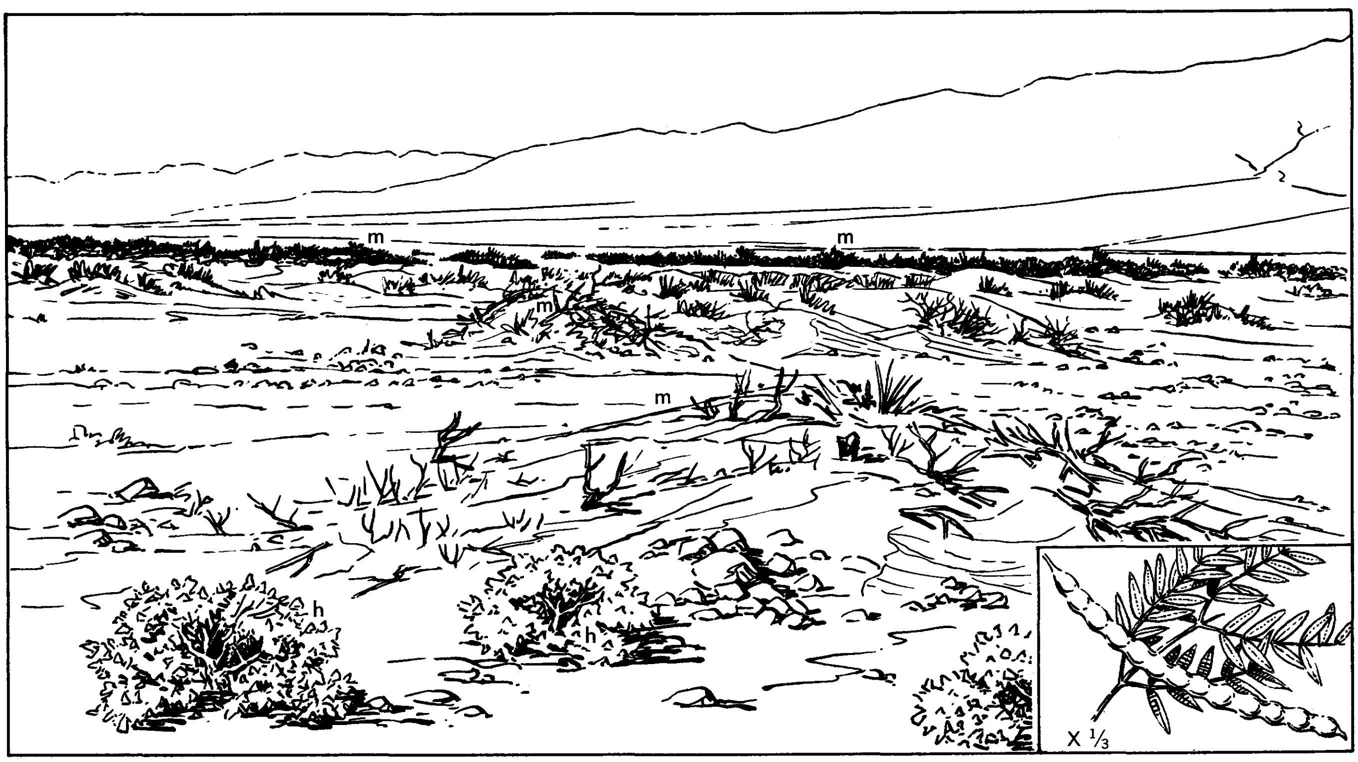

FIGURE 34.—Honey mesquite leaf and bean (inset) and view across stabilized sand dunes with mesquite (*m*) on Furnace Creek fan. Desertholly (*h*) in foreground. Sketch by John R. Stacy, from photograph.

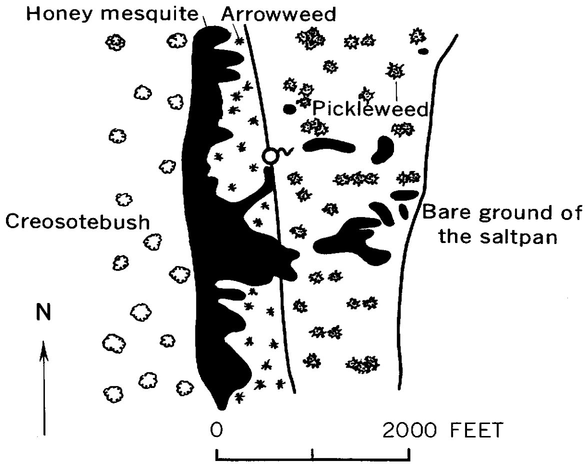

FIGURE 35.—Map showing distribution of honey mesquite in the vicinity of Tule Spring. The creosotebush is in the gravel; the honey mesquite and arrowweed are in sandy ground; the pickleweed is in silt. The ground slopes east from about 250 feet below sea level where there is creosotebush to about 270 feet below sea level in the saltpan. Boundaries limiting the plants are remarkably straight except for the east edge of the mesquite. Stands of mesquite that extend east probably mark the position of aquifers—channellike deposits of gravel that are discharging good quality water under the arrowweed and pickleweed, both of which are in highly saliferous ground. (For general pattern see transect, *F*, fig. 26.)

These dunes with mesquite trees show some striking differences in the microclimate of the ground surface and of the air near the ground. Figure 36 illustrates some variations that were measured at one of the dunes at a time when the air temperature was not quite 70°F. Despite the considerable differences between the north and south sides of the dunes there are no noticeable differences in the distribution of the perennial shrubs. Evidently, the range of microclimate around the dunes is well within the range of tolerance of the perennial shrubs associated with the honey mesquite.

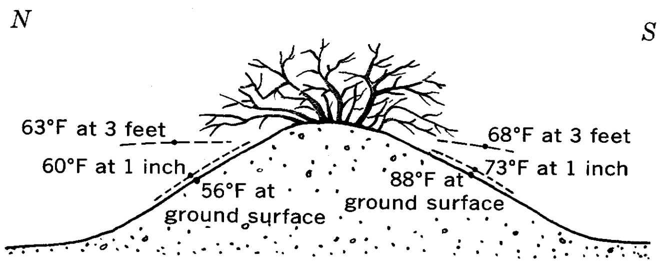

FIGURE 36.—Variations in temperature (in °F) measured at a sand dune covered by honey mesquite, 1:30 p.m., November 22, 1957. Location is by Salt Creek at west edge of Salt Creek Hills; altitude 90 feet below sea level.

The dunes with honey mesquite provide homes for a considerable population of rodents and other small mammals (Grinnell, 1937). Many or most of the rodents are nocturnal. They live in the highly humid deep parts of the dunes and some need no drinking water (Schmidt-Nielsen and Schmidt-Nielsen, 1950). Birds and insects too are abundant in these places; there are few lizards or snakes.

Although the limits of the honey mesquite are sharply defined, they are sinuous in detail and the positions shown on the map (pl. 1) are inexact, partly because small areas had to be exaggerated to be shown and partly because many small areas between dunes are without mesquite. The area of the honey mesquite is substantially less than would appear from the map.

In much of the Southwest, mesquite is said to be spreading, especially in the eastern part of the range (Dayton, 1931, p. 76) but in Death Valley, at many places around the saltpan, the mesquite stands are deteriorating. At the north end of the valley, where Salt Creek discharges to the saltpan, there is a belt of sand dunes with honey mesquite. Several of the mesquite trees at the west end of the belt and at the east end are dead; the present area of live trees is less than half what it has been. At the foot of the fan at Blackwater Draw are several patches of dead mesquite. North of Tule Spring are numerous dead mesquite trees west of the present stand. A mile south of Gravel Well, some old dunes, evidently once covered by mesquite but now covered only with pickleweed, contain stone tools of the Death Valley III occupation (A. P. Hunt, 1960), probably dating about A.D. 1000. Mesquite trees more dead than alive are in the wash high on the gravel fan 3 miles south of west of Bennetts Well. Mesquite on Furnace Creek fan (fig. 34) also has retreated, but that area has been disturbed by cutting for firewood, by diversion of the water supply, and by Indians who burned the mesquite when hunting rabbits and rodents (Spears, 1892, p. 77). Most of the change there may be due to interference by man. The only places where new growth of mesquite has been observed is at the edge of the saltpan below Park Service Headquarters, an area disturbed by irrigation at headquarters. One young mesquite was noted in the wash below Barrell Camp on the west side of Cottonball Basin. No other compensating areas of discernible advance of the honey mesquite were found, but whether the general deterioration is attributable to decrease in water supply or increase in salinity of the ground water is not known.

In some places the mesquite has become isolated because the gravels and the xerophytes have spread panward onto the ground of the phreatophytes. Best example of this is at the dunes a mile northwest of

Park Service Headquarters (fig. 23*D*). The dunes and their honey mesquite are isolated by gravel having a stand of desertholly; the gravel and the "holly" are advancing westward onto the sand facies of the carbonate zone which supports a stand of arrowweed. This feature is on a scale sufficient to show on the map (pl. 1).

Although the ground water under the honey mesquite contains, in general, less than half a percent of dissolved solids (table 22), the water-soluble salts in the surface layers of soil between dunes may total a few percent by volume. (See, for example, transects at Shortys Well and Tule Spring, fig. 26*E*, *F*.)

Some semiquantitative partial chemical analyses of acid-soluble salts in soils at stands of honey mesquite are given in table 23. Some of the ground is high in sodium chloride (S25, S156). At other places it is high in sodium sulfate (S17, S20), and at still other places it is high in calcium sulfate (S148a–d). In general, this ground contains more carbonate and less chloride than does the ground at the other phreatophytes, but no doubt the distribution of mesquite has been controlled more by the quality of the ground water than by the composition of the soils.

MIXED STANDS

Springs on the gravel fans have mixed stands of phreatophytes (pl. 1), and these are the only places in Death Valley where the vegetation can be described as dense. At these springs the crowns commonly touch and the growth may be sufficient to cause difficulty getting through it. These stands are a mixture of many species including some trees. The plants are mostly phreatophytes but include some xerophytes. Common phreatophytes are:

honey mesquite (***Prosopis juliflora***)
screwbean mesquite (***Prosopis pubescens***)
desert baccharis (***Baccharis sergiloides***)
arrowweed (***Pluchea sericea***)
alkali sacaton grass (***Sporobolus airoides***)
saltgrass (***Distichlis stricta***)
rush (***Juncus Cooperi***)
tamarisk (***Tamarix gallica***)
four-wing saltbush (***Atriplex canescens***)
common reed grass (***Phragmites communis***)
rabbitbrush (***Chrysothamnus*** sp.)
sedge (***Scirpus*** sp.)
cattail (***Typha angustifolia***)
inkweed (***Suaeda suffrutescens***)

Several or most of these plants are at Nevares Springs and at the several springs along the washes below it. Others are at Travertine Springs and at Texas Spring. They are also represented, although the stands are less dense and contain fewer species, at Table Spring and at Scraper Spring.

An altitudinal zoning can be observed in these mixed stands. The lowest springs on the gravel fans are characterized by honey mesquite; those higher on the gravel fans have in addition screwbean mesquite; and those in the mountains only a little higher than the fans have willows.

Water at the springs on the gravel fans is of good quality, and contains only about 600 parts per million of dissolved solids (table 24).

These mixed stands of phreatophytes are in three kinds of environments: on mounds of travertine where some springs discharge, in bottoms of broad deep washes below the springs where there is underflow in the Recent gravel in the bottom of the wash (see areas I, II, and V in transect *C*, pl. 2), and on hillsides where springs issue from gravel deposits overlying imperme-

TABLE 23.—*Semiquantitative and partial analyses of acid-soluble salts, in percent, in soils at stands of honey mesquite*

[Analysts and analytical methods given on p. 3–4]

	Furnace Creek fan						West side Cottonball Basin		West side Badwater Basin					
	S17	S20	S59	S60	S61	S63	S25	S53	S156	S148a	S148b	S148c	S148d	S148e
Ca	2.9	4.5	8.3	5.1	7.5	7.0	2.7	7.6	2.0	5.0	5.0	7.5	5.0	3.5
Mg	1.4	1.5	3.0	1.8	2.3	2.4	1.0	4.1	1.2	.8	.5	.8	.5	2.0
K	.6	.5	.4	.3	.4	.5	.5	.3	.3	.3	.2	.2	.2	.3
Na	18	16	1.1	7.2	1.9	1.9	13	3.5	9	.3	.3	.9	.8	1.6
CO_3	13	5.2	9	6	11	9	4.2	14	1.6	4.8	1.4	2.4	3.0	3.4
SO_4	26	30	2.1	16	4.9	3.9	7.4	4.1	6.4	6.2	12	12	12	3.7
Cl	3.0	2.4	10	6	13	9.6	19	7.2	13	1.0	.4	6	6	1.4
Total	65.1	60.3	34.4	42.7	39.3	34.8	47.9	41.4	34.2	18.3	19.7	23.8	21.7	14.6

S17. Caliche layer of sodium sulfate, 0.5–3 in. below surface, Furnace Creek fan; NW¼NE¼ sec. 20, T. 27 N., R. 1 E.
S20. Caliche layer of sodium sulfate near top of Furnace Creek fan; SE¼SE¼ sec. 20, T. 27 N., R. 1 E.
S59. Furnace Creek fan, sand and silt. SW¼NE¼ sec. 28, T. 27 N., R. 1 E.
S60. Top 4 in. of silt, Furnace Creek fan. S½ sec. 28, T. 27 N., R. 1 E.
S61. Silt, midway between upper and lower edge of mesquite, Furnace Creek fan. SW¼ sec. 28, T. 27 N., R. 1 E.
S63. Caliche layer 6–14 in. below surface, Furnace Creek fan. SE¼SE¼ sec. 28, T. 27 N., R. 1 E.
S25. Caliche layer impregnated with rock salt at lone mesquite tree by west side jeep trail. SW¼ sec. 19, T. 17 S., R. 47 E.
S53. Top 10 in. of sandy ground at mesquite grove, including thin salt crust. NE¼ sec. 20, T. 16 S., R. 46 E.
S156. Sandy ground by mesquite, ½ mile north of Tule Spring.
S148*a* to *e*. Sandy ground at east edge of the mesquite at Shortys Well *a*, channel sample of top 24 in.; *b*, salt-cemented layer in *a*; *c*, 18 in. of sand overlies *a*; *d*, 8 in. sand overlies *c*.
S148a. Sandy ground at east edge of mesquite at Shortys Well. 24 in. of sand at bottom of pit.
S148b. Salt-cemented layer in 148a.
S148c. Sand 18 in. thick, overlies 148a, contains soft nodules of sulfate salts.
S148d. Sand 8 in. thick, overlies 148c; contains nodules like 148c.
S148e. Surface layer 6 in. thick, overlies 148d.

TABLE 24.—*Partial analyses, in parts per million, of spring waters in the Furnace Creek Wash area*

[Samples listed by USGS Nos. Values in parentheses are calculated]

	27/1-25D1(?)	27/1-23R1	28/1-36G1
Source of water	Stream flowing on bedrock.	Setting box	Near source
Collection point	Travertine Springs.	Texas Springs.	Nevares Springs.
Date collected	3-25-54	4-5-57	11-29-56
SiO_2	43	25	----------
Fe	----------	----------	----------
Ca	26	35	42
Mg	22	20	22
Na	145	155	138
K	11	12	12
Li	.13	----------	----------
HCO_3	321	348	317
CO_3	----------	0	0
SO_4	158	160	173
Cl	39	43	34
F	3.0	2.0	2.9
NO_3	0	0	1.8
B	0	1.0	1.2
Dissolved solids	----------	716	625
Sum	605	(599)	583
Hardness	----------	----------	192
Percent sodium	(65)	(65)	(59)
$K \times 10^6$	949	1,010	----------
pH	8.05	7.9	7.9
°F	90	91	104
Source of data	[1] USGS	[2] DWR	[3] DPH

[1] Analyzed in U.S. Geological Survey Quality of Water laboratory.
[2] California Division of Water Resources.
[3] California Department of Health.

able strata. No doubt there is considerable range in salinity of the water in different parts and at different depths in each of these environments, depending on local conditions of discharge and evaporation. Few of these plants, though, are salt tolerant.

The extent of the stands, especially the small ones, is exaggerated on the map. At most places the boundaries are sharp, but there have been too many artificial changes involved in developing the water to determine whether these phreatophytes are advancing or retreating.

As would be expected, animal life of all kinds gathers in these places, chiefly because of the good supply of good water but also because the vegetation is dense. These places too were sought by the prehistoric occupants of the valley who came partly for the water, partly to gather plant foods, and partly to hunt the game that was lured there (Hunt, A. P., 1960, p. 190).

AQUATIC AND MARSH PLANTS

Numerous marshes at the edge of the Death Valley saltpan have growths of algae, but the one at Badwater is the only one known to contain truly aquatic flowering plants—that is, plants that grow wholly submerged. The aquatic plant at Badwater is ditchgrass (*Ruppia maritima*). Whether it is native or introduced is not known; it may have been introduced because the locality is a favorite visitors' attraction and the plant is absent at the other perennial marshes. If the ditchgrass is native, it may be a relict from Recent pluvial times when there was more water than now and when the aquatic plants presumably were more numerous and more extensive.

The water in which the ditchgrass grows contains between 4 and 5 percent of dissolved solids, depending on the season and whether the year is a dry or wet one. (See table 12, W20-56g and W56g.)

At other marshes (fig. 37) where the salinity is less than about 5 percent (see W60g, W65g, W93g, table 19), the plants grow with their lower parts submerged and their upper parts in the air. The marshes at Coyote Hole (4 miles southeast of Morman Point) and Eagle Borax are unusual in having considerable growths of common reed grass in addition to saltgrass, rush, and pickleweed.

BARE AREAS

From the preceding discussion it will be noted that there are two principal kinds of bare areas in Death Valley: on one kind, the saltpan, water is plentiful both as shallow ground water and as surface water, but the salinity exceeds 6 percent and flowering plants do not grow there. The other kind of bare ground is on the gravel fans where the supply of vadose water is deficient. The deficiency may be due to excessive runoff because of an impermeable layer at the surface, or because of excessive slope. Even where the slope and permeability appear favorable, the ground may be bare if the catchment area for recharge of the vadose water is small. On the gravel fans the bare areas largely coincide with the older gravel deposits, whose surfaces have a smooth desert pavement.

FACTORS AFFECTING PLANT DISTRIBUTION

Factors affecting plant distribution include the climatic conditions, adaptability of the plants, and the edaphic factors—that is, those geologic factors which pertain to the ground and soil, especially the water supply.

The importance of climate in affecting the distribution of the largest plant groups—the plant zones (see Merriam, 1892, 1898)—shows conspicuously in the altitudinal and latitudinal zoning of plants. In the Death Valley region the plants can be divided into four major altitudinal zones (Coville, 1893, p. 21-24).

The lowest zone, the Lower Sonoran, is characterized by the creosotebush, which occurs from the bottom of Death Valley to an altitude of about 4,000 feet on the adjoining mountains. In places creosotebush extends upward to 5,000 feet. All the plants described in this

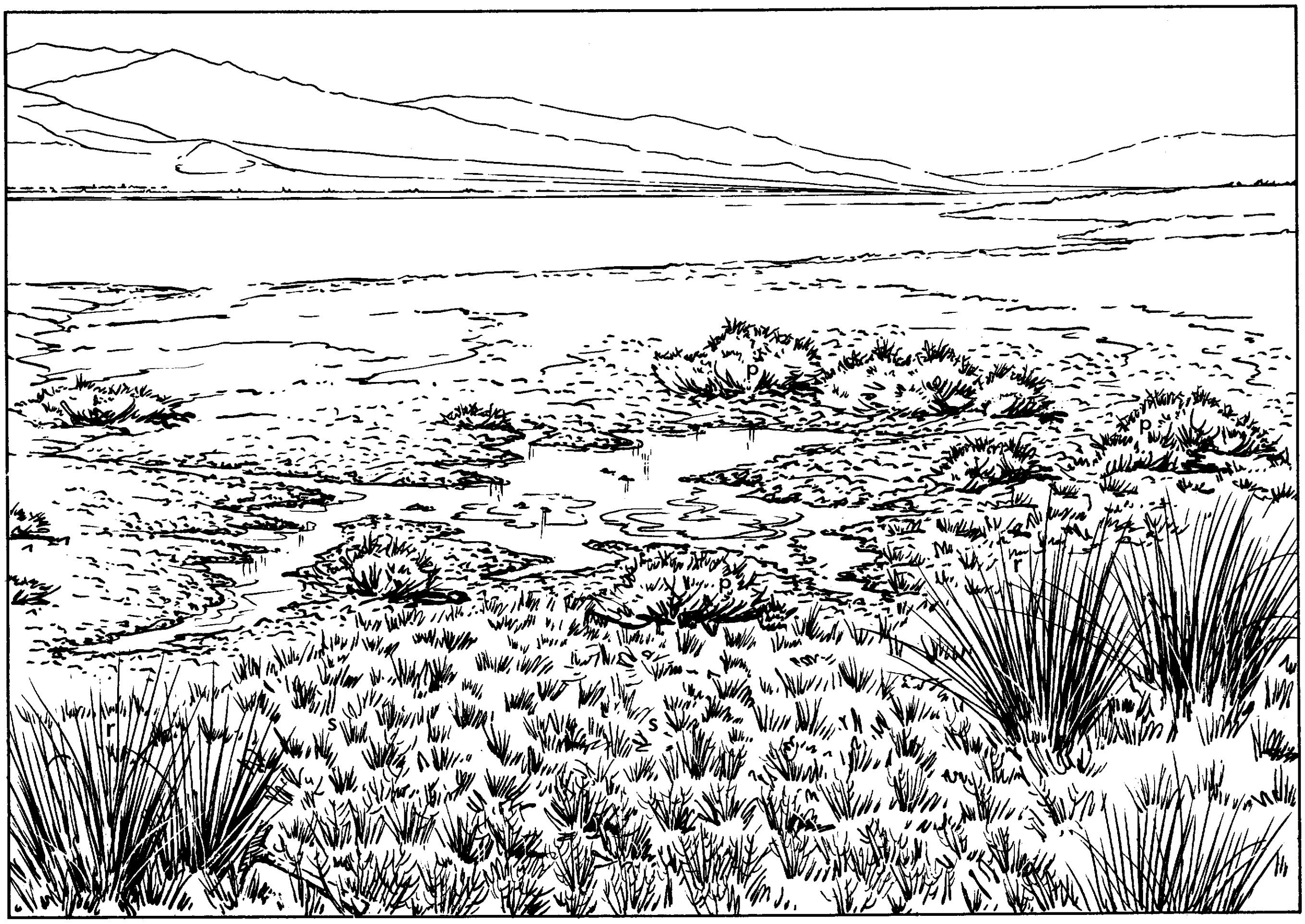

FIGURE 37.—Rush (*r*), saltgrass (*s*), and pickleweed (*p*) in marsh in cove north of the Coffin Canyon fan. In 1956, a dry year, the water in the pool between the pickleweed plants contained 4.8 percent total dissolved solids; in 1957, a wet year, it contained 4 percent dissolved solids. Sketch by John R. Stacy, from photograph.

report are part of the Lower Sonoran zone. Next higher is the Upper Sonoran zone—characterized by shadscale, sagebrush, pinyon, and the California or Utah juniper—extends from about 4,000 feet to about 8,500 feet. In most western mountains the next higher zone, the Transition zone, is characterized by the yellow pine, but this tree is absent on the Panamint Range (Coville, 1893, p. 24). The Transition zone there is marked only by the Sierra juniper and mountain-mahogany. Above 9,000 feet and extending to the peaks is the Boreal zone characterized by bristlecone pine and limber pine.

Although climate has caused this altitudinal zoning of the plants, the geologic factors appear to have been paramount in controlling the distribution of plants within the plant zones. The distributions show on plate 1 have been controlled by geologic factors, a control shown conspicuously by the occurrence of xerophytes on the gravel fans in contrast to the occurrence of the phreatophytes along the foot of the fans, and the occurrence only of thallophytic plants on the saltpan beyond the 6 percent brine line.

In other regions plant distribution has been affected also by such factors as grazing (Talbot, 1937), tilling, burning, parasitism, fallen foliage, and snow (Weaver and Clements, 1938; Oosting, 1948; Clarke, 1954). In Death Valley, except for the luxuriant growth of introduced plants at the mouth of Furnace Creek and at Park Service Headquarters, the introduction of tamarisk at Eagle Borax (p. 32), and the possible introduction of sacaton grass (p. 37), there has been little disturbance of the natural vegetation.

CLIMATIC OR ATMOSPHERIC FACTORS

The climatic or atmospheric factors affecting plant distribution include temperature, humidity, precipitation, light, and wind. Regional differences in these factors correlate with the regional and altitudinal zoning of plants (Merriam, 1892, 1898; see also Beadle, 1951). Within a climatic region and within a plant zone there are local differences in the atmospheric factors which are on a scale sometimes referred to as microclimate, and these differences also correlate with plant distribution.

Within a region like Death Valley, where there are basins and mountains, the differences in temperature at different altitudes are reflected by differences in the altitudinal range of the plant zones. Even within the Lower Sonoran zone the plants are zoned altitudinally. Going upward from the valley bottom is the zoning shown on plate 1 and, according to Went and Westergaard (1949, p. 35), the total number of plants, both shrubs and annuals, increases sharply and about doubles at an altitude of 1,000 feet. There is reason to believe, however, that these altitudinal differences within the plant zones shown on plate 1 are due more to water supply than to temperature (p. 47).

The annual range in temperature in Death Valley is about 100° F, and the daily range at times is as great as 50°F, but the plants in the area shown on plate 1 largely are spared the temperature changes most damaging to plant growth—namely, those that involve freezing or thawing. For all practical purposes, this occurs only on the upper parts of the gravel fans and in the mountains. Plants growing there have a winter resting season. Plants in the lower parts of the valley, like the desertholly and the creosote bush, however, rarely experience frost, and these plants grow and flower when water is available. Even in midwinter the temperatures at these altitudes are mild enough to permit plant growth. These plants though can survive prolonged high temperatures. The very high ground temperatures (up to 190°F) may account for the absence of low-growing forms, like grasses. Also, summer annuals are lacking (Went and Westergaard, 1949, p. 36), perhaps because of the high ground temperatures.

Another effect of temperature differences, noticeable only in the mountains, is the local inversion of plants due to cold air draining down the valleys. Where much cold air moves down the valleys, high altitude plants extend to lower than usual altitudes. A similar inversion of plants is observed on the gravel fans (pl. 1) but this inversion on the gravel fans seems to be due to variations in vadose-water supply rather than to differences in temperature (p. 48).

Presumably the general zoning of plants according to altitude is due more to temperature than to precipitation, because similar changes in plant distribution are encountered with change in latitude where precipitation remains constant or nearly so. Some effects of rainfall and temperature in Death Valley have been reported by Went and Westergaard (1949). They found that rain followed by 85°F minimal temperatures resulted in no germination. An October rain followed by 60°F minimal temperature caused germination of creosotebush. A November rain followed by 48° to 50°F minimal temperature evidently was too low to cause germination of creosotebush but did cause germination of winter annuals. It has been shown (fig. 4) that a good crop of annuals is obtained only when the winter rainfall is 2 or 3 times the average. In years with only average rainfall, as in 1956–57, the annuals grow on those parts of the gravel fans where surface water accumulates, as in the shallow swales; uplands between the swales remain bare (fig. 7).

The adaptability of plants to light or shade shows conspicuously in forested lands, where there are different stories of trees, shrubs, and herbs. Even a desert like Death Valley provides some examples. Annuals commonly favor the shady north side of the perennial shrubs, lichens grow on the under side of stones at altitudes below sea level, and mosses extend to similar low altitudes across the shady north foot of the Panamints west of Cottonball Basin. Shadiness though has had little or no effect on the distribution of the perennial herbs, the woody shrubs and trees, and the parasites. All these plants are widely spaced and they seem to receive about equal light.

Winds distribute pollen and seeds but also increase transpiration and desiccation. Wind causes distorted growths, like the so-called "flag" forms of trees in exposed positions. In the sandy zone around the edge of the Death Valley saltpan, mesquite trees and some of the shrubs may have their roots exposed due to wind erosion (fig. 16) or the upper parts of the plants may become partly buried by shifting sand. Too, locally along the summit of the Panamint Range there is a timberline, and this must be controlled more by wind than by temperature, for the growing season there probably averages at least 90 days.

The distribution of plants that we see today has been affected not only by the present climate but probably even more by the changes in climate that occurred during the late Pleistocene and Recent. The present climate has lasted for only 2,000 years. Shortly before the Christian Era enough moisture was available to form a lake 30 feet deep in Death Valley (Hunt and others, 1965b; Hunt, A. P., 1960, p. 289). The several thousand years of the Recent that preceded this lake seem to have been even drier than the present. Before this, in late Pleistocene time, enough moisture was available to produce deep lakes.

In late Pleistocene time the plant zones may have extended 1,500 to 2,000 feet lower than they do now (Laudermilk and Munz, 1934; Hansen, 1947; Dillon, 1956). Burroweed and incienso probably extended farther down the fans. Also, judging by the response of annuals to variations in rainfall under the present climate (fig. 4), we may suppose that there were substantial stands of annuals most years during pluvial times. The phreatophytes around the edge of the saltpan were flooded by the 30-foot Recent lake; these plants have again established themselves in their present locations during the past 2,000 years. The pure stands of desertholly and cattle spinach at the foot of the fans are mostly below the high-water mark of the Recent lake, and they too must have developed during the past 2,000 years. Creosotebush still has not spread downward over all the ground that was flooded.

PLANT ADAPTABILITY TO DROUGHT

Adaptability of xerophytes to drought is a problem for discussion by plant physiologists, not a geologist, but a few notes may be pertinent.

It has been shown that some plants are capable of maintaining growth for extended periods with vapor as their only source of water, and when vaporous moisture is available to roots they may be able to reduce the soil moisture below the wilting percentage and even below the hygroscopic capacity (Breazeale, McGeorge, and Breazeale, 1951). In addition, some moisture may be available to plants in the form of dew, and some may be taken directly from the atmosphere in the vapor phase.

There are limits, however, to which even the most xeric plants can survive without access to vadose water, for it has been shown that during wet periods the Death Valley xerophytes can seed themselves and grow on ground from which they cannot obtain sufficient water to survive during ensuing dry periods (p. 16, fig. 7). Moreover, the chemistry of the plant ash shows that the principal movement of water is upward, as it is in plants growing in humid climates or wet environments. The composition correlates with the ground on which the plants grow, and there is an increase upward of the more soluble constituents.

However, the vapor in the soil atmosphere may be a critical factor enabling desert plants to survive as much drought as they do. Even the most xeric plants, of course, die quickly when taken from the ground, but perhaps they could survive a long time if housed in an atmosphere having vapor pressures like those in the ground reached by the roots.

GEOLOGIC (EDAPHIC) FACTORS

Geologic (edaphic) factors affecting plant distribution include the physical, chemical, and hydrological properties of the substratum. Important physical properties include texture, toughness, temperature, slope, and permeability. Important chemical properties include the availability of nutrients and toxics. Important hydrological properties include the amount and composition of the soil air and soil moisture.

The texture and tenacity of the substratum determines its permeability. Loose substrata, like the sand dunes on Furnace Creek fan and at the foot of Hanaupah and Starvation Canyon fans, favor movement of water and air in the ground and are easy for roots to penetrate. Such ground favors plants having long much-branched roots, or runners. Firm clay or silt, on the other hand, favors plants with vertical roots. Bare-rock surfaces support only lithophytes; such as lichens and algae. Some of the salt-crusted areas in the carbonate zone, which otherwise are favorable for plant growth, are barren. In part this may be because the crust is nearly as impenetrable as bare rock.

Ground temperatures in Death Valley are high, and temperatures up to 190°F have been recorded. The temperatures vary, of course, depending on the texture, composition, color, porosity, and vegetative cover on the ground, but in Death Valley the variation is between hot and hotter. The hottest surfaces are sandy ones that face south. On gravel fans the hottest ground is the dark, smooth desert pavement on the old gravel deposits.

The temperature gradient in the ground (p. 7) favors plants that root deeply.

Permeability of the substrata is only one of the factors affecting the amount and availability of soil moisture. The moisture content of a piece of ground also is controlled by the slope of the ground surface and by its catchment area both for surface-water runoff and for groundwater discharge.

The driest habitats are where the ground is impermeable and the slopes are steep, as in the hills of the Tertiary silt and clay formations above Artists Drive and along Furnace Creek. Such hillsides are bare (fig. 8*A*). The well-developed desert pavement on old gravel deposits is like an impermeable layer at one surface and causes high runoff. Also, these surfaces are dark and hot. They are the driest habitats on the gravel fans and are bare except near the foot of the mountains (fig. 8*B*, *C*, *D*).

Gently sloping ground that is moderately permeable collects water from other areas. In the saltpan, such areas are bare, not because of deficient water supply but because of excessive salts. On the gravel fans three kinds of moderately permeable ground having gentle slopes can be distinguished (fig. 38). On some upper Pleistocene gravels the surfaces are roughened with natural levees of small boulders and cobbles which concentrate runoff in shallow washes between the levees.

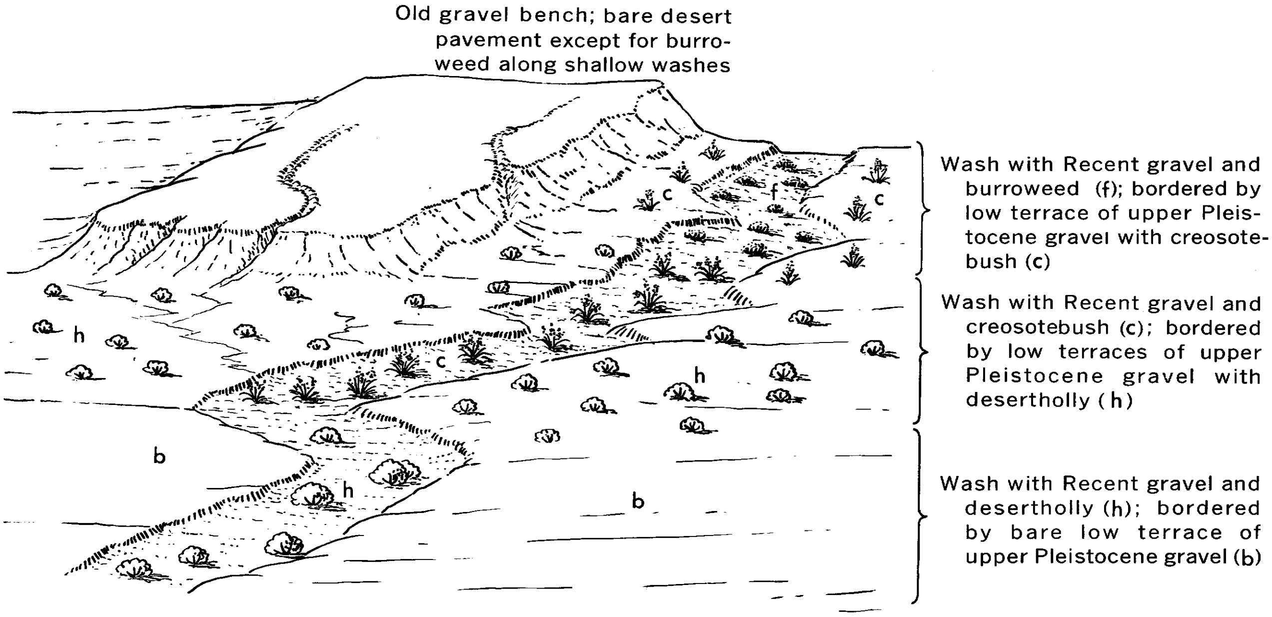

FIGURE 38.—Diagram illustrating relation between xerophytes and upper Quaternary gravel deposits in Death Valley.

As illustrated on figure 38, these surfaces support stands of shrubs that differ from those in the adjoining washes covered with Recent gravel. Creosotebush grows on the upper Pleistocene surfaces where the Recent washes have stands of burroweed or incienso; desertholly grows on the surfaces where the washes have creosotebush; but the surfaces are bare where the washes have desertholly. Surfaces on the old gravels also are bare.

These differences in distribution of individual species correlate also with differences in the number of species and density of growth in the different habitats. The plants capable of surviving in dry habitats extend into the less dry ones, and as a consequence the number of species increases as the available moisture increases. The densest growths and largest number of species are in the washes. The benches high on the fans have less dense growths and fewer species than the washes. The least dense growths and fewest species are at the foot of the fans.

The differences in vegetation on the three kinds of gravel where slopes are comparable correlate with differences in availability of soil moisture which in turn is controlled by differences in permeability of the top layers of the ground and differences in the topographic situation that affect the catchment area for surface-water runoff.

Where ground is permeable and slopes are steep, as in hills of Precambrian and Paleozoic rocks and in hills of Tertiary volcanic rocks, conditions are marginal even for the xerophytes. They seed and advance onto such areas in wet cycles, but locally they are not able to survive protracted periods of drought (fig. 7).

Density and kind of vegetation on permeable ground where slopes are moderate depend on the catchment area. The tops of gravel benches having small catchment areas may be bare whereas similar ground that collects runoff from bordering hills may support healthy stands of xerophytes. Recent gravel in the washes is loose and has greater catchment areas than other parts of the fans. The vegetation in these areas is more closely spaced and species more varied than in other parts of the fans.

Ground conditions, however, rarely are homogeneous to the depths penetrated by plant roots. Impermeable layers alternate with permeable ones; tough layers alternate with layers that are easily penetrated by roots, and, in Death Valley, saline layers alternate with non-saline ones.

An impermeable layer at the surface causes excess runoff and prevents infiltration of water. Such surfaces, typically covered with desert pavement, occur on the old gravel deposits on the gravel fans (fig. 39), and they are bare except on the uppermost parts of the fans.

Impermeable layers below the surface collect vadose water in a perched ephemeral water table (fig. 39*B*). In the vicinity of Cow Creek and the East Coleman Hills the gravels are only a few feet thick and overlie fine-grained Tertiary formations. Roots of xerophytes that penetrate these gravels spread at the contact

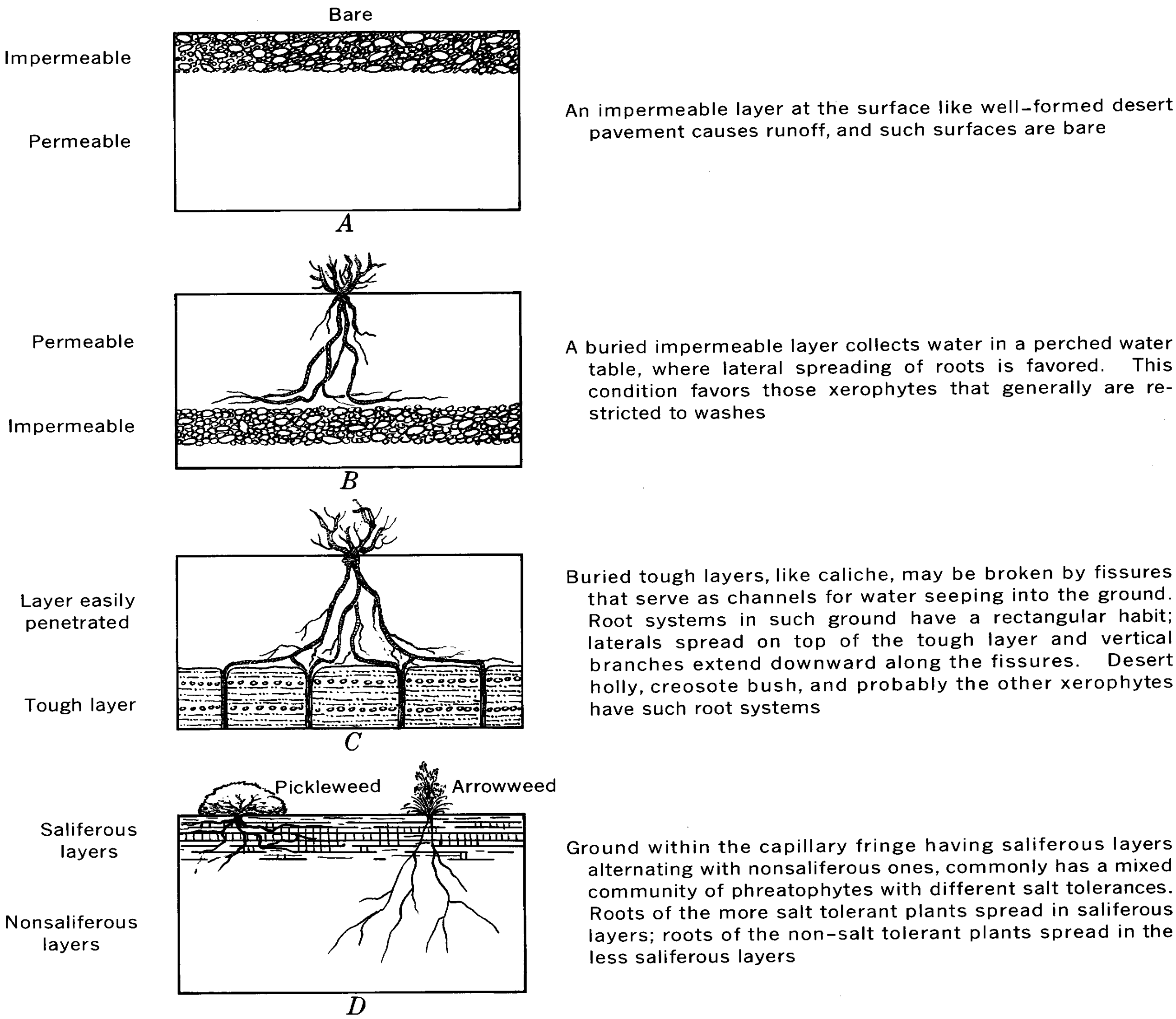

Figure 39.—Inhomogeneities in the ground affect plant occurrence and the depth, lateral spread, and general pattern of root systems.

between the permeable gravel and underlying impermeable fine-grained beds. Roots of the creosotebush have been traced to depressions in the top of buried caliche layers (Cannon, 1911). In terms of water available for plant growth these situations are similar to localities where surface catchment areas are large, because subsurface impermeable layers collect water from the ground above and such contact favor lateral spreading of roots. Where there is a buried hardpan the roots of perennials may reach no deeper than those of annuals (Cannon, 1911, p. 96).

A buried caliche layer may be broken by joints which serve as drainage channels for water seeping into the ground. Root systems of desertholly, creosotebush, and probably other xerophytes have a rectangular habit in this kind of ground; horizontal laterals spread at the tops of the tough layers, but branches extend vertically downward through the fissures (fig. 39*C*).

Ground having saline layers that alternate with nonsaline ones may have mixed phreatophytes reflecting diverse habitats within a small area. An example is along the floodplain of Salt Creek where State Route 190 crosses it. There roots of the most salt-tolerant plants, pickleweed for example, are rooted in or close to the saliferous layers near the surface; the roots of the plants that are not so salt tolerant, like arrowweed, extend to greater depths and spread in the layers that contain little salt (fig. 39*D*).

It seems evident that inhomogeneities in the ground are a major factor controlling the depth, lateral spread, and general pattern of root systems both of phreatophytes and xerophytes, partly because the inhomogeneities affect root penetration but chiefly because they affect distribution of soil moisture.

These inhomogeneities in the ground and the adaptations of roots to them can be observed in gravel banks that have been eroded. Some additional information about xerophyte roots can be inferred from the general habits of the plants.

Xerophytes in Death Valley become green and some may even flower after rains. But these rains penetrate only inches into the ground, except along washes that receive floods. Seemingly, therefore, the plant roots that gather moisture after rains must be the shallow laterals; it seems doubtful that the vadose water at the level of the deep roots is increased by downward percolation. Death Valley rains simply do not provide enough moisture to wet so much material. Between storms the ground near the surface becomes greatly heated and dried; during these protracted times, the shallow laterals must serve little purpose, and perhaps the deep roots then supply the moisture needed to keep the plants alive.

As noted earlier (p. 47), vapor in the soil atmosphere may be a critical factor in keeping desert plants alive during periods when vadose water is deficient. It seems reasonable that during winter vapor would move from deep horizons, which are warmer, to the near-surface horizons which are colder (Lebedeff, 1928), and that in summer when the surface layers are warmed, vapor would diffuse downward. The vapor moving upward could be supplied by the capillary fringe; the vapor moving downward could be supplied by evaporation of dew, which to me is surprisingly considerable in Death Valley. Condensation of vapor may be an important factor in the recharge of vadose water available for plant growth.

Too, distinction must be made between substrata that are physically dry and those that contain substantial quantities of water which is not available to the plants because of excessive salinity. The soil of the xerophytic plants is physically dry; in the saltpan, beyond the silt facies of the carbonate zone, the soils are wet, but their salt content exceeds 6 percent and the water is not available to plants. This ground is "physiologically dry."

The evidence collected in Death Valley indicates there is a sharp difference in the quantity of vadose water in the different gravel formations and that this difference correlates with orderly, repeated differences in the distribution of the different species of xerophytes.

The distribution of the xerophytes also shows some correlation with the composition of the gravels. Cattle spinach and incienso are most abundant on those fans that have little salt and that have a high proportion of quartzite and schist. These are the fans on the windward side of the saltpan and derived from Precambrian and Lower Cambrian rocks. Desertholly is most widespread on the fans that contain much salt, especially those leeward of the saltpan, and most of these contain a high percentage of debris from the formations of limestone and dolomite. Burroweed grows mostly on the upper part of fans that have desertholly at their base.

The fans that are composed very largely of fine-grained sediments however, like the fans south of Furnace Creek nearly to Badwater, have sparse vegetation and the only plant represented there is the most xeric one, desertholly. The reason evidently is the excessive runoff on surfaces of fine-grained sediments; such surfaces are impermeable, and very little of the very little Death Valley water gets into the ground (fig. 11).

Examples of plant distribution that correlate with differences in kind of ground are of course legion. Perhaps the most striking examples are in the Colorado Plateau where Cretaceous shales are characterized by mat-saltbush, an *Atriplex*, the sandstone benches and gravel benches are characterized by shadscale, and the sandy ground on the Jurassic formations is characterized by sand sagebrush or blackbrush (Cannon, 1960; Tidestrom, 1925; Hunt and others, 1953, pl. 3). The Great Basin contains examples of differences in vegetation that apparently reflect differences in salinity (Flowers, 1934; Shantz and Piemeisel, 1940), and examples of differences in vegetation growing on chemically altered rocks and on rocks not altered (Billings, 1950). The serpentine soils in parts of California and Maryland provide extreme examples (Walker, 1948; Shreve and others, 1910). These different habitats differ in many ways physically and chemically, but they also differ in the content of soil moisture available for plant growth.

Death Valley soils have little to no visible humus and the microfloral population of the soil is small. Leaf litter collects around the base of the perennial shrubs but elsewhere there is almost none. Crude measurements in the field, made by heating soil samples collected around the base of shrubs, indicate an organic content of less than 0.5 percent, even where there is visible organic matter. The organic content of ground between xerophytes probably amounts to no more than a trace. It probably is higher, perhaps as much as a percent, in the damp though saline ground in the phreatophyte zone.

A few colonies of the soil microflora were obtained by inserting sterile culture plates in the ground immediately following rains and leaving them in position for about 2 weeks (Waksman, 1952, p. 43); a repeat of this experiment while the ground was dry gave almost no colonies. It seems reasonable to infer that the microflora, like the xerophytes, rests during dry periods, but grows and flowers when water becomes available. Shrubs like creosotebush and desertholly seem to be less dependent on organic substances than most plants, but surely they are not as independent as lithophytes.

Zoning of the phreatophytes in Death Valley with respect to salinity of the ground water appears in two ways. Where the isochlors parallel the foot of the gravel fans, the belts of phreatophytes do also, and the belts are arranged in the order of increasing salt tolerances. Good examples of this zoning are at the mouth of Cow Creek, and at the foot of Hanaupah and Starvation Canyon fans (pl. 1). Where the isochlors are oblique to the foot of the gravel fans, the belts of phreatophytes also are oblique, and as the salinity of the ground water at the foot of the gravel increases, the range of the less salt-tolerant species becomes narrowly restricted and finally ends as the more salt-tolerant species crowd against the xerophytes on the gravel fans. Where the salinity of the ground water at the foot of the gravel exceeds about 6 percent, there are no phreatophytes; the xerophytes there end against the bare ground of the saltpan. (See transect *B*, fig. 23.) Good examples of this oblique zoning are around the east and north sides of Cottonball Basin and northward from Tule Spring to Trail Canyon fan (pl. 1).

The differences in quality of the ground water in the different stands of phreatophytes may be tabulated as indicated in the next column.

Similar ranges in salinity under different phreatophytes have been observed at the edge of Great Salt Lake. Salinity limits reported there for *Salicornia* and *Allenrolfea* range from 0.25 to 6.0 percent, and limits for saltgrass and inkweed range from 0.25 to 4.0 percent (Flowers, 1934).

Plant name	Number of salinity determinations	Range, in percent, of total dissolved solids in ground water		
		Minimum	Mean	Maximum
Honey mesquite	9	0. 03	0. 2	0. 6
Arrowweed	9	. 2	. 5	1. 8
Sacaton grass	2	. 5	. 7	1. 0
Common reed grass	2	. 5	1. 1	1. 8
Saltgrass	15	. 05	2. 2	7. 0
Rush	6	. 5	2. 4	5. 0
Pickleweed	11	. 2	3. 6	6. 0

The phreatophytes can tolerate comparable minimums in salinity; their distribution in Death Valley correlates with the differences in the means or maximums. As a result, the number of species growing in the different belts of the phreatophyte zone decreases panward as the salinity increases, as illustrated diagrammatically on figure 40.

Although more systematic sampling no doubt would extend the extremes of salinities indicated for the phreatophytes, the relative tolerances of the plants probably would be found as indicated except possibly for the sacaton and reed grass, which are not represented by adequate samples. A complete study however would have to consider several additional facts about the occurrence and quality of ground water. In the capillary fringe the salinity of the ground water decreases downward from the top of the fringe, where there is subsurface evaporation and deposition of salts, to the water table. Further, the salinity of ground

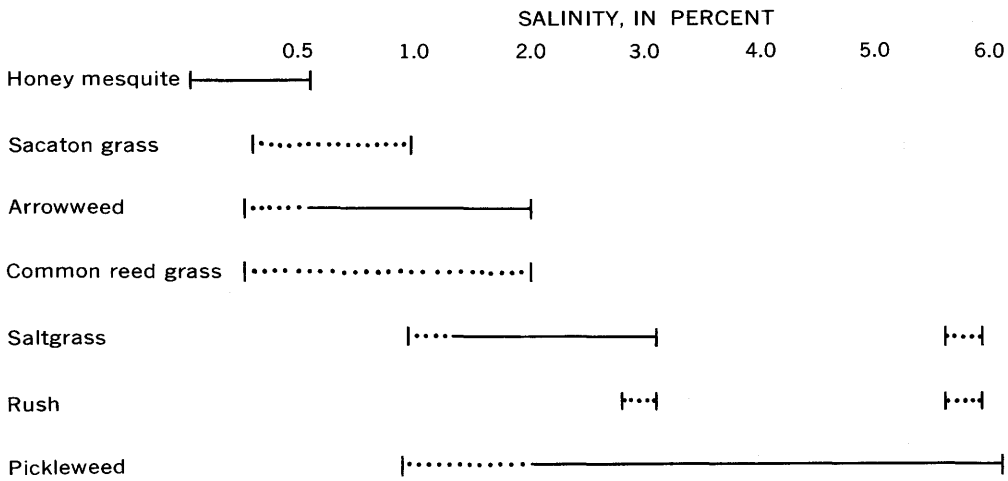

FIGURE 40.—Distribution of species of phreatophytes with reference to salinity of ground water in Death Valley. Solid lines indicate abundant growth; dotted lines indicate sparse growth. The number of species decreases as the salinity of the ground water increases into the saltpan.

water near the surface, the water most accessible to roots, varies depending on the discharge, which is partly a function of season. In the marshes, for example, salinity is less in wet years than in dry years (Hunt and others, 1965A). It is clear that plants drawing on such a water supply have a wide range of salt tolerances.

Differences in salinity within a stand of plants commonly are reflected by differences in healthiness, stature, or density of the plants (see, for example, Magistad, 1945; Hurd and Sutcliffe, 1957; Kurz and Wagner, 1957, p. 87–90), but such effects, if present in Death Valley, were not evident to me.

Apparently the quantity of salts is more important than the kind of salts in controlling phreatophyte distribution. Warming (1909, p. 218), for example, noted that at various places in Europe the vegetation is essentially alike whether the ground contains sodium carbonate, sodium chloride, or sodium and magnesium sulfate. In Death Valley, also, the phreatophytes appear to be more sensitive to quantity than to kind of salts, for, with one exception, the botanical composition of the phreatophyte stands is much alike in all parts of the valley where salinities are comparable regardless of their chemical composition.

The exception is along the east side of Cottonball Basin where there is no pickleweed and the ground is unusually high in sodium sulfate and sodium carbonate. Arrowweed is more typical. It is a high-sulfate plant; it is high in sodium along the east side of Cottonball Basin but is high in calcium in Badwater Basin where the ground contains calcium sulfate (table 25). The high sodium chloride content of the pickleweed (table 25) might be expected from its environment, but that of the inkweed is more surprising. Inkweed is common between dunes with mesquite and between these mesquite stands and the desertholly. If the plant in these environments is a phreatophyte, it probably obtains water from the capillary fringe which extends upward into saliferous layers, rather than from the water table, which at these locations contains less than 0.5 percent total dissolved solids.

Probably it is not coincidence that the pickleweed, which has a high content of chloride, grows on the panward side of the arrowweed, which has a high content of sulfate. This duplicates the pattern but not the position of the zones of salts. Whatever the cause, it is another striking example of the close correlation between the geology and plant distribution, for the plants are zoned with respect to their composition as well as according to the total amount of dissolved solids in the ground water. The chloride zone of the saltpan and the massive gypsum in the sulfate zone are bare. The sulfate marshes and the silt facies of the carbonate zone have pickleweed which is high in sodium chloride. The sandy silt and silty sand of the carbonate zone has arrowweed, which is high in sulfates. In the sand facies is mesquite (table 26).

TABLE 25.—*Average composition of ash in some Death Valley plants (roots excluded)*

[Data from tables 5, 7, 9, 11, 13, 15, 16, 17, 21]

	Ca	Mg	K	Na	SO_4	Cl	Carbonate or phosphate needed to balance cations	SiO_2?
Xerophytes								
Desertholly	6	2	7	26	4	25	30	------
Cattle spinach	11	6	8	14	4	14	40	<5
Creosotebush (leaves only)	19	4	14	4	6	8	45	------
Cheesebush	16	6	16	<1	6	7	45	<5
Phreatophytes								
Arrowweed in Cottonball Basin	7	5	11	15	20	7	35	------
Arrowweed in Badwater Basin	16	3	8	8	27	8	30	------
Saltgrass	2	1	2	6	5	9	5	70
Rush	4	2	19	8	13	9	20	25
Inkweed	3	5	9	20	8	20	35	------
Pickleweed	2	2	5	32	7	27	25	------

TABLE 26.—*Arrangement of vegetation with respect to composition of ground and salinity of ground water*

Vegetation	Composition of ground	Salinity of ground water (percent)
Bare ground	Chloride zone Massive gypsum of the sulfate zone	>6
Pickleweed with 40 percent NaCl	Sulfate marshes Silt facies of carbonate zone	2–6
Arrowweed with 35 percent sulfate	Sandy silt	0.5–2
Mesquite	Sand facies of carbonate zone	<0.5

The high sodium chloride plant among the xerophytes is desertholly, which correlates with the fact that most of the specimens analyzed (table 5) were collected from the low parts of the fans where the sodium chloride content of the soil is greatest. But the specimen of desertholly from the higher and less saliferous part of the fan at Hell Gate (P 116, table 5) also contains much sodium chloride.

The low sodium chloride xerophytes seem to be highest in carbonates. These are cheesebush, which grows in the comparatively salt-free washes along the foot of the fans, and creosotebush, which also grows along the washes and on salt-free high parts of the fans (table 25). Both the cheesebush and creosotebush are high in calcium.

The apparent high-silica content of the saltgrass and rush may be due to the fact that the specimens analyzed were collected during the winter season and included a high percentage of dry strawlike matter.

PLANT GROWTH AND PLANT SUCCESSION

In dry years, in the driest habitats in Death Valley—that is, on the low parts of the gravel fans—there is an orderly plant succession among the xerophytes. In that environment the first shrub to appear on new ground, such as a mudflow or road shoulder, is the honeysweet (*Tidestromia oblongifolia*). Even during dry years this shrub establishes itself on new ground within a season. It generally is accompanied by a spurge. Desertholly generally is not found on new ground until a season has passed. Creosotebush, in general, is not found on new ground in this environment until several seasons have passed, though at higher altitudes where the ground is less dry and less salty it may be the first shrub to appear.

Example of the plant succession are best shown along the roads and trails. For example, along the highway to Badwater and along State Route 190 around the north side of Cottonball Basin, the road shoulders, which are bladed several times a year, have stands of honeysweet and spurge, especially at low places where runoff collects (fig. 41).

On the north side of Cottonball Basin, along the north side of the highway, are some flood-control ditches that were last bladed about 1953. These are straight washes extending diagonally across the fans, and in them and on the enbankments beside them are growths of desertholly (*h*), honeysweet (*t*), and spurge (*sp*) (fig. 42). There is little or no creosotebush even where the ditches were bladed through a stand of creosotebush.

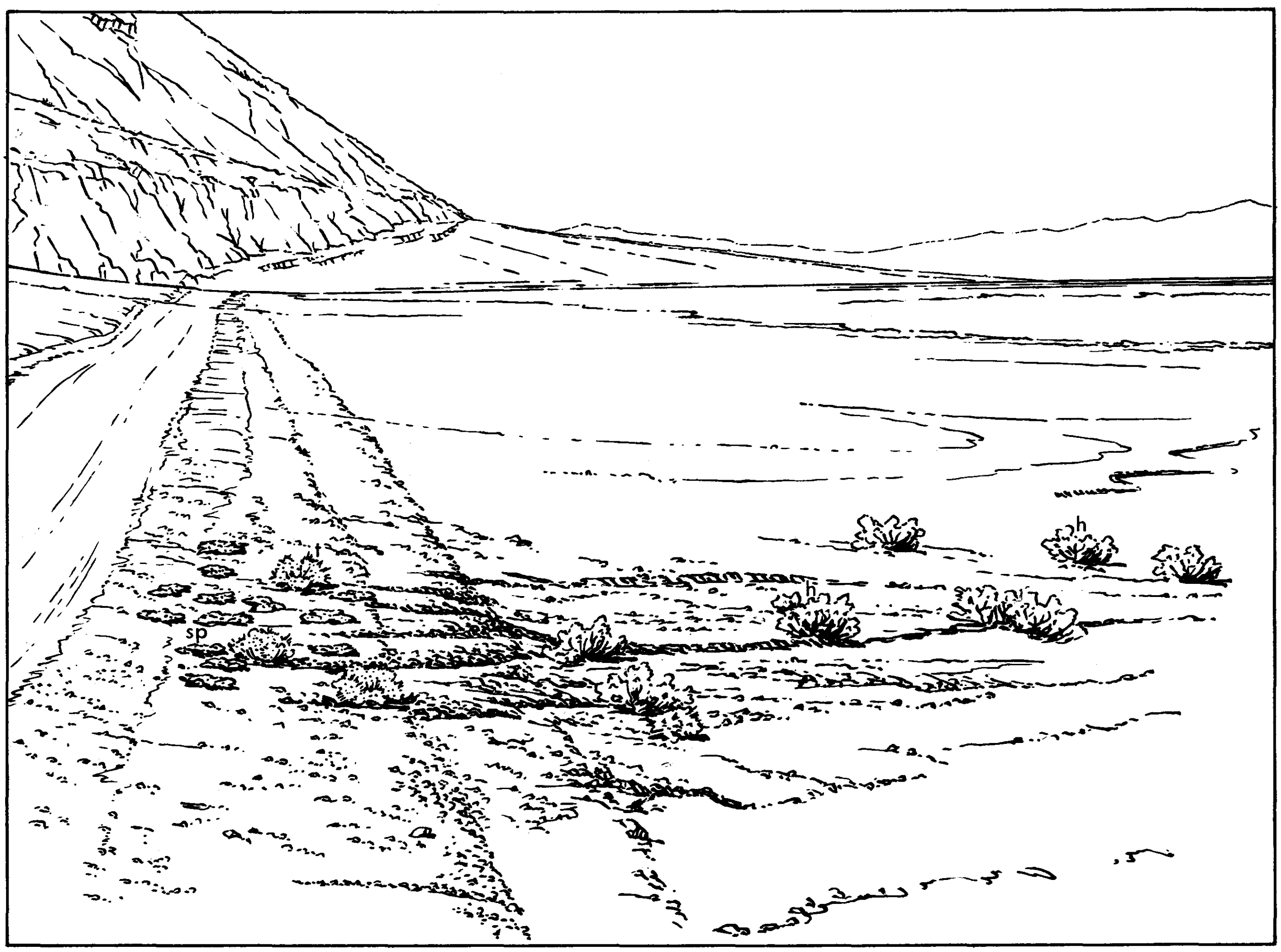

FIGURE 41.—Road shoulders receive runoff from the pavement and therefore offer a less dry environment than do the adjoining gravel fans. But road shoulders are disturbed and plants growing there must be able to seed themselves quickly. In this view, about a mile north of Badwater, a spurge (*sp*) and honeysweet (*t*) grow at the bottom of a broad low dip in the shoulder; down the wash, below the road, is desertholly (*h*). Sketch by John R. Stacy, from photograph.

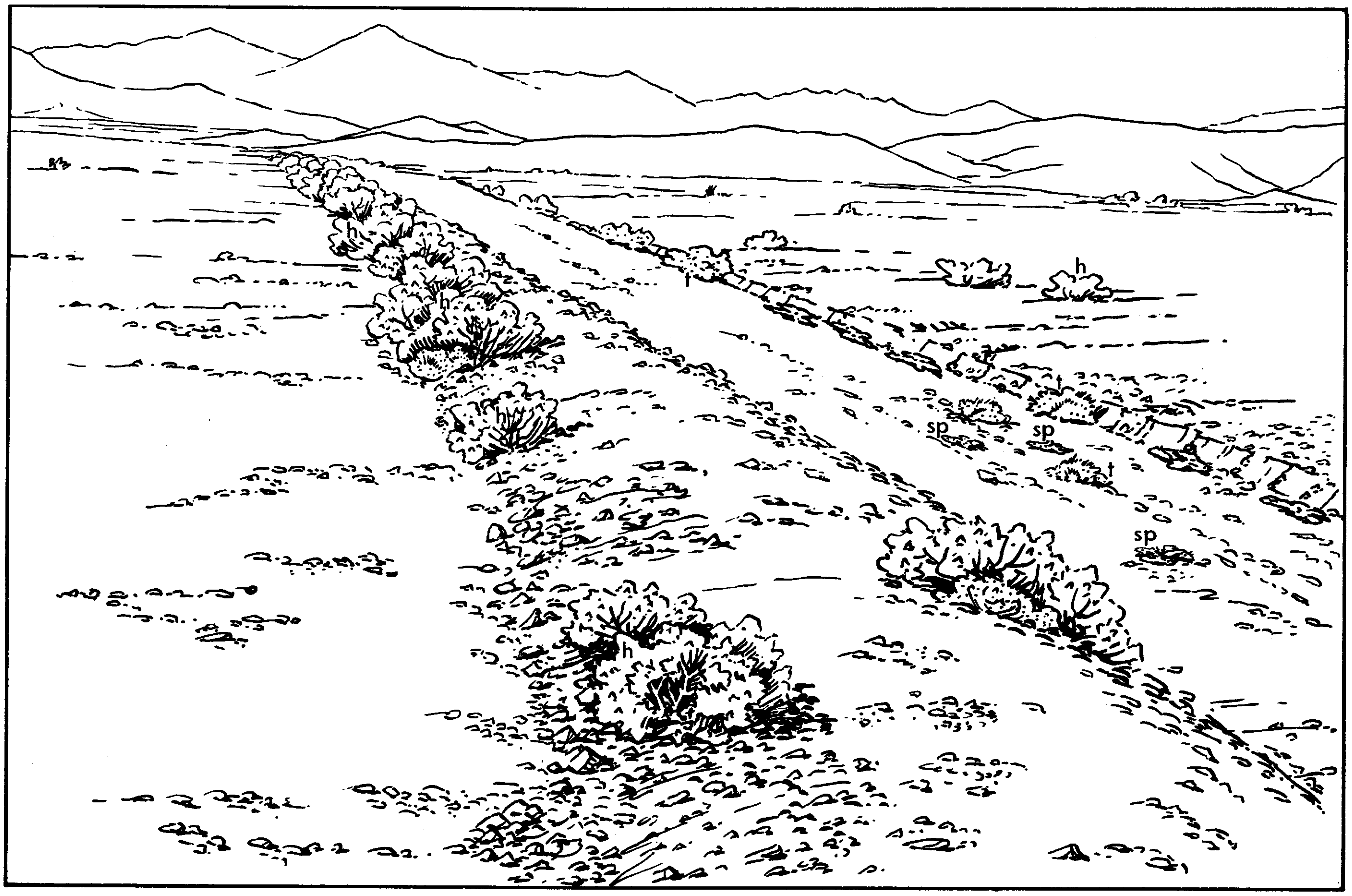

FIGURE 42.—A flood-control embankment, last bladed about 1953, supports healthy stand of desertholly (*h*). Honeysweet (*t*) and spurge (*sp*) grow in the ditch at the right. Location is 1.5 miles northwest of the North Side Borax Camp. Sketch by John R. Stacy, from photograph.

In the same part of the area, along the foot of the gravel fans, is the old bladed road which has had little use since the paved highway was built 15 years ago. Desertholly has moved onto the old road, but there is no honeysweet or creosotebush. If the road were higher on the fans creosotebush would probably have moved in.

Old trails, virtually abandoned since vehicular travel took the place of packtrains, are overgrown with creosotebush.

Desertholly also grows in nearly pure stands along some road shoulders and along some washes high on the fans. On plate 1 an example may be noted along the road to the Queen of Sheba mine in the southwest corner of the area. For about a mile southeast of Salt Well, desertholly grows on the shoulders of roads through stands of cattle spinach, especially where surface water has been ponded and fine sediments have accumulated. One and one-half miles south of Bennetts Well an abandoned old road crosses a stand of cattle spinach, but growing in the road and along the washes is desertholly. Another abandoned stretch half a mile northwest of Bennetts Well is overgrown with cheesebush, creosotebush, arrowweed, and saltgrass.

Honeysweet and spurge are scarce on the west side of Death Valley and on the fans from Badwater south to the cove at Mormon Point. In these areas desertholly is the common roadside shrub. Possibly this distribution is the result of ground salinity, for the ground is slightly more saline where the honeysweet is absent. This also may explain why there is little or no honeysweet along the old abandoned road at the foot of the gravel fans north of Cottonball Basin.

At higher altitudes creosotebush becomes the roadside shrub and grows along the road shoulders.

The plant successions, however, probably are due to the readiness of the different plants to seed and to germinate in the particular environment, and not at all a case of seral succession in which one plant prepares the way for the next (Weaver and Clements, 1938, p. 60). It seems unlikely that shrubs so widely spaced could exert an important influence.

Also, whereas this plant succession among the xerophytes prevailed during drier-than-average years, given a wet period the creosotebush probably could seed and germinate as readily as its more xeric associates. The occurrence of creosotebush along the irrigation ditch above Furnace Creek Ranch and along road shoulders at higher altitudes suggests this is probable. The plants as mapped on plate 1 probably represent stable communities that will stand until a change in climate or a geologic change causes a change in their water supply.

One can only theorize as to how plants that are dependent on ground water seed themselves, for the water table under many phreatophytes is deep. At localities where water enters the ground, as at spring sites and along washes, roots of seedlings could follow the downward percolating water to the water table. But around the edge of the Death Valley saltpan the hydrologic regimen is reversed; the phreatophytes are where almost no water percolates downward. The water table is deepest under the mesquite, and perhaps these plants can seed themselves only when there is a succession of wet years that provide downward percolating water that roots may follow downward to the capillary fungi on water table. The deterioration of the mesquite stands and the scarcity of young mesquite plant in the valley (p. 42) may reflect protracted draught.

The water table is shallowest under the belt of pickleweed, and here the capillary fringe reaches the surface in wet months of normal years. This condition, evidently favorable for seedlings, could account for the comparative stability of the stands of pickleweed and the fact that locally this plant has spread (p. 32).

DISTRIBUTION OF FUNGI AND ALGAE

By CHARLES B. HUNT and L. W. DURRELL [1]

GENERAL

The correlation between the geology and the occurrence of the woody plants led to the hypothesis that there was a similar correlation between the geology and the occurrence of the microflora.

In a preliminary test of this possibilty, samples were collected and cultured on various kinds of soil plates as described by Waksman (1952, p. 43, 45–50). None of the colonies were identified, but orderly differences were found at various positions around the edge of the saltpan. Encouraged by this, Hunt collected a series of soil samples using sterilized collecting tools and containers, and the samples were studied by Durrell. The study confirmed significant differences in the microflora in the different environments sampled.

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This difference served as basis for systematic sampling of Death Valley soils by Durrell. Because of interest in the possible occurrence of pathogenic fungi as well as ordinary soil kinds, Chester W. Emmons, Chief of the Medical Mycology Section, National Institutes of Health, and Roger O. Egeberg, Director of the Los Angeles General Hospital, also participated in the collecting. One hundred and eleven samples were collected by Durrell and serve as the basis for this report. A large number of samples also were collected and studied by Emmons and Egeberg in a search for *Coccidioides immitis* and other pathogenic fungi. Pathogens of man were not found, but the sampling added to the list of fungi isolated.

Very little work has been done on the occurrence of fungi and algae in desert soils. Most of the studies simply list species that have been found under particular conditions. So far as we can determine there has been no attempt to establish limits to the distribution of microfloras or of species in the natural desert environment. Principal works contributing to the subject are those by Bonar and Goldsmith (1925), Drouet (1943), Bolyshev and Evdokimova (1944), Fletcher and Martin (1948), Nicot (1960), and Durrell and Shields (1961); see also Gilman (1957) and Durrell (1962).

Of particular interest in connection with our study of Death Valley soils is the study by Nicot (1960) on certain soils of the Sahara Desert. She states,

> The most characteristic and frequently obtained patterns in isolations are the net predominance of strongly pigmented species from the genera *Helminthosporium, Curvularia, Alternaria,* and *Stemphylium.* * * * one finds Pyrenomycetes and some Mucorineae and a small number of species of *Fusarium.* * * * Among the mechanisms of protection against desiccation and strong light * * * is the brown pigment characteristic of most of the the organisms isolated.

These finds are duplicated by our studies in Death Valley and by those at the Nevada Test Site (Durell and Shields, 1961; Shields, Durell, and Sparrow, 1961).

Marine microbiology has been the subject of intensive and extensive study (see bibliographies in ZoBell, 1946, 1957), and several conclusions reached by the marine microbiologists contribute to understanding the occurrences and processes involved in the microflora in Death Valey.

Marine fungi isolated from decomposing cordage and wood submerged in sea water could be grown in sea water having three times the normal salinity, about 10 percent (Barghoorn and Linder, 1944, quoted by ZoBell, 1957, p. 1036), which is about the salinity limit we found for fungi in Death Valley brines.

Diluting sea water with fresh water inhibits the growth of many marine species of bacteria (Lipman,

1926) and diluting Great Salt Lake water (salinity almost 30 percent) with fresh water inhibits growth of the bacterial flora there (ZoBell, 1946, p. 203). Conversely, increasing the salinity of sea water inhibits growth of the marine bacteria. Few marine bacteria grow in a sea-water medium to which 12 percent sodium chloride has been added (ZoBell, 1946, p. 119).

In Death Valley, from samples beyond the 15 percent brine line, we found few bacteria which would grow in nutrient broth. These results accord well with what has been learned about the salinity limits of marine bacteria and with reported occurrences of bacteria in Great Salt Lake, which has a salinity of almost 30 percent. Great Salt Lake water inhibits growth of bacteria from sewage, soil, and the oral cavity, but the water contains an indigenous flora that, conversely, does not grow well in more dilute media (ZoBell, Anderson, and Smith, 1937). Relative numbers of bacteria that developed on nutrient agar with various dilutions of Great Salt Lake water have been reported as follows (ZoBell, 1946, p. 203):

Source of bacteria	Relative number of bacteria developed on nutrient agar with—			
	Fresh water	Fresh water mixed with indicated percentage of Great Salt Lake water		
		25	50	75
Soil	100	12.6	0.8	0
Great Salt Lake	3.8	51.2	96.4	100

The precipitation of calcium carbonate from sea water is facilitated by bacteria in several ways (ZoBell, 1946, p. 100), and very possibly the microflora in Death Valley has contributed to the precipitation of some of the mineral species there; for example, the minute, euhedral, doubly terminated calcite crystals that occur in the clay (Hunt, and others, 1965b) could very well be the product of bacterial activity.

Our study of the microflora in Death Valley was confined to the lower parts of the fans, the belt of phreatophytes, and adjoining parts of the saltpan.

SAMPLING AND CULTURING METHODS

The geochemistry, mineralogy, and hydrology of the saltpan had been investigated as part of the study of the general geology of Death Valley. In the course of these investigations hundreds of analyses of the salts and brines were made. The results of these determinations are presented in Hunt and others (1965b), they served as the basis for selecting the transects where samples could be collected to determine changes in the microflora. The transects are along radii across the edge of the saltpan (fig. 43); 111 samples of soil and salt were collected for laboratory study.

The samples were taken from the surface and to a depth of 6 inches with a sterile trowel, placed in plastic freezer bags, and sealed. The trowel was dipped in alcohol and flamed between each digging.

For studying the fungi in the laboratory, 1-gram portions were taken with a sterile spoon that was flamed between samplings. These gram portions were placed in sterile Petri dishes, and agar at 45°C poured over them (Warcup, 1950). The cultures then were incubated at room temperature. Several agar media were used. The most satisfactory medium was rose bengal agar (Smith and Dawson, 1944) containing a small amount of streptomycin. This agar isolated more species of fungi than any other. None of the media used added any species to the list obtained with rose bengal agar. No special media were used for Phycomycetes or for *Streptomyces*, although these organisms frequently appeared on some of the media used.

For studying algae, 1- to 2-gram samples were removed from the bags and placed in flasks containing a shallow layer of quartz sand and a small amount of nutrient media (Bristol-Roach). Before innoculation the flasks had been cotton-plugged and steam-sterilized at 15 pounds for 15 minutes. After innoculation the flasks were replugged and capped with metal foil to retard water loss and held under fluorescent light for 30 to 60 days at 25°C. As incubation proceeded, patches of algal growth developed on the sample of soil and on the sand substrata. Often only one patch of growth developed, indicating that only one algal cell, or one filament, had innoculated the flask. After sufficient growth the algal patches were removed with a long sterile needle and microscopically examined and identified.

DISTRIBUTION AND KIND OF SAMPLES

The locations of the 12 sampling transects around the Death Valley saltpan are shown on figure 43. The samples are listed and described in table 27; figures 44A-L are graphic representations of the transects showing the major changes in environments along them.

Sampling is a general problem for any of the outdoor sciences, and a side problem developed in connection with ours. Many of the samples collected for this study gave higher pH values than did the samples collected in previous years for geochemical and mineralogical study. The difference commonly was in the range 0.5 to 1.0 pH, but was found to be as high as 1.5. The answer apparently lies in the different purposes of the sampling programs and the different kinds of spots sampled. For chemical and mineralogical study the samples were collected away from vegetation, but for the fungal and algal studies organic-rich soil, like that under shrubs, was sought. The differences in pH almost

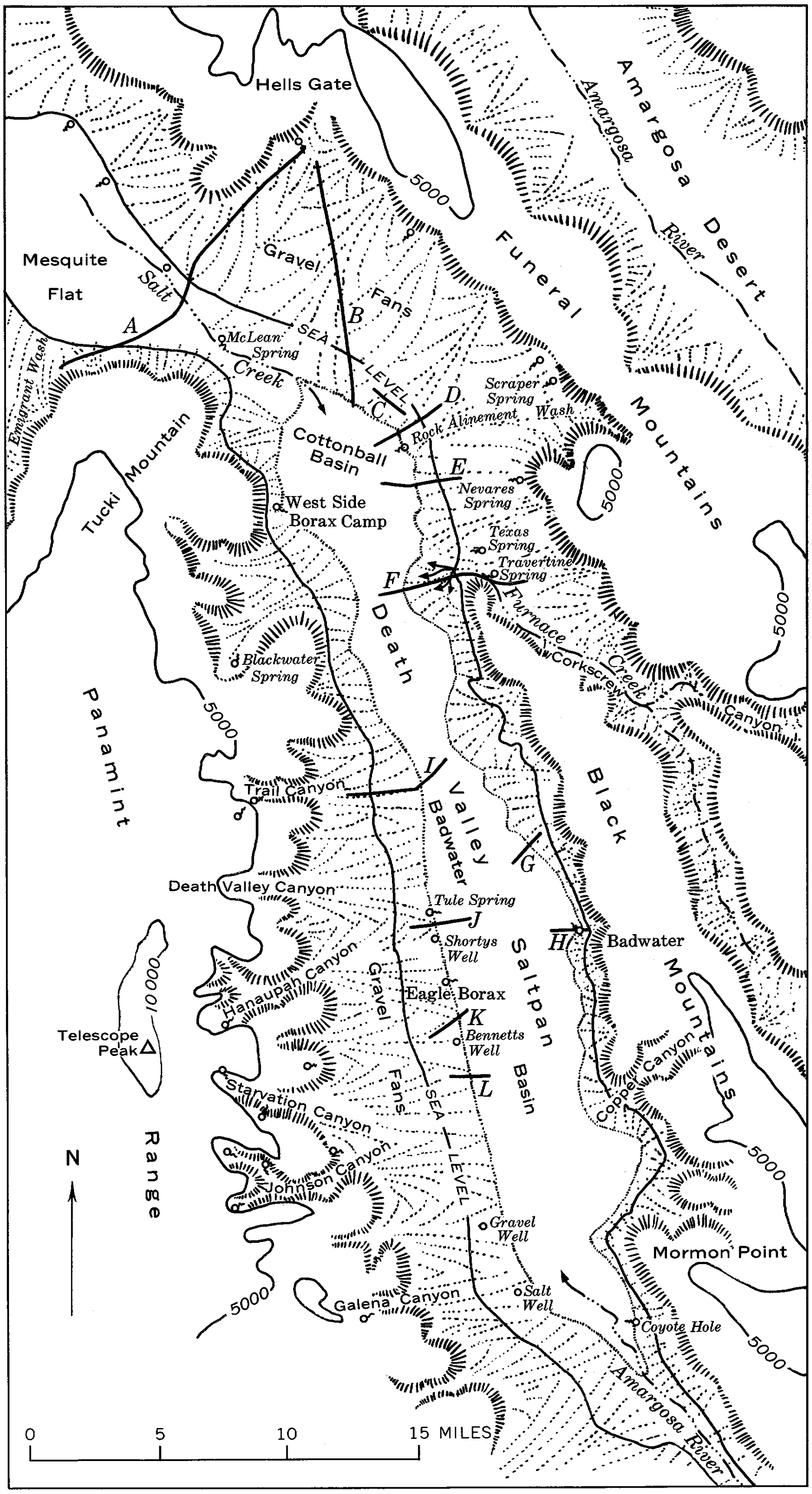

Figure 43.—Index map of Death Valley saltpan showing locations of transects where samples were collected for study of their fungi and algae.

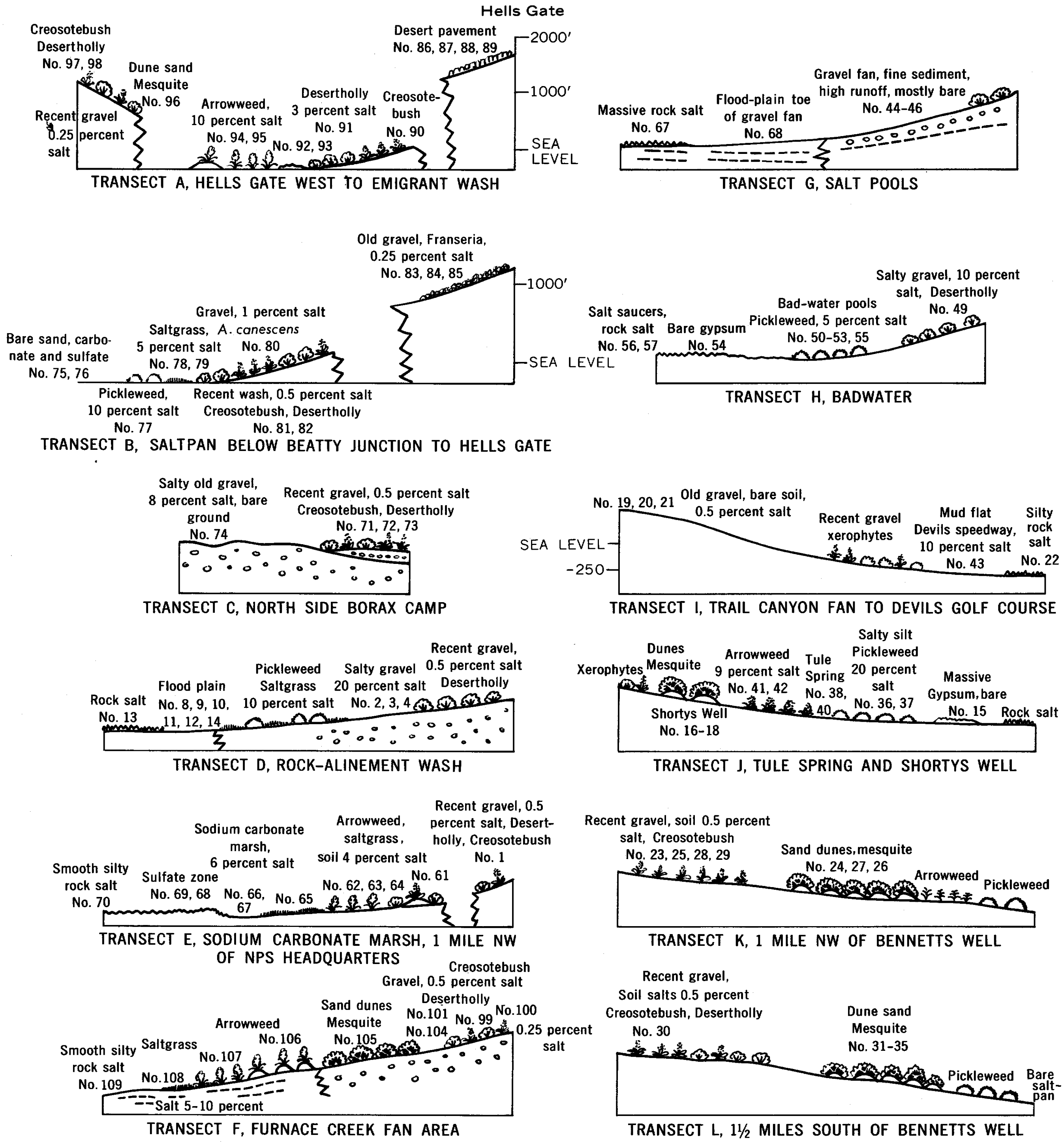

FIGURE 44.—Transects around the Death Valley saltpan. Numbers refer to samples described in table 27.

certainly are a measure of variation in organic matter near and remote from shrubs, which in Death Valley are widely spaced. A specific example of this difference is given in a section on the geochemistry of the saltpan (by Hunt and others, 1965b); surface water at location W–17–56s gave a pH of 6.0, but an algal growth there gave a pH of 7.5. Also, near shrubs, there probably is a seasonal variation in pH.

TABLE 27.—*List of samples showing distribution of algae*

[Samples collected November 3–9, 1960, in and around the Death Valley saltpan. For salinities and other geologic information see transects on figs. 23, 24, 25, 26]

No.	Description	Location	Algae
1	Silt crust in dried pond	By State Route 190, under creosotebush; on Recent gravel; middle of west side of sec. 28, T. 28 N., R. 1 E., Chloride Cliff quadrangle.	*Phormidium dimorpha, Chlorococcum humicola.*
2	Saliferous gravel	At foot of fan ½ mile north of Salt Springs, NE¼ sec. 20, T. 28 N., R. 1 E., Chloride Cliff quadrangle.	
3	Piece of wood by old road	Same as sample 2	
4	Bottom of wash floored with modern gravel; less saliferous than sample 2.	Same general location as sample 2 but 50 feet from both the foot of the fan and the edge of the pickleweed.	
5	Soil under pickleweed; sandy ground	Same as sample 2	
6	Pickleweed roots about 4 inches below surface; sandy ground.	Same as sample 2	
7	Clayey ground under saltgrass	Near sample 2	*Phormidium tenue.*
8	Under crust of salt, mostly sodium sulfate; salinity, 5 to 6 percent.	On damp ground at spring zone on the panward side of the pickleweed in the area of sample 5.	
9	Running water	In sandy wash 1–2 cm deep and about 30 cm wide	*Microcoleus vaginatus, Calothrix castellii, Phormidium tenue.* Black algae?
10	Do	Near sample 9	Filamentous algae in bulbous growth. Algae not found where salinity was about 8 percent. *Microcoleus vaginatus.*
11	Pink crust under water	Same as sample 9	*Microcoleus vaginatus.*
12	Layer of sodium sulfate nodules 3 inches below the surface.	Same general area as samples 2 to 11, but 500 feet from the edge of the pickleweed and approximately at the center of sec. 20; mud flat on the flood plain.	
13	Rough silty rock salt	Near sample 12	
14	Nodules of borax-rich sodium sulfate	On the flood plain near sample 12	*Coccochloris stagnale.*
15	Surface of the gypsum deposit	On the panward side of the pickleweed, 1,500 feet east of the spring, at Tule Spring at the center of the north edge of the Bennetts Well quadrangle. (See also samples 36–41.)	
16	Dune sand under mesquite tree	At Shortys Well, Bennetts Well quadrangle	*Microcoleus vaginatus.*
17	Underground roots and stems	do	
18	Silt crust in dried pond	300 feet east of Shortys Well	*Phormidium tenue, Anabaena variabilis.*
19	Under stones of desert pavement	Trail Canyon fan, Furnace Creek quadrangle, by road at altitude of 250 feet.	*Anacystis montana, Phormidium tenue, P. Retzii, P. subcapitatum.*
20	Silty layer under desert pavement	do	*Phormidium tenue.*
21	Damp sand in wash at a creosotebush	do	
22	Silt on the rough silty rock salt	At Devils Golf Course, near center sec 33, T. 26 N., R. 1 E., by road across the saltpan, Furnace Creek quadrangle.	
23	Gritty sand in center of prehistoric rock circle	At foot of the gravel fan a few hundred feet from the mesquite zone, 1 mile northwest of Bennetts Well, Bennetts Well quadrangle.	
24	Dune sand	Near sample 23	
25	Wood of *Atriplex polycarpa*	do	
26	Soil under mesquite tree	do	
27	Wood of mesquite	do	
28	Laminated silt crust, under a creosotebush, where water had been ponded in wash.	do	*Chlorococcum humicola.*
29	Soil near an anthill	do	
30	Soil in unexcavated rock circle beside the storage pit that was excavated.	500 feet west of BM 229, 1½ miles south of Bennetts Well	
31	Old wood, probably *Atriplex polycarpa.* An old rootstalk from just below the surface.	Between sand dunes along the Old Road, 1½ miles east of south of Bebbetts Well.	
32	Soil at edge of a sand dune	Same as sample 31	
33	Rodent hole with droppings	do	
34	Clayey or silty soil forming the base of the dune sand.	do	*Chlorococcum humicola, Phormidium foveolarum.*
35	Old mesquite wood, blackened	do	
36	Wood of pickleweed	500 feet east of the spring, Tule Spring area. (See also sample 15.)	
37	Soil under pickleweed	do	
38	Soil sample	At edge of Tule Spring	*Phormidium tenue, Oscillatoria agardhii.*
39	Black muck	do	
40	Green algae	Afloat on Tule Spring	*Chlorococcum humicola, Rhizoclonium hieroglyphicum.*
41	Rabbit droppings	In arrowweed belt just west of Tule Spring	
42	Soil under arrowweed	do	
43	Soil on flood plain at the speedway	Devils Speedway, near BM 270 by road across the saltpan, Furnace Creek quadrangle	
44	Mudflow, 1 day old where it crosses the highway	East side of Death Valley, by the highway to Badwater at junction with the road to the salt pools; Furnace Creek quadrangle.	*Phormidium tenue, P. subcapitatum.*
45	Duplicate of sample 44	do	*Phormidium tenue.*
46	Soil under desertholly	Same general area as sample 44	
47	Massive salt rock	At the salt pools	
48	Salt-crusted mud	At the flood plain on the east side of the massive rock salt at the salt pools.	
49	Soil under desertholly	By the highway to Badwater, 1 mile south of the junction with the road to the Natural Bridge; Furnace Creek quadrangle.	*Coccochloris stagnale.*
50	Algae in the pool	Badwater, Bennetts Well quadrangle	*Phormidium ambiguum.*
51	Algae from beneath thick crust of gypsum 1 to 2 cm thick.	do	*Phormidium angustissimum.*
52	Algae from a second pool	do	*Phormidium angustissimum, Anacystis montana.*
53	Algae under gypsum crusts	do	*Anacystis montana, Coccochloris stagnale, Microcoleus vaginatus, Phormidium foveolarum.*
54	From surface of old gypsum deposit	300 feet west of the Badwater pools	
55	Algal scum floating in patches on the water	Middle pool at Badwater	*Anacystis montana, Microcoleus vaginatus.*
56	From muddy edge of a saucer	Salt-saucer area, 1 mile west of Badwater	
57	Piece of wood on a salt saucer; probably blown in	do	

TABLE 27.—*List of samples showing distribution of algae*—Continued

No.	Description	Location	Algae
58	Bermudagrass sod that had been fertilized with sheep manure.	Old headquarters of National Park Service	*Phormidium dimorpha.*
59	Sandy soil under the mesquite	Mesquite dunes, three-quarters of a mile northwest of National Park Service headquarters.	*Anabaena variabilis.*
60	Sandy soil with organic litter, near a rodent hole	do	*Phormidium subcapitatum.*
61	Sandy soil under desertholly	100 yards north of sample 59	*Anabaena variabilis.*
62	Sandy soil under saltgrass	Near sample 61	*Anabaena variabilis.*
63	Rabbit droppings	do	
64	Soil under arrowweed	Near sample 62	
65	Sandy and salty soil under rush	Between sample-64 location and the edge of the sodium carbonate marsh.	
66	Algae under salt-crusted sand	At the sodium-carbonate marsh west of sample 65	*Phormidium angustissimum.*
67	Sodium carbonate soil	In the marsh	*Phormidium tenue.*
68	Surface sand	Salt-heaved sulfate zone at the west edge of marsh; NE¼SE¼ sec. 32, T. 28 N., R. 1 E., Chloride Cliff quadrangle.	
69	Algae under pebbles	Wash, 500 feet west of sample 68	*Chlorella vulgaris.*
70	Silty layer on the smooth silty rock salt	NW¼SE¼ sec. 32, T. 28 N., R 1 E.; about one-half mile west of sample 59.	
71	Soil under desertholly, in Recent gravel	At the North Side Borax Camp, center N½NW¼ sec. 17, T. 28 N., R. 1 E., Chloride Cliff quadrangle.	
72	Algae, on bare ground between desertholly in Recent gravel.	do	*Microcoleus vaginatus.*
73	Soil under creosotebush	do	*Microcoleus vaginatus.*
74	Soil, and white rocks with algae on under sides; saliferous old gravel; bare ground.	do	*Anacystis montana, Phormidium tenue, Microcoleus vaginatus.*
75	Surface of bare sand of carbonate zone	Northeast corner sec. 13, T. 16 S., R. 46 E., Chloride Cliff quadrangle.	
76	Caliche layer of thenardite (sodium sulfate) about 3 inches below the surface.	do	
77	Sandy and salty mound under a pickleweed	do	
78	Soil under saltgrass on sand of carbonate zone	SE¼NE¼ sec 11, T. 16 S., R. 46 E., Chloride Cliff quadrangle, one-half mile southeast of Beatty Junction.	
79	Wood of old stump of desertholly in wash with Recent gravel.	do	
80	Soil under *Atriplex canescens* on gravel fan	do	*Anabaena variabilis.*
81	Soil under desertholly in wash with Recent gravel	By the road to Beatty, one-half mile north of Beatty Junction; about 100 feet below sea level.	
82	Soil under creosotebush	do	
83	Soil under *Franseria dumosa*	In Recent wash, by the road to Beatty, 6 miles north of Beatty Junction; alt. about 1,200 feet.	*Phormidium foveolarum.*
84	Soil under creosotebush	do	
85	Algae under quartz pebbles; bare desert pavement on old gravel by the wash.	do	*Anacystis montana, Nostoc muscorum, Tolypothrix distorta.*
86	Soil under *Opuntia basilaris*	Along road southwest from Hells Gate to Mud Canyon; near BM 1577, north side sec. 32, T. 14 S., R. 46 E., Chloride Cliff quadrangle.	*Nostoc commune, Microcoleus vaginatus.*
87	Soil under creosotebush	do	*Phormidium dimorpha.*
88	Soil under *Franseria dumosa*	do	
89	Soil under desertholly	do	*Phormidium subcapitatum.*
90	Soil under creosotebush, in Recent gravel	By State Route 190, sea level, center SW¼ sec. 24, T. 15 S., R. 46 E., Stovepipe Wells quadrangle.	
91	Soil (gravel) under desertholly	Same as sample 90, but 50 feet below sea level	*Nostoc muscorum.*
92	Soil under pickleweed	Flood plain of Salt Creek near BM 72 in sec. 23, T. 15 S., R. 46 E., Stovepipe Wells quadrangle.	
93	Sandy soil under *Atriplex canescens*	do	
94	Soil under arrowweed	Flood plain of Salt Creek at Devils Cornfield, center sec. 26, T. 15 S., R. 45 E., Stovepipe Wells quadrangle.	*Nostoc muscorum.*
95	Soil under pickleweed	do	*Anabaena variabilis.*
96	Sandy soil under mesquite	By State Route 190, near BM 3, 2 miles east of Stovepipe Wells Hotel, Stovepipe Wells quadrangle.	
97	Soil under creosotebush, in Recent gravel	By State Route 190, near BM 635, 4 miles southwest of Stovepipe Wells Hotel.	
98	Soil under desertholly	do	
99	Soil under desertholly, in Recent gravel	Toe of Echo Canyon fan, SW¼NW¼ sec. 25, T. 27 N., R. 1 E., Furnace Creek quadrangle.	*Chlorococcum humicola.*
100	Soil under creosotebush	do	*Anabaena variabilis.*
101	Algae in the spring	Travertine Springs	*Oscillatoria agardhii, Anabaena variabilis.*
102	Damp mud by a ditch at the spring	do	*Phormidium foveolarum.*
103	Algae in dirt ditch below a spring	do	*Chlorococcum humicola, Lyngbya thermalis, Gomphosphaeria aponina, Chamaesiphon incrustans.*
104	Algae from wall of concrete ditch from spring	do	*Phormidium tenue.*
105	Soil under desertholly, in Recent gravel	Furnace Creek fan, NE¼SE¼ sec. 21, T. 27 N., R. 1 E., at burial mound area.	*Chlorococcum humicola.*
106	Sand under mesquite	Furnace Creek fan, 1,000 feet south of Indian Village	
107	Soil under arrowweed	Furnace Creek fan, SE¼SE¼ sec. 20, T. 27 N., R. 1 E	
108	Soil under saltgrass	Toe of Furnace Creek fan, SE¼NW¼ sec. 29, T. 27 N., R. 1 E.	
109	Silty layer on the smooth rock salt	1,000 feet west of toe of Furnace Creek fan, sec. 29, T. 27 N., R. 1 E.	*Anabaena variabilis.*
110	Muddy soil	Date palm orchard, Furnace Creek Ranch	*Phormidium tenue, P. Retzii, P. angustissimum, Chlorococcum humicola, Anabaena variabilis.*
111	Algae in irrigation ditch	do	*Chlorococcum humicola, Phormidium tenue.*
112	Ditch by cabin	do	*Protococcus viridis, Phormidium tenue, P. angustissimum.*
113	Under side of lime rock	do	*Phormidium tenue, Anacystis montana, Microcoleus vaginatus.*

LISTS OF FUNGI AND ALGAE

The most striking feature of the fungi isolations (table 28) is their predominately dark color. The table indicates the dark species. The species of *Stemphylium* are very dark. This is a variable and confusing genus. Most of the cultures were of *S. ilicis*, but several were of the "tetracoccosporium" type. A few had very large brown spores and probably are *S. saciniforme.*

TABLE 28.—*List of fungi found in Death Valley*

Species	Samples containing listed species		
	Number	Percent of total	Dark species
Rhizopus nigricans Ehrenberg	20	24	---------
Actinomucor repens Schostakowitsch	3	---------	---------
Mucor varians Povak	2	---------	---------
racemosus Fresenius	1	---------	---------
spinescens Lendner	2	---------	---------
Thamnidium sp	2	---------	---------
Pythium echinulatum Mathews	1	---------	---------
Chaetomium elatum Kunze and Schmidt	2	---------	X
cochlioides Pallister	2	---------	X
Montemartina myriadea Curzi	1	---------	---------
Fimetaria sylvatica (Daszewska) Griff. and Seaver	2	---------	X
Trichosphaeria pilosa (Persoon) Fuckel	1	---------	---------
Phoma sp	5	---------	X
Sphaeronaema sp	46	55	X
Naemosphaera sp	4	---------	X
Ceratopycnis sp	3	---------	X
Cephalosporium sp	3	---------	---------
Aspergillus sulfureum (Fres) Thom and Church	1	---------	---------
Aspergillus micro-virido-citrinus Costantin	1	---------	---------
niveus Beochwits	5	---------	---------
niger VanTiegem	3	---------	---------
Wentii Wehmer	25	30	X
ustus (Bainier) Thom. and Church	1	---------	---------
fumigatus Fres	4	---------	---------
nidulans (Eidam) Wint	1	---------	---------
flavus oryzae Link	2	---------	---------
terreus Thom	1	---------	---------
Penicillium oxalicum Thom	33	40	---------
Scopularoipsis brevicaulis Bainier	2	---------	---------
Gliocladium pencilloides Corda	1	---------	---------
Botrytis carnea Schum	7	---------	---------
Beauveria densa (Link) Picard	1	---------	---------
Mycogone nigra (Morgan) Jensen	4	---------	X
Pullularia pullans (deBary) Berkhout	2	---------	X
Stachybotrys atra Corda	5	---------	X
Nigrospora sphaerica (Sacc) Mason	1	---------	X
Humicola brevis (Gilman and Abbott) Gilman	1	---------	X
Cladosporium herbarum (Persoon) Link	7	---------	X
Curvularia tetramera (McKinney) Boedijn	7	---------	X
geniculata (Tracy and Earl) Boedijn	1	---------	X
Stemphylium ilicis Teng	48	65	X
sarciniforme (Cav) Wiltshire	2	---------	X
ilicis (*Tetracoccosporium* type)	4	---------	X
Alternaria tenuis Nees	13	15	X
Fusarium sp	29	35	---------
roseum (Link) Snyder and Hansen	1	---------	---------
Cylindrocarpon heteronemum (Berk and Broome) Woll	2	---------	---------
Myrothecium convexum Berk and Curtis	2	---------	---------
Sclerotia	27	32	X
Streptomyces sp	5	---------	---------

Sphaeronaema sp. also is common; it too appeared in more than half the cultures. A large number of species have been described for this genus, but the organism here considered does not fit the description of any. It may be a new species. The same can be said for the *Naemosphaera*, *Ceratopycnis*, and *Thamnidium* that are listed.

To our list could be added *Podaxis pistillaris*, a large bulbous fungus that is common in the region. It was not observed around the saltpan, but does grow on the flood plain of the Amargosa River about 2 miles upstream from the edge of the salt. It was not included in this study.

The correct names of the fungi and algae are given in the lists, table 28 and 30. All references in the text, where genus only is used, refer to these listed organisms.

About a third of the cultures were black with sclerotia submerged in the agar. Nicot (1960) also mentions such blank hyphal masses. Numbers of these sclerotia were carefully cut out and replanted. When less crowded they developed into *Stemphylium* or *Sphaeronaema.*

An interesting feature of the dark-spored fungi is their apparent resistance to radiant energy. Normally fungus spores are killed in from ½ minute to 4 minutes exposure to ultraviolet light of 2,500 to 2,600 angstroms. In the dark spore of *Stemphylium ilicis*, after exposure to these rays for 60 minutes, germination was more than 90 percent the following day. Samples exposed in the reactor at Brookhaven developed *Stemphylium* although they were irradiated with 600,000r gamma.

It may be that the melanin pigment in this fungus acts as a light shield. Spectrographic tests indicate that light from 2,200 to 8,000 angstroms does not pass these spores. Durrell and associates have attempted to extract this pigment but so far without success.

Several of the fungi found in Death Valley (table 28) are unusual. *Botrytis carnea* is rare; it has been reported from Europe in humus. *Beauveria densa* is generally considered a parasite of insects. Certain of the dark species are undoubtedly undescribed species, and the *Thamnidium* listed is a new species.

DISTRIBUTION OF FUNGI AND ALGAE

Of the 111 samples of soil and salt that were collected, 61 contained algae representing 22 species, and 100 contained fungi representing 48 species. In general, algae were obtained beyond the limit of the flowering plants (6 percent brine line) as far as the 8 percent brine line. Fungi were obtained from samples collected to about the 10 or 12 percent brine line. Using ordinary nutrient broth and agar, bacteria were obtained from samples out to the 15 percent brine line. More extensive sampling probably would extend these limits, but the results leave little doubt that some such limits affect the distribution of algae, fungi, and heterotrophic bacteria in the Death Valley saltpan.

In addition, the fungi population was found to decrease in numbers of species and in numbers of spores as the salinity increased. The fungi are most abundant in the xerophyte zone, which is removed from the saltpan. They are of intermediate abundance in the phreatophyte zone at the edge of the pan, and they are least abundant on the saltpan.

TABLE 29.—*List of fungi, by samples*

No.	Fungi	Transected soil type	pH
1	*Actinomyces, Curvularia, Myrothecium, Thamnidium, Penicillium, Stemphylium, Botrytis, Rhizopus, Sphaeronaema.*	Fine silt, olive-buff	9.3
2	*Penicillium*	Fine sandy, drab-gray	9.2
4	No growth	Sandy gravel, drab-gray; 5 to 6 percent salt	8.9
5	*Sphaeronaema, Phoma, Naemosphaera*	Silty, drab-gray, organic matter	9.9
6	*Naemosphaera*	Silty, drab-gray, organic	9.6
7	*Fusarium, Aspergillus sulfurea*	Sandy benzo-brown	8.9
8	*Penicillium, Beauveria, Cephalosporium Aspergillus niveus*	Sandy light-gray	9.0
12	No fungi	Hard lumps, light-gray	8.6
13	*Penicillium, Alternaria.* (Very few.)	Hard salty lumps, pale-drab-gray	8.1
16	*Stemphylium, Sphaeronaema, Penicillium, Fusarium, Montemartina*	Sandy, gray-tan, organic	7.7
17	*Scopularopsis, Penicillium, Trichosphaeria*	----	----
18	*Stemphylium, Sphaeronaema, Fusarium, Rhizopus, Actinomucor, Fimetaria.*	Fine silt, light-drab	9.1
20	*Stemphylium, Sphaeronaema, Mycogone, Fusarium, Aspergillus Wentii, A. niveus.*	Fine silt, ecru-drab	9.9
21	*Stemphylium, Sphaeronaema, Penicillium, Fusarium*	Silt and gravel, gray-tan	8.0
22	No fungi	Lumps, fine silt, ecru-drab	9.2
23	*Sphaeronaema, Curvularia, Alternaria, Stemphylium, Cephalosporium, Fusarium, Aspergillus Wentii.*	Lumpy silt, drab-gray	8.8
24	*Stemphylium, Spaeronaema, Penicillium, Rhizopus, Aspergillus nidulans.*	Fine silt, wood-brown	9.5
26	*Stemphylium, Sphaeronaema, Penicillium*	Silty sand, drab-gray, organic matter	8.0
28	*Stemphylium, Sphaeronaema, Rhizopus, Fusarium, Aspergillus Wentii.*	Lumpy silt, drab-gray	9.6
29	*Stemphylium, Sphaeronaema, Fusarium*	Coarse sand, drab-gray	7.7
30	*Stemphylium, Sphaeronaema, Botrytis, Aspergillus Wentii*	Sandy, drab-gray	8.3
32	*Stemphylium, Sphaeronaema, Fusarium*	Sandy, light-drab, organic matter	7.4
33	*Stemphylium, Sphaeronaema, Cladosporium, Penicillium*	Sandy light-drab, organic	7.7
34	*Stemphylium, Chaetomium, Fusarium*	Fine silt, tawny-olive	8.2
36	*Curvularia, Penicillium, Fusarium*	Lumpy silt, drab-gray, organic matter	8.6
37	*Fusarium*	Silty, drab-gray	8.4
38	*Aspergillus Wentii,* 2 species *Mucor*	Lumpy sandy silt	8.5
39	*Mucor, Aspergillus Wentii, A. niveus*	Drab-gray, organic	7.0
41	*Aspergillus Wentii, Chaetomium, Curvularia, Naemosphaera*	Silt, drab-gray, organic matter	8.2
42	*Penicillium, Cladosporium, Fusarium*	Silt, fawn-color, organic matter	7.4
43	*Stemphylium, Aspergillus fumigatus, Chaetomium*	Sandy, light-brown	8.4
44	*Mucor, Penicillium, Rhizopus, Phoma, Naemosphaera, Aspergillus Wentii.*	Lumpy granular, brown	8.4
46	*Stemphylium, Rhizoys, Fusarium, Phoma Aspergillus Wentii*	Sand small rocks, drab-gray	8.5
47	No growth	Rock salt	7.9
48	*Cladosporium*	Mud, drab-gray	9.1
49	*Stemphylium, Sphaeronaema, Curvularia, Penicillium, Aspergillus Wentii, A. terreus.*	Sandy, rocky, drab-gray	9.8
54	*Stemphylium, Curvularia, Cladosporium, Penicillium, Alternaria, Aspergillus flavus, A. Wentii.*	Granular lumpy, pale, drab-gray, gypsum	8.7
56	No growth	Salty hard lumps	8.9
58	*Stemphylium, Curvularia, Mycogone, Phoma, Aspergillus Wentii*	----	9.2
59	*Stemphylium, Sphaeronaema, Aspergillus Wentii*	Sandy, drab-gray, organic	9.0
60	*Stemphylium, Sphaeronaema, Fusarium*	Silty, drab-gray, organic	8.6
61	*Stemphylium, Sphaeronaema, Penicillium, Rhizopus, Alternaria, Fusarium, Aspergillus Wentii.*	Fine sandy silt	9.9
62	*Stemphylium, Sphaeronaema, Rhizopus, Penicillium, Cylindrocarpon, Phoma, Fusarium.*	Sandy, light-drab	9.6
63	*Stemphylium, Sphaeronaema, Alternaria, Thamnidium, Rhizopus, Aspergillus Wentii.*	Silty sand, drab-gray, organic matter	9.5
64	*Stemphylium, Sphaeronaema, Aspergillus Wentii*	Sandy, brown, organic	9.3
65	No growth	Sandy, lumpy, drab-gray	9.4
66	do	Salty sandy crust, light-olive-gray	9.7
67	do	Silty, lumpy, drab-gray	9.6
68	do	Granular lumpy, dark-gray	9.2
70	do	Lumpy, granular, buff	9.2
71	*Stemphylium, Sphaeronaema, Stachybotrys, Penicillium, Aspergillus Wentii.*	Fine sand, drab-gray, organic matter	9.3
72	*Stemphylium, Sphaeronaema, Alternaria, Fusarium, Rhizopus, Aspergillus Wentii, Pullaria,*	Lumpy silt, light-tan	8.2
73	*Stemphylium, Sphaeronaema, Penicillium, Rhizopus, Aspergillus niveus.*	Sandy silt, full of rocks, drab-gray	7.8
74	*Stemphylium, Sphaeronaema, Aspergillus niveus, Penicillium*	Lumpy, porous, light-gray-tan	9.7
75	*Penicillium, Stachybotrys, Alternaria, Chaetomium, Aspergillus Wentii.*	Fine sandy silt, buffy-brown	8.7
76	No growth	Lumpy, gray-tan	8.5
77	*Stemphylium, Alternaria, Mycogone, Phoma, Ceratopycnis*	Lumpy silt, drab-gray, organic matter	10.0
78	*Sphaeronaema*	Sand and silt, gray-buff	8.9
80	*Stemphylium, Alternaria, Cladosporium Ceratopycnis, Aspergillus Sulfureus.*	Coarse sand, light-gray	9.5

TABLE 29.—*List of fungi, by samples*—Continued

No.	Fungi	Transected soil type	pH
81	*Stemphylium, Penicillium, Sphaeronaema*	Gravel, drab-gray, organic matter	8.6
82	*Stemphylium, Sphaeronaema, Gliocladium Botrytis, Penicillium*	Sandy, lumpy, drab-gray	7.7
83	*Sphaeronaema, Penicillium, Rhizopus*	Sandy granular, drab-gray	9.3
84	*Stemphylium, Sphaeronaema, Rhizopus, Penicillium, Fusarium, Stachybotrys, Botrytis.*	Sandy, lumpy, drab-gray, organic matter	8.4
86	*Stemphylium, Sphaeronaema, Penicllium Botrytis, Aspergillus Wentrii, A. fumigatus.*	Lumpy, gray-brown	8.4
87	*Sphaeronaema, Stachybotrys, Rhizopus, Actinomucor, Penicillium*	Gravelly loam, gray-brown	8.8
88	*Stemphylium, Sphaeronaema, Botrytis, Rhizopus, Mucor spinosa, Myrothecium, Phoma, Fusarium, Scopularopsis, Aspergillus Fumigatus.*	Silty, rocky, drab-gray	9.1
89	*Sphaeronaema, Rhizopus, Fusarium*	Silty, rocky, drab-gray	9.0
90	*Stemphylium, Sphaeronaema*	Sandy, drab-gray, organic matter	7.5
91	*Stemphylium, Sphaeronaema, Alternaria Penicillium, Fusarium*	Sandy, drab-gray	9.2
92	*Stemphylium, Alternaria, Fusarium, Aspergillus Wentii, A. microviride.*	Fine sandy, drab-gray	9.5
93	*Stemphylium, Sphaeronaema, Cladosporium, Alternaria, Aspergillus Wentii, A. niveus.*	Sandy, drab-gray, organic matter	9.1
94	*Stemphylium, Aspergillus Wentii, A fumigatus, A. niger*	Sandy, drab-gray, organic matter	9.2
95	*Stemphylium, Alternaria, Aspergillus niger, A. flavus oryzae*	Sandy, drab-gray	9.4
96	*Stemphylium, Sphaeronaema, Fimetaria, Rhizopus, Aspergillus Wentii.*	Fine sand, drab-gray, organic matter	8.4
97	*Stemphylium, Sphaeronaema, Penicillium, Fusarium, Aspergillus Wentii.*	Lumpy silt, drab-gray	8.4
98	*Stemphylium, Sphaeronaema, Fusarium, Penicillium, Aspergillus Wentii.*	Silt and gravel, drab-gray	9.7
99	*Penicillium, Sphaeronaema, Ceratopycnis*	Gravel and silt, drab-gray	9.9
100	*Stemphylium, Sphaeronaema, Rhizopus, Penicillium, Fusarium, Pullularia.*	Gravel and silt, drab-gray	9.0
105	*Stemphylium, Sphaeronaema, Fusarium, Penicillium*	----	9.4
106	*Stemphylium, Cladosporium, Mycogone, Fusarium roseum, Penicillium, Cylindrocarpon.*	Coarse sand, drab-gray, organic matter	8.7
107	*Stemphylium, Sphaeronaema*	Silt carbonate zone, gray-brown silt, arrowweed	9.3
108	*Stemphylium, Stachybotrys, Botrytis*	Silty gray-buff	8.9
109	Very little growth; 1 *Fusarium*, few of *Stemphylium* and *Aspergillus Wentii.*	Fine silt, avelenius	10.0
110	*Sphaeronaema*, many *Fusarium, Mucor, Aspergillus, Curvularia, Pythium, Rhizopus, Cephalosporium.*	Wet lumpy, buffy-brown	----

TABLE 30.—*List of algae found in Death Valley*

Green algae

Chlorococcum humicola (Naeg.) Rabenhorst
Protococcus viridis Agardh
Rhizoclonium hieroglyphicum (C.A.Ag) Kuetzing
Anacystis montana (Lightf.) Dr. and Daily

Blue-green algae

Gomphosphaeria aponina Kuetz.
Chamaesiphon incrustans Grunow
Oscillatoria Agardhii Gomont
Phormidium tenue (Menegh) Gomont
Phormidium angustissimum W. and G. S. West
Phormidium fovcolarum (Mont) Gomont
Phormidium subcapitatum Boye P.
Phormidium ambiguum Gomont
Phormidium dimorpha Lemm
Phormidium foveolarum (Mont) Gomont
Lyngbya thermalis Roth
Microcoleus vaginatus (Vauch.) Gomont
Anabaena variabilis Kuetz.
Nostoc commune Vauch.
Nostoc muscorum Agardh
Tolypothrix distorta Kuetz.
Calothrix castellii Fremy
Coccochloris stagnale Sprengel

In the xerophyte zone, where the ground contains little salt but is dry except for wetting by dew and the infrequent rains, 30 samples averaged 5 species of fungi per sample and yielded a total of 26 different species. Further, no sample from the xerophyte zone failed to yield fungi.

In the phreatophyte zone, where the ground is damp but salty, the number of species and individuals is fewer than in the xerophyte zone, and the population decreases panward. In the mesquite zone 14 samples averaged 4 species per sample and yielded a total of 18 different species. In the belt of arrowweed and pickleweed 16 samples averaged 3 species per sample and yielded a total of 22 different species. The only samples from the phreatophyte zone that yielded no fungi were from the very salty ground with pickleweed.

In the bare saltpan, beyond the 6 percent brine line, 15 samples averaged 2 species per sample, but half these species were obtained in only 2 samples. The remaining 13 samples averaged only 1 species per sample and 9 of the 15 samples yielded no fungi.

Altogether a total of 50 species of fungi were identified. Seven of these species were obtained in more than 10 samples and were distributed as follows:

Genus	Frequency of occurrence in—			
	29 samples	30 samples	16 samples	All 75 samples
	Xerophyte zone	phreatophyte zone	Beyond 6 percent brine line	
Stemphylium	25	21	3	49
Sphaeronaema	28	15	0	43
Penicillium	20	7	5	32
Fusarium	16	10	1	27
Aspergillus Wentii	13	8	3	24
Rhizopus	13	4	0	17
Alternaria	4	5	3	12

Four kinds of fungi that were obtained in 5 or more samples were restricted to samples from the xerophyte and phreatophyte zones. These fungi are *Phoma*, *Aspergillus niveus*, *Mucor*, and *Stachybotrys*. *Cladosporium* was found in the saltpan and the phreatophyte zone but not in the xerophyte zone.

The inverse relation between salinity and population of fungi was found also by Chester W. Emmons who participated with us in the sampling. He too collected about 100 samples, but for a very different purpose, namely to detect the possible presence of pathogenic fungi. His samples were taken by inoculating a plate at the site of collection with a sterile cotton-tipped swab. No attempt was made to equalize the samples and, in fact, heavier inoculations were deliberately made in the more saline ground where it was felt there was less probability of encountering large numbers of spores. Even so, he found fewer fungi in the zone of pickleweed than in the zone of arrowweed, and fewer in the arrowweed than in the mesquite (Emmons, written communication, 1961).

In a laboratory test of the salinity controls, the two most common fungi, *Stemphylium* and *Sphaeronaema*, were cultured on media containing 1, 3, 6, 10, 20, and 30 percent NaCl. These fungi grew well in salt concentrations as high as 6 percent. The osmotic pull of such a solution, roughly twice the concentration of sea water, is about 50 atmospheres.

In another laboratory test of temperature limits, *Stemphylium* and *Sphaeronaema* were grown, though poorly, at 131°F.

Although the occurrence of fungi increases with decrease in the salinity, the sampling failed to test the correlation with the content of organic matter (p. 56). In general the content of organic matter decreases as the salinity increases.

The algae (table 27) did not show comparable zoning. Twenty-nine samples from the xerophyte zone yielded 12 species. Fifteen samples from the phreatophyte zone yielded 9 species. And 23 samples from the saltpan, out to the 8 percent brine line, yielded 10 species. Five species appeared in more than 5 samples. Of these, 3 species (*Anabaena variabilis*, *Microcoleus vaginatus*, and *Phormidium tenue*) appeared in all three major zones—xerophyte, phreatophyte, and bare saltpan. One species (*Chlorococcum humicola*) was found in the xerophyte and phreatophyte zones but not in the saltpan, and one (*Anacystis montana*) was found in the xerophyte zone and the saltpan but not in the phreatophyte zone.

On the gravel fans, algae occur regularly under translucent stones, most of quartz and quartzite but some of white limestone or calcite too. Every such stone overturned was found to have algae on the under side, where dew collects, where there is protection from the evaporation, and where ample light can come through the translucent rock. Durrel (1956) has previously noted such occurrences in other areas, and has referred to them as "microgreenhouses". The algae found under translucent stones in Death Valley include:

Phormidium tenue
P. Retzii
P. subcapitatum
Microcoleus vaginatus
Anacystis montana
Nostoc muscorum
Tolypothrix distorta

At the edge of a few opaque pebbles, *Chlorella vulgaris* was found. It occurred at the ground line on the shaded side of the pebble.

Algae also occur at sulfate marshes, like the pool at Badwater and Cottonball Marsh. These pools consist of lumpy growths of gypsum, a few inches in diameter, coated by sodium chloride. In dry seasons sodium chloride is deposited; in wet seasons the chloride is flushed out of the system and gypsum or other sulfates are deposited. The salinity of the water is as high as 6 percent. Algae grow on the bottom side of the translucent lumps of gypsum. The species found included *Anacystis montana*, *Microcoleus vaginatus*, and four species of *Phormidium*. The occurrences also illustrate the discrepancy in pH values that has already been noted (p. 56). In dry seasons the water in these pools has a nearly neutral pH but the algae layers are distinctly alkaline.

On crusts of sodium chloride *Phormidium tenue* and *Anabaena variabilis* were found. Cottonballs of the borate minerals ulexite or probertite were found to contain *Coccochloris stagnale*.

The salty water in which the algae were found has an osmotic pressure up to about 50 atmospheres. Sea water, which contains about 3.3 percent salts, has an osmotic pressure of slightly under 20 atmospheres. Almost all the species found in Death Valley are blue-green algae.

In brief, around the Death Valley saltpan the microflora responds to environmental differences very much as do the flowering plants, especially in regard to availability and salinity of the moisture. The striking concentric zonation of plants around the saltpan—from flowering plants, to algae, to fungi, to heterotrophic bacteria, and probably to autotrophic bacteria—provides an example of the progressively greater adaptability of the more primitive plants to severe conditions of environment.

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