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HEADQUARTERS
QUARTERMASTER RESEARCH & DEVELOPMENT COMMAND

TECHNICAL REPORT
EP-53

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A STUDY OF DESERT SURFACE CONDITIONS

QUARTERMASTER RESEARCH & DEVELOPMENT CENTER
ENVIRONMENTAL PROTECTION RESEARCH DIVISION

APRIL 1957 NATICK, MASSACHUSETTS

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Unclassified report

An empirical classification of world representative desert surface types has been developed in the course of twenty months of research, using field and laboratory techniques, in the desert regions of southwestern United States. Each of the principal types was encountered during the course of the field investigations, and is represented both in the United States and in foreign desert regions. On the basis of land forms and their associated surface characteristics, the classification recognizes the following types: (1) Playas, of which there are five subtypes; (2) Desert Flats; (3) Bedrock Fields, in three categories; (4) Regions Bordering

(over)

1. Deserts--Geography
2. Deserts--Classification
I. Clements, Thomas
II. Merriam, Richard H.
III. University of Southern Calif., Los Angeles

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HEADQUARTERS QUARTERMASTER RESEARCH & DEVELOPMENT COMMAND

OFFICE OF THE COMMANDING GENERAL

NATICK, MASSACHUSETTS

11 April 1957

The Quartermaster General
Department of the Army
Washington 25, D. C.

Dear Sir:

The inclosed report, "A Study of Desert Surface Conditions," the result of a field study in the deserts of southwestern United States, will provide a factual basis for the design and evaluation of Quartermaster equipment intended for use in desert environments. Desert surface conditions accentuate many of the problems of design of clothing and equipment, and an understanding of such conditions is therefore necessary in order to meet the problems adequately. By analyzing the various types of desert surfaces as to ruggedness, trafficability, sharpness, color, vegetation, and composition, the authors provide a guide that can be applied not only to deserts of the United States but to those in other parts of the world as well.

Sincerely yours,

C. G. Calloway

C. G. CALLOWAY
Brigadier General, USA
Commanding

1 Incl
EP-53

HEADQUARTERS QUARTERMASTER RESEARCH & DEVELOPMENT COMMAND
Quartermaster Research & Development Center, U S Army
Natick, Massachusetts

ENVIRONMENTAL PROTECTION RESEARCH DIVISION

Technical Report
EP-53

A STUDY OF DESERT SURFACE CONDITIONS

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Project Reference:
83-01-001-B

April 1957

Foreword

The relationship between desert surface conditions and military operations has been a matter of concern to the Department of the Army for many years. To the Quartermaster Corps, desert surfaces present a special series of problems in individual protection, equipage, and supply. Desert water supplies, commonly limited in quantity, are often rendered unfit for drinking by the presence of salts. Corrosion of metal is accelerated by contact with alkali. Blowing sand and dust cause damage to metal surfaces and mechanical equipment. Clothing is torn by thorny vegetation. Footgear and tires wear rapidly on the rough and abrasive surfaces, and movement by foot or vehicle is slowed or prevented by sand or by the mud of undrained basins. These and many other problems are caused by characteristic surface conditions of desert regions.

In spite of the importance of desert surface conditions to military operations, very little is known of the quantitative distribution and significance of various types of desert surfaces. To remedy this gap in information, a contract was negotiated with the University of Southern California, with Dr. Thomas Clements, Head, Department of Geology, as principal investigator. This report is a product of that contract. The essential material pertaining to the classification and description of desert surface types remains as submitted except for minor editorial changes and redrafting of all maps and graphs except Figure 8.

Appreciation is expressed to Dr. Erwin Raisz and Ginn and Company for permission to use a portion of the Map of the Landforms of the United States, from Atwood's "Physiographic Provinces of North America," as the base for Figure 1.

AUSTIN HENSCHEL, Ph.D.
Chief
Environmental Protection Research Division

Approved:

JAMES C. BRADFORD, Colonel, QMC
Commanding Officer
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Scientific Director
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Contents

Contents (Continued)

Contents (Continued)

ABSTRACT

An empirical classification of world representative desert surface types has been developed in the course of twenty months of research, using field and laboratory techniques, in the desert regions of southwestern United States. Each of the principal types was encountered during the course of the field investigations, and is represented both in the United States and in foreign desert regions. On the basis of land forms and their associated surface characteristics, the classification recognizes the following types: (1) Playas, of which there are five subtypes; (2) Desert Flats; (3) Bedrock Fields, in three categories; (4) Regions Bordering Through-flowing Streams; (5) Alluvial Fans and Bajadas; (6) Dunes; (7) Dry Washes; (8) Badlands; (9) Volcanic Cones and Fields; and (10) Desert Mountains.

Each type may be floored by one or more of several different materials, depending upon the type of desert, the stage of the erosion cycle, and upon the weathering agents most active in the area. Generally, the change from one to another is gradational, and few if any sharp boundaries exist between materials. The following surface materials were noted during the course of the field research: salt, lime, clay, silt, sand, gravel, boulder, desert pavement, and bare rock.

The greatest contrasts between the deserts of the United States and those of the Eastern Hemisphere are found in the amounts and distribution of Dune areas, Fans and Bajadas, and Bedrock Fields. In North Africa and Arabia, the Dune and Bedrock categories constitute much more of the desert surfaces than in the United States. On the other hand, Fans and Bajadas comprise a much larger percentage of American deserts than they do of foreign deserts.

Part I Methods and Classification

1. INTRODUCTION

a. Definition of "desert"

For the purposes of this study a desert is defined as a region of low rainfall and high evaporation as the result of which plant growth is scanty or lacking and erosion carves a distinctive topography. Deserts may be divided into three general classes: cold deserts, warm deserts, and hot deserts. Hot deserts, the subject of this report, are defined as deserts having a mean temperature of 86°F or higher in the hottest month. Under the temperature conditions of the Southwest, mean annual rainfall must be less than about 12 inches per year if an area is to be called desert. The heart of the desert actually has less than four inches.

b. Objectives

Intended primarily to serve as a basis for classifying desert surface types as they affect military activities, this report deals chiefly with the surface conditions of southwestern United States deserts and their representativeness of world desert conditions. The study is limited to those portions of California, Nevada, and Arizona having a hot, dry climate (fig. 1). It was undertaken with the following objectives:

(1) To classify the types of surface characteristics of desert areas into militarily significant groups.

(2) To develop keys for use in interpreting the surface characteristics of other areas.

(3) To map the distribution of surface types in selected control areas in the deserts of southwestern United States according to the new classification developed in (1) above.

(4) To determine the percentage of each surface type in the deserts of southwestern United States.

(5) To make estimates of the percentage of each surface type in the other deserts of the world.

c. Methods

The area covered in the field study extends from the San

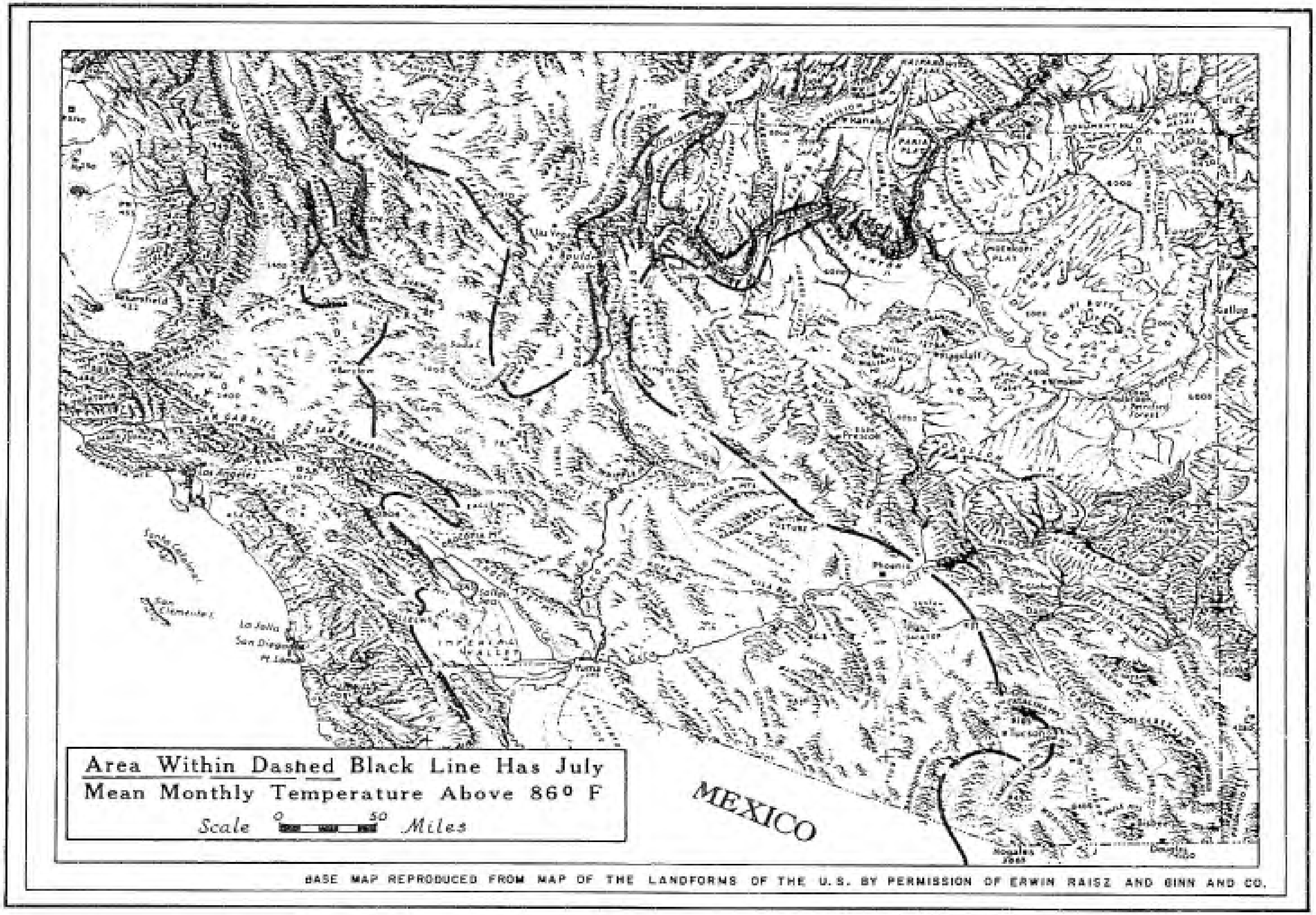

Figure 1. Hot desert, southwestern United States

Bernardino-San Gabriel-Tehachapi Mountains and the Sierra Nevada in California on the west to Tucson and Phoenix, Arizona, on the east; from the Mexican border on the south to the Grand Canyon, Lake Mead, Las Vegas, Death Valley, and Owens Valley on the north. The area comprises approximately 80,000 square miles, with a maximum north-south dimension of 320 miles and a maximum east-west dimension of 280 miles. Included are part of the Sonoran Desert (including the Colorado Desert), and the Mojave Desert.

Observation sites were selected in the various types of desert traversed, and part or all of the following observations were made at each station:

(1) Type of surface according to the classification developed as part of the study.

(2) Nature of the surface.

(3) Colors of undisturbed surface, of freshly turned earth, of vegetation (if sufficiently dense), and overall surface (looking across the surface) including the effect of vegetation. The observations were made according to the National Research Council's Rock Color Chart, except as noted in the section on Playas (Section 4).

(4) Trafficability in terms of a scale developed by Merriam and elaborated by Clements, and penetrability as determined by the cone penetrometer. (Trafficability scale follows on page 4.)

(5) Sizes of rock particles covering the surface, as well as size frequencies, by laying out a square and counting the fragments of different sizes, were determined. Occasional samples were taken for further examination in the laboratories.

(6) Sharpness of rocks on the surface, using the Sharpness Scale worked out during progress of the study. (Sharpness scale follows on page 5.)

(7) Petrologic types of the surface materials, by means of hand lens, aided when necessary by acid.

(8) Types of vegetation, density of vegetation, sizes, and rough percentages of coverage.

Trafficability Scale for Deserts

1.	Roads; paved, good	1_2 - 2-lane		
		1_3 - 3-lane		
		1_4 - 4-lane		
		1_6 - 6-lane		
2.	Roads; paved, poor	2b - pavement broken		
		2d - partially drifted over		
		2n - narrow		
		2w - partially washed out		
		2/ - steep grade		
3.	Roads; unpaved, graded	3g - gravelled	3/g	same but
		3d - dirt	3/d	steep
4.	Roads; unpaved, not graded	4f - firm surface	4/f	
		4g - loose gravel	4/g	same but
		4m - muddy when wet	4/m	steep
		4r - rocky	4/r	
		4s - sandy	4/s	
		4w - deep washes	4/w	
5.	No roads; surface firm; passable any type vehicle	5g - packed gravel	5/g	
		5m - packed mud or clay	5/m	same but
		5p - stone pavement	5/p	steep
		5r - rock surface	5/r	
		5s - packed sand	5/s	
6.	No roads; surface yields slightly; passable ordinary passenger car	6g - gravelly	6/g	
		6m - muddy or clayey	6/m	same but
		6r - rocky	6/r	steep
		6s - sandy	6/s	
		6w - shallow washes	6/w	
7.	No roads; surface passable with difficulty for 2-wheel drive vehicles	7g - gravelly	7/g	
		7m - muddy or soft clay	7/m	same but
		7r - rocks, scattered	7/r	steep
		7s - sandy	7/s	
		7w - washes	7/w	
8.	No roads; passable for 4-wheel drive vehicles only	8g - heavy gravel	8/g	
		8m - deep mud or soft clay	8/m	same but
		8r - many large rocks	8/r	steep
		8s - deep sand	8/s	
		8w - steep-sided washes	8/w	
9.	Impassable for wheeled vehicles	9b - many large boulders	9/b	
		9bd- badlands	9/bd	excessively
		9m - very deep mud	9/m	steep
		9g - very heavy gravel	9/g	
		9s - deep, loose sand	9/s	
		9v - thick vegetation	9/v	
		9w - very deep washes	9/w	
		9o - other	9/o	

Sharpness Scale for Desert Rocks

Knife-edged	10.0	
	9.0	Angular
	8.0	
	7.5	
	7.0	Subangular
	6.0	
	5.0	
	4.0	Subrounded
	3.0	
	2.5	
	2.0	Rounded
	1.0	
Spherical	0.0	

2. CLASSIFICATION OF DESERT SURFACE TYPES

The classification of desert surface types given below is empirical, based upon the landforms actually observed in the field by the authors. The final classification was adopted after extensive discussion with other members of the Department of Geology of the University of Southern California and representatives of the Quartermaster Environmental Protection Division and review of the available literature. The types described are believed to be characteristic, in varying proportions, of deserts throughout the world. The distribution of these types within the study area is shown on the fold-in map at the end of this report.

PLAYAS

The word "playa" is Spanish for shore or beach, but in North America it applies to the flat or nearly flat low part of an enclosed basin in an arid region, also known as a dry lake. In times of heavy rain it may be covered with a shallow sheet of water for a short period and then is called a **playa** lake. Playas are subdivided into the following classes:

Dry These have a hard, smooth, flat surface of silt and clay.

Moist These, which are also known as "salines", are found with two kinds of surface crust: salt-encrusted, in which the water table is very close to or at the surface, and as the result of evaporation, salt is formed on the surface; clay-encrusted, in which the water table is not as close to the surface and capillary action is not strong enough to bring all the salts to the surface, hence the crust is predominantly clay, but with at least 30 percent salt.

Crystal Body These are related to the moist type and generally are salt-encrusted, with a massive body of nearly pure salt at or near the surface.

Compound These have water tables at different levels in different parts of the playa and therefore exhibit the characteristics of both the Dry and Moist types.

Lime Pan These are of extremely limited occurrence in the deserts of southwestern United States, although present in other parts of the world. The floors of these are hard and consist of calcium carbonate in the form of travertine.

Artificial This type has resulted from man's interference, generally with the drainage into a lake, causing it to become dry.

DESERT FLATS

Desert flats, which are also known as "valley flats" and "alluvial plains", are essentially flat surfaces extending from the edges of the playas to the alluvial fans or alluvial aprons. In some cases they are hardly more than a transition zone a few feet or yards wide; in others they are miles in width. In a few cases there may be no playa at all, and then the desert flat occupies the entire floor of the basin.

BEDROCK FIELDS

Surfaces cut on bedrock, with only a thin veneer of detrital material, are of three types: pediments, desert domes, and hammadas.

Pediments These are surfaces cut on bedrock at the foot of an uplifted mountain block, as the latter is eroded back.

Desert Domes If uplift in the desert is broad and low, and the initial relief is slight, weathering and sheet-flooding may produce convex domes cut on bedrock. These have been called Desert Domes.

Hammadas These are widespread flat surfaces of bare rock, usually considered to have been cut by wind action, but possibly they are only flat-lying beds of resistant rock exhumed by the wind.

REGIONS BORDERING THROUGH-FLOWING RIVERS

Although by definition the desert is a region of such aridity that no rivers of sufficient size to drain the area could arise therein, certain rivers rising in more humid regions flow through deserts to the sea. The desert areas bordering such rivers have distinctive characteristics, and therefore are placed in a separate category.

ALLUVIAL FANS AND BAJADAS

Alluvial fans are formed where streams resulting from the sudden infrequent storms rush from canyons and deposit their material at the foot of the mountains. They may become dissected as the result of uplift and renewed erosion.

Where several alluvial fans have coalesced to form a continuous slope along the foot of desert ranges, they are known as bajadas. Like the alluvial fans, bajadas may become dissected. Bajadas are also called alluvial aprons, alluvial slopes, and sometimes piedmont slopes.

DUNES

Accumulations of wind-blown sand are known as dunes. They may exist in semiarid or humid regions, as on long beaches, but they are more characteristic of certain parts of the desert, where low moisture and scanty vegetation give free play to the wind.

DRY WASHES

Where there is sufficient rainfall from time to time, and sufficient slope for a definite course to develop, a stream channel forms much as in humid regions. Unlike the latter, however, in desert areas such channels are occupied by a stream only at rare intervals. During most of the year they exist simply as dry washes, floored with sand and gravel.

BADLANDS

Where lake beds, volcanic ash, alluvial fans, or other soft deposits have been uplifted and subjected to erosion by occasional rains, deeply cut, winding channels and knife-edged ridges result. Because of the extremely rough topography, these have been called badlands.

If the ridges have been rounded off and the channel floors have become flat, the topography may be spoken of as subdued badlands.

VOLCANIC CONES AND FIELDS

In many of the desert areas, late Pleistocene or Recent volcanic activity has occurred, resulting in volcanic cones, lava flows, and cinder fields, and although not genetically related to deserts, these features present problems in the desert, and are well preserved in the desert environment.

DESERT MOUNTAINS

Mountains present in desert regions vary from low dry hills of residual rock to lofty ranges with enough rainfall to support a rather heavy growth of vegetation, including conifers. They may be subdivided on the basis of the rock types of which they are composed, whether granitic, metamorphic, sedimentary, or volcanic.

3. CLASSIFICATION OF SURFACE MATERIALS

Deserts are floored with a variety of materials, depending in part upon the type of desert, in part upon the stage in the erosion cycle, and in part upon the most active erosion agent. At least eight surface materials have been recognized in the progress of field work on the present project: salt, lime ($CaCO_3$), clay, silt, sand, gravel, boulder, and bare rock. They may grade into one another, and also may occur in combinations.

a. Salt

Salt surfaces are found on the moist, compound, and crystal body playas, and generally are of one of three types: smooth, rough, and puffy (self-rising).

(1) Smooth Salt Surfaces. These are found on those playas where the water table as a rule is sufficiently far below the surface that capillarity plays little part in bringing salt and water to the surface. During the infrequent flooding, considerable quantities of salt are taken into solution and spread evenly over the surface as the water evaporates, leaving a white shining surface that reflects the light of the sun in a dazzling manner. Wind blowing over the surface mixes sand and silt with the salt and picks up fragments of the suncracked salt film, exposing the darker clay layer beneath. Thus in a relatively short time the surface loses its glaring whiteness, although remaining light in color.

(2) Rough Salt Surfaces. Where the water table is quite shallow, capillarity brings the water and its dissolved salts to the surface. The water evaporates, leaving the salt, which gradually builds up into mounds and pinnacles that may reach individual heights of several inches to a foot and a half. These pinnacles, which are almost pure salt mixed with a small amount of clay, are exceedingly hard and sharp and are capable of cutting rubber tires to pieces in short order. If the playa becomes flooded, the salt pinnacles dissolve and the surface remains smooth for a short time. However, capillarity recommences its work as soon as the surface water is gone, and the pinnacles again build up.

(3) Puffy or Self-rising Surfaces. On some moist playas capillarity is not sufficiently active to build pinnacles but brings a limited amount of salt to the surface where it mixes with the clay and

silt in proportion of about one-third to one-half salt. This forms a puffy, rolling type of surface as the capillary water with its dissolved salt works up into it and evaporates. While the surface crust is weak and breaks easily, and the material below is soft and tends to be fluffy, the subsurface as a rule is firm at shallow depths.

b. Lime (Calcium Carbonate)

Lime pan is the term applied to a playa, the surface layer of which is calcium carbonate precipitated as the water evaporates. Although not uncommon in other deserts of the world, the only one encountered in the present study area is in Death Valley at the northwest margin of Mesquite Flat. It was on this particular lime pan that the following observations were made.

The calcium carbonate comprising the surface is in the form of travertine, and is porous. It is white to cream colored, and reflects the glare of the sun rather dazzlingly. Erosion by both wind and water have affected the surface; shallow channels have been cut and the surface wind-scoured with occasional low rises of somewhat more durable material. Some clay is mixed with the calcium carbonate and in places the lime has been dissolved away, leaving a limey-clay surface. Small solution pits dot the surface in spots.

Figure 2. Clay surface, dry playa. El Mirage Dry Lake.

c. Clay

Water that floods a dry-type playa is muddy with suspended sediment. The very fine sand and silt drop out first, followed by the clay, which then forms a thin layer on top. The surface beds of a dry playa, therefore, are clay with less amounts of silt and sand.

These form a hard, solid top, which, in combination with the almost perfect flatness of the playa, makes an ideal racetrack or landing field (Fig. 2). The color is light yellowish gray or grayish orange and the surface is generally shiny. Very small clay surfaces also exist in dune areas and result from the washing of clay and silt out of the sand by rain and their deposition in the hollows between the dunes.

d. Silt

Silt surfaces are found where Pleistocene or older lake beds (not playas) are exposed. The silt generally is mixed to some extent with clay and fine sand, and sandstone or even gravel beds may alternate with the beds of silt. The surface has a tendency to be somewhat fluffy and, to some degree, resembles self-rising ground in appearance, but does not contain salt.

e. Sand

Sand is associated with three of the desert surface types: desert flats, dry washes, and dunes. On desert flats and dry washes the sand is generally coarse, and grades into a sand and gravel surface. In dunes, the sand is finer and as a rule is loosely compacted.

f. Gravel

Gravel occurs most commonly in combination with sand to form what is termed herein sand and gravel surfaces. Certain desert types or parts thereof, however, are composed entirely of gravel, of which special varieties formed by cinders in one case and wind-sorted pebbles in another, have been observed.

(1) Sand and Gravel Together, sand and gravel comprise the predominate surface material within the study area. It dominates the surfaces of practically all desert flats and is found commonly on the lower margins of alluvial fans and bajadas. Many washes also have a sand and gravel surface.

(2) Gravel Surface As here used, gravel refers to the smaller rock fragments, ranging in size from granules (2 mm. to 4 mm.) to pebbles (4 mm. to 64 mm.) or roughly from 1/8 inch to 2½ inches. Occasional rocks of larger size may also be present. As a rule, gravels are found on the margins of desert flats, on the middle portions of alluvial fans and bajadas, and in washes. Rare occurrences are in gravel bars formed by Pleistocene lakes (Fig. 3).

(3) Cinder Surfaces As the term "cinder" is here used, it refers to the small particles of vesicular lava blown from a volcano. The sizes range from 2 mm. up to 64 mm. (1/8 inch to 2½ inches), with some larger fragments occasionally present. They are generally black,

Figure 3. Gravel surface, beach ridge. Death Valley.

since they are most commonly basaltic in composition. They are many feet deep around the vent, thinning out to a layer no thicker than the individual cinder at distances of a very few miles. From the nature of their origin, they might form the surface on any desert type; they have been encountered in the present study on alluvial fans, on desert flats, in washes, and on low desert mountains (Fig. 4).

g. Desert Pavement

Desert pavement is formed where wind carries away the sand, silt, and clay that together with rock fragments comprised a previously-formed deposit in the desert, leaving behind only the last-named. For this reason, the materials are spoken of as "lag gravels". Although the proportion of rock fragments to the other constituents may originally have been small, concentration has made them the predominant material and the desert pavement develops as a mosaic of flat-lying interlocking fragments usually from $\frac{1}{4}$ inch to 3 inches long (Fig. 5). Occasionally, however, rocks up to 8 inches long may form a pavement.

Figure 4. Cinder surface, north end of Death Valley.

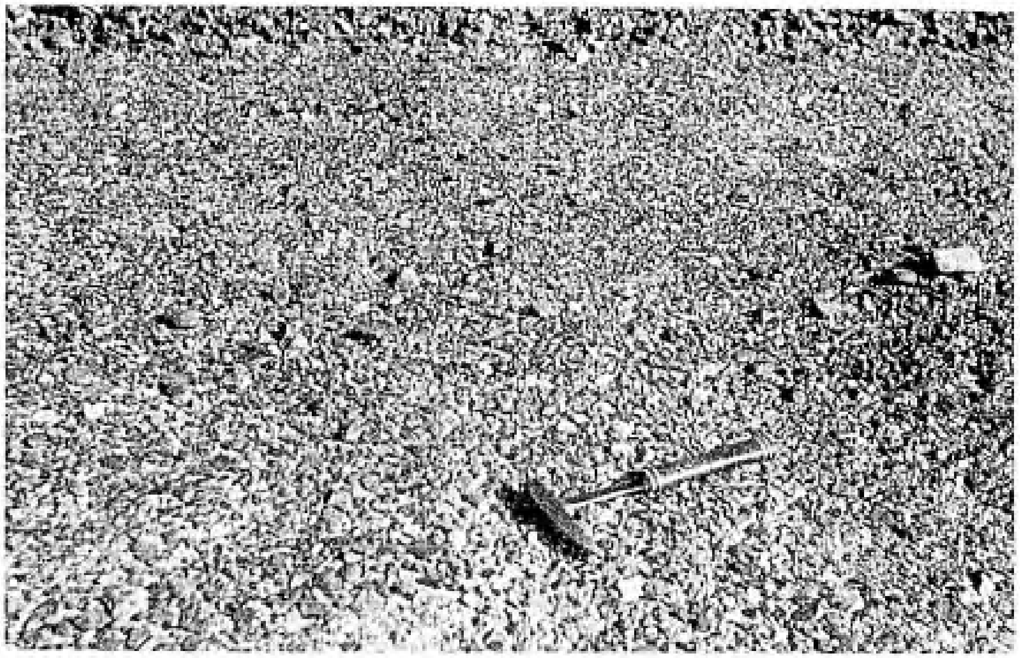

Figure 5. Desert pavement of water-worn pebbles, River terrace, Colorado River.

Desert pavements occur on many desert surface types: desert flats, alluvial fans, bajadas, and regions bordering through-flowing streams. Uplifted and dissected surfaces in particular are likely to be covered with desert pavement, and these generally show a deep patina of desert varnish. Colors, therefore, are commonly dark, ranging from pale yellowish brown (10YR6/2) to dusky brown (5YR2/2). Where such pavements occur on a series of terraces, the darker colored ones will be found on the highest (oldest) terraces.

h. Boulder

Boulders are defined technically as 256 mm. (approximately 10 inches) in maximum dimension or larger. Rocks of this size occur occasionally on practically all surfaces, but when they become so abundant as to offer a hazard to traffic, the surface then comes under a separate category and may be called a rocky or boulder surface (Fig. 6). Since the former term might imply bare rock, the latter is adopted for this study.

Boulder surfaces occur commonly on the higher parts of alluvial fans and bajadas where individual rocks may be several feet in diameter. They may also occur in washes, on pediments, on lava surfaces, and around the margins of volcanic cones. The boulders may be light to dark in color, depending upon the type of rock. Where they occur on dissected fans or bajadas they are dark with desert varnish.

Figure 6. Boulder surface. North of Vidal Junction, California.

i. Bare Rock

Bare rock surfaces occur on pediments, hammadas, lava flows, and desert mountain ranges. There may be a thin veneer of detrital material over the rock surface, but as a rule the bare rock is readily visible (Fig. 7). Colors depend largely upon the nature of the rock itself, light if granitic, black if basaltic, and with almost all shades between. Since the pediments and hammadas are areas of active erosion, desert varnish would not be expected, and none was observed in the field.

Figure 7. Bare rock surface. Type area, pediment, near Old Woman Springs, California.

Part II Description of Desert Surface Types

4. PLAYAS*

A common feature of desert regions is the nearly flat, sun-baked expanse of clay and salt known as a playa or "dry lake". There are several hundred playas in the deserts of western United States, and playas have been reported from most of the deserts of the world. In the Sahara and Arabia they are called sebkhas; in Persia they are known as kewire; in India, rei; in Algeria, chotts; in Morocco, merdjas; in the Gobi Desert, nor; and in the Atacama Desert, salares.

Sixty-five dry lakes in southeastern California and eight dry lakes in western and southwestern Nevada were visited during all seasons in 1950, 1951, and 1952. In addition, a surface sample from a playa or sebkha from the Arabian Desert was used for comparative purposes in some of the sedimentary investigations. The locations of the playa lakes that were examined are shown in Figure 8.

The two primary conditions necessary for the formation of playa lakes are: (1) a basin of interior drainage, and (2) an excess of evaporation over precipitation and runoff. Inasmuch as these conditions are most common in the Basin and Range Province, most of the playas of the United States are found within its confines. There are several hundred dry lakes in the states of California, Nevada, and Utah. A few are found in southeastern Oregon, five or six in Arizona and several in New Mexico in the vicinity of the White Sands National Monument. Free[18] cites the presence of local pans or playas in the Red Desert of south central Wyoming, in the San Luis Basin of Colorado, in the coulee area of eastern Washington, and in the Colorado Plateau. Also, brackish lakes are found in the Sand Hills of Nebraska and in portions of Kansas, eastern Colorado and the Llano Estacado region of Texas. The pans and brackish lakes outside of the Basin and Range Province are generally relatively small and are found in small local areas of interior drainage, as on lava flows, between sand dunes and in solution basins on flat-lying limestone cap rocks.

a. Relief and Elevation

The playa is perhaps the flattest physiographic feature that can be found. From a position near the center of a large dry lake the surface appears to be a perfectly flat, featureless plain. Actually, the central portions of a playa are lower than the edges. The lowest portion of the playa, however, is not necessarily in the center. Total relief on the largest dry lakes is generally less than 10 feet and on some of the

*The section on playas was contributed by Richard O. Stone.

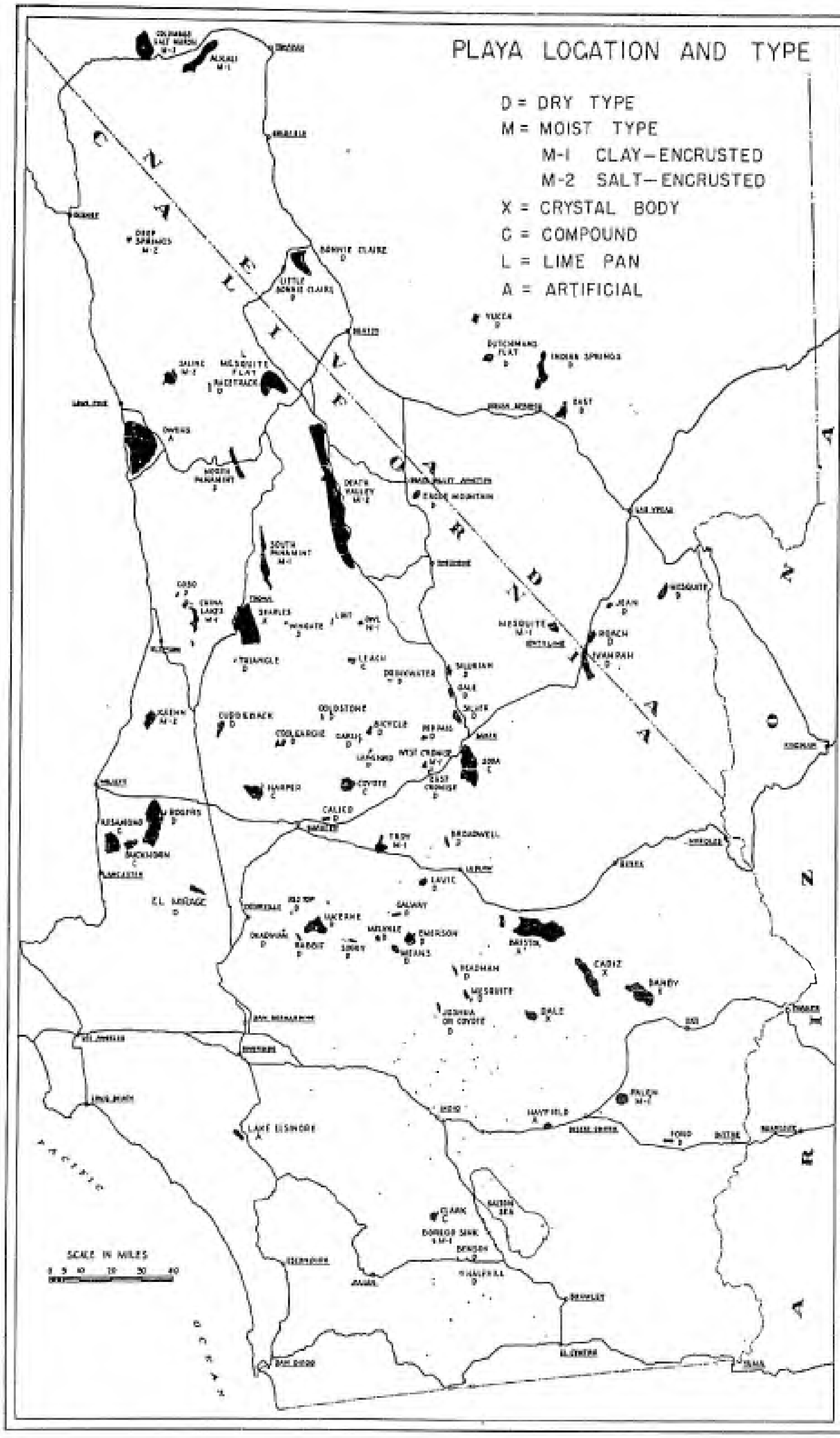

Figure 8. Playa Location and Type

smaller playas it is a matter of only a foot or two (Fig. 9). Small surface irregularities such as shallow dry washes, sink holes, and spring mounds occur on some playas but they are not common features. One exception to the low relief of playas is the so-called playa island. At Buckhorn Dry Lake, playa islands, some of which are several hundred yards long and 50 or more feet high, rise above the playa surface. The Grandstand, which stands about 70 feet above the surface of the Racetrack Playa, is a similar island. These features are remnants of irregularities in the old valley floor which are slowly being engulfed by the playa sediments and technically should not be considered as part of the playa.

The elevation of playa lakes is a function of the elevation of the enclosed basin in which they are located. Where the regional elevation is low, playas are found at elevations of a hundred feet or less. In the case of some of the playas near the Sierra Nevada, playas are found at elevations of two or three thousand feet. Elevation in itself has no control over playa formation except where elevation is great enough to influence the dominance of precipitation and runoff over evaporation.

The elevations of playas in the California deserts range from a maximum of 3,708 feet at Racetrack Playa to a minimum of -282 feet near Badwater in Death Valley. Table I shows the elevations of some of the more prominent dry lakes.

b. Drainage

Playas occupy the lowermost portion of interior basins. Drainage in the basin is towards the playa. On most dry lakes the lowest area is roughly in the center of the playa as at Rogers, Rosamond, Owens, and Searles Lakes. At El Mirage Dry Lake, runoff tends to flow to a point southwest of the center of the lake. Similarly, at Bristol Dry Lake the drainage is not simply towards the center but is much more complex. Gale[22] (p. 5) states,

> "Drainage that enters the playa at the northwest corner near Amboy is seen to divide, as though by distributory channels, at the head of a low alluvial fan slope, a mile or two south of Amboy. Thence one channel skirts the foot of the Bagdad lava flows, going southward into the western end of the so-called Salt Lake which covers the lowest portion of the Bristol Playa. Another channel meanders eastward and then on a fairly well defined course to the southwest."

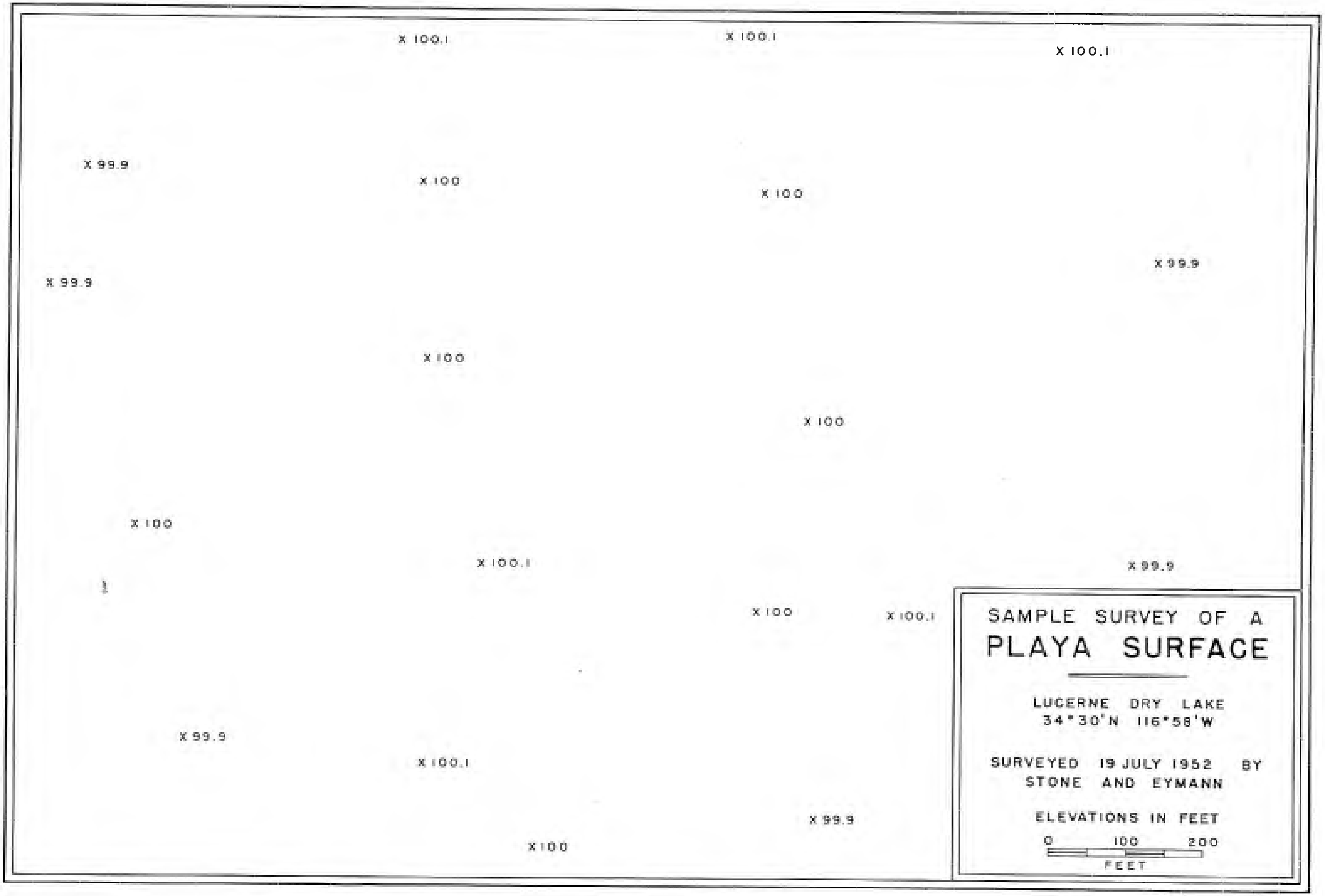

Figure 9. Sample Survey of a Playa. Lucerne Dry Lake, California.

TABLE I: ELEVATIONS OF PLAYAS IN CALIFORNIA AND NEVADA

PLAYA	ELEVATION (feet)
Racetrack Playa	3708
Owens Lake	3350
Soggy Lake	2874
Lucerne Dry Lake	2850
Jean Dry Lake	2795
Mesquite (Stateline) Dry Lake	2545
Lost Lake	2335
Emerson Dry Lake	2294
Buckhorn Dry Lake	2281
Rosamond Dry Lake	2271
Rogers Lake	2210
China Lake	2150
Leach Dry Lake	1920
Mesquite (Twentynine Palms) Lake	1880
Searles Lake	1616
Saline Lake	1500
Dale Lake	1181
Silver Lake	919
Soda (Baker) Lake	910
Bristol Dry Lake	600
Cadiz Lake	600
Clark Dry Lake	570
Borego Sink	448
Benson (Ocotillo) Dry Lake	160
Halfhill Dry Lake	80
Death Valley	-282

Drainage at Danby Lake is also complex, involving a series of southerly sloping drainage channels, some of which are 4 or 5 feet deep. Drainage to portions of a dry lake other than the approximate center may be the result of differences in sedimentation from different directions, or from possible tilting of the playa surface. If large drainage channels cutting across the playa are present, tilting should be suspected.

Runoff waters enter the lakes largely by means of small channels which run for varying distances onto the playa surface. These channels appear as slight undulations of the playa surface and gradually merge with the surface as they progress onto the playas. It is believed that drainage water initially enters the playa by means of such channels but if the storm is torrential and runoff great, it may enter from all sides of the playa as sheet wash.

(1) Location in Drainage Basin It is commonly believed that playa lakes are more or less centrally located in the bottom of enclosed desert basins. During the course of the present field work it soon became apparent that this condition is not always true. Many of the dry lakes are found less than a mile from one of the bounding mountain ranges and from 3 to 8 miles distant from the opposite longitudinal range.

Examples of asymmetrical position in the drainage basin are Lucerne, Clark, China, Calico, and Silver Lakes. This position is the result of differences in the amount of sediments contributed to the valley by the bordering mountains. In most cases, this difference is due to differences in runoff but in some cases wide differences in rock hardness result in differences in sediment contribution even where runoff is nearly equal. It is also probable that differences in the physiographic age of the bounding mountain ranges, or tilting of the basin (which is probably the case in Death Valley) could have similar effects on playa position.

Numerous dry lakes are almost centrally located in the valley floor, and in these instances it is assumed that the amount of sediment being contributed by each bounding range is nearly equal. Rosamond, Buckhorn, and Rogers Lake in Antelope Valley are nearly centrally located, also Leach, Searles, Bristol, and Coyote Dry Lakes.

(2) Size Relationship to the Drainage Basin Large playas are generally found in large drainage basins and small playas in small drainage basins, but it is possible for small playas to be in large drainage basins and for moderately large playas to be found in small drainage basins. The character of the rocks which make up the surrounding mountains, the physiographic age of the mountains, the amount of vegetation, and the character and amount of runoff all influence the size of a playa that is found in a desert basin. The largest playas in the California deserts, such as Searles, Bristol, Rogers, Cadiz, and Soda (Baker) are in large drainage basins, yet Kaehn Dry Lake is not one of the largest playas, even though Fremont Valley in which it is located is among the largest drainage basins. Conversely, Cuddeback, Lavic, and El Mirage Dry Lakes, which are nearly the same size as Kaehn, are found in much smaller drainage basins.

c. Classification

The appearance, composition, and character of the upper few feet of sediments in playa lakes are all characteristics which may be used to classify the various types of playas. All of these factors are directly related to the depth of the water table and it is on this relationship that a classification has been derived, made up of the following classes:

(1) Dry, (2) Moist, (3) Crystal, (4) Compound, (5) Lime Pan, and (6) Artificial.

(1) Dry Playas Fifty-nine percent of the playas visited were dry playas, the most common type in the California deserts. Dry lakes have a very hard, smooth, flat surface and are wet only during or immediately after moderate or strong rains (Fig. 10). The water table is generally found at considerable depths and is always more than ten feet below the surface, thus precluding the effects of capillary rise of ground water. The surface material consists of varying mixtures of sand, silt, and clay but the character of the material in an individual lake is often remarkably consistent in the upper 10 to 30 feet. At Rogers Lake, a typical dry playa, the upper 25 feet vary only slightly in color, texture, and grain size. The log of a well drilled at Mesquite (Henderson), Nevada, indicated that the upper 395 feet consist of unvarying playa clays and silts. The surface sediments are sun-baked to extreme hardness, in some cases becoming almost as hard as cement. Mudcracks of various sizes and shapes characterize the surface of many dry playas. Salt encrustations occur on dry playas only after rains, when there may be a thin surface efflorescence around depressions. This material disappears upon complete drying of the playa.

Rogers Lake, located in Antelope Valley, California, is taken as the type example of the dry playa. The surface is not only extremely

Figure 10. Dry playa (flooded). El Mirage Dry Lake.

flat, smooth, and dense, but has in places acquired a noticeable surface polish due probably to a combination of wind polish and the action of moving waters on the surface after light rains. Other examples of dry playas include El Mirage, Ivanpah, East Cronise, Silver, Silurian, and North Panamint in California and Jean and Roach Playas in Nevada.

(2) Moist Playas Twenty-three percent of the playas visited exhibited the irregular, puffy, and slightly rolling surface characteristic of this type (Fig. 11). These lakes are also distinguished by a thin surface crust of salt or clay which breaks easily, and by soft spongy ground which is found immediately beneath this crust. On some of the moist lakes, a "honeycomb" structure an inch or two beneath the surface and consisting of a mixture of salt and clay is found. This material is full of minute, interconnecting holes and tubes along which capillary waters have moved. On most other lakes the zone immediately beneath the surface to a depth of an inch to several feet consists of fine granular clay and silt which is mixed with small crystals of salt, largely sodium chloride, and gypsum. The salt crystals are usually less than a quarter of an inch long. Beneath the loose, powdered zone are moist sediments, the upper portions of which are high in salts.

The water table at moist lakes is within 10 feet of the surface. Generally it is within a foot or two, and may even be at the surface in the central area of some of the playas. This is true at Kaehn Dry Lake, where a foot of water often stands in the center of the lake.

Figure 11. Solution cavities in surface of moist type playa. South Panamint Playa.

Two distinct types of crusts are found on moist playas, a salt crust and a clay crust. The type of surface crust is the basis for the subdivision of moist playas.

Salt-encrusted Moist Playas As previously stated, climatic conditions in the desert promote strong capillary rise of ground water. The rising capillary waters take into solution much of the salt present in the sediments. When the water reaches the surface, it evaporates, leaving the salts it carried on the surface. A nearly flat encrustation of almost pure salt from one-eighth to one-quarter of an inch thick or a rough surface of gray salt and clay an inch or two thick may form. Examples of salt-encrusted playas include Death Valley, parts of Kaehn, and Mesquite (Stateline), and Columbus and Teeles Marshes in Nevada. In Death Valley an unusual form of the salt-encrusted surface is found. Here, brown but nearly pure rock salt covering an area of several thousand acres, crusts the surface. This salt has been dissolved and recrystallized to form an expanse of extremely hard, sharp, and pointed pinnacles which range from a few inches to 3 feet in height (Fig. 12). A similar surface occurs on part of Bristol Dry Lake.

Clay-encrusted Moist Playas The surface material of these lakes is predominantly clay, although it contains appreciable amounts of salt. The slightly rolling and spongy surface is typical of this type of moist playa. Beneath this surface is a zone from 1 to 4 feet thick containing a loose, fine, granular mixture of silt, clay, and salt crystals. Beneath this zone, moist sediments are found. It is suggested that the depth to the water table is the controlling factor in the formation of a clay crust, since the moist layer is found at greater depths than on the salt-encrusted playas. In clay-encrusted moist playas the water table depth approaches the maximum depth of capillary rise, and hence capillary action is not sufficiently strong to bring all of the salts to the surface. The surface is predominantly clay, but contains 30 to 45 percent salt. Examples of clay-

Figure 12. Rough salt surface on moist type playa, Death Valley, California. Dr. Clements is in foreground with cone penetrometer.

encrusted playas include South Panamint, Borego Sink,Troy Dry Lake, and portions of Bristol, Dale, Danby, Cadiz, and Searles Lakes.

(3) Crystal Body Playas At a few of the dry lakes, the central area consists of a massive body of nearly pure salt, the interstices of which are filled with brine. The crystal body is located in the lower central area, and the surrounding portion is moist, "self-rising" ground. The type example of the crystal body playa is Searles Lake. At Searles, the exposed portion of the salt body covers approximately 12 square miles and averages 70 feet in depth (Ryan[45], p. 447). The interstices are permeated with brine, which makes up to 50 percent of the total volume and which stands within 6 inches of the surface. Beneath the upper 70-foot crystal body is a layer of impervious mud from 12 to 15 feet thick, and then a lower crystal body, 35 feet thick. The surface is in part smooth, but considerable areas are covered with large blocks of salt which have been thrust up during their crystallization.

Six percent of the playas are of the crystal body type, and in addition to Searles, include Bristol (Fig. 13), Cadiz, Danby, and Dale Dry Lakes. In the four last-mentioned lakes, the crystal body is buried beneath 3 to 70 feet of overburden. A bore hole drilled in Death Valley is said to have penetrated a thousand feet of salt, but the records of this hole have not been seen by the authors.

Crystal body lakes are believed to be the result of evaporation of large Pleistocene lakes. The mud layers represent the sediments deposited

Figure 13. Crystal body playa. Bristol Dry Lake, California. Amboy Crater in distance.

during a permanent lake stage while the salt layers resulted from the evaporation of the lake waters. In many of the basins evidences of the deep Pleistocene lake are plainly visible on the walls of the enclosing valley in the form of terraces, deltas, and old beach lines.

(4) Compound Playas As has been noted, the controlling factor in the formation of dry and moist playas is the depth to the water table. It is unreasonable to expect that the water table would constantly be everywhere less than or greater than 10 feet beneath the surface of a playa. Consequently, some playas exhibit the characteristics of both moist and dry playas and are classed as compound playas. Coyote, Rosamond, Buckhorn, Leach, Soda (Baker), and Danby Dry Lakes are this type. At Leach Dry Lake, "self-rising" ground is found on the west side of the lake close to the mountain front. The water table slopes to the east, away from the mountains, and the eastern portion of the lake shows the massive, hard clay surface. A similar situation exists at Coyote Dry Lake where puffy ground is found on the south and southwestern portions of the lake. Danby Playa, which is classified as a crystal body type, is unusual in that it shows characteristics of both moist and dry types as well. The east side of the lake is smooth and mud-cracked, whereas the remainder of the lake has the typical puffy and spongy surface. The central area is underlain with a crystal body at a depth of 3 to 10 feet. In all, ten percent of the dry lakes examined were classified as compound.

It is possible for a dry lake to have its surface character altered with changes in the level of the water table. In 1929, Thompson [46] made a ground water survey in the Antelope Valley and found that the southern half of Rosamond Dry Lake contained moist "self-rising" ground while the northern half was the dry type. Today it is almost impossible to find the features of the moist type playa in the southern portion of the lake. Increased agricultural demands in the Antelope Valley since 1929 have so lowered the water table that the entire surface of Rosamond now appears to be the dry type. It is similarly possible that a rise of the water table beneath a dry type playa would over a period of years result in its conversion to a moist playa.

(5) Lime Pan Playas The only playa within the study area that might be classed as a lime pan was observed at the northwest end of Mesquite Flat in Death Valley, close to the Cottonwood Mountains (Fig. 14).

The surface is made up of calcium carbonate in the form of travertine mixed with some clay. Solution pits occur rather commonly, and here and there low travertine mounds rise above the general level. Occasional shallow washes also cross the surface. These features all suggest the

Figure 14. Lime pan playa. North end Mesquite Flat, Death Valley.

possibility that there has been some disturbance of the valley floor in recent time and that the surface is no longer receiving deposition, but on the contrary, is undergoing erosion. Certainly the wind is eroding the surface, since the southerly margin of the lime pan is bordered by dunes made up largely of travertine sand grains.

The origin of this lime pan playa is rather obvious. The Cottonwood Mountains, near whose foot it lies, are in this part composed largely of limestones of Paleozoic Age. The drainage from a large canyon cutting the mountains has been concentrated in a rather small basin formed by a re-entrant in the mountain front, and is cut off from the drainage of the main part of the north end of Death Valley by alluvial fans. As a consequence, water highly charged with calcium carbonate in solution has been concentrated here, and on evaporation has left the calcium carbonate as a deposit on the playa floor. It is anticipated that lime pans would be found in any area of limestone mountains where the calcium carbonate is not over-shadowed by detrital sediments from other types of rocks.

(6) <u>Artificial Playas</u> One of the requirements for the formation of a playa in a given area is that evaporation must exceed precipitation and runoff. In the event that this situation is brought about by the activities of man the resulting dry lake has been classified as artificial. The type example of an artificial playa is Owens Lake. Prior to

1913, Owens Lake was a saline lake similar to Mono Lake. In 1913 most of the runoff to Owens Lake was diverted for the purpose of supplying the city of Los Angeles with water. Owens Lake immediately began to evaporate and soon became a playa. However, if runoff in the Owens Valley were permitted to enter the lake it would revert to a saline lake. Although classed as artificial, due to its mode of origin, it shows the characteristics of a salt-encrusted, moist playa.

Another example is the Hayfield Reservoir, which was used by the Los Angeles Metropolitan Water District for storage of Colorado River water. High evaporation and leakage rates ultimately caused its abandonment. The present dry-playa appearance of the Hayfield Reservoir has resulted from the past activities of man, and therefore it is classed as an artificial playa.

d. Surface Features

(1) Mud Cracks Mud cracks or shrinkage cracks form when fine-grained sediments lose their contained water. The irregularly-shaped mud surfaces between mud cracks are known as mud polygons. The playa surface which is flooded for short periods and then exposed to the highly desiccating effects of desert temperatures and winds is typically mud-cracked. Grabau [26] (1932, p. 709) believed that the playa is such an ideal surface for mud crack formation that most mud cracks existing in the geologic column should be referred to this origin. Many of the surfaces of the California dry lakes are intricately mud-cracked, but there is such a wide variation in size, shape, and character of the cracks and polygons that they cannot be discussed in detail in this paper.

(2) Washes Shallow erosion channels cross the edges of many dry lakes and run towards the central area. These channels or washes are probably the principal entryways of sediment-laden waters during times of storm. It is apparent that storm waters do not enter a playa as a continuous sheet but rather by means of extensions of normal drainage channels that cut through adjoining fans or the valley floor. These channels tend to gradually flatten with distance across the playa, and finally merge into the flat surface. The general trend of the washes is towards the central area, but some cut diagonally across the edges of the playa.

The washes vary widely in size, but are usually not more than 5 to 10 feet wide and 6 to 8 inches deep, although larger washes have been noted on some of the playas, as at Eight Mile Flat in Nevada, where a dry wash 3 feet deep and 40 feet wide occurs.

The sediments in and along the washes tend to be slightly coarser than the material of the playa (Fig. 15). A sample from a wash at Rogers

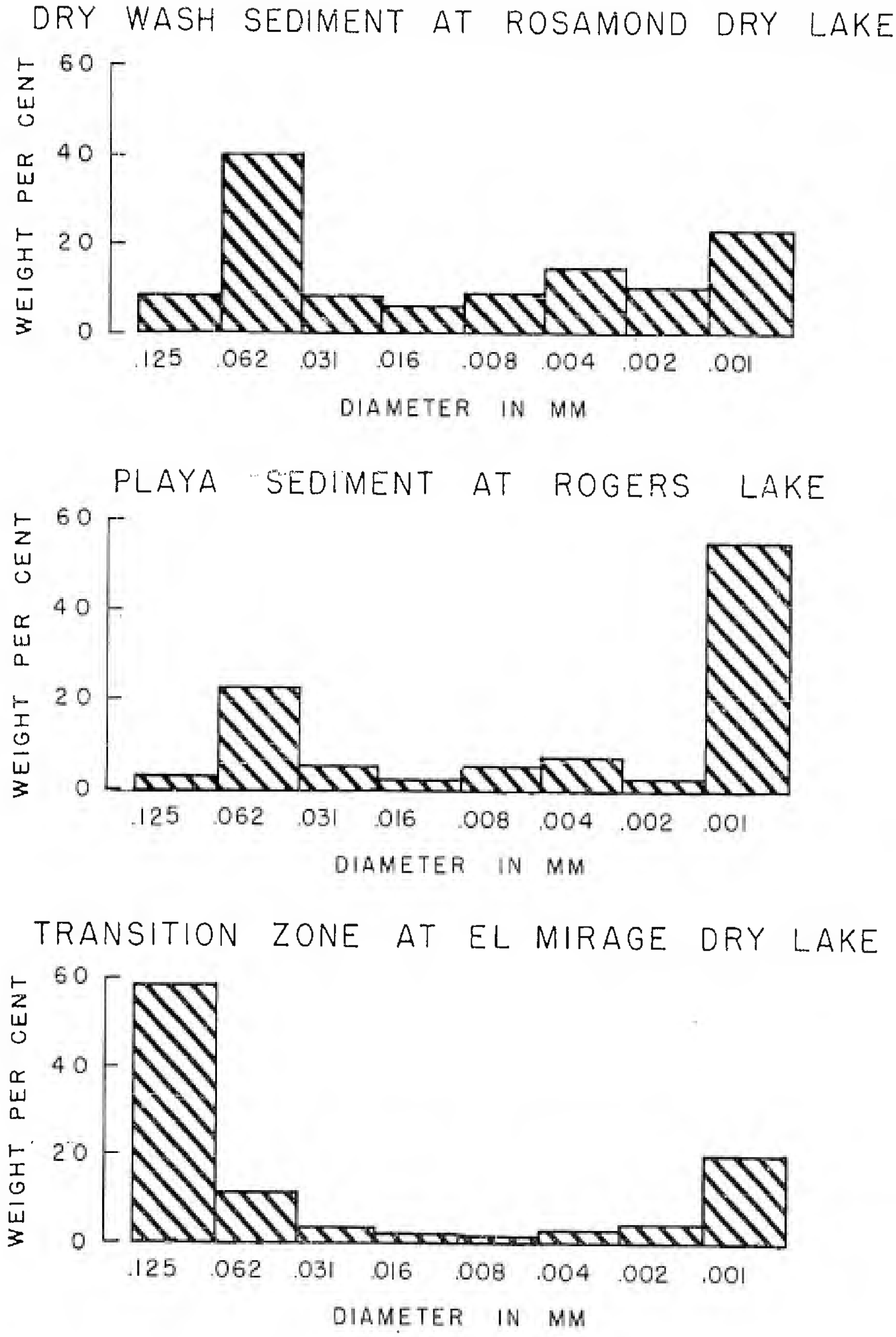

Figure 15. Histograms of surface sediments of playas.

Lake had a median diameter of 10 microns as compared to a median diameter of about 1 micron for a sample from the playa surface adjoining the wash. The wash sediments are high in sand and granule-size material, and at the point where a wash enters the playa, occasional pebbles and, rarely, cobbles are found on the surface.

(3) Transition Zone Around the edges of playa lakes is a zone which may vary from a few yards to several hundred yards in width, which contains a high percentage of granule-size material and which supports a sparse growth of vegetation. This zone, which is definitely a part of the playa, since it is nearly flat and high in playa clays, has been termed the "transition zone". It represents a zone of gradation, both in sedimentary character and plant life, between the central area of the playa and the alluvium bordering the playa. When streams during flood time reach the playa there is a rapid check in velocity as the low gradient of the playa surface is reached. Hence, the coarsest material being transported is dropped on the playa edge. The surface is littered with a profusion of very coarse sand, granules, and occasionally pebbles and cobbles. Dry lakes which are close to mountain slopes or have fans or bajadas abutting on their edges have pronounced transition zones. Such transition zones are present at Deadman and Mesquite Lakes near Twentynine Palms. Dry lakes in wide valleys that are surrounded by flat plains with only a slight gradient change between the desert flat and the playa have a transition zone that is closer in grain size to the remainder of the playa. At El Mirage and Rogers Dry Lakes there is an abundance of very fine sand in the transition zone sediments.

On a few of the dry lakes, material of cobble and even boulder size is found. This material is generally restricted entirely to the transition zone, although in some cases it occurs abundantly on the playa proper. It is brought to the playa by normal processes of stream transportation, particularly during times of extremely high flood. It is of interest to note that scoriaceous basalt is the most common material of which the cobbles and boulders are composed. The low density of this material doubtless accounts for its being carried in preference to other rock types of equal size.

Boulders of scoriaceous basalt were noted at Eight Mile Flat in Nevada and at Broadwell and Silver Dry Lakes. It is possible, where the playas are close to volcanic cones, as at Broadwell, that this material reached the playa as a direct result of volcanic activity. Their greater abundance, however, around the outer edges of the lake rather than in the central areas, where they are usually missing, leads to the conclusion that they have been carried to the playa by stream or sheet wash action.

(4) Playa Scrapers and Furrows Playa scrapers and furrows that occur on the Racetrack playa in the Ubehebe Peak area near Death Valley have been described by Agnew and McAllister. A playa scraper may be a pebble, boulder, or cobble-size rock, a mud curl, a machine gun cartridge, or even burro droppings. It is believed that they have been propelled over the muddy surface of a playa by strong gusts of wind. A playa furrow is the trail that the scraper makes as it is pushed across the slippery playa surface(Fig. 16). Fragments weighing several hundred pounds have been reported, but rock fragments about a foot in diameter and 6 to 8 inches high are more common.

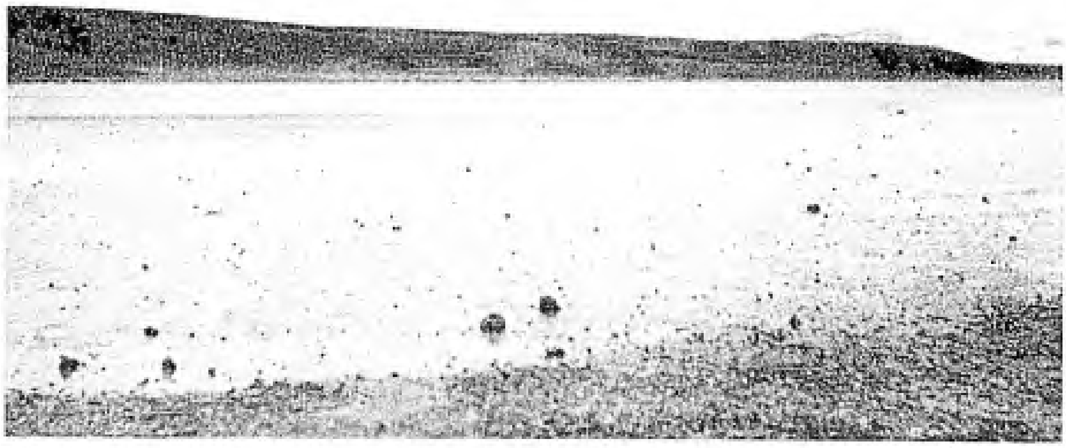

Figure 16. Trails of wind-blown rocks on Little Bonnie Claire Playa (wet).

It was proposed by Agnew and McAllister that the scrapers were propelled from the transition zone of the playa by strong gusty winds when the playa surface was muddy and slick. If the conditions necessary for the occurrence of playa scrapers were only a slick lake surface and the presence of strong winds or erratic whirlwinds, scrapers and furrows should be found on numerous if not all playas. At all of the playas that were visited, care was taken to see if either were present.

Scrapers and furrows have been reported by Clements[9] on Little Bonnie Claire Playa in Nevada, and they are known to exist on North Panamint Playa. Although not seen on other playas, they are believed by Clements to be formed on all playas where there are rocks. Unless deeply cut, the furrows are destroyed by the next succeeding rain or even by the wave action of water still present when the track is made. All but the deepest furrows need the slanting rays of the early morning or late afternoon sun to be seen at all. At present, wind action is the best explanation.

(5) Sink holes On playas that contain a buried crystal body, sink holes may appear on the lake surface as a result of the solution of a portion of the crystal body. Four such sink holes are found at Dale Dry Lake (Fig. 17). The largest, which is approximately 500 feet long, 100 feet wide, and 50 feet deep, was formed when water was pumped down a bore hole in order to make additional brine. The crystal body in the vicinity of the bore hole dissolved and the surface sediments slumped, forming a large sink hole. The three smaller sink holes formed as a result of natural processes. Their location and appearance indicates that they, too, were the result of the solution of a portion of the underlying crystal body. Minute sink holes were noted at Bristol Lake, where the crystal body is covered by 7 feet of overburden.

(6) Spring Mounds At Rosamond Dry Lake there are three roughly circular mounds, two or three hundred feet in diameter and 2 to 3 feet high, which are covered with such moisture-loving plants as salt grass, rushes, and sedges. The sediments of these mounds consist largely of very fine sand and silt with a small amount of medium and coarse sand. Hamilton[29] (p. 148) attributed their formation to the moisture of artesian springs which held wind-blown sand, and to the addition of sediment brought to the surface by the artesian flow. However, upon plotting the positions of abandoned water wells (many of which were artesian) on aerial photographs of Rosamond Lake, it was found that in each instance the mound marks the site of an abandoned well. Leakage from the wells encouraged the growth of the vegetation described, and induced the holding of wind-blown sand and silt. These features might best be termed "artificial spring mounds", since their origin was dependent on the activities of man. Spring mounds were not noted on any of the other lakes, but it is possible that in other desert regions, if artesian flow occurs on playas, they could form naturally.

e. Surface Gradient

From data collected from the 15-minute series of topographic maps by the United States Geological Survey at Rogers and Searles Lakes in 1942, from a topographic map of Dale Dry Lake, from personal communications from land surveyors, and from a plane-table survey of Lucerne Dry Lake, the gradient of typical playa surfaces has been determined.

At Rogers Lake, the elevation of the playa within 2 miles of the northern end is 2272 feet, while at the southern end, 8 miles distant, it is 2271 feet. The overall angle formed by the surface and a horizontal plane, therefore, is only about 5 seconds along the north-south

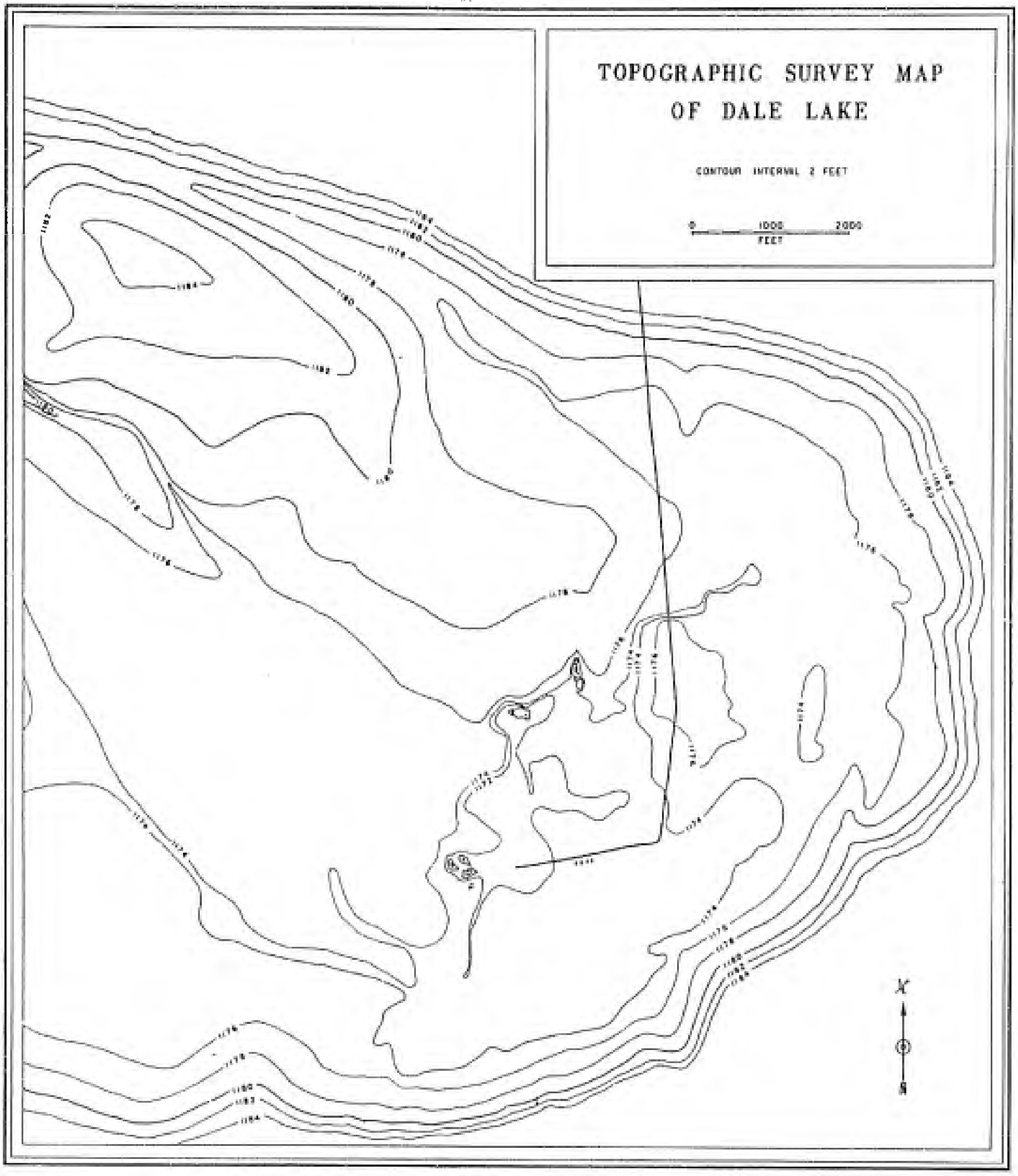

Figure 17. Topographic Survey Map of Dale Lake.

axis. On a north-south traverse across the center of the lake the station elevations at one-mile intervals are 2272, 2271, 2271, 2272, 2271, 2270, 2270, 2270, 2271, an indication of the extreme flatness of the lake surface. The southern half of the playa has even less variation in elevation; five of the six stations in the area, all recorded at one-mile intervals, are at elevations of 2270, and the other is 2271 feet. One portion of the lake in this area shows no apparent variation in elevation over a distance of 3 miles. The maximum gradient noted on the lake was a variation of only 2 feet in 4 miles, an angle of about 18 seconds.

Elevations immediately adjacent to the lake in the transition zone are 10 to 20 feet higher. A typical gradient in the adjoining area is a rise of 20 feet per mile, a slope of 15 minutes, which, although small, is appreciably greater than those found on the playa.

Other playas show similar surface gradients with variations from 0.1 foot per mile to 3 feet per mile on Searles Lake, 0.1 foot per mile on Mesquite (Twentynine Palms) Dry Lake, while Dale Dry Lake, which is tilted to the west, has a gradient in a north-south direction of one foot per mile and from east to west of 4 feet per mile. The maximum gradient on this lake is 24 feet per mile between the southern rim and the sink-hole area (Fig. 17). As a general rule, the difference in elevation between the edges and the lowest part is approximately the same for playas of all sizes. Hence the smaller and narrower playas tend to have somewhat higher gradients.

f. Trafficability of Playa Surfaces

The best of all surfaces found in the desert, from the standpoint of trafficability, are the clay surfaces of dry type playas. The bearing strength of the surface at Muroc Dry Lake has been measured as three-quarters of an inch depression for a single wheel loading of 150,000 pounds. Such surfaces thus make excellent landing fields. Tests made in dry playas during the present study showed a trafficability of 5m when not flooded, and 6m or more (rarely 7m) when covered with water. Occasional washes may reduce the 5m to 6w.

Other playa surfaces, however, are inferior from the trafficability point of view and may be impassable. A comparison of trafficability on the different types of playa surfaces is given on Table II following.

TABLE II. TRAFFICABILITY OF PLAYA SURFACES

Type of surface	Trafficability	Surface penetration (lb.)	Penetrometer tests: Penetration at 1 ft. depth (in.)	Penetrometer tests: Penetration at 1 ft. depth (lb.)	Penetrometer tests: Maximum penetration (in.)	Penetrometer tests: Maximum penetration (lb.)
Clay, dry	5m, 6w	36, 110, 150	1	140	2	150
Clay, flooded	6m-7m	50	1	150	3	150
Smooth salt, dry	6m	46			4	150
Smooth salt, wet	9m	10 to 30	36	10	36+	150
Rough salt	9o	28	1	150	2½	150
Channels between areas of rough salt	5m-6m	150			1	150
Self-rising	6s-7s	10, 20, 115			5-24	150
Lime pan, travertine	5r-6w	150			0	150
Lime pan, lime and clay	6m	14			6	150

g. Sedimentary Characteristics

(1) Color From a distance, most playa surfaces appear to be white or gray, a deception that is brought about by the smooth, hard reflecting surface. In order to record accurately the color of playa, the United States Department of Agriculture Soil Color Chart was used. This chart is based on the standard Munsell color code, and differs from the Rock Color Chart of the National Research Council (Goddard, E. N., *et al*[25]) in that only colors within the range of soils are shown. The color of surface and depth samples of sediments were recorded in the field, whereas the color of the moist sediments was recorded in the laboratory.

The most common color of the surface sediments of dry type playas is very pale brown. A color comparison of the surface sediments of 46 dry type playas showed that 32 were very pale brown, 8 were gray, 4 were white, and 2 pale yellow. Of these colors, 90 percent fall within the range of 10YR8/2 to 10YR5/1.

The color of salt-encrusted surfaces of moist playas differs sharply from the surface color of other types. Their colors range from a dazzling white (N9), as at parts of Kaehn Lake and Columbus Marsh, to white (5Y8/2), to pale yellow (5Y7/3), to light gray (2.5Y7/0). The surface color of these playas is controlled by the purity of the salt crust. The most common surface color is somewhere in the gray range, 5Y6/1 to 5Y7/3.

The surface colors of clay-encrusted moist playas are similar to those of the dry type, usually very pale brown. Some, as at the Borego Sink and Eight Mile Flat, have slightly lighter colors, ranging from light gray to yellow, and at Troy Dry Lake, the surface color has a slightly pink hue, being pinkish white, 7.5YR8/2.

On crystal body playas in which the crystal body is exposed, the color of the playa is similar to that of the salt-encrusted playas, ranging from white through gray. At Searles Lake, portions of the crystal body have a definite red tinge, which is imparted to the salt by the presence of numerous minute, salt-loving bacteria. If the crystal body is covered with alluvium, the colors of the sediment are the same as the moist, clay-encrusted playas.

The colors of subsurface sediments of playas are darker than the surface sediments. Once below the surface, there is no appreciable change in color with depth. At Rogers Lake, no color changes were noted between depths of 6 inches and 26 feet. At other lakes, samples from 4 to 48 inches were obtained, and no changes in color with increasing depth were noticed. If a change in sediment type were encountered at greater depths, such as from clay to sand or gravel, a color change would be expected, but no sediment changes were encountered at the shallow depths investigated.

On dry type playas, most of the subsurface sediments were very pale brown, but with a lower value (darker color) than the corresponding surface sediments. The wet subsurface sediments of moist playas have a color radically different from that of the surface material. The most common color of these sediments is 5Y6/3, pale olive. In crystal body lakes there is little variation in color with depth in the salt body. The subsurface salts are slightly darker than the surface salts, since they are in contact with brines. The puffy ground around the edges of crystal body lakes and covering the surface of some of them is darker than the surface sediments, and, where moist, is generally pale olive. Freshly dug sediment from ditches on Bristol Dry Lake is dark yellowish brown, 10YR4/2.

When the surface sediments of all of the dry playas were moistened, they became darker. The chroma, or degree of saturation, increased, and the value decreased, i.e., became darker. In some cases the hue changed from 10YR to 7.5YR, an indication of increasing red values or darker coloration. Very commonly the very pale browns when wet became brown, reddish brown, and even dark brown. This was evident after rains when some of the playas which had previously appeared as dull gray or white patches of alluvium appeared as bright brown and reddish brown areas.

(2) Grain Size In determining the grain size of playa sediments, a sample was first split to 15 to 30 grams and then washed through a 1/16 mm screen. The material retained on the screen was analyzed either by sieving through standard screens or by means of the sand settling tube (Emery,[14]). The material that passed through the 1/16 mm screen was diluted to 1000 ml and filtered several times through Pasteur filter candles. After the last filtration the suspension was thoroughly agitated for 5 to 10 minutes with a malt mixer. The suspension was again diluted to 1000 ml and analyzed by the pipette method. The washing and diluting agent used throughout the procedure was a 0.0035N solution of sodium hexametaphosphate, a strong dispersing agent.

The sediments of playa lakes vary over a wide range, their character being controlled by such diverse factors as rock hardness, physiography, intensity and amount of precipitation and runoff, amount of vegetation cover, and the geologic age of the bounding mountain ranges. Typically, playa lake sediments are an intimate mixture of sand, silt, and clay, and the sediment may be classed as a sandy silty clay. In an average playa lake the sand content varies between 5 and 15 percent, the silt content from 15 to 35 percent, and the clay between 50 and 80 percent. The sand is generally fine, and in most cases made up almost entirely of material between 1/8 and 1/4 mm in diameter. The clay content is typically greater than 60 percent, and of this, 30 to 40 percent is less than one micron in diameter, within the range of colloidal material. In a few of the playas, as much as 90 percent of the sediment was finer than silt, of which as much as 60 percent was of colloidal size. Rogers Lake is the type example of a playa of this sort.

The average diameter of surface sediments from playa to playa varies over a rather wide range. The finest sediments were found at Rogers Lake, where most of the samples had an average grain size of less than one micron, and one was only 0.67 micron. A maximum average diameter of 75 microns occurred in the sediments of Deadman (Twentynine Palms) Dry Lake. The average median diameter of 25 dry lakes was about four microns, which can be considered typical of playa sediments.

Playa lake sediments are poorly sorted. Sorting coefficients of from four to seven are common. This may be expected, since all of the size groups from coarse sand to colloidal material are represented in the sediments of playas. However, a playa sediment may exhibit fair or even good sorting. In a few instances, there was a preponderance of very fine sand or coarse silt, as at parts of El Mirage Lake, or of clay, as at Rogers Lake. In these cases, sorting coefficients of 2.5 to 4 exist, indicating good or average sorting. Typically, however, poor to very poor sorting of playa sediments is characteristic.

There is no apparent variation of grain size with the playa type. The sediment content of playas of five different types are compared in figure 18, and it is apparent that there is no consistent variation with the type of playa.

A comparison of the character of the surface sediments and the sediments at a depth of 6 to 12 inches is also shown in figure 18. In general, the surface sediments are slightly coarser than the sediments at shallow depths, the former commonly containing more sand size grains than does the subsurface material. Much of this surface sand is being swept across the playa to an ultimate resting place outside the playa, but its presence at any given moment results in the slightly coarser character of the surface sediments as compared to the subsurface sediments.

Once below the surface there seems to be no particular relationship between grain size and depth. At Rogers Dry Lake, open cuts in the playa extending to a depth of 26 feet have been excavated in the process of mining playa clays. Samples were taken at one-foot intervals along a fresh exposure at one of these pits, and the materials analyzed by the pipette method. The grain size distribution showed no definite gradation with increasing depth.

The average diameters of the subsurface samples were generally slightly less than one micron. The coarsest was the sample from a depth of one foot, which had an average diameter of 1.2 microns, while the finest material was found at 11 feet, where the sediment had an average diameter of 0.65 micron.. The results of the analyses are shown graphically in figure 19.

Some variation in grain size occurs from one end of a playa to the other, as well as from one side to the other. At El Mirage Dry Lake a series of samples was taken at half-mile intervals along the long axis, and a similar series at one-tenth of a mile intervals along the short axis of the lake, near its midpoint. Each sample consisted of a

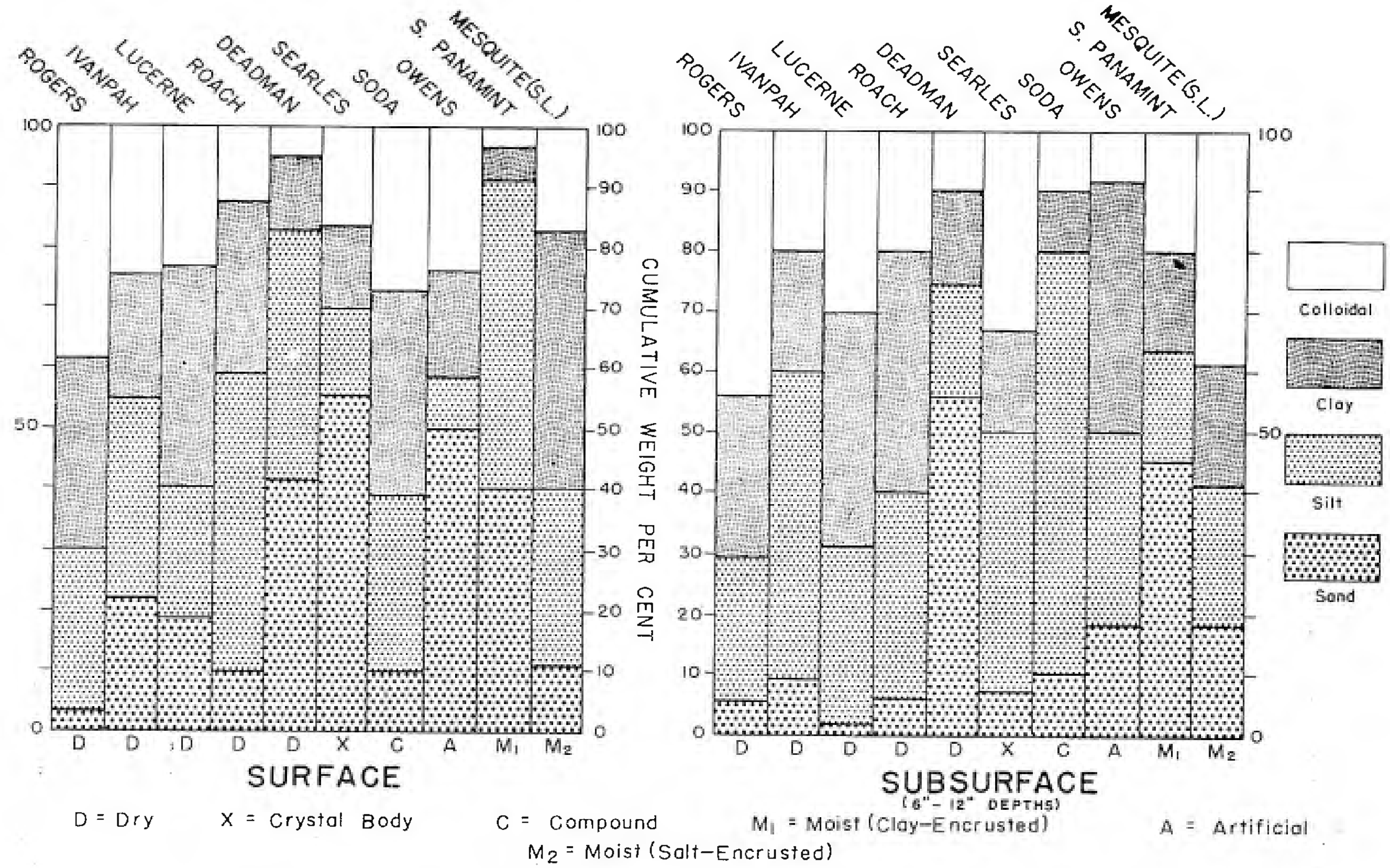

Figure 18. Surface and subsurface grain size variation by playa type.

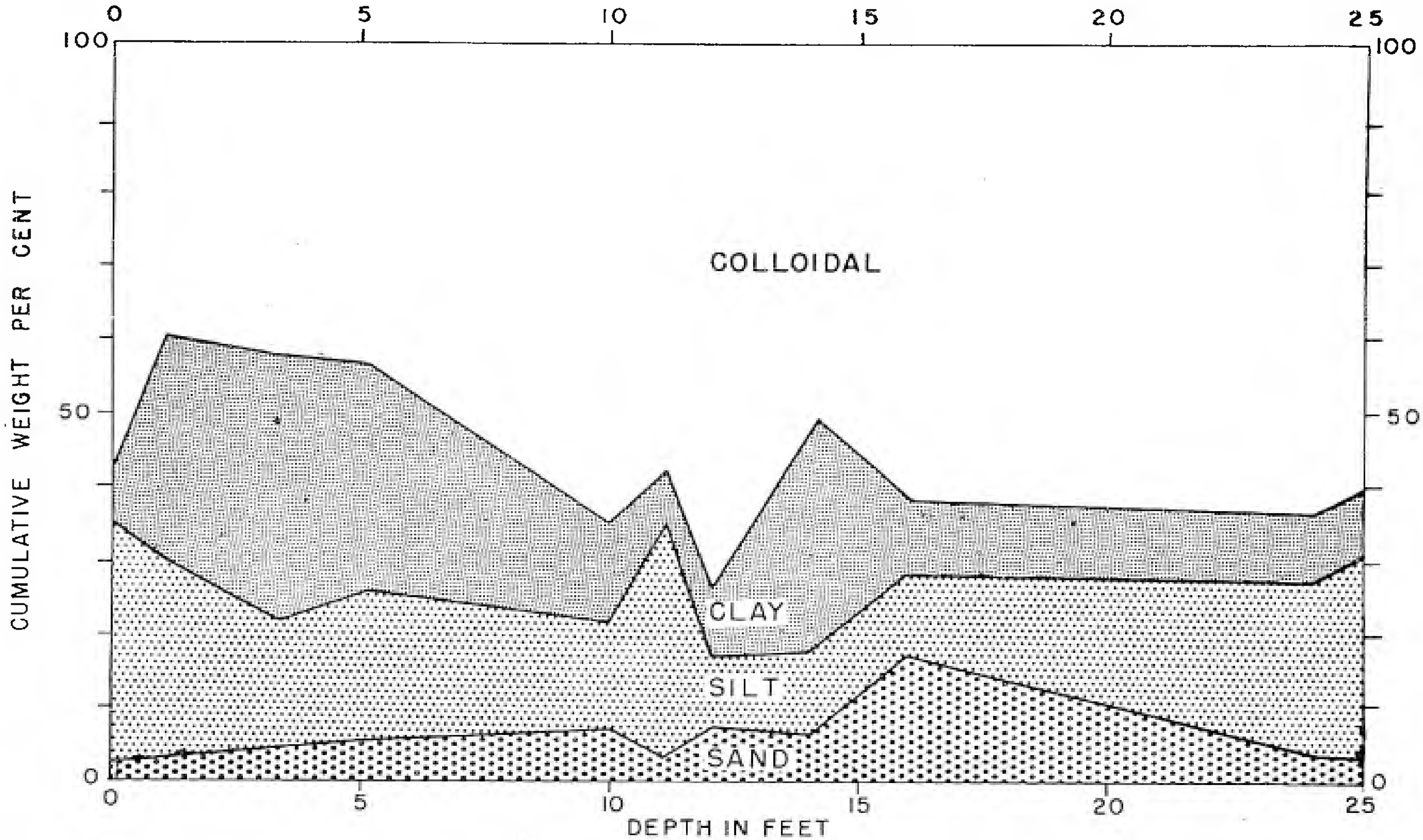

Figure 19. Variation of grain size with depth at Rogers Lake.

composite of the upper 6 to 8 inches of sediment. Results of the pipette analyses are presented in figures 20 and 21.

Both series of grain size analyses show that there is no regular gradation in grain size with relation to distance from the edge of the playa. The finest material along the long axis was found a half mile from the northwest end of the playa and the coarsest material two and a half miles from the northwest end and within a half mile of the center of the lake. Yet, the samples on each side of the coarse sample were among the finest that were analyzed. Other examples of this heterogeneity of grain size distribution are shown on the figures, which also show the greater coarseness of the samples from the transition zone and the adjoining desert flat.

The heterogeneity of grain size distribution, both laterally and vertically, in typical playas, shows that the environment of deposition in playa lakes is very different from that existing in most permanent lakes. The heterogeneous distribution of sediments found in playas can be explained by considering the following factors: (1) The sediments contributed to a playa by individual storms may come from widely separated points. (2) The variation in intensity of storms will cause considerable variation in the size of material being contributed from storm to storm. (3) With each flooding of a playa lake there is a mixing of new sediment being contributed to the lake with sediment that has been previously deposited. This recurring mixing of the new and old sediment may result in destroying any existing gradation of grain size in the playa sediments. (4) The water sheet of a playa lake is usually very shallow, from an inch or two to a few feet. This thin sheet of water over most of the lake surface permits the depostion of fine material over much of the area rather than in only the deeper central areas as in the case of permanent lakes. (5) Perhaps the most important factor is the effect of wind in keeping the surface materials stirred while the water is present, and in mixing them when dry.

The grain size analyses indicate that there is a definite relationship between the grain size of playa sediments and the physiography of the drainage basin. In general, those dry lakes which are located in large and relatively flat basins contain the finest sediments, while those found at the base of alluvial slopes or mountain fronts contain much coarser sediments. The finest playa sediments analyzed were from Rogers Lake, which is located in an especially large and flat basin. The coarsest sediments were from the South Panamint and Deadman (Twentynine Palms) Playas, both of which are near the foot of one of the enclosing mountain ranges.

(3) Mineral Content The material that would not pass through the 1/16 mm screen during the grain size analyses was dried and examined under a binocular microscope. Lengthy grain counts were not made, because it was evident that the minerals of the sediments reflect the rock types

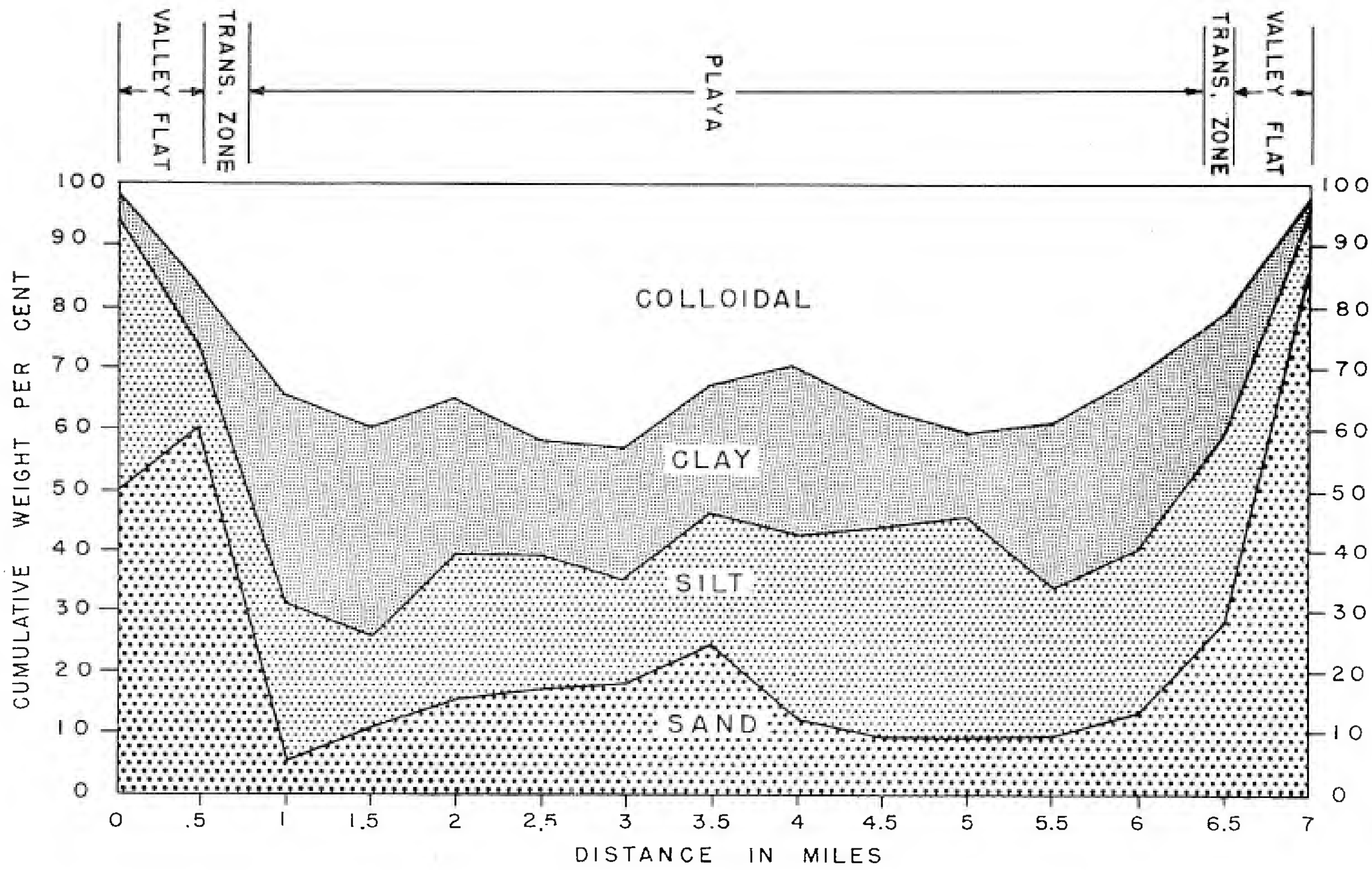

Figure 20. Lateral variation of grain size along the long axis of El Mirage Dry Lake.

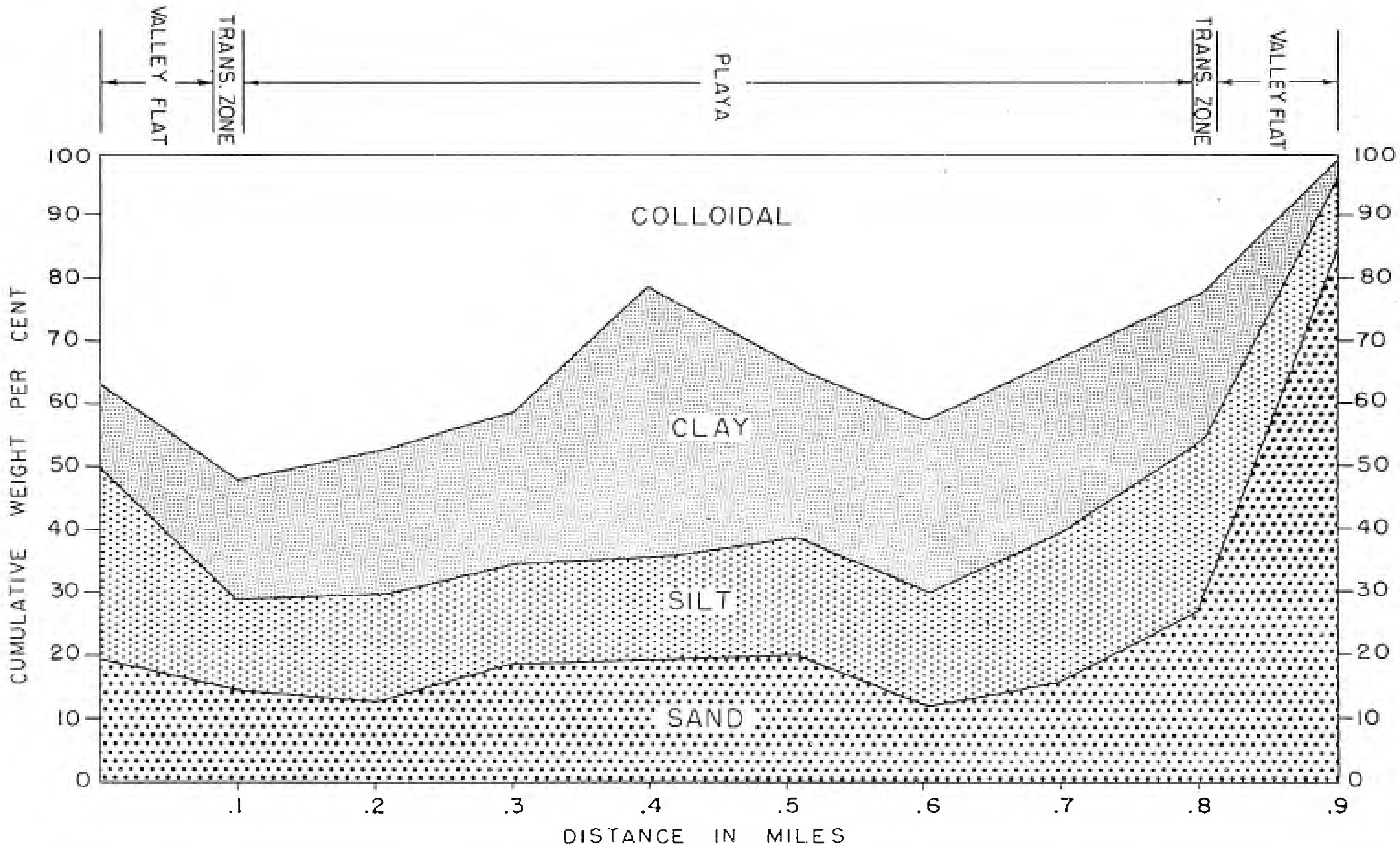

Figure 21. Lateral variation of grain size along the central short axis of El Mirage Dry Lake.

of the surrounding mountains. Microscopic examinations were made in order to determine the degree of rounding of the grains and to determine the principal mineral types.

The sand fractions of playa sediments are largely very fine sand and fine sand, from 1/8 to 1/16 mm in diameter. The sand grains are typically subangular (6.0-5.0) and show little evidence of transportation. The quartz fraction may contain numerous grains that are subround (5.0-3.0) and have frosted and pitted surfaces indicating aeolian transportation. The coarse fraction consists of the common detrital minerals: quartz, orthoclase, plagioclase and biotite mica. The sample from the Arabian sebkha was unusual in that over 90 percent of the grains were quartz, most of which were subround to round (5.0-1.5) and with highly frosted and pitted surfaces.

The angularity of the sand grains, the freshness of the feldspar grains, and the abundance of the common detrital minerals in the sediments are the result of the dominance of mechanical weathering over chemical weathering and also rapid transportation and deposition under arid conditions. The frosted, subround to round quartz grains indicate that wind as well as water is an active agent of transportation and deposition at playa lakes. The great abundance of aeolian quartz grains in the sample from Arabia indicates that the playa is located in an area of active wind erosion and is doubtless bounded by dunes of quartz sand.

The mineral content of playa lake sediments is directly related to the rock types of the surrounding mountains. In volcanic areas, small fragments of volcanic rocks as well as magnetite and hematite are often found. The dominance of quartz, feldspar, and mica denotes an abundance of granitic source rocks, a type which is known to abound in the desert regions of California.

(4) Water-soluble Salts In determining the soluble salt content of playa sediments, 150 ml. of distilled water was added to 15 to 20 grams of powdered and dried sediment. The resulting suspension was then mixed for 5 minutes with a malt mixer. After settling, the clear liquid was carefully decanted from the remainder of the suspension. This procedure was repeated three times. The remaining slurry was then baked to dryness at a temperature of 105°F, weighed, and soluble salt content determined by the loss in weight.

The percentage of water-soluble salts found in 20 samples is presented in figure 22. It will be noted that the soluble salt content of dry playas is much lower than that for the moist type. The surface sediments of dry playas all contained less than 3.5 percent, as compared to a minimum of 9 percent and a maximum of 34 percent for surface samples of moist playas.

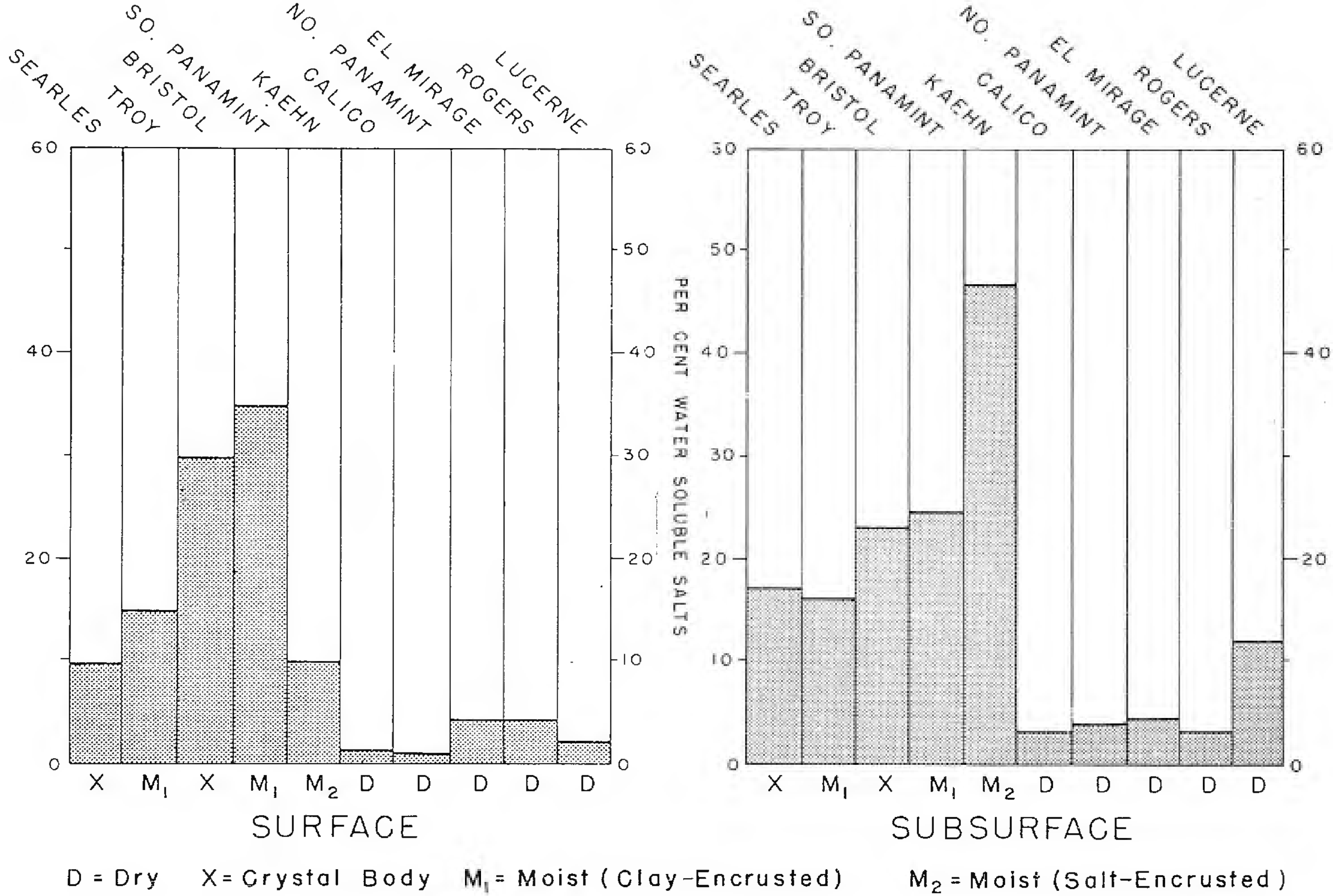

Figure 22. Water soluble salt content of playa sediments.

These figures are in general agreement with the work of Thompson[46] (p. 67), who found that dry playas have a soluble salt content of less than 2 percent and moist playas from 2 to 20 percent. On dry type playas, there is generally a slight increase of soluble salts with increasing depth, but on moist playas there is no definite trend. Water standing on dry playas after a rain, or in dug "tanks", was always found to be sweet.

The soluble salt content of only 4.95 percent in the sebkha sample from Arabia strongly suggests that the playa is the hard-surfaced, dry type.

(5) Calcium Carbonate To determine the calcium carbonate content of playa sediments, the samples that had been used for the water-soluble determination were weighed and then treated with 100 ml of dilute (1:2) hydrochloric acid. The suspension was agitated until effervescence stopped and was then decanted. Dilution and the decantation were repeated until all traces of the hydrochloric acid had disappeared. The sample was then evaporated to dryness at a temperature of 105°C and weighed. The loss in weight was taken as the calcium carbonate content, though some of it may be due to magnesium carbonate and other acid-soluble salts.

The calcium carbonate content of moist and dry playas, surface and subsurface samples, is shown in figure 23. Sediments of dry playas contain more calcium carbonate than do those of moist playas. The lime content of the dry playas ranged from 9 to 27 percent, and that of moist playas from 3 to 15 percent. There is no apparent increase or decrease in calcium carbonate content with depth on different types of playas. No determination of calcium carbonate on the limepan playa was made, but it probably is around 75 percent.

(6) Moisture Certain of the field samples were immediately placed in tightly stoppered bottles and returned to the laboratory for analysis. The water content was determined by drying 15-gram samples at 105°C. The results may be slightly high due to the loss of volatile compounds, but this error is believed to be negligible. In order to determine the maximum possible moisture content of a playa sediment still in the form of plastic mud, two samples were prepared in the laboratory by saturating with water and then drying.

The samples recovered from dry playas during the summer had a moisture content of less than 5 percent. Surface material at Rogers Lake had a moisture content of 4.5 percent; at El Mirage, 5.4 percent; and at Jean, 3 percent. Depth samples from these lakes had a slightly lower moisture content. A sample from a depth of 15 feet at Rogers Lake contained 4.1 percent, and one from 20 inches at El Mirage, 3.6 percent. Samples taken from the moist sediment zone of moist playas had a greater moisture content. A sample from Bristol Dry Lake contained 9.5 percent, one from Mesquite (Stateline) contained 6.8 percent, and one from Death Valley 11.2 percent.

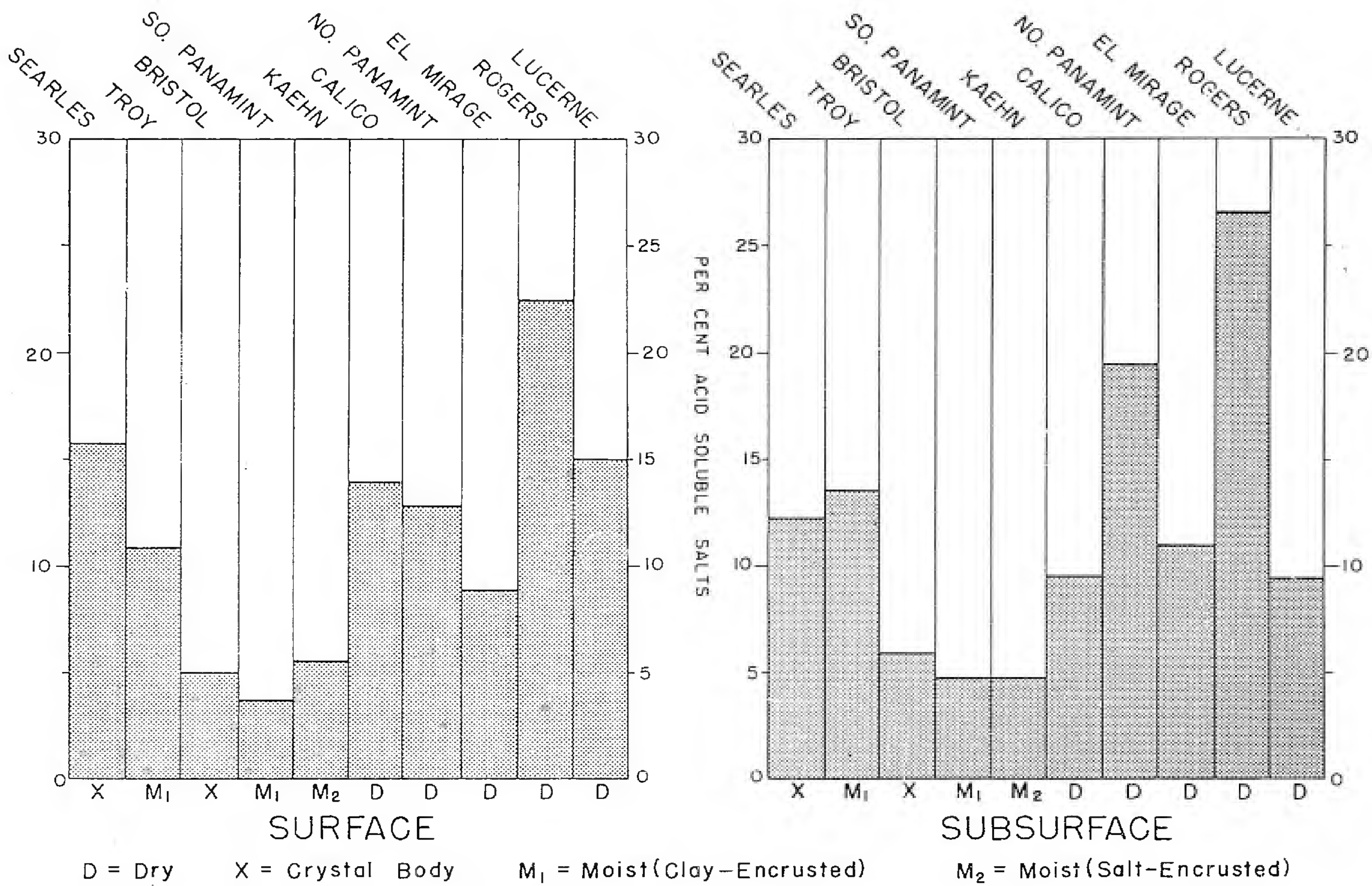

Figure 23. Calcium carbonate content of playa sediments.

Two samples recovered from dry lakes two days after storms were analyzed. Rosamond Lake sediments contained 10.4 percent moisture, and Buckhorn sediments contained 21.1 percent moisture. In the experimental work in the laboratory, where samples were saturated with water, it was found that the sample from the 15-foot interval at Rogers Lake contained 41.3 percent moisture and the Mesquite (Stateline) sample contained 35.2 percent moisture.

The moisture content of playa lake sediments is controlled by the intensity of desiccation since the last rain. Immediately after a dry lake has been covered with water, the sediments may contain nearly a maximum of moisture, which may be as much as 40 percent by weight. After periods of desiccation the percentage of moisture in the sediments may be only 3 or 4 percent. The playa sediments contain sufficient clays so that even after long periods of desiccation they still contain small amounts of moisture. As might be expected, on dry type playas there is a slight decrease in moisture content at depth, since the subsurface sediments are not subject to periodic wetting as are the surface sediments.

(7) Hydrogen Ion Concentration The pH or hydrogen ion concentration of playa lake sediments was determined by means of a Beckman pH meter using calomel and glass electrodes. The instrument was first standardized using a buffer solution of known pH. Sediment samples were mixed with distilled water, forming a thick slurry. The electrodes were immersed in the slurry and the pH recorded. Readings were made at room temperature, about 22°C. Temperature corrections were not made, since they would only minutely change the resulting reading and since wide temperature variations exist on playas.

Surface and depth samples from the several types of dry lakes were tested, as well as samples of playa salts.

The pH of dry lake sediments ranged from 6.6 to a maximum of 9.7. The pH of dry playa sediments varied from 7.8 at Lucerne to 9.0 at North Panamint. Subsurface samples showed a slight increase in pH with increasing depth. At Rogers Lake the surface sample had a pH of 8.9; the sample from a depth of one foot, 9.2; the ten foot sample, 9.0; and the fifteen foot sample, 9.6. The sediments of moist playas had a slightly lower pH range. They varied from a low of 6.6 at Palen to a high of 9.1 at Alkali (Nevada). In moist playas, the depth samples were also slightly higher than the surface samples. Salts from the crystal body at Searles Lake had a pH of 9.02, and those from Bristol Lake, 8.9.

The hydrogen ion concentration of dry lake sediments is a function of the concentration and type of salt present. In those lakes high in sodium chloride a pH reading near 7 was common, typical of a salt of a strong acid and a strong base. The high or alkaline pH readings occurred in dry lakes that had a high concentration of sodium carbonate, the salt of a strong base and a weak acid.

Moist playas are generally not as alkaline as dry playas, and may even be slightly acidic, probably because of the abundance of such nearly neutral salts as sodium chloride, calcium chloride, sodium sulfate, and calcium sulfate. Also, the relatively greater abundance of calcium carbonate in dry playas gives the sediments a more alkaline character.

(8) Playa Soils Playa lake soils are the intrazonal halomorphic soils characteristic of imperfectly drained arid regions. Two soil types are found on playas: solonchak or saline soils and solonetz or alkaline soils. Baldwin, Kellogg, and Thorp[6] (p. 1118) describe the solonchak soils as light colored, high in soluble salts, poor in organic matter, and with a friable and granular upper zone. This is the soil type found on the moist or "self-rising" soil playas. Similarly, the solonetz soils are described as commonly having a thin surface layer of light-colored material overlying a darker subsoil of columnar structure that is high in calcium carbonate. These are the soils of the dry playas. Commonly, there are patches of both of these soil types present at an individual playa.

According to Jenny[34] (p. 37) the concentration of salt and alkali in playa soils makes them of little value from the standpoint of agriculture, although he believes that in the future these soils might be reclaimed for use by the removal of excess salts by leaching and by treating the soils so as to convert the sodium clays to calcium clay by adding such chemicals as gypsum, sulfur, alum, and iron sulfate. Nevertheless, the senior author found a barley crop being raised under irrigation on a dry type playa north of Twentynine Palms. At the time it was seen, in July of 1951, it was doing very well. Alfalfa also is grown on the south end of Kaehn Dry Lake.

h. Geologic Age

(1) Fossil Evidence Remains of past life in playa sediments are rare. Fossils were collected at East Cronise, Halfhill, and Silver Lake playas, but were strikingly absent at most of the other dry lakes. The fossils found were all fresh-water mollusks, which have such a wide geologic range that they are of little value in dating the sediments.

The presence of a Pleistocene fish in the sediments of Searles Lake, and mammalian remains at Resting Springs, China Lake, and Rogers Lake certainly indicate that much of the sediment of playa lakes was deposited during the Pleistocene epoch.

(2) Lake Varves and Radioactive Carbon At Searles Lake beneath the 70-foot-thick crystal body is a finely laminated black parting mud with an average thickness of 12 feet. Microscopic examination of this mud revealed that there are 1,000 annual laminae or varves to the foot. It thus required 12,000 years for the mud to be deposited. On the basis of the character and thickness of the overlying salt body it has been estimated (Ryan[45], p. 448)

that less than 4,000 years were required for its formation. The upper parting mud is correlated with the Tioga or latest Wisconsin glacial stage, while a lower mud is correlated with Tahoe or earliest Wisconsin stage.

A sample from the base of the parting mud was analyzed for its Carbon 14 content, and on this basis the sediments are believed to be at least 16,000 years old. This figure agrees very closely with the figures reached from the lake varve and crystal body age determination described above.

(3) Pleistocene Hydrology Most of the dry lakes of the desert are related to large Pleistocene lakes or to Pleistocene waterways. Lake Bonneville in Utah and Lake Lahontan in Nevada were the largest Pleistocene lakes existing in the southwestern portion of the United States. In California, the Pleistocene lakes include Lake Manly, Lake Mohave, Lake Thompson, and several smaller lakes. As desiccation took place, numerous smaller lakes resulted, the remnants of which are the dry lakes of today. Many have been correlated with the Tahoe stage of glaciation, and some, as Lake Mohave, are believed to be contemporaneous with the Tioga stage of glaciation (Hubbs and Miller[30]). An excellent example of a series of dry lakes which were connected during the Pleistocene are Owens, Indian Wells, China, Searles, South Panamint, and possibly Death Valley. Many of the other playas of California were similarly related to Pleistocene lakes and waterways (Free[18], Hubbs and Miller[30]), and probably had their origin during the epoch.

(4) Physiographic Relationships Some of the smaller dry lakes are apparently not related to Pleistocene lakes. Their age may be roughly estimated by physiographic relationships. A good example is Lavic Dry Lake. In Pleistocene time the drainage in Lavic Valley was probably northwestward towards Troy Lake (Thompson[46] p. 652). Lava flows during late Pleistocene or Recent time from the Pisgah crater blocked the normal drainage channel forming a second basin of interior drainage, and a second lake, Lavic, came into existence. Lavic Dry Lake is certainly younger than Troy Dry Lake, its age being very late Pleistocene or Recent. In other basins, the original drainage channels may be blocked by the formation of large alluvial fans. At Broadwell Dry Lake, it is probable that drainage was originally towards the lower Soda Lake Valley to the north. The drainage pass later became filled with alluvium and Broadwell playa was formed. Inasmuch as Quaternary lava (Thompson[46] p. 657) is found in the blocking alluvium, it would appear that the Broadwell Dry Lake originated in post-Pleistocene time, and it is certainly younger than the Soda (Baker) Dry Lake.

i. Rate of Sedimentation

The present rate of accumulation of sediments in dry lakes could not be measured or accurately estimated because of the relatively short period of time during which the investigation was made. However, several lines of evidence indicate the magnitude of sedimentation. These are lake varve and radioactive carbon investigations at Searles Lake, fossil evidence, physiographic relationships, and direct observations.

The lake varve and radioactive carbon work performed at Searles Lake shows that approximately 12,000 years were required during the humid times of the Pleistocene for the 12-foot-thick parting mud to be deposited, a rate of .012 inch per year. It is reasonable to expect that the present rate of sedimentation at Searles Lake under arid conditions is less. The presence of the remains of Pleistocene mammals at China and Rogers Dry Lakes within 3 feet of the surface also suggests that the rate of sedimentation is very slow. Assuming post-Pleistocene time to be 20,000 years and that the mammalian remains have not been transported, sedimentation has taken place in these lakes at a rate of 0.00015 inch per year. Of course, some sediment may have been removed from the playa by deflation, but, on the other hand, the remains may represent early Pleistocene forms.

The position of the crystal bodies of several of the dry lakes yields interesting clues relative to the rate of sedimentation. At Searles Lake the crystal body is exposed over an area of nearly twelve square miles in the central portion of the basin. Final desiccation of Lake Searles is believed to have started 4,000 years ago (Ryan[45], p. 448). Whatever the rate of deposit of clastic sediments at Searles Lake since this time, it has been insufficient to cover the entire lake surface. The crystal bodies at Cadiz, Danby, and Bristol Dry Lakes are covered with from 3 to 8 feet of overburden. At these lakes an average of about 6 feet of sediment has been deposited since the final desiccation of the lakes. It is not known when the final desiccation of these more southerly lakes began, but it probably pre-dated that of Searles Lake. The maximum rate of sedimentation in these lakes is thus about one foot in a thousand years.

Observations made during the field study, though far from conclusive, also indicate that the rate of sedimentation in dry lakes is very slow. Several dry lakes were covered with thin sheets of water during summer storms in 1951 and 1952, including El Mirage, Ivanpah, Jean, Roach, and Soda (Baker) Dry Lakes, and yet inspection of these lakes after the water had evaporated showed little if any addition of new sediment. Some fresh material was found on the lake surface, but it was believed to be in part older playa sediments that had again been taken into suspension.

In any discussion of the rate of sedimentation, the effects of deflation must be considered. (Blackwelder[7], p. 140) cites the classic example of Danby Dry Lake, where wind has lowered a portion of the basin 14 feet. This is the only lake where proof of such deflation can be shown, and it may be an exceptional case. It is the opinion of the author that the amount of deflation in desert basins, and particularly on dry lakes, may be greatly exaggerated. If wind is an effective erosive agent on playa lakes, it is on the surfaces of moist playas, where the surface crust has been broken and the fine granular material beneath the crust is exposed. Morrison (unpublished report of the United States Geological Survey on Lake Lahontan) also believes that deflation is effective only on moist playas. Dust storms do occur on and around dry lakes, but it appears that the source of much of the dust is the looser alluvium bordering the playa rather than the playa surface. It is possible, therefore, that this material is being added to dry lakes rather than being removed by the wind. Even assuming a maximum deflation of 14 feet for all playas, total sedimentation would still be generally less than 20 feet since Pleistocene time.

From all of this scattered evidence it is concluded that the bulk of the sediments found in dry lakes was deposited during the Pleistocene. Sedimentation since that time has been very slow, probably something less than one foot in a thousand years.

j. Economic Considerations

Although dry lakes appear to be merely flat expanses of desert wasteland of no apparent use to man, in the past forty years they have become areas of important economic activity. They are valuable not only for the clay, brine, and evaporites in the lake sediments, but some are excellent sources of ground water and are occasionally suitable for agricultural purposes. In recent years they have been widely used for military purposes and for automotive testing and racing. Only their importance from the point of view of ground water and military uses will be considered here.

(1) Ground Water Playas, by virtue of their position in the lowest portions of enclosed basins, are excellent sources of ground water. Water can almost invariably be found beneath dry lakes, but in some instances it is too saline to be of use. Also, beneath dry playas, ground water is generally encountered at considerable depth.

Ground water beneath dry playas is usually of good quality, since the salt content of the sediments of these lakes is considerably less than that in the moist playas. At Rogers Lake, excellent water is found at depths as shallow as 26 feet, and additional aquifers are encountered at 54 and 142 feet. The Mojave Mud Corporation has five wells on Rogers Lake, and the Air Force has a similar number there. The wells on the southern end of the playa are artesian. At Rosamond Dry Lake, artesian flow existed until recent years, when the rapidly falling water table in the area caused the abandonment of the wells. The southern part of Kaehn Dry Lake also has artesian water. At East Cronise Lake, excellent water is obtained from the playa edge. At the southern rim of the playa a well drilled to a depth of 42 feet delivered a maximum of 600 gallons a minute. In a well on the edge of Coyote Dry Lake, sweet water stands at a depth of 15 feet, and dug "tanks" on the playa of Red Lake, Arizona, furnished water for cattle which is muddy but sweet (Fig. 24).

At other dry playas, ground water occurs at depths of 200 to 600 feet or more, and in these wells the water may be highly saline. At Mesquite Lake near Henderson, Nevada, water was obtained at a depth of 325 feet but was too saline to be of value. A similar situation exists at Mesquite Lake near Twentynine Palms, where saline water occurs at depths of from 400 to 600 feet.

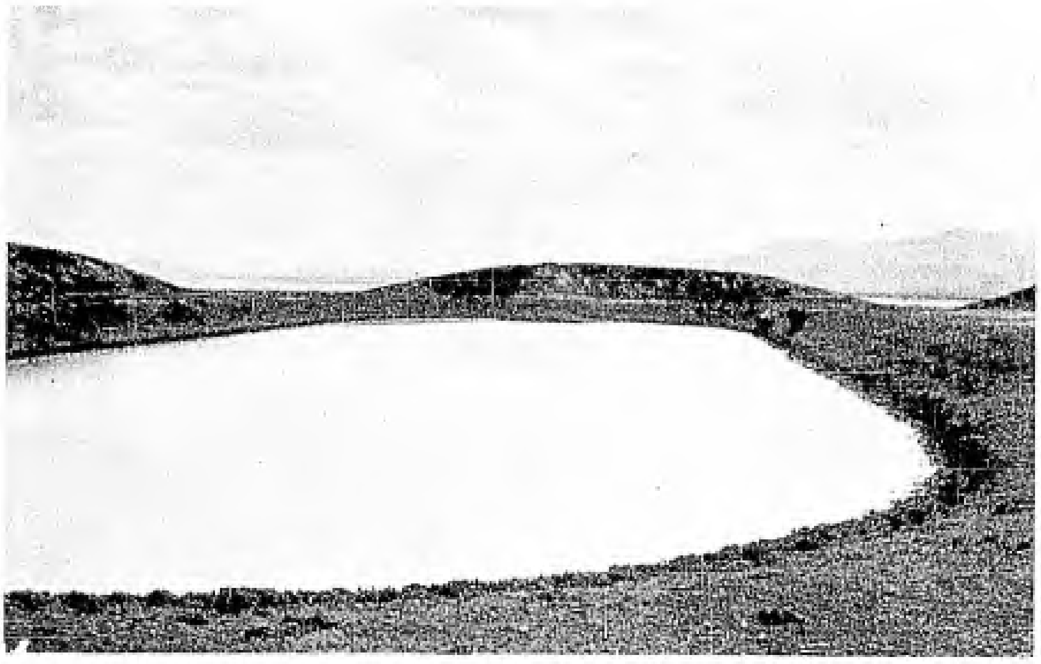

Figure 24. "Tank" or cattle-watering pond on clay playa. Red Lake, Arizona.

On moist playas and crystal body playas, the water is within 10 feet of the surface, and in extreme cases may be at the surface. In most cases, as at Searles, Dale, and Owens Lakes, the water is highly saline. In a few, as at Kaehn Dry Lake, artesian flow of potable water occurs at one end of the playa, probably separated by a fault from saline waters at the other end. On many of the moist playas, shallow pits 5 to 10 feet deep have been dug, in which saline water collects as a result of seepage from the surrounding sediments. Usable water from such a pit 7 feet deep is found at Troy Dry Lake. At most of the moist playas, suitable water is available in the alluvium bordering the lakes. This condition exists at such lakes as Searles, Owens, Dale, Bristol, Troy, and many others. In Algeria, a large salt marsh, the Chott Chergui, is being utilized to obtain tremendous quantities of water. Underhill[47] (p. 100) believes that eventually a total flow of 700 or even 1,000 cubic feet of water per second will be obtained.

(2) Military Uses During and since World War II, the dry lakes of California and Nevada have been of great use to the Armed Services. The flat, hard-packed, vegetation-free areas in sparsely populated regions have proven ideal for aircraft landing fields, gunnery ranges, bombing ranges, and for testing such new weapons as guided missiles and atomic bombs.

The most noted of the dry lakes used by the military is Rogers Lake (Muroc), where the Edwards Air Base is located. The lake, which is roughly 13 miles long and 5 miles wide, provides a landing field more than sufficient for all types of aircraft. The bearing strength of the massive clay body (measured as three-fourths of an inch depression for a single wheel loading of 150,000 pounds) can easily support the heaviest aircraft. Its isolated location is ideal for the testing of secret and experimental equipment. At nearby China Lake the Navy has a similar installation where guided missiles and experimental aircraft are tested. Frenchman's Flat and Yucca Flat in southwestern Nevada have been the sites of experimental tests of atomic bombs and atomic weapons.

Other dry lakes that are being used by the military are Benson Dry Lake, where the Navy maintains a gunnery and bombing range, and Bicycle and Indian Springs Dry Lake, Nevada, where the Air Force has gunnery and bombing ranges. During the war a primary flying school and glider school was in operation at Mesquite (Twentynine Palms) Lake and a gunnery range at Clark Dry Lake. The Palen playa near Desert Center was extensively used by General Patton in the training of armored divisions in desert warfare.

5. DESERT FLATS*

Bordering playas there is, as a rule, a relatively flat surface which extends to the alluvial fans or the bajadas at the base of the mountain rim. This surface has been designated a desert flat. Other terms applied to the feature are "valley flat" and "alluvial plain", both of which, however, have broader meanings and are sometimes applied to surface features in other environments.

Desert flats are not limited to areas surrounding playas; large flat expanses have been encountered in the Mojave Desert that are not near playas nor very close to bajadas. On the other hand, some playas pass directly from the transitional zone to alluvial fans or bajadas without intervening desert flats. Some basins lack both playa and desert flat, but as a rule these have exterior drainage.

Perhaps the largest desert flat area encountered in California during the present study is that south of Randsburg in the western part of the Mojave Desert. This unbroken plain is fully 10 miles in a north-south direction and 15 miles in an east-west direction. There are small areas where drainage collects, but these can hardly be called playas. Other large flats occur in Indian Wells Valley around Inyokern, around Goffs approximately 30 miles west of Needles on the Santa Fe Railroad, and in the Amargosa Valley east of Death Valley, partly in California and partly in Nevada.

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* The section on desert flats was written by Thomas Clements.

In Arizona, very large desert flats occur southeast of Salome on the road to Hassayampa, southwest of Tucson on the Ajo road, north of Ajo, and south of Quartzsite along the road to Yuma. The area of the first of these is estimated to be 600 square miles. Smaller flats occur throughout the desert area, down to those less than a mile square.

a. Topography

As the name implies, desert flats are areas of very low relief, and except for playas are the flattest surfaces to be found in the deserts. In the larger areas of this type there may be inselbergs rising above the general level, and Recent volcanic cones or flows may also break the flatness. Washes occasionally cross the surface, leading down to the playa, but these usually are shallow, with depths of a foot or two up to five feet. On some desert flats there are small dunes, where sand moving across the surface has been stopped by vegetation. These generally are not more than 10 or 20 feet high. On the whole, however, there is little to relieve the monotonous flatness of the surface (Fig. 25).

(1) Gradient Desert flats slope gently toward the playa or toward the lowest part of the area if no playa is present. The gradient, as determined from the plane-table survey of the type area near Goffs (Fig. 26), is 24 feet to the mile. The desert flat around Death Valley Junction in Amargosa Valley has a gradient of 13 feet to the mile, and the one at the northwest end of South Panamint Playa has a gradient of 55 feet to the mile. Still others may approach 100 feet or perhaps more. The range is from 13 feet to 100 feet to the mile, with an average for the large ones of around 15 feet and for the smaller ones of about 50 feet to the mile.

(2) Surface Materials The surfaces of desert flats are so commonly sand and gravel that for a time in the early part of the present study the tentative name "sand and gravel flat" was used for them. However, it soon became apparent that other types of surfaces also occurred, although sand and gravel is the most common. Sand alone covers some flats, and gravel alone is found on others, or parts of a single flat may be covered by each and by a combination of the two. The sand is generally medium to coarse grained, from $\frac{1}{2}$ mm. to 2 mm., with granule size particles 2 to 4 mm. commonly present. The sand tends to be subangular (7.5). Gravel is granule to small pebble size, 2 mm. to perhaps 50 mm. (2 inches), and the particles angular to subround (7.5 - 2.5). Both the sand and gravel show direct relationship in composition to the rock types comprising the surrounding mountains: generally granitic (arkosic) or volcanic.

Some surfaces consist of rocks, and others are gradations between gravel surfaces and rock surfaces. In some cases, rocks occur sparingly with

Figure 25. Desert flat south of Searchlight, Nevada.

the gravel; in others, rocks from pebble to boulder size (10 inches) or larger cover the surface. As a rule, the rocks average about 6 inches (cobbles) in the maximum dimension, and are angular to subrounded (9.0-5.0), some of them being exceedingly sharp. They are frequently patinated and are representative of the rocks of the surrounding mountains. If limestones are present, the cobbles are on the subrounded side.

An occasional desert flat was observed with a surface composed of rocks and boulders up to 2 feet in diameter. Such flats are usually small and close to the source of the boulders, which in the cases observed were basaltic lava washed from nearby flows.

Desert pavement covers portions of many desert flats. The surface is generally made up of angular to subangular (8.0-5.0) pebbles from ¼ inch to 2 inches in maximum dimension, forming a mosaic of small stones. Occasional larger rocks ranging in diameter from 6 inches to a rare 20 inches are scattered over the surface. These too are angular to subangular, the average being around 6.0. While the pavements on desert flats may be patinated, they frequently are not. Since the darker patina indicates an older surface, the presence of a deep desert varnish suggests that the surface is old enough to have been subjected to uplift, in which case it may be interrupted by deep washes.

b. <u>Origin</u>

Desert flats are essentially graded surfaces that have been developed by sheet wash at the foot of an alluvial fan or bajada. In the stage of

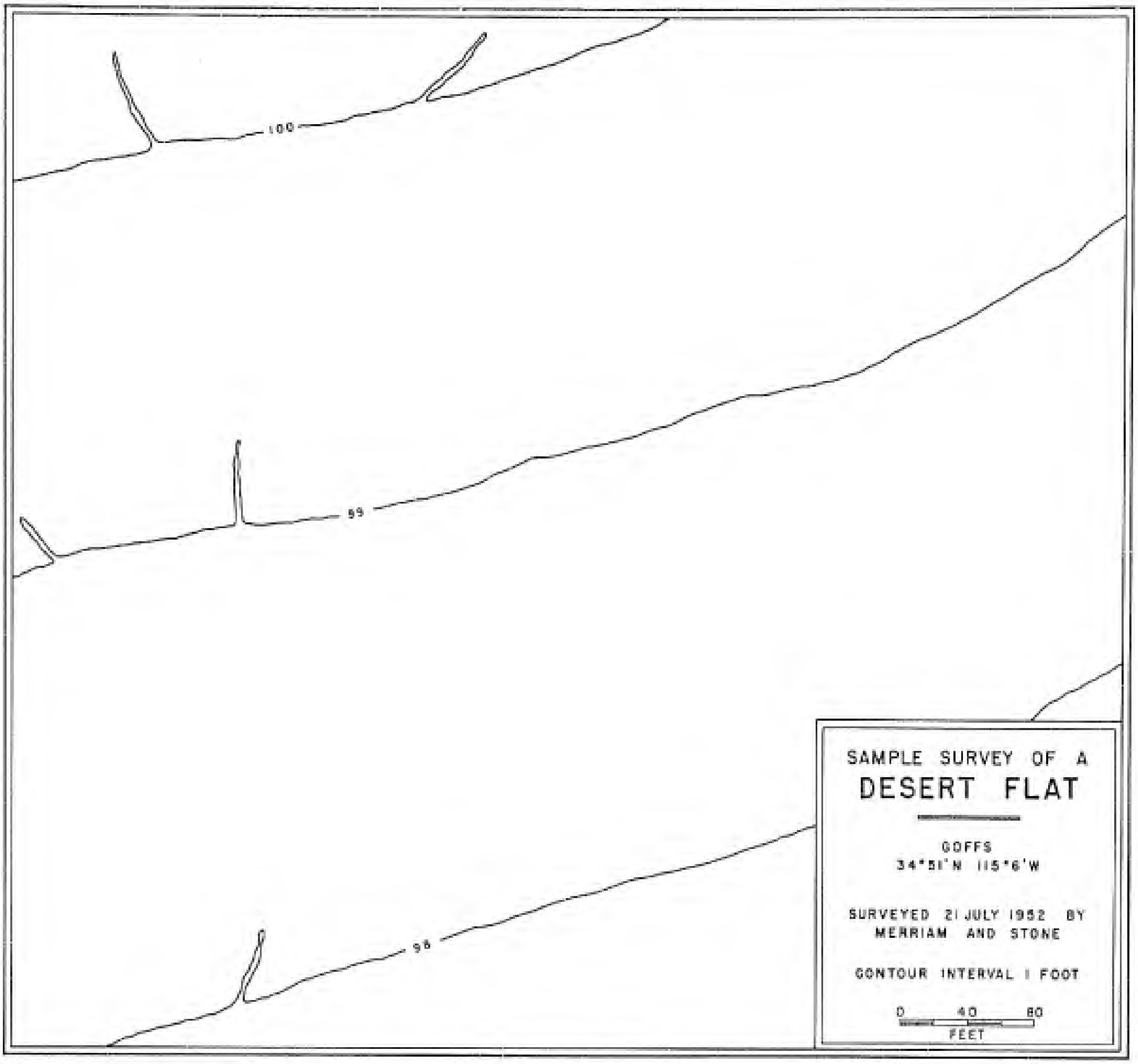

Figure 26. Sample Survey of a Desert Flat.

early youth in the erosion cycle, a desert basin, formed as a result of downdropping of one block relative to the adjacent blocks, may have a flat floor, but this would be purely coincidental, depending upon the original flatness of the surface and upon an equal lowering of the block as a whole.

Rapid erosion of the newly uplifted marginal blocks would quickly build fans at the bases of the blocks, with the development of a flat playa in the lowest part of the toes of the fan. It would not be until later in the stage, probably middle youth, when the declivities of the fans were less steep, that desert flats would normally develop. At first these would be narrow, with rock-covered surfaces, gradually broadening as the bottom of the basin filled. The surface material would become finer as the lowered gradients of the fans or bajadas reduced the competency of the sheet wash, and first gravel surfaces and later sand and gravel surfaces would develop, followed by sand.

Maximum development of the desert flats would be expected at the end of youth, but they would persist into maturity after capture of the basin by a lower one or by tributaries of a through-flowing river. Now, however, the flat would be static, since erosion would be diverted to the newly developed channels beginning to dissect the basin deposits. Wind action would carry away the sand, and desert pavement would develop on the surface of the flat.

As the mature stage progressed, the rocks of the pavement would develop a deeper and deeper patina of desert varnish, and the developing drainage would cut more and more into the surface. Washes would develop across the surface, and as these continue to cut downward and headward, the desert flat would become more and more dissected and would finally lose its character as such. In late stages it would be represented by isolated remnants that would be terrace-like in their occurrence. These would disappear entirely in old age, as the broad pediments develop.

c. Vegetation

The vegetation on desert flats is characteristic of the desert area as a whole. The commonest plants are creosote bush (*Larrea divaricata*) and burro bush (*Franseria dumosa*), with Mormon tea (*Ephedra nevadensis*) generally present. Cactus is found on some of the flats in the form of a cholla (*Opuntia bigelovii*). Salt bush (*Atriplex canescens*) occurs in some areas, and Joshua trees (*Yucca brevifolia*) may be found at high elevations.

Vegetation is apparently most abundant on gravel and rocky surfaces of the desert flat, less so on sandy surfaces, and as a rule is lacking altogether on desert pavement. Rather thick growth may be present in the washes. This variation in growth is especially well shown on the broad desert flat south of Quartzsite, Arizona. The northern part of this flat is essentially a gravel surface, traversed by shallow washes. Vegetation is sparse, consisting largely of creosote bush and bunch grass (Hilaria sp.) with a scattering of ocotillos (Fouquieria splendens) and saguaros (Cereus giganteus). The washes are marked by an almost continuous growth of desert ironwood (Olneya tesota) and palo verde (Cercidium floridum) considerably greater in height than the growth on the flat proper. On desert pavement surfaces, vegetation is entirely lacking. Farther south, the washes become more numerous and support an almost luxurious growth of cat's-claw (Acacia greggii), palo verde, and smoke tree (Dalea spinosa), some of them reaching a height of as much as 25 feet. Similar growth is found on similar surfaces in other parts of the desert, with the exception of the saguaro, which normally is not found west of the Colorado River.

d. Trafficability

As a general rule, desert flats lend themselves readily to easy movement of wheeled vehicles. The relative flatness makes grades imperceptible, and normally this desert type can be counted upon for a trafficability of 5 to 6. On the sand flats, this occasionally becomes 7s and rarely 8s with loose dry sand. The penetrometer on the last shows surface penetration at 6 to 10 lb. and 8 inches to 24 inches penetration at 150 lb. On the 6s, surface penetration is at 18 lb., with 6 inches at 114 lb.

Sand and gravel surfaces generally have a trafficability of 6sg, with surface penetration at 18 to 25 lb. and penetration of 1 to 4 inches at 150 lb. Occasionally, trafficability on these is 7sg with a surface penetration at 14 lb. and 4 to 5 inches at 90 lb.

Gravel surfaces seldom vary from a trafficability of 6g, but rocky surfaces may have such large rocks as to reduce trafficability to 7r to 9b. Penetrometer tests have no significance on these surfaces.

Desert flats covered with desert pavement offer the best trafficability of all, 5p, and usually show surface penetration only at 150 lb. However, if used by heavy traffic the stones of the pavement become displaced, and the sand or silt below may be soft. Another eventuality to be looked for on desert pavements, especially old ones with deeply patinated stones, is the presence of washes which may reduce the trafficability of the area as a whole to 8s or even 9s.

e. Color

The colors on desert flats vary with the type of surface and with the rock types represented in the neighboring mountains. The general color, looking across the surface, is also affected by the growth. Sand flats are pale grayish orange (10YR8/4) or pale orange pink (5YR8/6) when dry, and medium gray (N5) when wet. Freshly dug soil from one foot in depth is yellowish gray (5Y7/2) to yellowish orange (10YR6/4).

Sand and gravel flats are light olive gray (5Y6/1), grayish orange (10YR6/4), and pale grayish orange (10YR8/4) and pale yellowish brown (10YR6/2). Rocky surfaces are pale brown (5YR5/2), and desert pavements may be blackish red (5R2/2), pale brown, pale yellowish brown (10YR6/2) or grayish orange pink (5YR6/2). The fresh soil beneath the desert pavement is light brown (5YR6/4).

The effect of vegetation is to lighten the color looking across the surface. This is principally due to creosote bush, the commonest plant. Colors range from light olive (10Y5/4) to grayish olive (10Y4/2).

6. BEDROCK FIELDS*

a. Pediments

Bordering the fronts of some desert mountain ranges are slightly inclined rock surfaces thinly veneered with fluvial gravels. These surfaces are known as pediments, although they are also sometimes referred to as rock plains or conoplains. They are formed as desert mountains retreat under the erosive influence of stream planation, sheet wash, and rillwash. It is often difficult to distinguish between the more common bajada slopes and pediments, and it is only when bedrock is exposed in the sides of gullies and shallow canyons or on the surface itself that the gently sloping feature can definitely be classed as a pediment.

(1) Distribution The first pediment that was recognized and which became the type for the class was the rather extensive pediment on the north side of the San Bernardino Mountains in California near Old Woman Springs (Fig. 27). This has been called the Rock Corral pediment, from an old corral near the upper end of the surface. It is cut on granite, with many residual knolls and boulders rising above the general level.

Another fair-sized pediment occurs in Joshua Tree National Monument, forming the floor of a partly enclosed basin that slopes gently towards Pinto Basin. The surface has a cover of gravel of some thickness over

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* The sections on pediments and desert domes were written by Richard O. Stone, and that on hammadas by Thomas Clements.

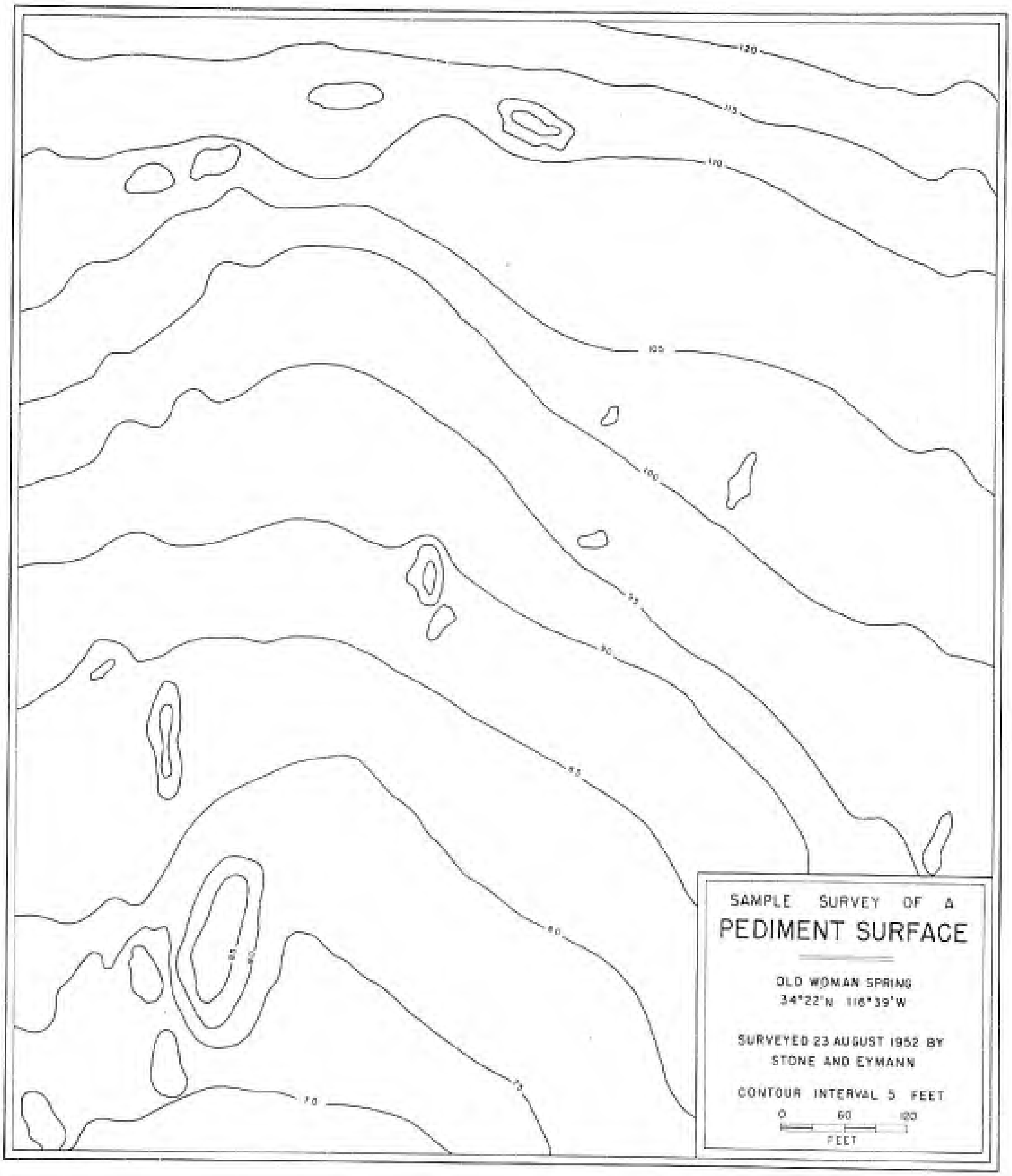

Figure 27. Sample Survey of a Pediment Surface.

part of it, but in other parts the bare granite on which it is cut shows through. Granite is also exposed in the washes.

A small pediment was found approximately 30 miles west of Needles, between Mountain Springs Camp and Goffs. This pediment, unlike the others already mentioned, is cut on gneiss, probably granitic gneiss.

Another small pediment, cut on granite and felsite, is about 17 miles south of Needles, between the Chemehuevi Mountains and the Sawtooth Range. This area is undergoing dissection at the present time. Others were found in the same general area some 12 to 15 miles to the west, where granite, and granite and rhyolite are exposed on a surface of low relief.

Small pediments occur on the easterly slope of the hills and mountains bordering the Colorado River on the west, along the road leading to the river from Searchlight, Nevada, and also on Nevada State Highway 77 leading to Davis Dam. Another of small size is east of Essex. A rather steep granite-surfaced pediment occurs on the road from Desert Center to Rice, and a doubtful one north of Vidal Junction. All of these are cut on granite and merge into bajadas. On the whole, the distribution is fairly wide through the desert area. Unfortunately, many of them are too small to be shown on the distribution map (Fold-in map at end of this report).

(2) Topographic Features The pediment surface is for the most part a gently sloping plain stretching from the base of a mountain towards the valley floor. Its surface is cut in many places by small dry washes and gullies. These drainage channels in the upper reaches of the pediment are sometimes 10 or 15 feet deep, but on most of the surface they are 5 feet or less deep and not more than 20 or 30 feet wide. On the surface of the pediment, large residual boulders and more resistant portions of the bedrock may be found projecting above the thin surface veneer of alluvium (Fig. 28). In the type area, the Rock Corral Pediment, the

Figure 28. Residual boulders or "nubbins" on surface of Rock Corral Pediment.

exposed bedrock areas are 20 to 30 feet in diameter and 5 to 15 feet in height. One bedrock mass is 45 feet in diameter. The slope of the pediment surface varies from the top to the toe. On the portions of the pediment that are close to the mountain the pediment may have a slope of 7 degrees. This gradually decreases with distance down the pediment. At the point where the pediment imperceptibly merges with the bajada the slope may be two or three degrees or less. The average slope of the Rock Corral pediment as a unit is $3\frac{1}{2}$ degrees. That of the pediment cut on metamorphic rocks between Mountain Springs Camp and Goffs is $1\frac{1}{2}$ degrees. The gradients, therefore, may vary from 650 to 135 feet per mile.

The surfaces of pediments are covered with medium to coarse sand, an abundance of granules, and some pebbles, the material of the cover being generally classed as coarse-grained. In places there are boulders and bedrock surfaces. Some of the latter are covered with coarse disintegration products, or grus, although others have a coating of material being carried over the surface and unrelated to the bedrock. In most cases the residual masses are made up of granitic rocks which weather by the peeling off of large concentric layers of material with resulting rounded and subrounded forms. The finer material which makes up the majority of the surface is angular to subangular (8.0-6.0). The surface colors range from yellow gray (5Y7/2) through grayish orange (10YR7/4) to yellowish brown (10YR3/2).

(3) Origin of Pediments Ideas as to the origin of pediments vary considerably. By some they are believed to be the result of lateral planation by the intermittent streams emerging from their canyons; by others they are thought to be formed by a combination of backwearing of the mountain slope as the result of weathering, and erosion by sheetwash as the products of weathering are swept away. Either would produce a relatively gently sloping rock surface merging at its lower extremity with the bajada, but showing a sharp break at its upper end where it meets the steep face of the mountain front.

Both modes of origin seem effective. Certainly as the desert basin fills and the gradients become less steep, lateral cutting takes place in the lower reaches of the canyons. This has been observed in the field during the present study. While sheetwash erosion on pediments has not been observed in action by the authors, the thin layers of detrital material on the bare rock surfaces suggest that it does occur.

Pediments would not begin to develop until well along in youth, probably late youth since in the earlier stages the streams are cutting dominantly downward, and the mountain front is retreating very slowly. As the basins fill and the alluvial fans coalesce into a bajada, the streams, intermittent though they are, become graded. Swinging back and forth over the bajadas as successive channels become choked with debris the stream can no longer carry, they impinge upon the sides of the canyons at their mouths and undercut the rocky walls, causing slides. With channels in the bajadas more or less choked, sheetwash would become more important as a means of transportation and also of erosion, removing the products of weathering from the spurs between canyons, and cutting the bedrock surface as well.

By the time maturity is reached, a number of small areas of pediments would have developed along the mountain front separated by areas of thick detrital material. Capture of the basin by a lower one would stop pediment cutting in both basins for a time, until the new drainage system had developed to the point where down-cutting in the captured basin and filling in the pirate basin became balanced, and lateral cutting would again commence.

The pediments cut during the mature stage would be on the rocks of the original mountain mass and on the basin fill as well, and would not necessarily be at the same angle of slope as the first-formed pediments, which might remain static for a long period of time before being cut to the new slope and the new level. Such soft-rock pediments have been reported from the Orocopia Mountains.

In old age, with sheetwash greatly reduced because of decreased rainfall, cutting would be immeasurably slow. Wind would remove the finest products of weathering and would abrade the rock surface as it swept the larger fragments back and forth. Eventually, however, vast expanses of rock surface (hammadas) would develop, alternating with desert flats, both having broad expanses of sand cover here and there. This could only happen if the area remained undisturbed tectonically. The presence of hammadas, therefore, is an indication of the development of the old age stage in the cycle of desert erosion, as well as a testimonial to the stability of the region as a whole.

(4) Vegetation Vegetation on the Rock Corral pediment is the normal low desert type, although the growth is denser than in most desert areas, probably because rainfall is higher in areas adjacent to high mountains. The plants growing on the surface of the type pediment include burro bush, creosote bush, Mormon tea, buckwheat (*Eriogonum* sp.), darning needle cactus (*Opuntia ramossissima*), rabbit brush (*Chrysothamnus* sp.), and scattered stands of yucca. Vegetation is most abundant along the small dissecting washes, where cat's-claw growing to a height of 7 feet was found.

On the pediment in Joshua Tree National Monument, Joshua trees up to 20 and 25 feet tall are growing, together with rabbit brush, grasses, and some creosote bush. This is at an elevation of around 4,000 feet. On some of the other pediments, particularly those nearer the Colorado River, Mojave yucca, cholla (both Bigelow's and deerhorn), ocotillo, and occasional barrel cactus grow.

The overall color of the vegetation on the type pediment is moderate to olive brown (5Y4/4), with a somewhat lighter color in the summer, somewhere in the range of pale greenish yellow (10Y8/2). On the pediment in Joshua Tree National Monument, the color of the vegetation is pale olive (10Y6/2). On others, it is pale dusky yellow (5Y6/4) to dark greenish yellow (10Y6/6).

(5) Trafficability Trafficability on pediment surfaces is good to fair. On the bare rock it is 5r, with no penetrability at 150 lb. Where there is a veneer of gravel it may be 5g to 6g with surface penetration at 55 lb., and 1 inch to 4 inches at 150 lb. However, many of the pediments have residual boulders that are several feet in diameter, and most are crossed by washes that may be five feet or more deep. On these trafficability is reduced to 7r or 7w.

b. Desert Domes

A relatively minor physiographic feature in the desert regions of southeastern California is the desert dome. This is a convex surface with extremely uniform and smooth slopes which are the result of prolonged exposure to the activities of desert weathering and streamflood. Commonly these domes have diameters of 3 to 8 miles and they rise 500 to 2000 feet above the adjacent lowlands. Some have an elongate form 10 or more miles long and are then referred to as desert arches. The earliest work on desert domes was done by Lawson,[37] who referred to them as "panfans". Later, more intensive work was accomplished by Davis.[12] Further references to desert domes are found in the work of Gilluly, Woodford, and Waters.[24]

(1) Distribution In the California deserts there are several domelike areas. The Cima Dome (Fig. 29), which is considered to be the type example for desert domes, is about 25 miles east of the town of Baker. Another important domal area is the Cuddeback Arch, 20 miles southeast of Randsburg. Other dome areas in the desert include the Noble Dome, on Cave Springs road between Barstow and the Granite Mountains; the Storrow Dome, 13 miles north of Barstow; the Kelso Mountains, in the Crucero-Cima trough, which represent an unfinished dome; a series of low-grade granitic domes of faint but regular convexity between Barstow and Lancaster; and two distinct granitic arches near Needles. Other similar features may be seen between the Lanfair and Piute troughs as well as in the eastern part of the Sheephole Mountains.

Figure 29. Surface of Cima Dome, California.

(2) Topographic Features Desert domes are moderately large topographic features with diameters of 3 to 8 miles. Total relief is around 1500 feet. Slopes are very gentle on the extremities of the dome, usually about one degree. On the upper reaches slopes are steeper but seldom exceed 4^{o}. The dome surfaces are generally quite smooth but are broken here and there by residual mounts such as Teutonia Peak on Cima Dome and Pilot Knob on Cuddeback Arch. Often smaller residual granite boulders or "nubbins" from a few feet to a hundred feet in diameter are found on the surface of the domes. Residual boulders are especially prevalent on the upper reaches of Cima Dome.

The surface material of desert domes is either bare rock or a thin veneer of fine-grained alluvium intimately mixed with granules and pebbles. These sediments tend to become coarser as the summit of the dome is approached. Individual fragments within the alluvium are subangular to subround, ranging from 7.5 to 4.0 on the angularity scale. The color of the surface sediments varies from area to area but the most common colors are pale shades of reddish brown (10R5/4), brown (5YR6/4), and yellowish brown (10YR6/2). Freshly dug ground is almost invariably somewhat darker than the surface but is still within the brown, reddish brown, and yellowish brown range.

(3) Origin of Desert Domes The geologic controls necessary for the formation of desert domes are granitic rocks, slowly uplifted rather than block-faulted, and conditions of arid erosion. Most of the domes found in the desert are formed on granitic rocks. Granite weathers not only by surface exfoliation but by the interior disintegration of grains, so that once a large angular joint block of granite is reduced by exfoliation into

a roundish core a foot or two in diameter, it breaks down into fine granular detritus or grus (Davis,[12] p. 214). Rocks other than granite, being less uniform, weather into angular blocks and grains and form hilly or mountainous forms. In addition, no other resistant mountain-making rocks commonly have a uniform structure over an area large enough to permit the formation of smooth, convex desert domes .

If, then, instead of the block faulting that characterizes so much of the topography of the North American desert, slow, gentle uplift occurs, there will not be the canyon cutting and fan building of the block faulted area. Rather, erosion will be by wide shallow streams or by sheetfloods. These will move more or less radially over the gently sloping surface, removing the products of disintegration. Since the granite is not porous there will be little loss of water except by evaporation, and during rainstorms this will be slight.

The wide, shallow streams and the sheetfloods will stand a good chance of reaching the periphery of the uplift, and, provided with more and more cutting tools as they advance, the streams cut more rapidly in the marginal areas than in the central area. As the lower areas around the uplift are reached, the coarse waste is deposited, building up a broad gently sloping gravel apron around and lapping over the margins of the dome. Domes probably appear in the mature stage of the arid cycle of erosion but are buried in their own waste or become hammadas in old age.

(4) Vegetation Almost all of the typical desert plants can be found growing on the slopes of a desert dome. At the Cima Dome, which is the type area, the vegetation consists of creosote bush, golden bush, rabbit brush, Mormon tea, Mojave yucca, cholla, burro bush, darning-needle cactus, and most particularly the Joshua tree. Of these the majority are scrubby bushes from one to three feet high, but the Joshua tree is a shaggy, spiny plant that reaches heights of 15 to 20 feet. On Cima Dome the trees are so dense that portions of the area are referred to as a Joshua tree forest.

(5) Trafficability All domes are readily passable to wheeled vehicles in most parts with trafficability generally 5r to 5/r. Slopes are gentle, nowhere exceeding 4 or 5 degrees. The few resistant knobs and the scattered granite nubbins present some obstacles to travel, but these are relatively isolated and can be easily avoided. The great profusion of Joshua trees on portions of the Cima Dome constitute an obstacle to travel and may reduce trafficability to 7, but they offer no appreciable difficulties except for short detours. Around the lower margins accumulation of products of weathering may cause heavy going with trafficability 7sg. Washes on domes generally are shallow and at worst are not likely to reduce trafficability more than to 6w or 7w. No penetrometer tests were made on domes, but penetrability can be assumed to be the same as that for pediments.

c. Hammadas

Hammadas (or hamadas) are large areas of bare rock of low relief. They may be the result of long-continued erosion under desert conditions, or they may be formed of flat-lying resistant rocks that have been exhumed by erosion of the overlying material.

(1) Distribution No hammadas were encountered in the course of the present field work, and so far as is known none exist in the North American desert. However, they are common in the Sahara where the term comes from, and are reported from the Kalahari, Arabian, Atacama, and Australian deserts.

(2) Topography Nothing is known of the topography of hammadas from first-hand experience. However, they are reported to be relatively flat rock surfaces, with occasional inselbergs rising above the general level. Presumably the relief would be something of the order of that found on pediments, a few feet to a few tens of feet. However, in some regions the rock surfaces are at different levels separated by escarpments, where the general relief may be measured in hundreds of feet, although that of individual surfaces is still low.

Colors of hammadas may differ according to the color of the rocks forming them. However, it might be expected that much of the surface would be dark from desert varnish, especially if formed by long-continued erosion rather than simply by exhumation, since parts of the surface would be covered by a thin layer of rock debris resulting from disintegration or derived from nearby inselbergs or escarpments. Colors in part probably would be similar to those found on pediments.

(3) Origin of Hammadas Apparently hammadas may originate in one of two ways. The first of these is by the normal processes of erosion in an arid region. Starting to develop in late youth as pediments, and probably interrupted during the transition from youth to maturity, the pediments would be widened as maturity progressed.

Hammadas as such would not be expected until old age, when the original mountain masses were completely worn down except for inselbergs, and the almost rainless area of low relief would be swept by hot, dry winds. These would remove finer material from the area as a whole and would scour the rocky surface, slowly lowering the general level. The time required for the production of hammadas by this process would be very great, and their presence would imply long-continued crustal stability. While formation of hammadas by this process is theoretically possible, the relatively few studies that so far have been devoted to hammadas have failed to produce substantiating evidence of such development.

According to the second theory of origin, flat-lying stratified rocks may be exposed at the surface by denudation of overlying, less resistant sediments. This denudation might be brought about by wind erosion, or by normal stream erosion during a preceding more humid time. It is essential that the area never was one of great relief, and that the amount of overlying material removed was not large.

Where flat-lying resistant beds are actually exposed on the hammada surface, as they are in some parts of the Sahara, the second method of origin is probably correct. If, however, the surface is granite or some other homogeneous, deep-seated rock, the first possibility seems more reasonable.

(4) Vegetation Little can be said here regarding vegetation on hammadas. The thin veneer of waste could not be expected to support very much vegetation except where springs of juvenile water reach the surface. Rainfall and temperature would be the controlling factors.

(5) Trafficability Trafficability on hammadas should be good, as a general rule, similar to that on pediments and domes, 5r to 6g. Washes might make some surfaces 7w, but it would be expected that washes would be broad and shallow. Where escarpments occur, traffic probably would be limited to occasional defiles.

7. REGIONS BORDERING THROUGH-FLOWING RIVERS*

Early in the present study it became apparent to the senior author that desert areas adjacent to the Colorado River differ considerably from the rest of the desert. Discussion with other members of the group disclosed that they had arrived at similar conclusions, and therefore another category was added to the earlier list of desert types, and called "regions bordering through-flowing rivers".

This type includes not only the areas immediately adjacent to the river, but also those basins beyond the bordering mountains that are being dissected by tributaries of the river. Technically any basin whose drainage reaches the river belongs in this group. Where the capture has been relatively recent, however, the basins retain the characteristics of interior drainage and so have been excluded from the following discussion,

* This section was written by Thomas Clements

excepting where it is necessary to point out features that have resulted from very recent capture.

a. Distribution

The most obvious occurrences of areas of this type in the desert of southwestern United States are immediately adjacent to the Colorado River. In some places the zone is quite constricted, where the river has cut through mountain ranges and is confined to narrow canyons, as in the vicinity of Picacho north of Yuma, north of Parker, and south of Hoover Dam. In other places the zone is many miles wide, as near Needles, the area between Parker and Blythe, and in the vicinity of Yuma. There are also some areas that are intermediate in width, as north of Parker Dam and between Davis Dam and Cottonwood Landing east of Searchlight, Nevada (Fig. 30).

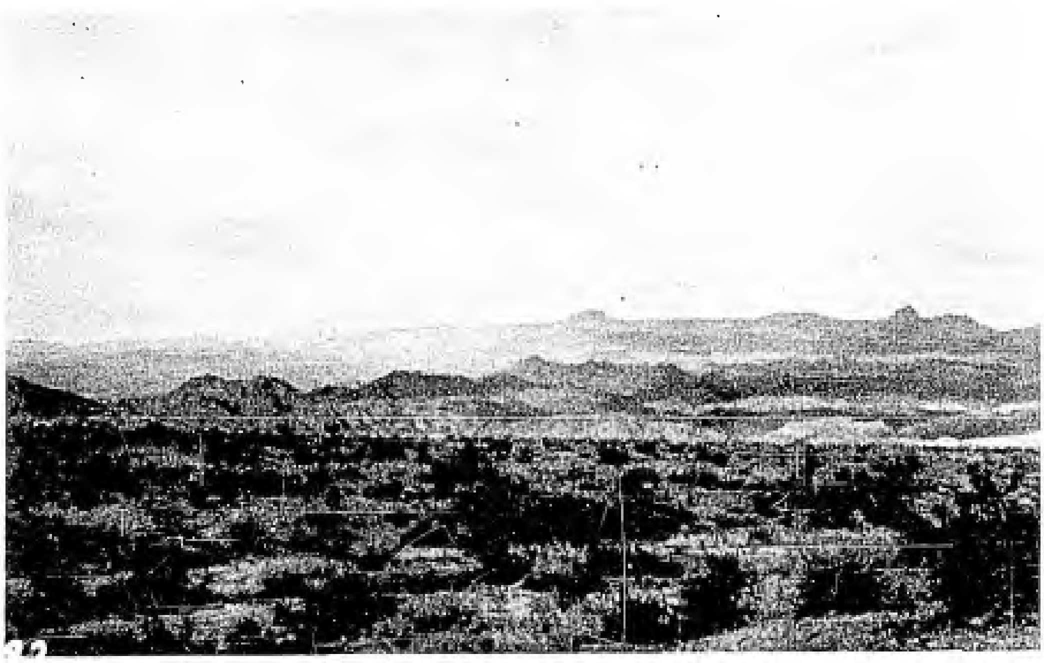

Figure 30. Area bordering through-flowing river near Davis Dam on Colorado River.

Basins that have been captured recently by intermittent tributaries of the Colorado River but have not yet been greatly modified are Piute Valley south of Searchlight, Chemehuevi Valley southwest of Needles, and the large basin around Vidal, west of Parker. The broad desert flats between Quartzsite and Yuma, the LaPosa and Castle Dome Plains along Arizona State Highway 95, have also been tapped by intermittent tributaries of the Colorado.

b. Topography

Within the study area, distinct terracing characterizes areas bordering through-flowing streams. Other than in narrow canyons, four terraces are generally found, not necessarily equally developed on both sides of the river. The greatest development of terraces occurs upstream from the narrow canyons, where lakes formed and sediments were deposited during canyon cutting in the harder rock downstream.

The youngest terrace, which is the lowest and borders the present-day river valley, is generally the widest, varying from a few hundred feet to a few miles in width. This is the least dissected of all the terraces, but is invariably cut by some washes, which may be from a few feet to 30 or more feet deep, with vertical sides. The riverward edge of this terrace likewise is a vertical cliff of the same order of height as those forming the sides of the washes.

The second terrace is also wide as a rule, although less so than the youngest, and it is generally more dissected. The break from the lowest to the second terrace is a somewhat subdued cliff. The main washes are deeper, with the lower section of the sides as steep as where they cut the lower terrace, whereas the upper walls of the washes are generally less steep. Tributaries to the main washes cut this terrace, whereas they are generally lacking on the youngest one.

The third terrace is very much less extensive than the first, and is well dissected, both by deep main washes and by many tributaries. The cliff at the break between the third terrace and the second is generally worn back to an easy slope.

The fourth and oldest terrace may be lacking altogether, and as a rule is represented by obscure remnants. However, here and there, as near Earp, California, and near Blythe, extensive remnants of even this terrace remain. The break between this and the next lower one may be eroded back so much that it cannot be called a cliff, but is a rather unobtrusive rise. Main washes cutting back into this terrace are steep-sided and may be 50 feet deep or more.

The river bottom itself must also be considered a part of this desert type, although it is well watered most of the year. It may be miles in width, with a flat bottom, frequently marked by meander scars, and much of it may be marshy. The main channel of the river may be no more than a very few feet deep. In the stretches of canyon, of course, the present-day river bottom occupies the entire cut, with vertical sides that may be hundreds of feet high. At flood time, water many feet deep may fill the canyon from side to side.

(1) Relief Relief over the river bottom itself is measurable in a few feet. Between the river bottom and the first terrace, relief varies in different areas from a few feet to a few tens of feet. The total relief between the bottom of the river and the highest terrace may be well over 100 feet, with local relief as great as 70 feet.

The terraces in this type of area have rather gentle gradients, and slope both riverward and downstream. Slopes of 1^{o} to 3^{o} have been measured, which give gradients of 90 to 225 feet per mile. Slopes on the breaks between terraces are from vertical to perhaps 30 degrees, with vertical ones the youngest, and more gentle slopes the older. The longitudinal gradient of the river bottom is very slight, generally 2 or 3 feet per mile.

(2) Surface Characteristics The surfaces of the terraces may vary considerably. On the terraces nearest the river, water-worn pebbles that are subround to round (5.0-1.0) are commonly present, whereas farther from the river more angular material washing down from the mountains may predominate. In the latter case the fragments may range from angular to subangular (8.0-5.0). Sizes vary from 1/4 inch to three inches, with occasional cobbles 6 to 8 inches in diameter present or even predominating. True desert pavement is well developed on some of the higher terraces.

Where the river has swung close to the mountains, and the terrace has been cut on steep alluvial fans or bajadas, the surface may be rocky with individual rocks of boulder size (10 inches or larger). On the other hand some of the terrace surfaces are sandy with long dune ridges. These may alternate with gravel surfaces, and there may be gradations from one to the other.

c. Origin

In regions of interior drainage, each basin has its own base level of erosion, or if the cycle has progressed to maturity, and capture has occurred, then the lowest basin determines the base level of the system, whether at 3000 feet above sea level or 200 feet below.

On the other hand, sea level constitutes the base level of erosion of an area adjacent to a river that flows to the seas. Sea level fluctuated greatly during the Great Ice Age, being lower during the glacial ages when water was withdrawn from the sea to form the ice sheets and higher during the interglacial ages when the meltwater returned to the sea. Base level fluctuated accordingly, and rivers such as the Colorado alternated between erosion and aggradation. Sea level may be considered to be rising at the present time, even though some portions of the continent may likewise be rising, perhaps faster than sea level. In spite of this the topographic features resulting from movements of sea level are those brought about by lowering of sea level during the last (Wisconsin) ice age.

Along most of the rivers of the California coastal region four terraces are found, representing stillstands in the process of downcutting. Each renewed lowering of sea level (or uplift of the land) is represented by the channel cut in the material deposited during the preceding stillstand. The senior author has also noted four correlative terraces on rivers in Colombia, South America, which suggests that fluctuations of the sea level rather than local earth movements have exerted the control.

Four such terraces are recognizable along the Colorado River, and since these are the result of fluctuations of sea level, similar terracing is to be expected along all permanent rivers flowing through desert areas. It is anticipated therefore that regions bordering through-flowing rivers, with topography similar to that occurring along the Colorado River, are to be found along the Nile, Tigris, Euphrates, and Indus Rivers.

d. Vegetation

Vegetation may be exceedingly thick in the river bottom with willow (*Salix* sp.), mesquite (*Prosopis juliflora*), cottonwood trees (*Populus fremontii*), and arrowweed (*Pluchea sericea*) the predominant plants. Creosote bush may be present in scattered clumps. In some parts of the Colorado River bottom, salt-cedar or tamarisk (*Tamarix* sp.) which has been introduced, is crowding out the native growth. The natural vegetation may be 10 to 25 feet tall with the cottonwood trees rising even higher. The thickness may be so great as to make passage impossible.

The dry washes cutting through two terraces may support a fairly good growth of cat's-claw, palo verde, desert ironwood, and in places, smoke trees and creosote bush. The first three may reach 20 feet in height, but the growth is never thick enough to impede traffic.

On the terraces proper the vegetation is similar to that of other desert areas, principally scattered creosote bush, burro bush, cholla, and occasionally prickly pear. The creosote bushes are somewhat taller, perhaps 5 or 6 feet on the lowest terrace, and somewhat closer together, than on the higher ones, where they are usually not over 3 feet high and are more widely scattered. The parts covered with desert pavement are bare of growth.

e. Trafficability

Trafficability varies greatly in different parts of this type. In the river bottom it may be from 5m to 8m, depending upon how recently it has been flooded. Vegetation may make it 9v to all excepting heavy trucks capable of breaking the heavy growth.

On the terraces proper it may be 5p on the desert pavements, 6g on the gravel covered surfaces, 7s to 8s where there is dune sand, and 8r on the rocky surfaces. Washes are the greatest impediment to traffic on terraces, and regardless of surface conditions may make trafficability from 7w to 9w.

f. Color

The colors of terrace surfaces vary considerably, generally being lightest on the youngest terrace and darkest on the oldest. The lowest terrace gravels have no desert varnish as a rule, but on the older terraces desert varnish is common, becoming darker with elevation. Color observed on the next to the youngest terrace near Earp, where some desert varnish had developed, was brownish gray (5YR4/1) with individual patinated stones dusky brown (5YR2/2). On the highest terrace, the general surface color was grayish brown (5YR3/2), and individual rocks were dusky yellowish brown (10YR2/2).

g. Recently Captured Basins

Basins that have been captured in comparatively recent geologic time by tributaries of through-flowing rivers have certain characteristics that distinguish them from ordinary desert basins of interior drainage. The most obvious distinction is the lack of a playa in the captured basins. There may be playa remnants but these are undergoing dissection, and may be cut up into badlands.

If there are no playa remnants, bajadas sweep down from both sides to meet at a wash. The wash is generally marked by a greater amount of vegetation, including desert ironwood of tree size, which can be seen standing above the general level of growth. The wash connects with the river, but in many of the observed cases its gradient was so low that it was difficult to tell which direction was downstream.

8. ALLUVIAL FANS AND BAJADAS*

Probably the most striking feature of the desert landscape of the southwestern United States is the tremendous development of alluvial

* The section on Alluvial Fans and Bajadas was written by Harold L. Reade and Richard H. Merriam.

fans. While these may form under semiarid conditions, they find their greatest expression in arid regions where block-faulting has given rise to alternating basins and ranges. Here all kinds are found, from the tiny cone at the mouth of a small canyon in a newly uplifted or rejuvenated mountain range to the broad alluvial apron or bajada formed by coalesced fans (Fig. 31). In the United States only desert mountains have greater areal representation than alluvial fans and bajadas.

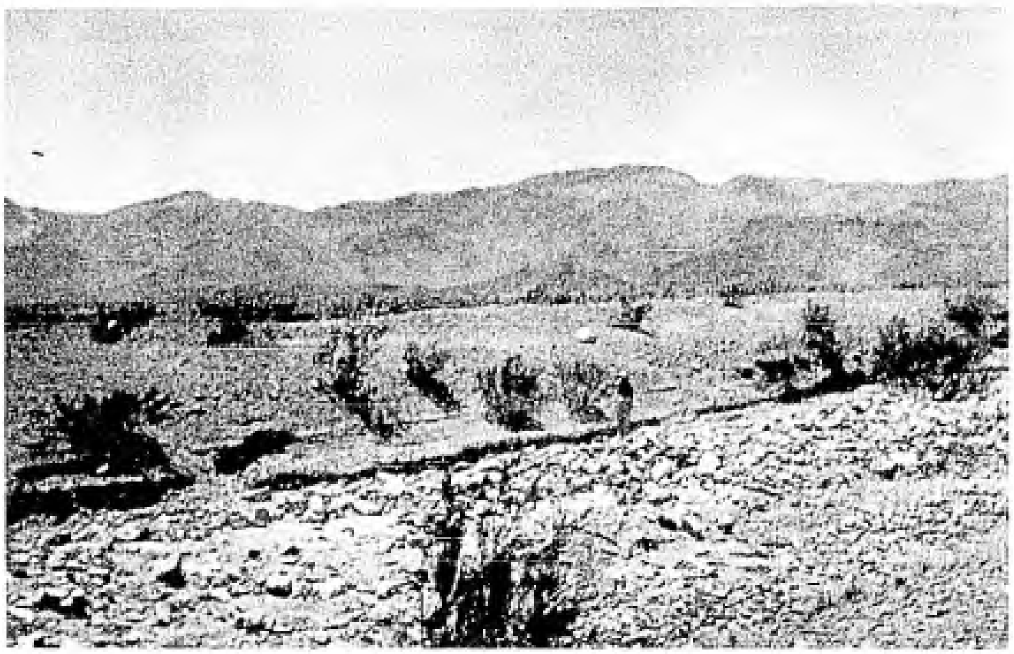

Figure 31. Bajada at foot of Argus Range, Panamint Valley. Wash in foreground.

Alluvial fans or alluvial cones are formed where sudden rushes of water from torrential rains emerge from canyons in mountains bordering desert basins, and losing velocity, quickly deposit their load of detrital material at the mountain foot. They are thus roughly analogous to a delta built at a river mouth.

The shapes of alluvial fans are somewhat variable, depending upon such factors as the configuration of the basin receiving the detritus, the proximity of other fans, and the size and position of washes. In general, however, they all are roughly triangular or fan-shaped, with the fan point or apex of the triangle at the canyon's mouth.

The sizes range from small, temporary features a few feet across to more than 10 miles in length and width. The smaller fans are commonly found at the base of recently uplifted mountains, whereas the larger fans form at the base of the larger mountains that have been less recently disturbed. The size to which a fan may grow is a function of: (1) the size of the mountain area from which it comes, (2) the stability of the mountain block, (3) the relative speed of formation, and (4) the size of the intermontane basin.

a. Distribution

Alluvial fans are particularly well developed in Death Valley, where they range from small cones along the recently uplifted southern portion of the Black Mountains on the east side of the valley to magnificent fans bordering the Panamint Mountains on the west side. In the north end of the valley, medium-sized fans mantle the lower slopes of the Grapevine Mountains, and, along the northern end of the Cottonwood Mountains, numerous fans have coalesced to form a bajada.

Large fans are also found in Panamint Valley, especially on the east side in the Amargosa Basin, and in most of the adjoining basins to the east. They may also be seen in the vicinity of Mojave, Barstow, Victorville, in Borego Valley, in the Salton Sink, and in the basins to the east.

b. Topography of alluvial fans

(1) Relief The difference in elevation between the toe of an alluvial fan and its apex may be no more than a very few tens of feet in small cones, and as much as 2,000 feet in large fans. Local relief may range from 1 or 2 feet on relatively smooth fans to 40 or 50 feet on those that are undergoing dissection by their own streams.

The smoothest fans are those derived from mountains composed of granite and related rocks or of unconsolidated sediments. Their surfaces are marked by numerous distributary channels of the temporary streams which are building the fan. These channels are rarely more than 1 or 2 feet deep (Fig. 32), and are wide, flat-bottomed features which branch and coalesce in a complex pattern. Additional irregularity is produced by sparsely distributed boulders or blocks which rise 2 or 3 feet above the general level of the surface.

The roughest fans owe their ruggedness to gullies or washes, and to numerous large boulders and blocks. The latter are usually found in fans which are comparatively steep, and those derived from hard rock that breaks into large blocks without disintegrating into fine debris. Blocks may be several feet in diameter and constitute 80 percent or more of the fan material.

Roughness due to gullies and washes occurs in the upper reaches of rapidly growing fans which are otherwise smooth. These erosional features are flat-bottomed, steep-sided channels which branch and rejoin to a

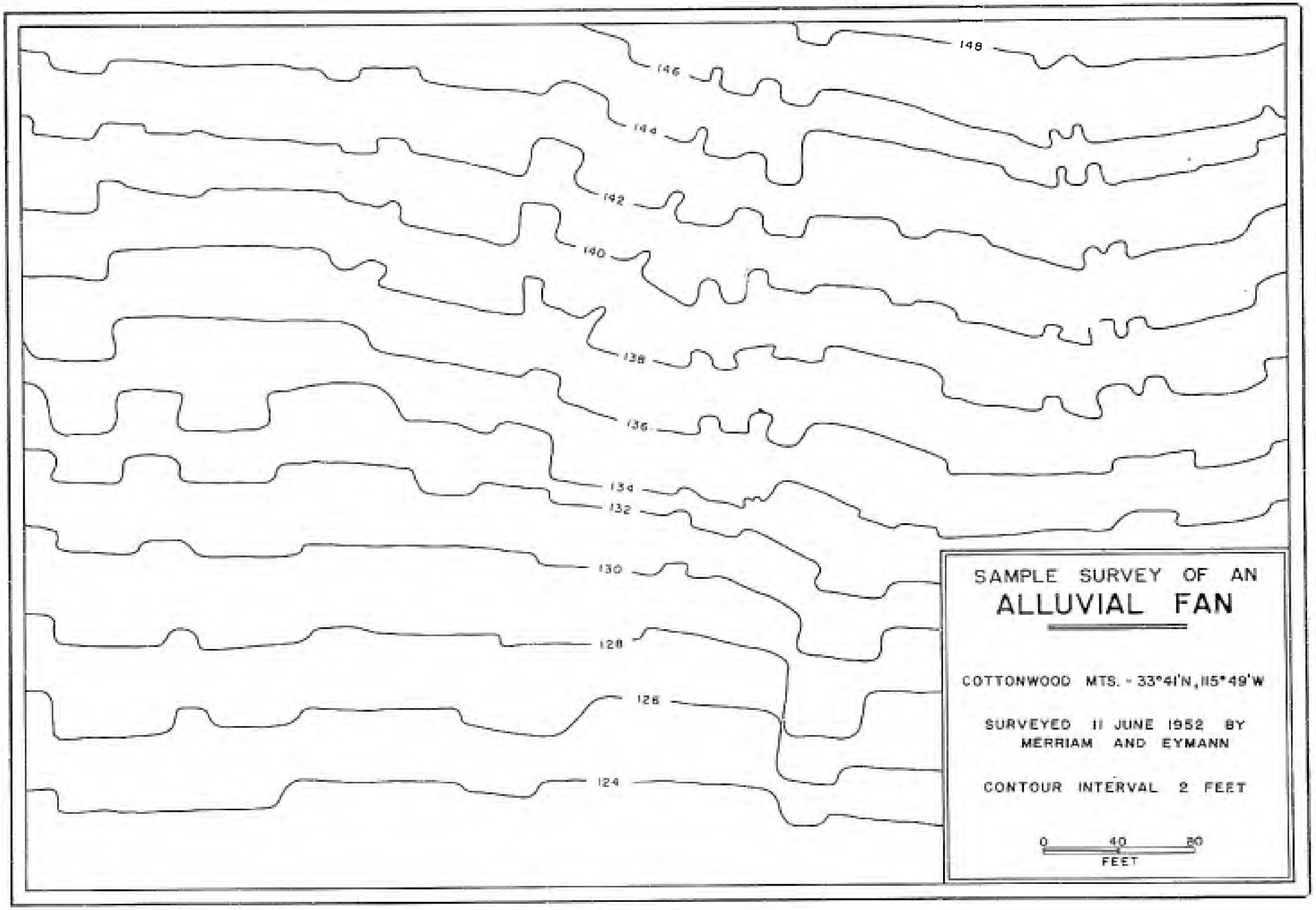

Figure 32. Sample Survey of an Alluvial Fan.

lesser extent than the distributaries of smooth fans. Some channels may be V-shaped; others may have nearly or quite vertical walls. They may be 20 to 50 feet deep, but those deeper than ten feet are uncommon.

(2) Slope The inclination of fans is generally about the same over the entire extent of any given fan, but varies from fan to fan. Generally, smaller ones are steeper and may have slopes of up to six degrees. The large fans of several square miles extent usually have a slope of 2 or 3 degrees.

(3) Composition All fans consist of fragmentary material carried down from the mountain by flash floods, sheetwash, and mudflows. Probably some of the fan building occurred during Pleistocene time, facilitated by greater annual precipitation.

The character of the fan material is in part determined by the source rocks and the manner in which they weather. In general, granitic types break down more completely so that the resulting fan is made up predominantly of fragments no larger than cobbles and mostly finer material. Material from some of the older (Tertiary) volcanic mountains acts in a similar way. In contrast is the material derived from metamorphic rocks which breaks down into blocks measuring up to a few feet across. The older, hard sediments also contribute a fair amount of coarse debris as do the younger volcanic terrains.

There is a systematic distribution of fan material according to particle size, with coarser material at the upper end and finest farthest from the apex.

c. Topography of bajadas

The properties of bajadas (also spelled bahadas) are identical with those already given for alluvial fans, with the exception of size and shape. The bajada, sometimes referred to as alluvial apron or alluvial slope, is a gently inclined surface from several miles to a few tens of miles long by a mile to a few miles wide. The slope varies from one to three degrees. They are analogous to the piedmont slopes of humid regions.

The toe may be somewhat scalloped, or it may be relatively straight, either merging with the desert flat or meeting the bajada from the opposite side of the basin in a wash. If the drainage along the wash is to a lower basin and the wash has a steep gradient, the lower edge of the bajada may be truncated by the wash and end in a cliff from a few feet to 20 or 30 feet high.

The upper edge of a bajada is very irregular, since re-entrants into the canyons mark the former apexes of fans. Between these the spurs of the intervening ridges project. Shallow depressions in the upper part of the bajada surface may still be present, marking lines where the coalescing fans met.

Since bajadas are formed in the later stages of a long period of deposition, it is quite likely that some have been disturbed by crustal movements with consequent rejuvenation of the intermittent streams. If so, the surfaces will be channeled by washes which may be cut to depths of many feet to some tens of feet.

Magnificent bajadas are widely developed in the desert regions of California, Nevada, and Arizona. They occur in most of the larger basins, where the erosion cycle has reached the stage of late youth or early maturity. Good examples are found in Death Valley along both sides of the northern part of the Cottonwood Mountains, and along the east side of the Last Chance Mountains. Excellent examples occur in Ivanpah Valley and Sacramento Valley in California, in Piute Valley in Nevada, Hualpai Valley in Arizona, and many other basins throughout the region.

d. Origin of fans

As already stated, fans are built where canyons cutting desert mountain ranges debouch into the adjacent basins. The streams, fed by the rare but torrential rains, drop the bulk of their load of detrital material at the mountain front. This is spread over the fan surface by creep, by sheetwash, by mudflows, and by the stream in its channel.

The first fans are small, steep, and cone-shaped, but with time they become larger and fan-shaped, with more gentle declivities. Most of the coarser material remains on the fan, with the largest near the apex, but the finer material is carried to the toe and spread out on the basin floor to build the desert flat. The finest particles are transported farthest of all and are deposited in the playa lake in the lowest part of the basin.

As time goes on, the mountains are worn lower and the basins are filled to a higher level. The runoff from the infrequent rains has lower velocity and lower competency, carrying smaller materials onto the fan and burying the earlier coarser material. The desert flat encroaches on the toes of the fans, which begin to coalesce to form bajadas. Fans as such may no longer exist by the time late youth is reached, although they may persist into maturity, particularly in the lower, pirate basin.

Rejuvenation may occur, of course, at any time, as the result of renewed uplift of the mountain range. The streams erode with renewed vigor, and cut new and deeper channels in the upper part of the fan, spreading both new material from the mountains and reworked fan deposits over the lower part.

The older part of the fan now becomes a "dead" fan, the material on its surface no longer moving downward. The finer particles are swept away by the wind, and the rock fragments are left to form a desert pavement, gradually darkening with desert varnish. It is a common sight in some basins to see two or three different shades of brown on a fan surface, with the much lighter live portion cutting across them all.

e. Vegetation

Growth on fans is not greatly different from that on desert flats, as a general rule. The commonest plants, as on the latter, are creosote bush and burro bush. The former is generally more luxuriant on large fans than it is on desert flats, since it receives more surface water, and may grow to 8 or 10 feet in height and the same in diameter. Where two fans meet laterally, the plants may be only a few feet apart, but on the rest of the fan a spacing of 20 to 30 feet apart is common. On the smaller fans the creosote bush may be only 2 or 3 feet in height.

Cholla, cottontop cactus, and prickly pear probably are more prevalent on fans than on the flats, and Mormon tea, buckwheat, and spiny abrojo are common. On fans at elevations of 3,000 to 4,000 feet, Joshua trees may be sufficiently abundant to constitute "forests". These trees, together with other species of Yucca, may cover as much as 75 percent of the ground surface. Near the foot of the higher mountains, especially those bordering the desert on the west, juniper occurs on the upper slopes of the fans. This usually is at 4,000 feet or more. Ocotillo and cat's-claw are found on some of the fans in the southern part of the area, and in Arizona. In the latter state they are accompanied by the saguaro.

f. Trafficability

Trafficability is determined largely by the degree of roughness of the fan, although the kind of surface and degree of slope also are factors. Young fans are not as likely to be dissected, but are steeper than older fans, and the surface material may be loosely compacted, so that heavier vehicles sink in. Trafficability is 6g to 7gw or 7sw with penetration at 18 to 50 lb., and 5 inches at 150 lb. Going up the fan, trafficability is 6/g to 7/s or 7/g.

On the older fans, and particularly those that have been rejuvenated, washes make travel more difficult, and as the upper portions are reached, boulders and blocks also impede traffic. In travelling across such fans it is necessary to work back and forth, following washes until they become too constricted for further progress, and then to climb out and follow down the surface between washes until blocked by another wash. On one occasion, it took the senior author and his party 4 hours by jeep to travel 7 miles across the lower portion of a large fan.

On the upper ends the deeper cuts and the boulders make travel across the fans impossible, trafficability being 9bw. However, it may be possible to travel either upslope or down if boulders are not too thick; trafficability is then from 6r to 7r or 7/r. On the occasional stretches of desert pavement found on rejuvenated fans, trafficability is 5p, with surface penetration only at 150 lb. Unfortunately, these pavements are generally disconnected.

In travelling over fans the following rules should be observed: (1) travel downslope as much as possible; (2) travel parallel to distributaries, rather than across them; (3) avoid the upper portions which are apt to be covered with large blocks and cut by deep gullies; and (4) avoid excessively sandy terrain, which may occur on the lower reaches of the fan.

g. Color

Surface colors vary through a rather limited range. The soil color depends largely upon the type of source rock. The commonest colors are grayish orange pink (5YR7/2), pale yellowish brown (10YR6/2), very pale orange (10YR8/2), and grayish orange (10YR7/4). Colors below the surface are generally slightly darker. For instance, on a fan with a surface color of very pale orange (10YR8/2), the fresh soil was a grayish orange (10YR7/4). Where desert pavement is present, however, the subsoil is nearly always lighter in color than the patinated surface gravels.

9. DUNES*

One of the minor desert types in the Colorado and Mojave Deserts is the dune. A dune consists of a mound or hill of wind-blown materials ranging in size from clay to coarse sand. The majority of the dunes consist of sand. Within the deserts of southwestern United States there are approximately 100 dune areas that together cover somewhat less than one percent of the desert region. Dunes, for the purpose of this report, have been divided into the following two types: (1) complex sand dunes, generally consisting of intersecting transverse dunes, and (2) isolated

* The section on dunes was written by James Eymann

dunes that vary in size from an acre to several square miles.

a. Distribution

Dunes of the complex type entirely blanket an area. Important locations of complex dunes include the Yuma Sand Hills or Algodones Dunes, south and east of the Salton Sea (Fig. 33); the Devil's Playground south of Baker; the dune area in Death Valley north of Stovepipe Wells; the area south of Rice; the dunes near Salt Springs north of Baker; the dunes at the north end of Panamint Dry Lake; and Dune Mountain southwest of Beatty, Nevada.

Figure 33. Yuma dune area, near Sandy Point Maintenance Station.

Areas of isolated dunes differ from the complex type in that the entire area is not covered with dunes, but consists of dunes separated by desert flat. Occasionally two or three dunes occur together. These isolated dunes may be any one or a combination of the following types: barchan, longitudinal, transverse, climbing, falling, or sand shadow dune. A special variety called a "fixed dune" results when a dune becomes covered with vegetation. Some of the areas of isolated dunes include the barchans at Clark Dry Lake (Fig. 34), the longitudinal dunes at Superstition Mountains west of Brawley, the transverse dunes at Newberry Springs, the area to the northeast of Rosamond Dry Lake, the Whitewater Creek area north of Palm Springs, the climbing and falling dunes at Cronise, Melville, Emerson, Jean, and Troy Dry Lakes, and the small shadow dunes that commonly occur around the margins of playas.

Figure 34. Barchan dune. Clark Dry Lake, Borego Valley, California.

b. Topography

(1) Complex Dune Areas The large complex dune areas display typical "peak and fuljis" topography (Fig. 35). This type of topography results when one barchan encroaches on another in such a way that the tips of one join with the foot or windward side of the leeward dune. Thus, a hilly surface is formed consisting of small isolated peaks followed to the leeward by fuljis or depressions. Some of the depressions are 50 to 60 feet in diameter and 5 to 15 feet deep. The overall slope of these hills in the Yuma Sand Hills is about 15 degrees, with the windward slope of individual peaks being somewhat greater, about 19 degrees. On the lee side, or slip face of individual dunes, slopes are approximately 32 degrees.

The dune area selected as the type for the present study, the Yuma Sand Hills, is the most spectacular within the Colorado and Mojave Deserts. The dunes extend from the south end of the Salton Sea along the east side of the Imperial Valley into Mexico, a distance of 50 miles. This region is from 4 to 7 miles wide, rises above the desert flat 250 feet, and covers approximately 250 square miles.

(2) Isolated Dune Areas Dunes of the isolated type vary in size. The larger ones, generally transverse dunes or barchans, have the following approximate dimensions: height, 20 to 30 feet; width, 100 to 150 feet; and length, 100 to 300 feet. An average small turret dune or sand shadow is about 3 feet high, 2 to 3 feet wide, and several feet long.

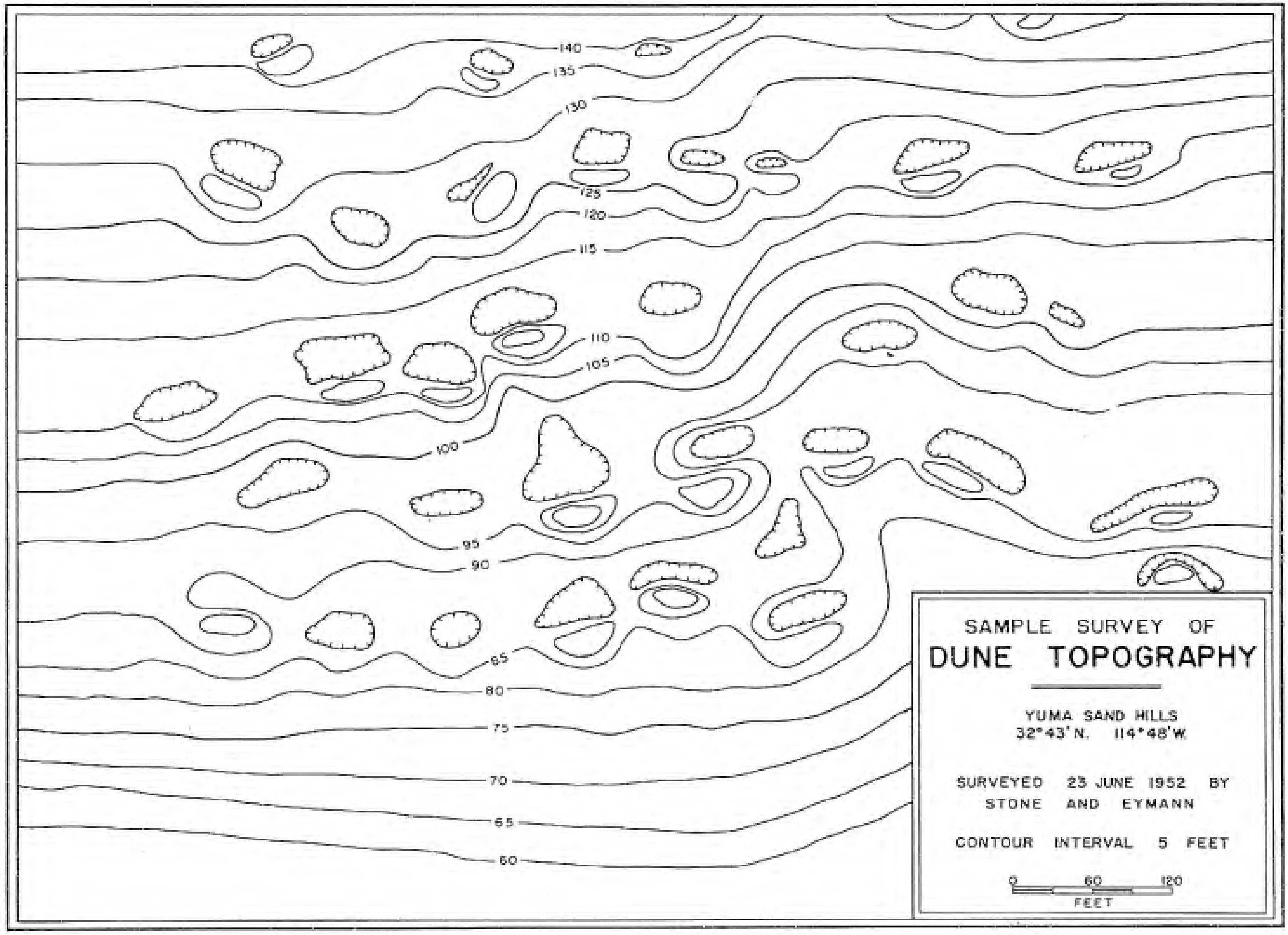

Figure 35. Sample survey of Dune Topography.

The dimensions of a typical longitudinal dune are: height, 10 to 30 feet; width, 60 to 150 feet; and length, 1,000 to 4,000 feet. The climbing and falling dunes that form on mountain slopes vary widely in size, and range in thickness from a few inches to several feet. They may climb to elevations of several hundred feet above the desert floor.

The general topography of isolated dune areas is that of knobs superimposed upon a relatively flat area, or in the case of longitudinal dunes, long, parallel sinuous ridges separated by areas of desert flat. The dunes themselves, except for the climbing and falling types, have a convex windward side with a slope of 19 to 20 degrees and a steep leeward side or slip face with a slope of about 32 degrees. The slopes of the climbing and falling dunes are usually those of the surfaces they ascend or descend.

c. Composition

The material comprising most dunes, whether isolated or complex, consists of frosted sand grains that are round to subround. Small dunes that commonly occur around playas where fine material is available for transportation by the wind consist of clay-silt material.

The minerals making up the bulk of the sand are quartz, feldspar, and mica; clay minerals and silt-sized quartz and mica make up the clay-silt dunes. Gypsum dunes occur near Mesquite Dry Lake northwest of Jean, Nevada, and calcareous dunes are found in Death Valley. Mechanical analyses of some dune materials are given in Figure 36.

d. Origin

Dunes form when there is a source of material finer than 2 mm. in diameter, a recurrent wind strong enough to move the material, and a place where the material can accumulate (Hack[28]).

The main sources of dune material are stream washes, arroyos, rivers, outcrops of sandstone, alluvial fans, and playas. Bagnold[3] has shown that a velocity of 23 mph is needed before the wind becomes visibly charged with material. Winds of this velocity occur frequently throughout the desert, particularly in the fall and spring. Places of accumulation include bushes, mountains, rocks, and other obstacles; however, dunes may form in the open desert free of vegetation or other obstructions. In the Colorado and Mojave Deserts dunes can be found along intermittent stream courses, around the margins of playas, on mountain slopes, behind vegetation, and on bare desert flats; the barchans of Kane Springs are good examples of this last type. Dunes may also form where the configuration of the mountains causes wind eddies.

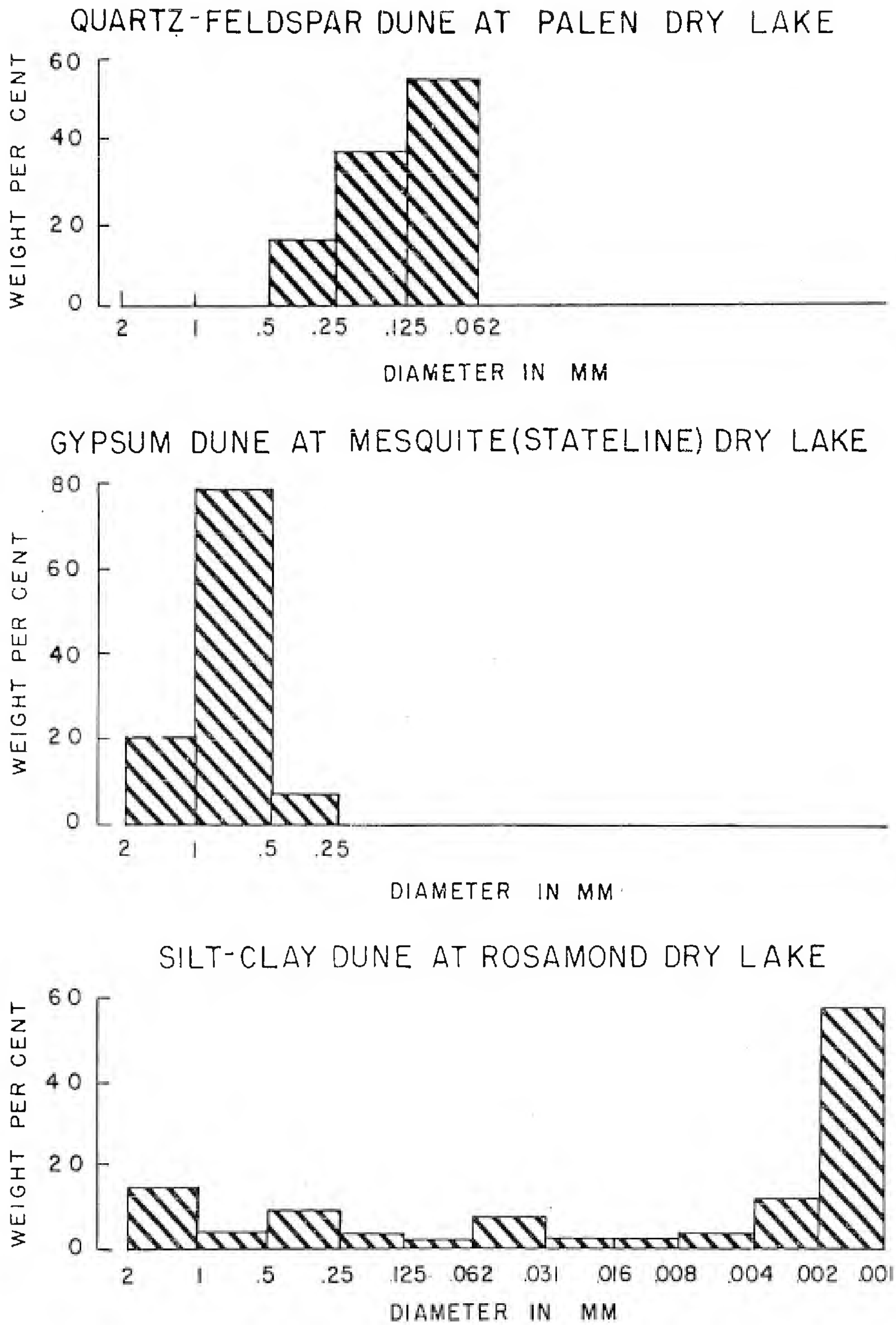

Figure 36. Histograms of sand dunes related to playas.

The type of dune that will form (i.e., whether transverse, barchan, longitudinal, or complex) is dependent upon the amount of material available, the strength and frequency of the wind, the wind direction, the topography, and the vegetation. Types of dunes and the conditions necessary for their formation, are:

Barchan--unidirectional wind, small sand supply, moderate wind velocity.

Transverse--unidirectional wind, large sand supply, moderate wind velocity.

Longitudinal--variable wind direction, large supply of sand, strong wind velocity.

Climbing--any amount of sand, variable wind direction, moderate wind velocity, appropriate topography.

Falling--same as for climbing dune.

Sand Shadow--variable wind direction, small sand supply, moderate wind velocity, vegetation.

Fixed--any of the above types with sufficient growth of vegetation to keep them fixed or stationary; not common in desert areas.

Complex--variable wind direction, an extremely large sand supply, strong wind velocity.

In the desert where physical weathering predominates, material of various sizes is carried by streams into washes and onto alluvial fans, desert flats, and playas. Fine material less than 2 mm. in diameter is available for transportation by the wind, accomplished by saltation, creep, or suspension. Most of the material carried by the wind moves within six feet of the ground, and 90 percent within the lowest 18 inches (Bagnold [3]). This material is carried along until a drop in wind velocity occurs, when it is deposited.

Once a dune is formed, the sand is moved from the windward side onto the slip face where it is trapped. Here the sand is piled until the angle of repose is exceeded and the sand grains become dislodged and flow under the influence of gravity down the slip face. In this way a dune migrates.

e. Vegetation

(1) Complex Dunes The complex areas contain very little vegetation. Growth on the Yuma Sand Hills, except in early spring, covers less than 1 percent of the surface area. The vegetation that does occur is found on the lower slopes of the sand hills in clumps generally 30 feet apart. Some of the more common types found on the Yuma Sand Hills are the creosote bush, Mormon tea, Indian rice (*Oryzopsis hymenoides*), sand cress (*Calyptridium monandrum*), desert buckwheat (*Eriogonum deserticola*) and small-seeded sand mat (*Euphorbia polycarpa*).

(2) Isolated Dunes Dunes of the isolated type have a coverage of vegetation varying from zero to 100 percent. The average is perhaps 20 percent, only the fixed dunes being well covered. Common plants found on these dunes are saltbush, creosote bush, Russian thistle (*Salsola kali tenuifolia*), mesquite, Fremont thornbush (*Lycium fremontii*), Thurber sandpaper plant (*Petalonyx thurberi*), *Ephedra* sp., and plicate coldenia (*Coldenia plicata*).

f. Trafficability

Trafficability over dune areas is generally poor to impassable, ranging from 7s to 9s. Particularly difficult areas occur on the windward side immediately adjacent to the slip face, and on the slip face itself. Here the sand acts as a "dry quicksand" and a person readily sinks into the sand a foot or more. In general the surface is firmer on the windward side, but even there dry quicksands may be encountered. This difference in surface conditions between the windward side and slip face is due to the method of deposition of the sand grains. Sand on the windward side is packed into place by saltation, whereas on the slip face the grains shear and roll downhill under the influence of gravity and packing is haphazard. When weight is applied to this latter type of deposit the sand grains tend to repack into a smaller volume. This results in a person sinking farther into the sand on the slip face than on the normal windward surface. The occurrence of dry quicksand on the windward side results only when a thin accretion layer overlies the pre-existing slip faces. It is impossible to locate these areas except by walking over the dune. When ascending a dune it is best to go up the windward side where the slope is less steep and the surface is firmer. It is very difficult to ascend the slip face since any slight disturbance causes the sand to flow down the slope.

(1) Complex Dunes The trafficability in this type of area is very poor, 8s to 9s, as the entire area consists of loose sand. When traveling over a complex dune area it is best to avoid the slip faces

and fuljis. Generally it is possible to walk on the windward surfaces between individual dunes, thus avoiding the more treacherous areas. These large dune areas should be avoided if possible. Penetrometer tests showed surface penetration at 7 to 12 lb., and 36 inches at 60 lb. in some places, and only 6 to 8 inches at 215 to 140 lb. in others.

(2) Isolated Dunes The trafficability through an isolated dune area is generally good to fair, 6s to 7s, because it is possible to bypass individual dunes. However, occasional sand sheets between dunes reduces trafficability to 8s. Where dunes are covered with vegetation the surface is firm but trouble may be encountered in traversing such a dune because of vegetation, particularly if it is mesquite which has sharp thorns. On free-moving dunes the trafficability is poor as the surface consists of loose sand. Penetrability tests show surface penetration at 5 lb. to 7 lb.; 75 lb. for the first 20 inches, 60 lb. for the next 10 inches, 38 lb. for the next 6 inches, which was the limit of the penetrometer.

g. Color

The range of colors observed in dune sands is very limited, the two commonly recorded being grayish orange (10YR7/4) and yellowish gray (5Y7/2). The calcareous dunes at the northwestern end of Mesquite Flat in Death Valley have a large percentage of light-colored travertine, and are a very pale yellowish brown (10YR7/2).

Ordinarily, vegetation is so meager on dunes that the color of the bare dunes is unaffected. However, mesquite may cover the tops of some dunes, as in Death Valley and west of Salton Sea. These are dark greenish yellow in summer (10Y6/6), and may give a general tone to the area of light olive gray (5Y5/2).

10. DRY WASHES *

The general sparseness of rainfall and its torrential nature in arid regions cause most of the streams to be intermittent or ephemeral. The stream courses contain water during and shortly after heavy rainstorms, and are dry the remainder of the time. These dry drainage channels are one of the most characteristic physiographic features of arid regions. In North America they are referred to by a wide variety of terms including dry washes, arroyos, washes, gullies, canyons, and coulees. They are known as wadi in the Sahara, as chapp in the Gobi, and laagte in the Kalahari.

* The section on dry washes was written by R. O. Stone.

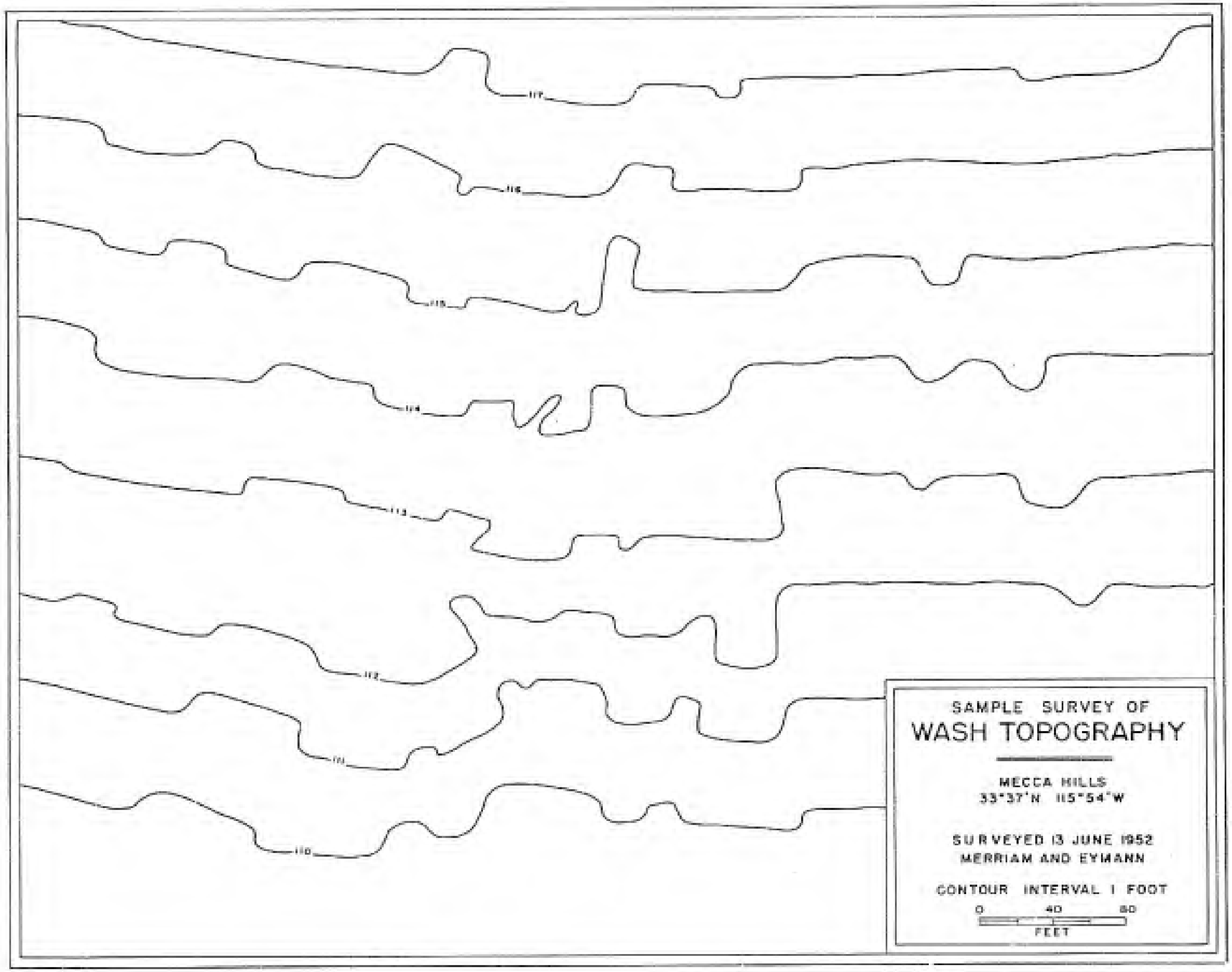

Figure 37. Sample survey of a desert wash.

a. Topography

The bed of a dry wash exhibits little relief (Fig. 37). It is a flat, almost smooth surface broken only here and there by small depressions and gentle rises. Generally the larger dry washes are bounded by cliffs that may be as much as a hundred feet in height, but are commonly from 20 to 40 feet high. These nearly vertical cliffs are the most pronounced relief features associated with dry washes (Fig. 38).

Figure 38. Aerial view of dry wash. Chocolate Mountains, California.

The slope of a dry wash varies widely along its length. At its head in the mountain areas the wash has slopes that approach that of the mountain itself, 30 or more degrees. Once the wash leaves the mountain area and crosses the bordering fans the slope drops abruptly to an average of two or three degrees. On desert flats, washes have a slope of one degree or less.

The surface of a dry wash is made up largely of sand or of sand and gravel. Mixed with the sand and on the surface are numerous pebbles, cobbles, and in some instances boulders. The larger fragments show the effects of stream transportation and are subangular to round (7.0 to 2.5). There is a decided tendency for the sorting of the surface material and the roundness of fragments to decrease towards the head of a dry wash, so that near the mountain front the surface of the wash may be covered with huge angular boulders.

b. Origin

Nearly all desert streams are consequent, that is, they simply flow down pre-existing slopes. Hence, the primary geologic control in the formation of dry washes is gradient. Sometimes streams follow zones of weakness such as faults, formation contacts, or zones of softer rocks, but this is unusual. The conditions necessary for the formation of dry washes are, therefore, precipitation and gradient.

c. Distribution

Dry washes are such widespread features of the desert that it is impossible to list specific areas where they are shown to better advantage than others. The bed of the Mohave River, which originates in the streams flowing down the easterly slopes of the San Gabriel and San Bernardino Mountains on the western margin of the Mojave Desert, and flows past Victorville, Barstow, and Daggett to finally lose itself in Soda Lake near Baker, is probably the largest wash in the desert region.

Many large washes lead down to the Colorado River, and smaller ones are found in every desert basin. They occur on alluvial fans and bajadas, they cross desert flats, and shallow ones cut playa surfaces. They are of all sizes from over a mile in width to a foot or two, and vary in depth from 100 feet or more to a few inches. Wherever flowing water becomes channelized a wash is formed.

d. Vegetation

Owing to the greater abundance of water along dry stream channels and the relatively shallow depth to the water table in these areas, a very distinctive group of plants grows along the courses of dry washes. Most of the trees found in desert areas occur in or near dry washes. Some of the more important ones are cat's-claw, palo verde, mesquite, desert ironwood, desert willow (*Chilopsis linearis*), cottonwood, and in the area surrounding the Salton Sink the washingtonia palm (*Washingtonia filifera*). Smoke trees are found in the washes in the Colorado and Sonoran Deserts.

Among the bushes and grasses that are commonly found along the sandy margins of dry washes are arrowweed, buckwheat, rabbit bush, desert holly (*Atriplex hymenelytra*), wire grass (*Juncus balticus*), and salt grass (*Distichlis spicata*).

e. Trafficability

Dry washes are easily traversed either on foot or by vehicles with four-wheel drive. The smooth even floors, almost free of obstacles, and the generally gentle gradients make an easy surface to travel upon. Yet, with ordinary vehicles dry washes may be next to impassable. Probably more vehicles become stuck in the sands of dry washes than in any other type of desert area.

The only obstructions to travel in a dry wash are the easily avoided trees and bushes and the cobbles and boulders that are found in and along the wash. The latter may make the upper portions of a wash impassable.

Penetrometer readings taken in dry washes showed surface penetration at 20 to 50 lb., and from 4 to 10 inches at 150 lb. The rating on the trafficability scale is 6sg to 8sg, and 5s immediately following a rain. Near canyon mouths, however, it may be 9/b.

f. Color

The color of the surface of a dry wash varies slightly with the predominant type of rock that is contributing detritus to the stream, but almost without exception the colors are light. The most common colors are very pale brown (5YR6/2), yellowish gray (5YR7/2), or very light gray (N8). The freshly excavated surface of a dry wash is the same color as or slightly darker than the surface material, unless wet. When the subsurface material is exposed a few days after a rain, it is considerably darker, a result of the wetting of the sand grains.

11. BADLANDS*

Extremely rough terrain, formed by the intricate dissection of soft rocks by torrential run-off characteristic of desert areas, is called badlands. Slopes are steep, and the narrow drainage channels generally wind in and out in a sinuous manner. Ridges between are narrow, and may be flat-topped or knife-edged, depending upon the degree of development of the feature (Fig. 39).

Figure 39. Badlands at Zabriskie Point, Death Valley.

If the washes are somewhat wider and flat-bottomed, and if the ridges between the winding channels are rounded, the terrain is spoken of as subdued badlands (Fig. 40).

a. Topography

As the name implies, badlands are distinguished by their rough, dissected surfaces. The relief varies from about 20 feet

* The section on badlands was written by R. H. Merriam and T. Clements.

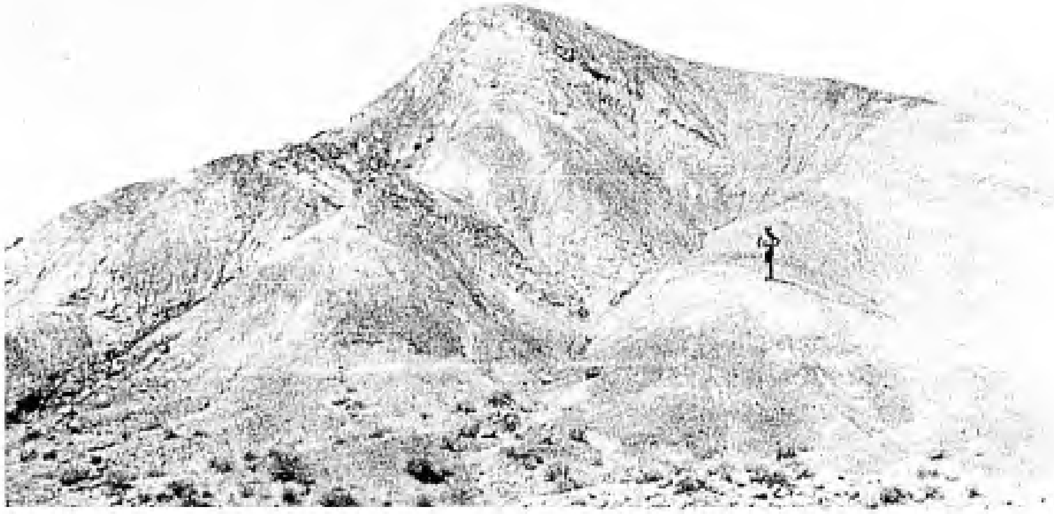

Figure 40. Subdued badlands. Calico Mountains, California.

to 200 feet (Fig. 41), although it is usually less than 100 feet and in subdued badlands generally less than 50 feet. Each particular locality is dominated by a rather narrow range of elevations.

Slopes are as steep as or steeper than in any other desert type. Vertical to nearly vertical cliffs are common, and occasionally they may even overhang. However, slopes may be as low as 45 degrees, and in the subdued type even lower. The drainage channels that cut up the area in such an intricate manner are narrow and slot-like, or very sharply V-shaped. The main channels may be flat-bottomed, and in the subdued badlands they may be quite broad.

Since badlands so commonly are developed on recently deposited flat-lying materials, the ridges between erosion channels may be flat-topped where the original surface has not been entirely destroyed, and often are capped with desert pavement. Otherwise the ridges are knife-edged and tend to be sinuous, although less so than the channels. The ridges frequently develop saddles where erosion has cut farther into the base of the ridge at one place than another. In subdued badlands the ridges are rounded.

The surface materials are generally clay, silt, and very fine sand. However, gravel may be present, both on the desert pavement remnants and in the erosion channels. Rock fragments may be scattered throughout the material from which the badlands have been cut, and may mantle parts of the ridges as residual accumulations. These too may be scattered over the bottoms of the washes. They are seldom larger than pebbles in size, although boulders may be present. The rock fragments of all sizes tend

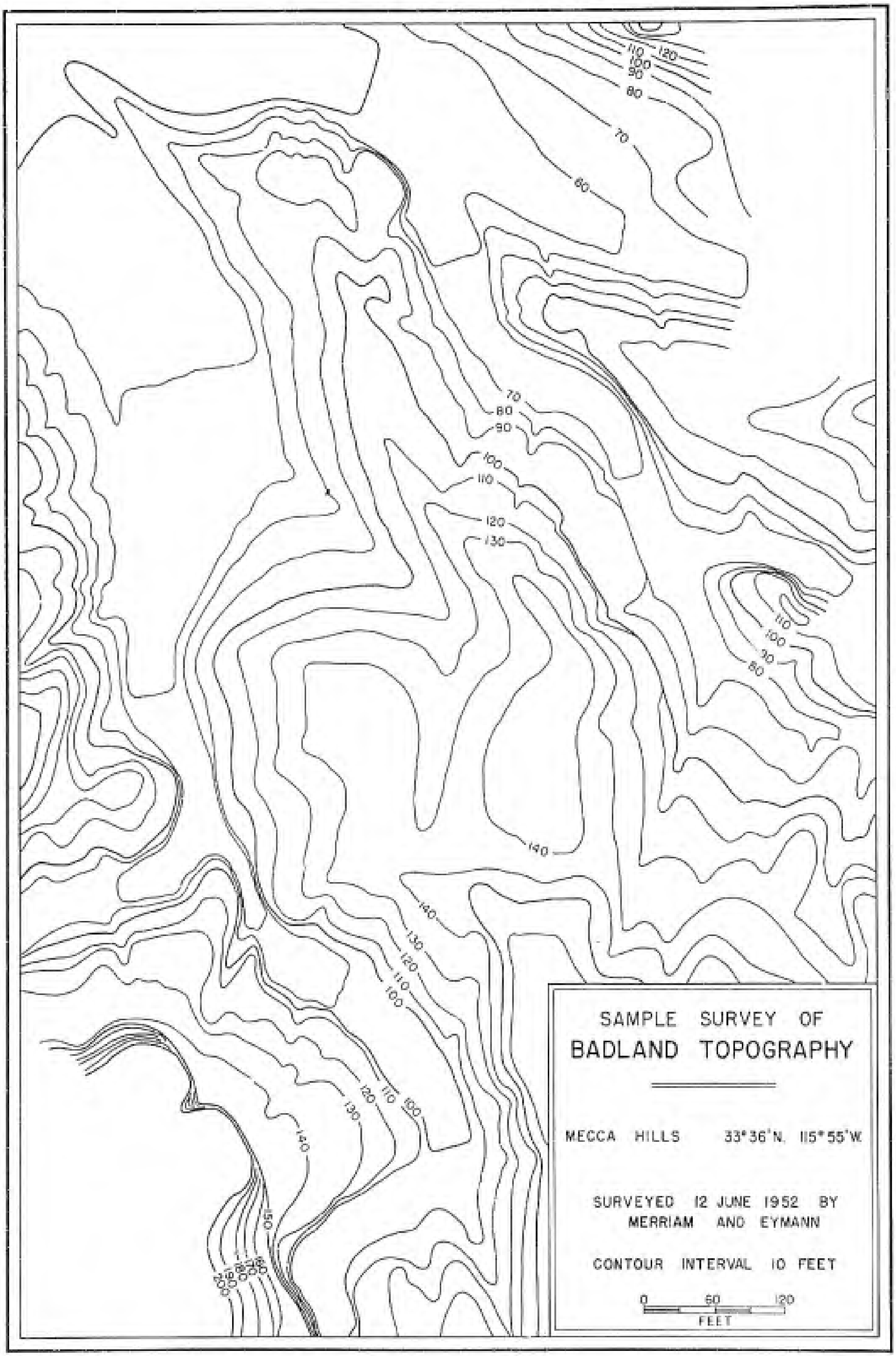

Figure 41. Sample survey of badland topography.

to be angular to subangular (7.5 - 5.0).

b. Origin

Badlands may form wherever a deposit of soft or slightly consolidated material such as Pleistocene lake sediments, volcanic ash, or fine-grained river deposits are subjected to erosion by torrential but infrequent rains. They are not limited to desert areas, but are fairly common in semiarid regions as well. If rains become too frequent or prolonged, however, the materials become thoroughly soaked and can no longer maintain the steep slopes characteristic of badlands. Slumping occurs, and a much more subdued type of topography results.

Badlands are most likely to develop on soft, flat-lying sediments, but unconsolidated massive material may also lend itself to badland formation. In the desert area under study they have developed most frequently in lake sediments.

c. Distribution

Badlands are not of great areal extent, but are rather widely distributed in the Mojave and Colorado Deserts. The type area is east of Mecca, California, where the Mecca wash has cut through tilted lake beds of late Cenozoic age. The San Felipe badlands occur west of the Salton Sea, and an excellent example is found at Zabriskie Point in Death Valley. Subdued badlands occur between Shoshone and Tecopa, near Afton, a few miles northwest of Barstow, and in the Orocopia Mountains.

d. Vegetation

Practically no vegetation grows in badlands, excepting on the remnant of the original surface. This is the typical desert growth, dominated by creosote bush. On the subdued badlands there generally is somewhat more vegetation, although it tends to be confined to the washes.

e. Trafficability

As the name implies, badlands are areas difficult to traverse. Trafficability generally is 9bd or 9/. Washes draining badlands may be traveled for short distances, but are generally too crooked and narrow for a vehicle. They also may be blocked by dry waterfalls.

Flat erosion remnants may have high trafficability, but are generally discontinuous, and the ridges between are too narrow and sharp-edged for an automobile of any type. Rarely a large wash may pass entirely through an area of badlands, making it possible to traverse them.

Trafficability in subdued badlands may be 7s to 8sw or 8/s. Penetrometer tests were not made in badlands, since trafficability is a function of the topography rather than strength of the surface.

f. Colors

The colors of badlands depend entirely upon the type of material from which they are cut, and, therefore, are quite variable.

12. VOLCANIC CONES AND FIELDS*

Volcanic cones and fields represented in this area are generally so young that they retain nearly all their original surface features. Included are Recent and late Pleistocene cinder cones, lava flows, and cinder fields. Although strictly accidents so far as their occurrence in deserts is concerned and not of great importance from the point of view of percentage of area covered, volcanics nevertheless are found in most deserts, and present problems peculiarly their own.

a. Topography

Most volcanic areas consist of a cone, or a cone and cinder field, or a cone and lava flow. In a few cases small extrusions of lava were observed without obvious cones, although in every case examined, crater-like depressions were found that probably were the vents from which the lava had come.

The cones seldom have a height of more than a very few hundred feet and they may be lower. Since most cones are composed largely of loose material ejected from the volcano, the slope of the cone is determined by the angle of repose of the constituent material. This is generally about 30 degrees. The individual cinders or pieces of scoria making up the cone range in size from 1/4 inch to blocks that may be several feet in maximum dimension, with all gradations in between.

The lava flows commonly have highly irregular surfaces, conforming somewhat to the contour of the land on which the lava was poured out, but owing most of their irregularities to the peculiar nature of lava itself. Pressure ridges 10 to 20 feet high mark the surface at frequent but irregular intervals, and the crests of the ridges may be broken by deep fractures.

Loose blocks, developed as the flow continued to move after partial

* The section on volcanic cones and fields was written by R. H. Merriam and T. Clements.

consolidation, are piled up here and there, with individual blocks several feet across. Many flows are traversed by lava tubes, tunnel-like structures with diameters of 10 or 20 feet. These are discontinuous, due to collapse of the roof at frequent intervals. Such collapses form large, vertically walled pits.

b. Origin

During the Pleistocene or Great Ice Age, vulcanism was particularly active in many parts of the earth, and in some regions the activity continued into the Recent. This is true in New Mexico, where a flow is known to have occurred after the passage of some of the early Spanish explorers, and in Arizona, where Sunset Crater has been dated as about 1200 A.D. on the basis of tree rings. In other parts of the southwest desert region, fresh cinder cones and lava flows occur in various localities, dating from perhaps two or three hundred to one or two thousand years ago. These are superimposed upon the desert topography and have had little time to be affected by the desert environment.

Late Pleistocene cones and flows occur in many parts of the desert. These were here before the beginning of desert conditions, and have been considerably affected by both the late Pleistocene and the Recent climates. The cones have been appreciably eroded and the roughness of the original surface modified to some extent (Fig. 42). In some cases shore lines have been cut upon the lavas by lakes present during the last part of the Pleistocene. The lava blocks of both cones and flows show polishing by wind-blown sand.

c. Distribution

Probably the best known and most typical cones and lava flows in the California desert are the Amboy (or Bagdad) flow near Amboy, and the Pisgah flow west of Ludlow, both on U. S. Highway 66. Almost as well known are the Ubehebe Craters and cinder field in Death Valley. All of these are considered to be Recent by the senior author of this report. Other Recent cinder cones occur in the south end of Owens Valley, at the edge of the Amargosa Basin southeast of Beatty, and a spectacular group of cones and flows in the Devil's Playground east of Baker.

Late Pleistocene cones and flows are located in the southern part of Death Valley and along both sides of the north end; along the road from Furnace Creek Ranch to Death Valley Junction; in Panamint Valley and Indian Wells Valley; and in the south end of Owens Valley. Large areas occur near Newberry, and cones and flows probably of Pleistocene age are found in the Sonoran Desert of Arizona.

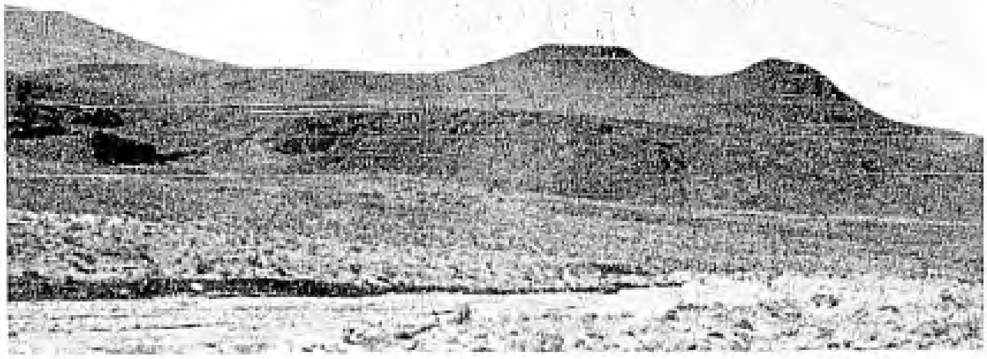

Figure 42. Volcanic terrain. Cinder cones west of Death Valley Junction.

d. Vegetation

Vegetation is virtually absent from the Recent cones and is scarce on the flows, although here and there creosote bush has established itself. Where wind-blown sand has accumulated in depressions, other common desert shrubs may be found. The Ubehebe cinder cones and cinder field in Death Valley support a rather luxuriant growth of desert holly. The Pleistocene flows generally maintain a fair growth of the desert plants characteristic of the particular area in which they are located.

e. Trafficability

Travel is difficult across lava flows because of the irregular blocks, pressure ridges, and the generally uneven surface (Fig. 43). Trafficability is 7rw to 8rw as a rule, with some parts definitely 9. If care is taken in picking the route it is possible to negotiate most parts of a lava flow in a jeep, although the jagged edges of the broken basalt are likely to cut the tires badly. Penetrability tests are no indication of trafficability on this type of surface.

In cinder fields travel is easier, although the loose packing of the cinders tends to bog down an ordinary passenger car. Trafficability is 7g to 8g. Penetrometer tests show surface penetration at 14 lb., 4 inches at 70 lb., and 6 inches at 150 lb.

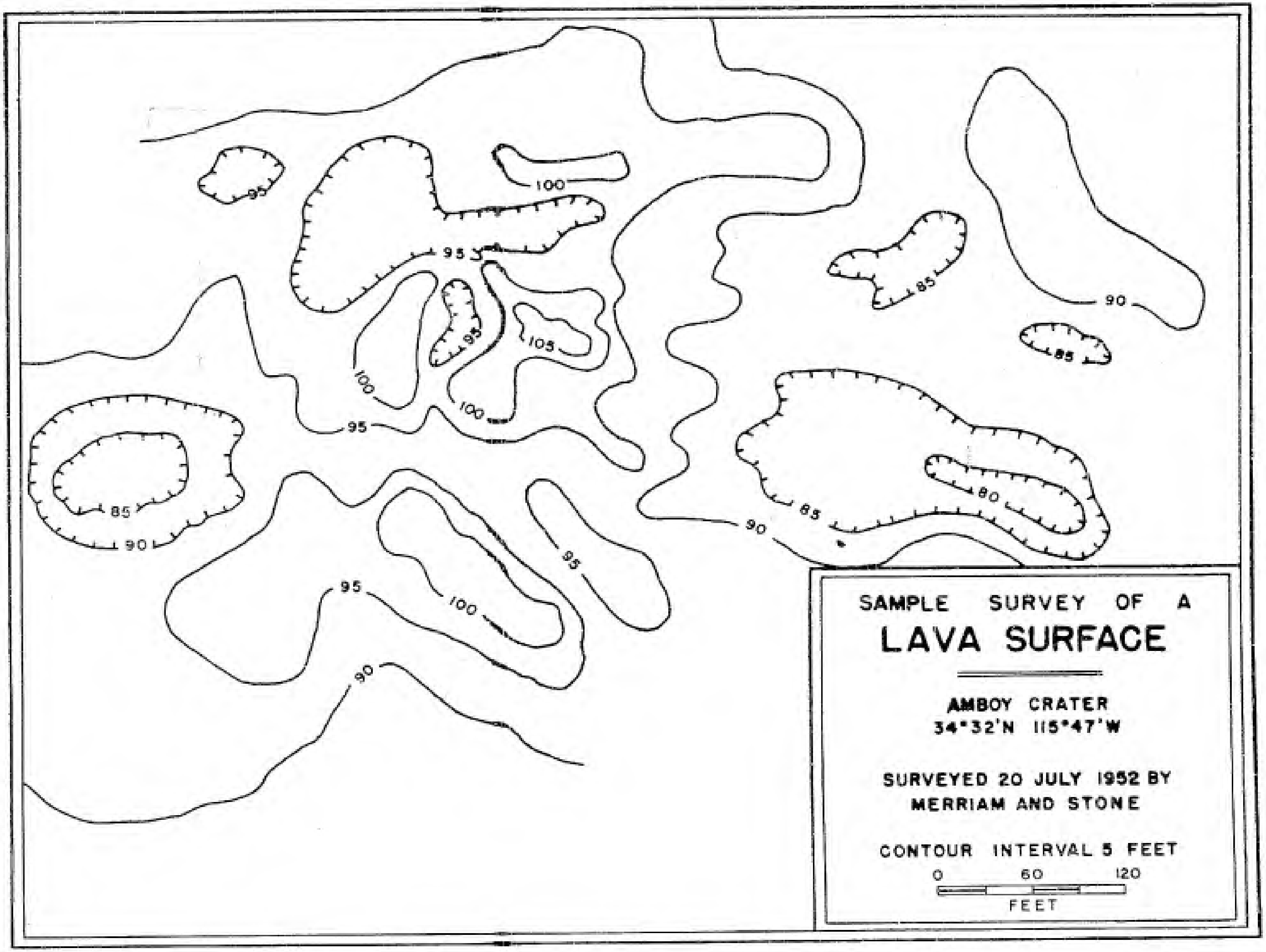

Figure 43. Sample Survey of a Lava Surface.

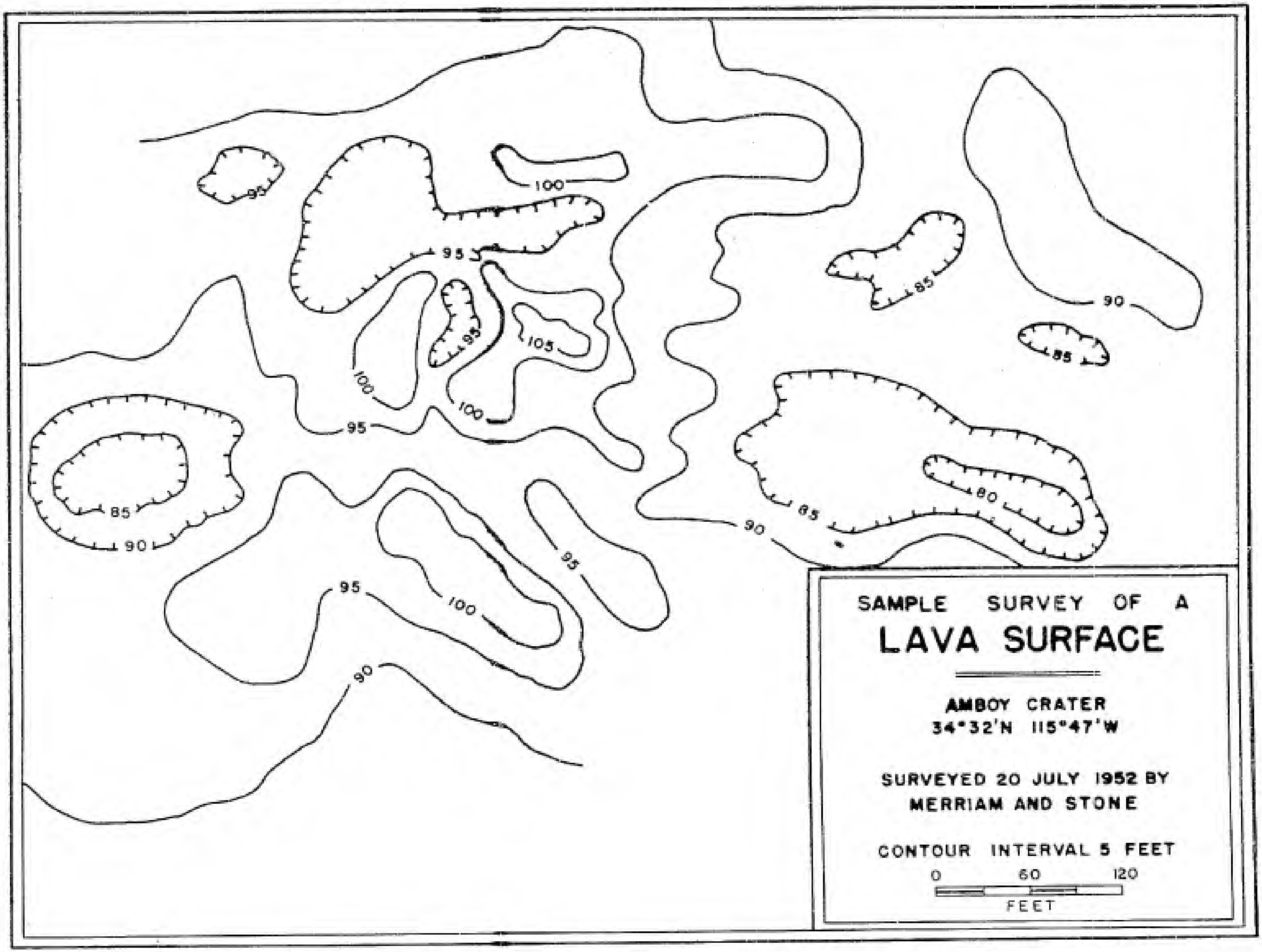

Figure 43. Sample Survey of a Lava Surface.

f. Color

Since all the Recent and Pleistocene lavas encountered in the desert areas are basalts, the colors are dark gray as a rule (N3). However, reds occasionally occur, both in the lavas and in the cinders (5R3/4). Where sand has drifted across the surface of the lavas the colors may be considerably lighter. The Pleistocene lavas may have weathered surfaces that are pale brown (5YR5/2).

13. DESERT MOUNTAINS*

Mountains in desert regions have their own characteristics, even though some of them are sufficiently high to receive more than the normal desert rainfall, and hence have considerable vegetative cover. Probably the most outstanding feature of desert mountains is their abundant rock outcrops. There is a general absence of rounded, smooth slopes such as characterize mountains of humid regions. The change in slope where mountain gives way to valley is abrupt rather than gradual.

Surface details in desert mountains are determined by rock type and structure. In general, rugged, irregular, complex terrain is the rule. Vertical or overhanging slopes are not uncommon, and sharply cut, sheer-walled drainage lines are abundant.

a. Granitic Mountains

Mountains composed of coarse-grained igneous rock, principally granitic to granodioritic in composition, and some of the coarsely crystalline metamorphics such as granite gneiss are included in this group.

Topography may be controlled by joints or gneissose lineation but the overall pattern is that of massive material. Drainage is dendritic and more or less uniform; there are no groups of parallel elongate ridges. The surface is characterized by huge rounded blocks or residual boulders, measurable in tens of feet. These units are separated by joints and have been slightly modified by erosion and weathering.

Surface material is decomposed granite or related material of similar properties. Rock surfaces are generally covered by a veneer of weathered rock which is quite abrasive and easily rubbed off. This is a hazard encountered in the climbing of steep surfaces.

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* The section on desert mountains was written by R. H. Merriam

The color of granitic and related mountains is very pale orange (10YR8/2) to grayish orange (10YR7/4). Some tend toward grayish orange pink (10R8/2) and others are somewhat darker.

Several ranges bear the name "Granite Mountains". The range situated approximately 20 miles northeast of Amboy in the Mojave Desert is the example for the type.

b. Mountains of Metamorphic Rock

Rocks which compose this group of mountains generally display a marked schistosity and have parallel structures such as relict bedding. The attitudes of the structures are variable but steep dips are the rule. Sheer cliffs, steep dip slopes, and elongate sharp ridges are common. Drainage channels are usually steep-sided sharp cuts with courses largely determined by schistosity and joints. These features are well illustrated by the Coxcomb Mountains in the Mojave Desert northeast of Desert Center, California.

Exceptionally, metamorphic rocks weather to form rounded hills with fairly smooth surfaces. This is true of a portion of the Gila Bend Mountains in Arizona.

Surface material in this group is variable but all are characterized by sharp, angular fragments such as flakes, chips, slabs and blocks. Some metamorphic rocks weather to granular, sand-like material resembling granitic weathering products, but this condition is unusual.

Colors of mountains composed of metamorphic rocks range through light gray and gray green. Alternating bands of light and dark rocks are common.

c. Mountains of Sedimentary Rock

(1) Limestone Mountains Many large ranges in southern Nevada and eastern California are composed of limestone and/or dolomite. They are fairly uniform and the two types are quite similar. A distinct structure is usually shown by the sedimentary beds comprising the mountains. The strata are massive and thick, and are disposed in various attitudes. Where bedding is nearly horizontal, step-like terraces and cliffs are formed. Where bedding dips steeply the topography is characterized by elongate parallel ridges.

Limestones and dolomites are strongly resistant to desert weathering. Solution is at a minimum but does occur. Joints and impure interbeds aid in breaking the formation into blocky fragments, but massive, unweathered surfaces are abundant. Many limestones contain small chert particles such as silicified fossils and similar appearing inorganic material. Weathering away of the less resistant limestone matrix leaves these chert particles projecting as sharp, jagged, hard points and snags. While in some cases they aid in giving the rock non-skid properties they may also be dangerous and destructive.

Various shades of gray and buff are typical of these mountains. Individual strata usually differ in color from adjacent strata. A minor amount may be dark gray, particularly if dolomite or dolomitic.

(2) Sandstone Mountains Sandstone usually occurs as interbeds in a series of several types of sediments. However, in parts of the desert area it forms mountain ranges (Fig. 44) and in such cases is responsible for certain distinctive features. Despite its sedimentary origin it usually lacks strong bedding planes and is characteristically massive, being cut only by widely spaced joints. Weathering and erosion have formed a surface dominated by large subrounded masses several tens of feet across separated by narrow, steep-sided drainage channels. Details of the surfaces are rounded, never jagged, but abrasive (resembling sandpaper). A thin layer of loose, weathered sand grains is found on most rock surfaces, making steep slopes hazardous to traverse on foot.

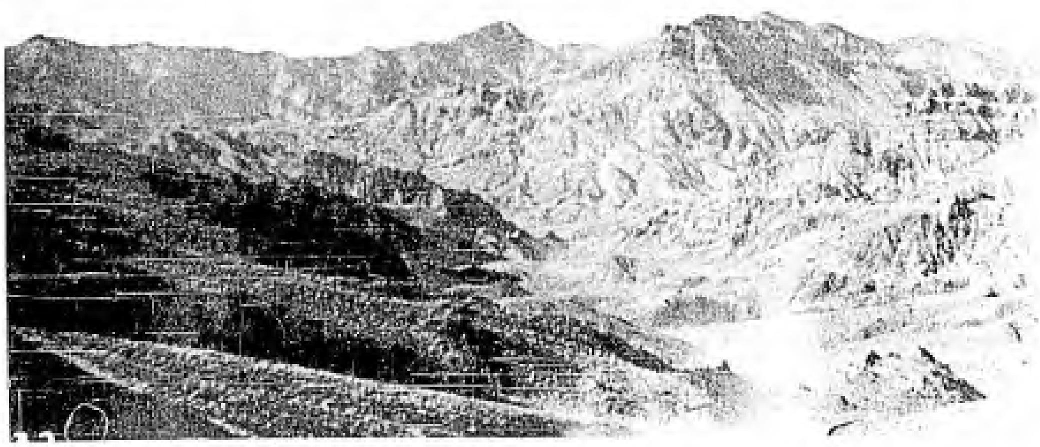

Figure 44. Desert range (sedimentary). Grapevine Mountains, near Death Valley.

A wide range of colors prevails in this group. The bulk is moderate reddish brown (10R4/6) but variations from this to white occur. Pale yellow or pale orange are not rare.

The sandstone portions of the northern Muddy Mountains, southern Nevada, illustrate the features of this group. Some of these mountains lie in the Valley of Fire State Park and are easily accessible.

(3) Shale Mountains True shale is rarely sufficiently resistant to produce mountains. Low, rounded hills ranging to subdued badlands are the usual product of desert weathering and erosion of shale bodies. Calcareous shale or shale slightly indurated by mild metamorphism or some other process is hard enough to form mountains which resemble those described above as "Mountains of Metamorphic Rock".

d. Volcanic Mountains

(1) Basaltic In the area studied, the mountains composed of basalt and related rocks belong to a group distinct from mountains in which rhyolite, dacite, and similar silicic rocks dominate. These two groups have different appearances, are fairly distinct in their distribution, and generally fall into separate ages. The basalts are chiefly Quaternary whereas the silicic volcanic rocks are nearly all Tertiary in age.

Due to their greater resistance and their relative newness the basalts may still exhibit their original features. The topography is often dominated by large areas of flat or slightly undulating surface which is the original configuration of a lava flow. Cinder cones are not rare but they constitute but a small percentage of volcanic surfaces. Most basaltic mountains are built of numerous more or less horizontal flows, sometimes aggregating several hundred feet in thickness. Because of vertical joints the flows tend to terminate in cliffs. Occasional softer flows or tuff interbeds produce slopes; thus a topography of cliffs and slopes or terraces is produced.

Surfaces are covered with loose blocks of the original irregular constituents of the flow. All such material is hard, angular, and often jagged. Weathering has generally produced but little change in most of these rocks although in some localities soil has been developed. Such residual soil is most common on tablelands (mesas).

Fresh or moderately weathered basaltic terrain is predominantly black or dark gray although weathering yields browner material. Locally brick red shades occur, especially in cinder cones.

(2) Rhyolitic This group is more diversified than the basaltic group. The rocks are older and have undergone more folding and faulting, hence bear less resemblance to their original volcanic form. Thick sections of massive agglomerate and related rocks are common. These may be responsible for the numerous nearly vertical surfaces.

Volcanic glass, in the form of obsidian, pitchstone, or perlite may occur in rhyolitic mountains. This rock breaks into fragments with sharp, almost razor-like edges, or into splinters with needle-like points, just as ordinary glass does when shattered.

Part III Desert Types: Map Identification and Estimated Percentages

14. MAP IDENTIFICATION OF DESERT TYPES*

In order to provide a basis for obtaining an idea of the occurrence of desert surface types without field inspection, an attempt has been made to deduce such occurrence on the basis of inspection of geologic and topographic maps. The ease and accuracy with which deductions can be made varies with the desert type and the detail of the map. Correlations may be made between desert type and lithology of the underlying or adjacent (possible source) material, or between desert type and topography.

a. Alluvial Fans can be located readily on both geologic and topographic maps. The latter give the slopes and permit deduction of particle size, and show size and frequency of the larger distributary washes.

Fans derived from granitic mountains are smooth and uniform, and lack coarse material. Even at the base of a granite mountain the fan will be principally of granule-size material.

Fans derived from metamorphic rocks and hard sediments often carry cobbles, blocks, and boulders, and may be nearly impassable to any vehicle in their upper portions.

b. Dry Washes can be located and their character determined with some accuracy using a good, large-scale topographic map. Washes with steep gradients are coarser and rougher. Those which drain large areas of high mountains are more apt to be floored with coarse debris. Washes traversing granitic terrain or soft sedimentary rocks may be fine, sandy, and smooth.

* The section on map identification was written by R. H. Merriam.

The continuity of channels is determined by the intricacy of braiding of the several channels in a given wash, as well as by the size, frequency, and distribution of the "islands". The continuity is an important factor in trafficability but is generally too detailed to be obtained from the average topographic or geologic map. Aerial photographs, preferably large-scale, are the best aid in this identification.

c. Subdued Badlands occur almost exclusively in moderately soft formations such as terrace gravels, Tertiary or Quaternary lake beds, and old alluvial fans. The distribution of such formations can often be obtained from a geologic map. Topographic maps of a scale of 1: 62,500 or larger usually show the extent and relief of this type of terrain. Since they are more or less equivalent to moderately dissected fans or terraces they should be expected flanking large drainage lines which may have undergone downcutting.

d. Sand dunes are frequently indicated on geologic or topographic maps but small areas are often missed. They should be expected only where there is sufficient fine material to build them. This material may be found in playas or older fine sedimentary formations such as lake beds. In some areas material at the extreme foot of alluvial fans that grade into desert flat terrain may be fine enough to be carried by the wind. The occurrence of such source formations appears on many geologic maps.

e. Desert Flats appear to occur principally on the floors of wide valleys or basins. Such valleys can easily be found on nearly any map of an area. Since the topographic maps give the surface gradients they are best for this purpose. There is no obvious correlation between lithology of source rock and this type of terrain.

f. Pediments have been found to occur almost exclusively on granitic rocks. However, not all granite areas are characterized by pediments. Geologic maps can be used to locate suitable rocks; these are potential pediment areas, but other means must be used to establish definitely the existence of a pediment in a given area. Topographic maps, if on a scale of 1:125,000 or larger, may show some pediments but not necessarily all. The presence of numerous, small, low knobs or islands surrounded by a surface resembling an alluvial fan is a strong indication that the area is pediment rather than fan.

g. Volcanic Terrain is largely limited to Quaternary basalts; a geologic map which shows rocks of this type may therefore be used in this prediction. Topographic maps are rarely of sufficiently large scale to give conclusive evidence for this type. Aerial photographs are excellent indicators.

h. Desert Pavements, while treated under surface materials rather than terrain types, should be considered here. They are composed largely of resistant rocks such as some of the volcanic, conglomerate, and metamorphic rocks. Mountains composed of granitic rocks or sediments other than conglomerate or quartzite rarely yield pavement materials. Consequently a study of geologic maps will aid in the prediction of desert pavements. Large-scale aerial photographs show this type well.

The distribution of pavements seems to bear some relation to old drainage systems. They generally cap old dissected surfaces and are more prominent near the Colorado River drainage.

15. ESTIMATES OF PERCENTAGES OF DESERT TYPES

a. Southwestern Desert Area of the United States

The distribution of desert types in the Mojave, Colorado, and Sonoran Deserts of California, Arizona, and Nevada was delineated on a map with a scale of approximately 1: 1,000,000 (Fold-in map at end of this report). The areas of each type were then determined by planimeter and the percentages calculated. It should be understood that on a map of such small scale, boundaries between types can be only approximate, and, as a consequence, the percentages given are not completely accurate.

Areas determined by planimeter, and percentages based upon these areas, are given for each type in Table III.

b. Foreign Desert Areas

Highly tentative estimates of percentages of desert types have been made for the deserts of North Africa and Arabia. North Africa has been divided roughly into the Sahara and the Libyan Deserts. The Nubian and a number of smaller, sometimes separately named, deserts have been grouped with the latter. The distribution of desert types in North Africa and in Arabia is not discussed, but the percentages are shown in Table IV where they are compared with the percentages in the desert of southwestern United States.

The greatest contrasts between the deserts of the United States and those of North Africa and Arabia are in areas of dunes, fans and bajadas, and bedrock areas. Fans and bajadas are not easily picked out on small-scale maps even as fine as those of Raisz,[41,42] and it is probable that they are much commoner in other deserts of the world than the figures would indicate. It is also suspected that the desert of Arabia has more bare rock surface than is shown in the table, probably being more nearly comparable with the Libyan Desert.

The contrast in dune areas is in part, without question, the result of difference in interpretation. Some of what has been included in the dune areas of North Africa and Arabia is doubtless to be found under the desert flat category in the North America desert. Nevertheless, a real difference still remains, and this is true of the bedrock surfaces (hammadas) as well.

TABLE III. AREAL COMPARISON OF DESERT TYPES IN SOUTHWESTERN UNITED STATES

Type	Area (square miles)	Calculated Percentage	Remarks
Playas	834	1.1	
Desert flats	15,834	20.5	
Bedrock fields	507	0.7	Includes pediments and domes.
Regions bordering through-flowing rivers	900	1.2	Calculated percentage believed low.
Alluvial fans and bajadas	24,210	31.4	Fans and bajadas not differentiated on map.
Dunes	450	0.6	Calculated percentage believed low.
Dry washes	2,345	3.6	
Badlands and subdued badlands	2,031	2.6	
Volcanic cones and fields	120	0.2	
Desert mountains	29,556	38.1	Calculated percentages for sub-types are: granitic, 15.5%, volcanic, 13.5%, metamorphic, 2.5%, and sedimentary, 6.6%.
Totals	76,787	100.0	

TABLE IV. COMPARISON OF AREAS OF DESERT TYPES (in %)

Type	Southwestern United States	Sahara Desert	Libyan Desert	Arabia
Playas	1.1	1	1	1
Desert flats	20.5	10	18	16
Bedrock fields including hammadas	0.7	10	6	1
Regions bordering through-flowing rivers	1.2	1	3	1
Fans and bajadas	31.4	1	1	4
Dunes	0.6	28	22	26
Dry washes	3.6	1	1	1
Badlands and subdued badlands	2.6	2	8	1
Volcanic cones and fields	0.2	3	1	2
Desert mountains	38.1	43	39	47
Totals	100.0	100	100	100

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84 Sands St., Brooklyn 1, N.Y.
Attn: Property Officer
Marked: Req. DUED #151

1 Chief of Transportation
Department of the Army
Temp Bldg. T-7, Gravelly Point
Washington 25, D. C.

2 Commanding Officer
Transportation Res & Dev Command
Ft. Eustis, Va.

CONTINENTAL ARMY COMMAND

1 C.G., U.S. Continental Army Command
Ft. Monroe, Va.

1 President, CONARC Board No. 1
Ft. Sill, Okla.

1 President, CONARC Board No. 2
Ft. Knox, Ky.

1 President, CONARC Board No. 3
Ft. Benning, Ga.

1 President, CONARC Board No. 4
Ft. Bliss, Texas

1 President, CONARC Board No. 5
Ft. Bragg, N. C.

1 President, CONARC Board No. 6
Camp Rucker, Alabama

AIR FORCE

2 Department of Air Force
Hqs., USAF, Wash 25, D. C.
(1 DC/S Material, 1 DC/S Dev.)

1 Commander
Air University
Maxwell AFB, Alabama

1 Commandant
USAF School of Aviation Medicine
Randolph AF Base
Randolph Field, Texas

1 Commander, Arctic Aeromedical Lab.
APO 731, Seattle, Washington

1 Commander
Air Res & Dev Command, P.O. Box 1395
Baltimore, Maryland

1 Commander
Wright Air Development Center
Wright Patterson AF Base, Ohio
Attn: Tech Library

1 Commander
Strategic Air Command
Offutt AF Base, Nebraska

1 Chief, Nutrition Div.
Air Development Center
Aero-Medical Lab.
Wright Patterson AFB, Ohio
Attn: Dr. Harry C. Dyme

1 Commander
AF Cambridge Research Center
Air Research & Development Cmd.
Laurence G. Hanscom Field
Bedford, Mass.
Attn: CRTOTT-2

NAVY

1 Director
Naval Research Laboratory
4th & Chesapeake St., S. W.
Washington 25, D. C.

1 Chief, Bureau of Ordnance
Department of the Navy
Washington 25, D. C.
Attn: R&D Div.

1 Naval Medical Research Institute
National Naval Med. Res. Center
Bethesda, Md.

2 Chief of Naval Research
Washington 25, D. C.
Attn: Code 402S

1 Chief, Bureau of Ships
Department of the Navy
Washington 25, D. C.
Attn: Code 331

1 Chief, Bureau of Med. & Surgery
Dept. of the Navy, Wash 25, D. C.
Attn: Code 33

1 Commander, U.S. Naval Ord. Test
Station, China Lake, Calif.
Attn: Code 753

1 Chief, Bureau of Aeronautics
Dept of the Navy, Wash 25, D. C.
Attn: Code AE 52

1 Chief, Bureau of Supplies & Accounts
Department of the Navy
Washington 25, D. C.

BOARDS & COMMITTEES

1 Army Committee on Environment
Chief, Research & Development
Pentagon, Washington, D. C.

1 Army Comm. on Insect and Rodent Control
Office, Deputy Chief of Staff for Logistics
Pentagon, Washington, D. C.

1 Army Research Committee
Chief, Research & Development
Pentagon, Washington, D. C.

MISCELLANEOUS

1 The Army Library
Pentagon Bldg., Washington 25, D. C.

1 Commandant, National War College
Ft. McNair, Washington 25, D. C.

1 Commandant, Command & General Staff School
Ft. Leavenworth, Kansas

1 Commandant, U.S. Military Academy
West Point, New York

1 National Research Council
2101 Constitution Ave., Washington, D. C.
Attn: Advisory Bd. on QM R&D

5 Armed Services Technical Information Agency
Document Service Center
Knott Building, Dayton 2, Ohio
Attn: DSC-SD

1 Commanding Officer, Detroit Arsenal
28251 Van Dyke St., Centerline, Mich.
Attn: Res & Engr. Div.

1 U. S. Department of Commerce
Weather Bureau Library, Washington, D. C.

1 Commanding Officer
Hqs., Mountain and Cold Weather Training Command
Fort Carson, Colorado

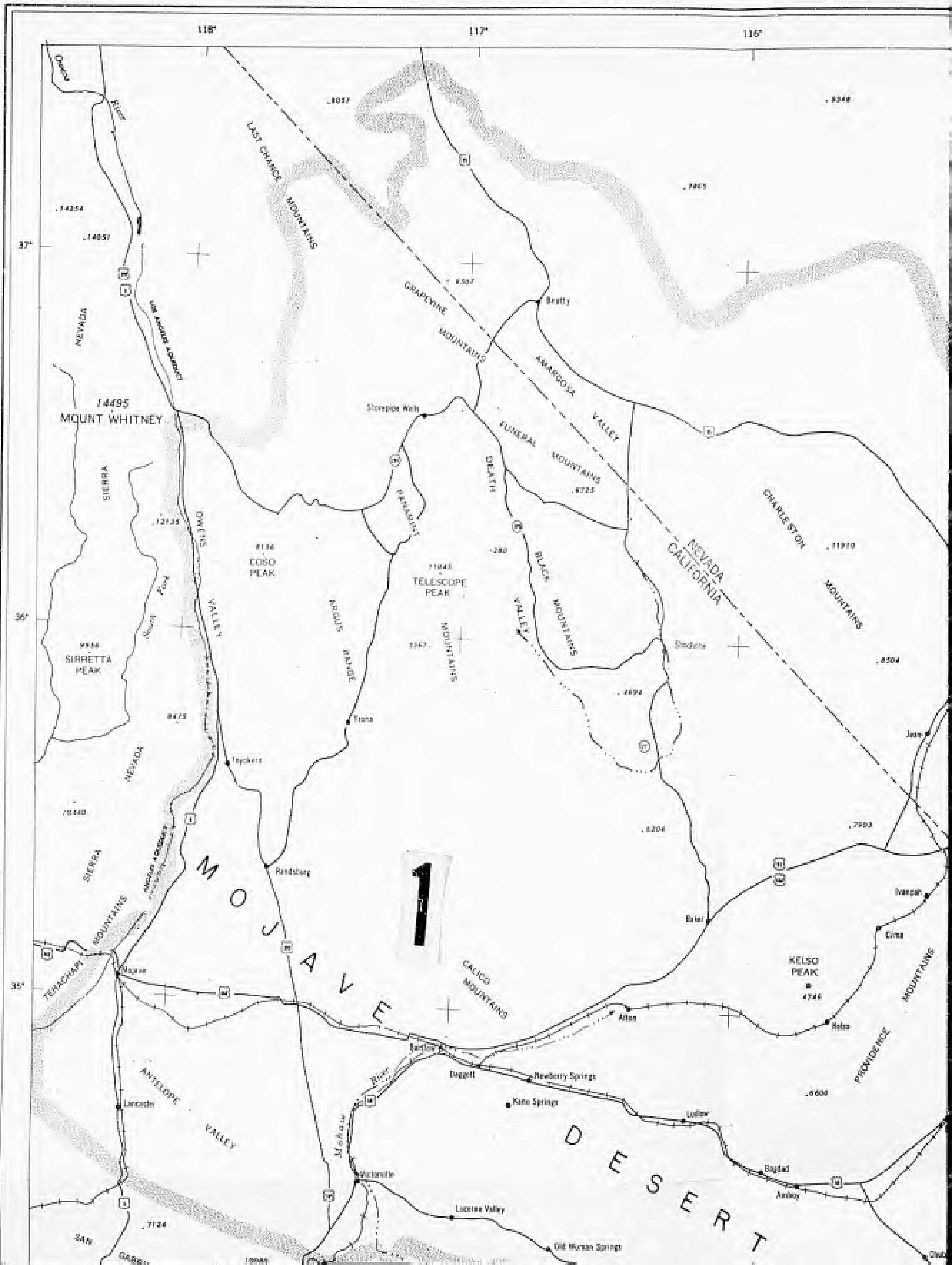
1 Central Intelligence Agency
Collection & Dissemination
2430 E St., N. W.
Washington 25, D. C.

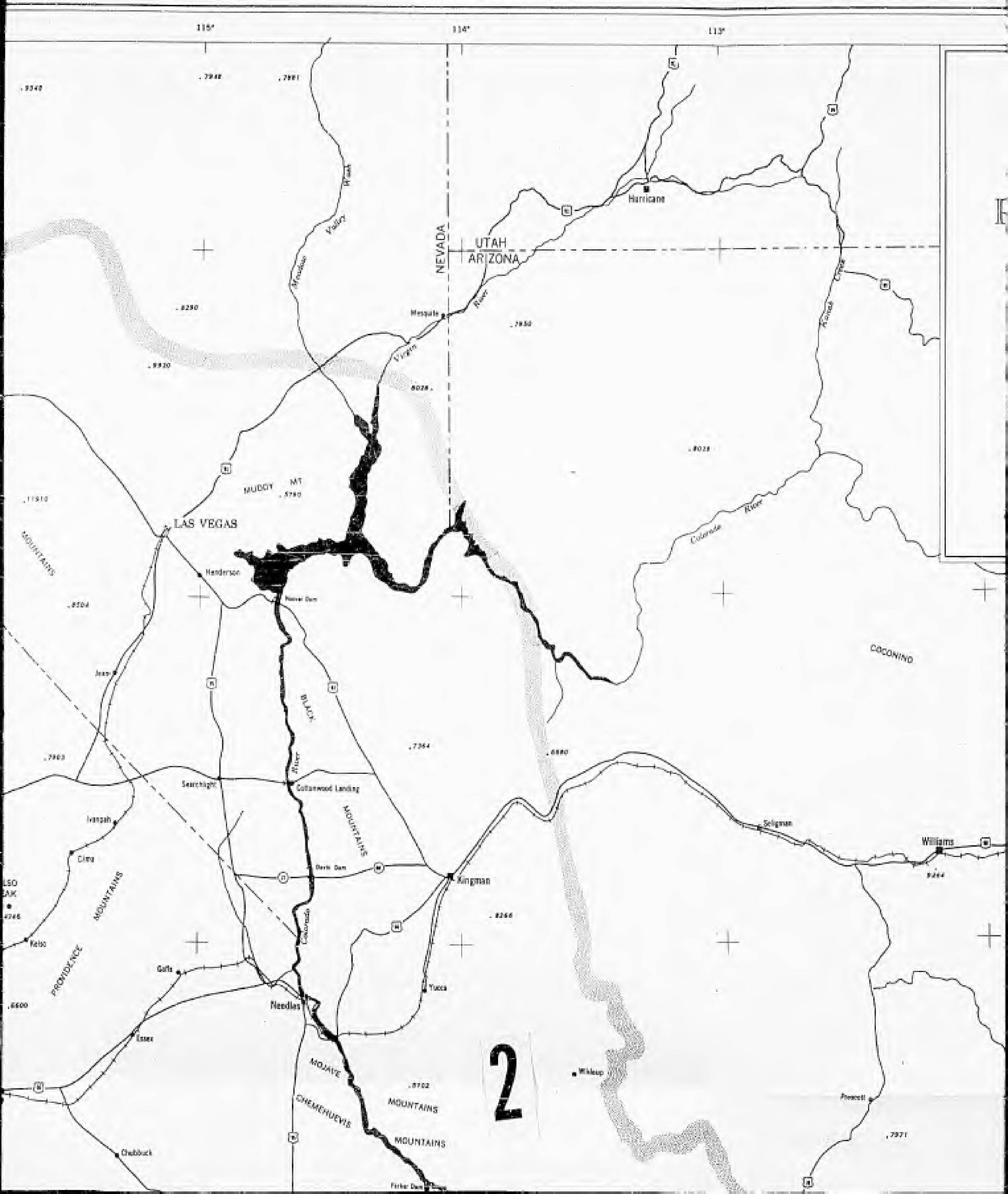
1 Marine Corps Equipment Board
Marine Development Center
Marine Corps School
Quantico, Va.

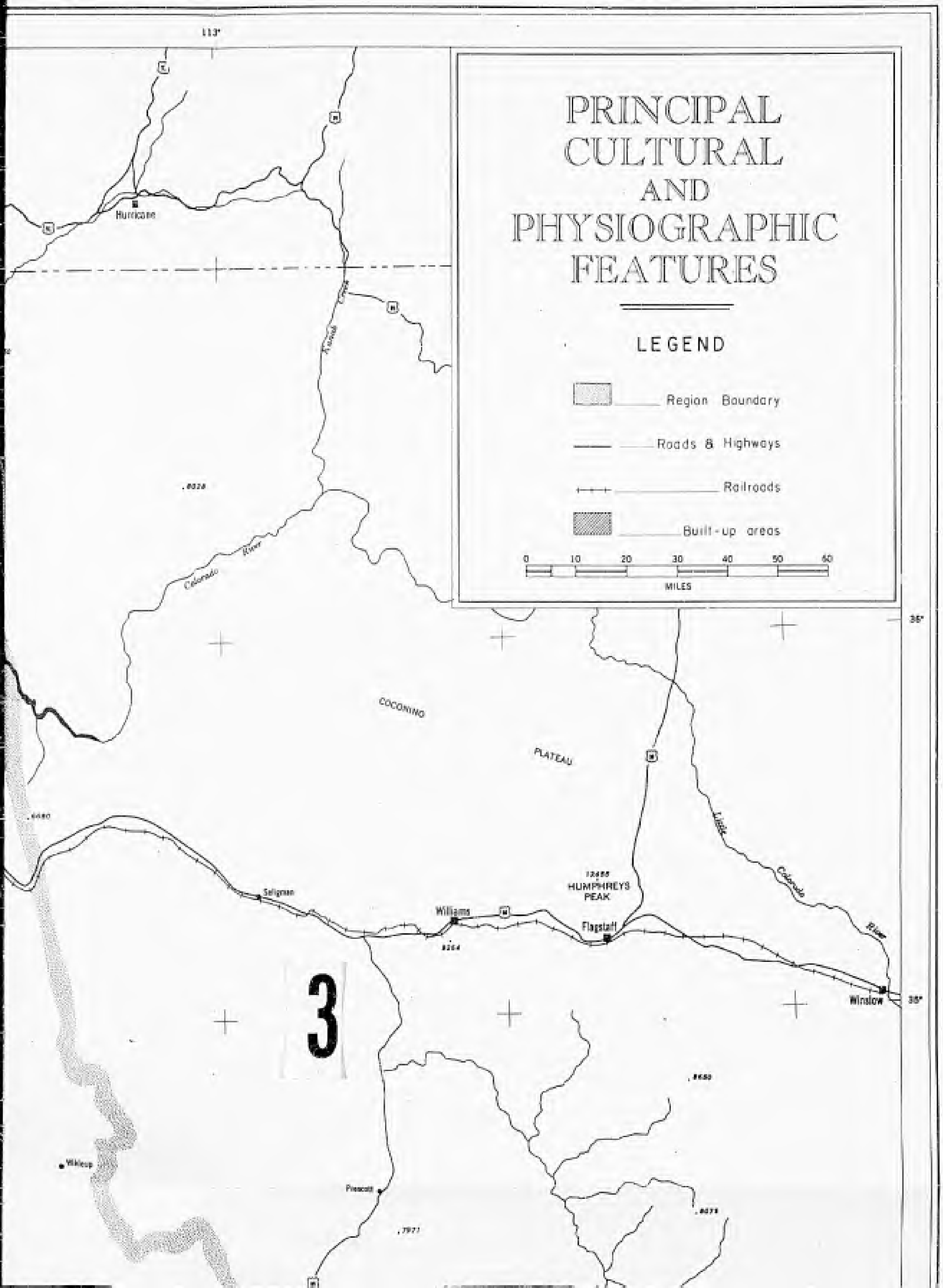
1 Office of Technical Services
U. S. Department of Commerce
Washington 25, D. C.
Attn: Tech Rpts Sec (THRU OQMG)

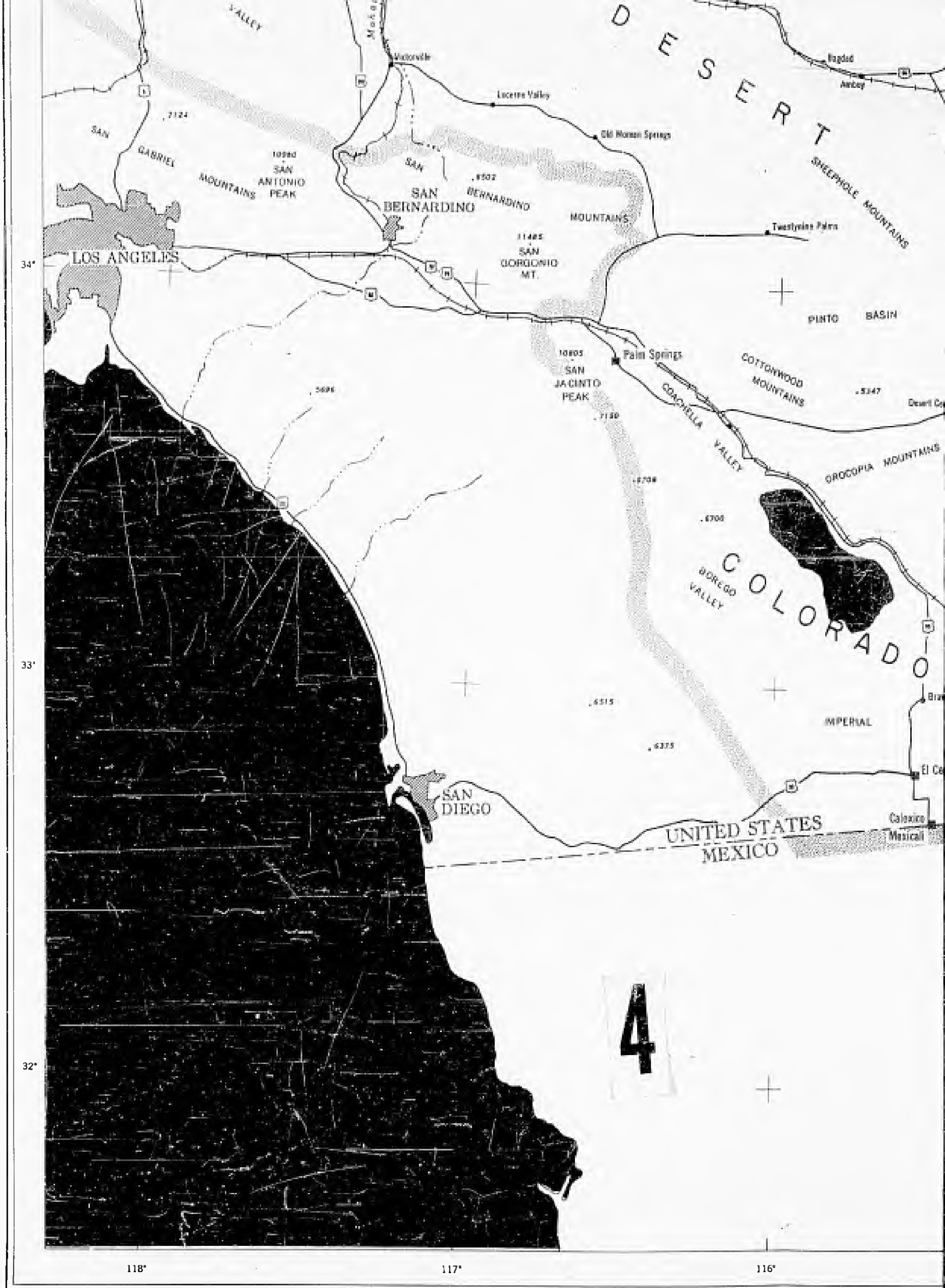
1 U. S. Department of Agriculture Library
Washington 25, D. C.

1 Commandant
Industrial College of the Armed Forces
Ft. McNair, Washington 25, D. C.

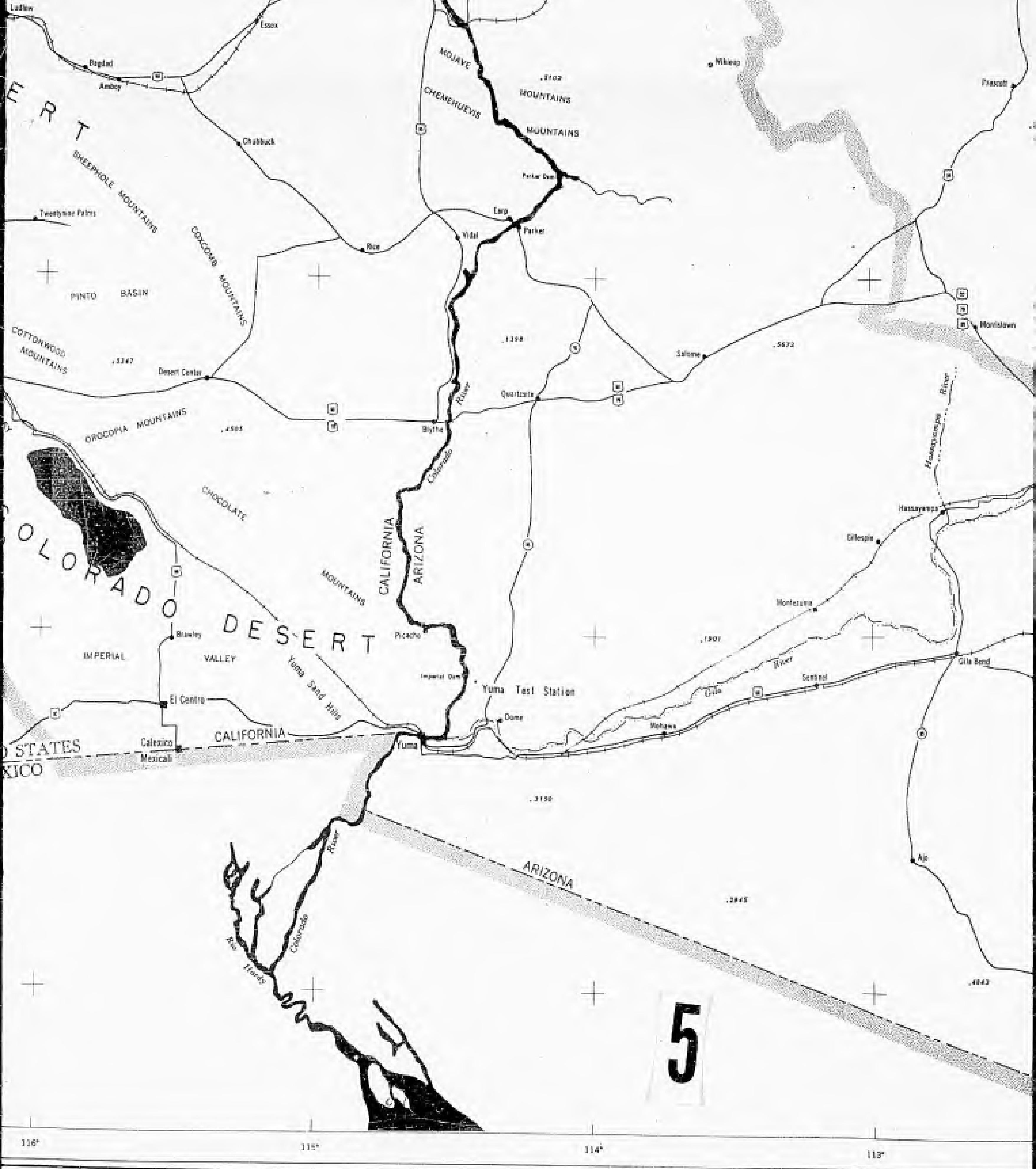

118°
117°
116°
37°
36°
35°
MOUNT WHITNEY
14495
SIERRA
NEVADA
LAST CHANCE MOUNTAINS
GRAPEVINE MOUNTAINS
AMARGOSA VALLEY
FUNERAL MOUNTAINS
DEATH VALLEY
BLACK MOUNTAINS
PANAMINT MOUNTAINS
TELESCOPE PEAK
11045
COSO PEAK
ARGUS RANGE
OWENS VALLEY
SIRRETTA PEAK
9934
NEVADA
CALIFORNIA
CHARLESTON MOUNTAINS
KELSO PEAK
4746
PROVIDENCE MOUNTAINS
CALICO MOUNTAINS
TEHACHAPI MOUNTAINS
ANTELOPE VALLEY
MOJAVE DESERT
Beatty
Stovepipe Wells
Shoshone
Trona
Inyokern
Randsburg
Baker
Ivanpah
Cima
Kelso
Afton
Mojave
Barstow
Daggett
Newberry Springs
Lancaster
Ludlow
Bagdad
Amboy
Victorville
Lucerne Valley
Old Woman Springs
1


115°
114°
113°
NEVADA
UTAH
ARIZONA
Hurricane
Meadow Valley Wash
Virgin River
Mesquite
MUDDY MT
LAS VEGAS
Henderson
Hoover Dam
MOUNTAINS
Jean
BLACK
River
MOUNTAINS
Searchlight
Cottonwood Landing
Ivanpah
Cima
Davis Dam
Kingman
PROVIDENCE
MOUNTAINS
Kelso
Goffs
Colorado
Needles
Yucca
Essex
MOJAVE
CHEMEHUEVIS
MOUNTAINS
MOUNTAINS
Chubbuck
Parker Dam
Wikieup
Colorado River
Kanab Creek
COCONINO
Seligman
Williams
Prescott
2

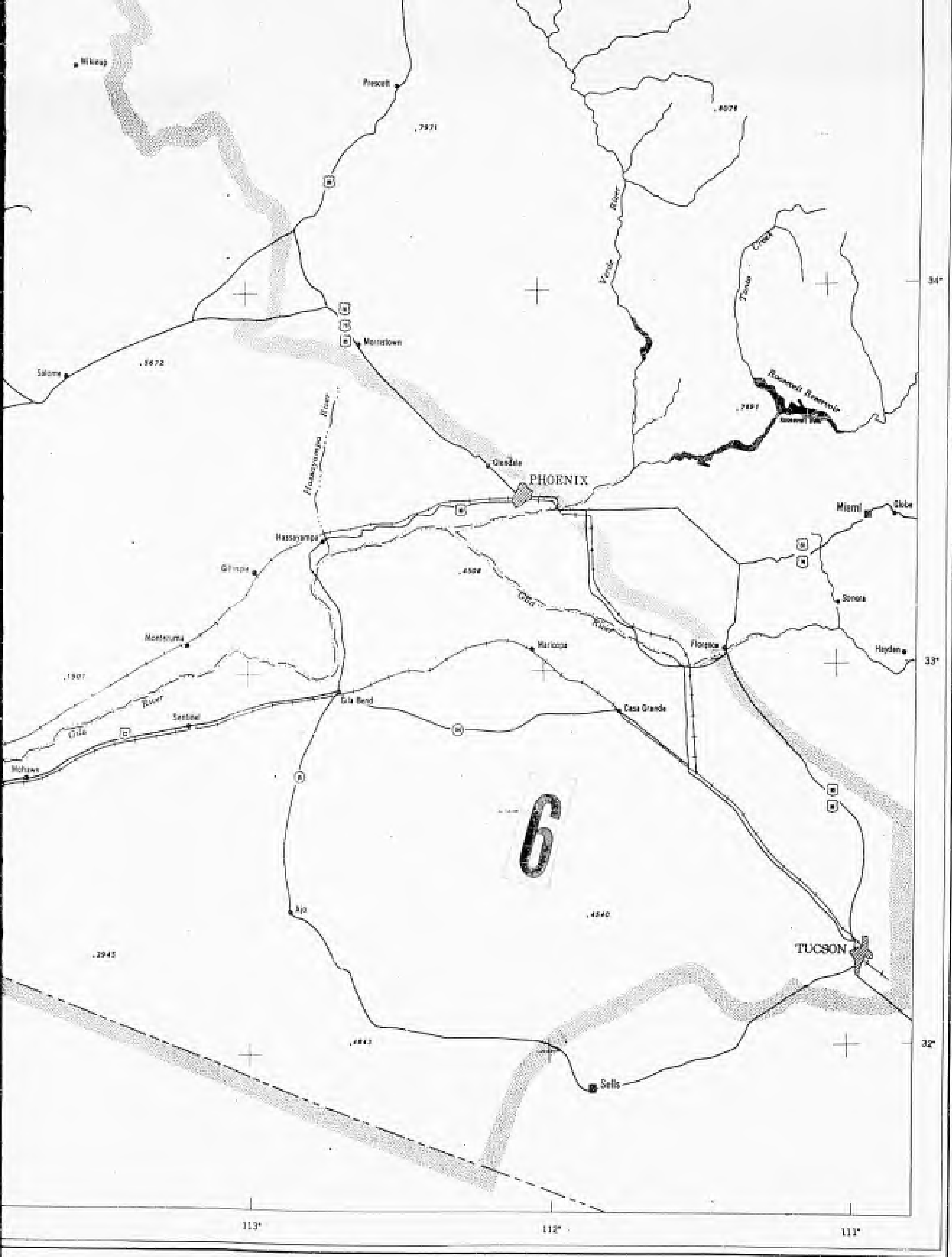

PRINCIPAL CULTURAL AND PHYSIOGRAPHIC FEATURES
LEGEND
Region Boundary
Roads & Highways
Railroads
Built-up areas
0 10 20 30 40 50 60
MILES
Hurricane
Colorado River
COCONINO PLATEAU
Seligman
Williams
HUMPHREYS PEAK
Flagstaff
Little Colorado River
Winslow
Wikieup
Prescott
3



Cartographic Section, EPD, April 1956 M-59



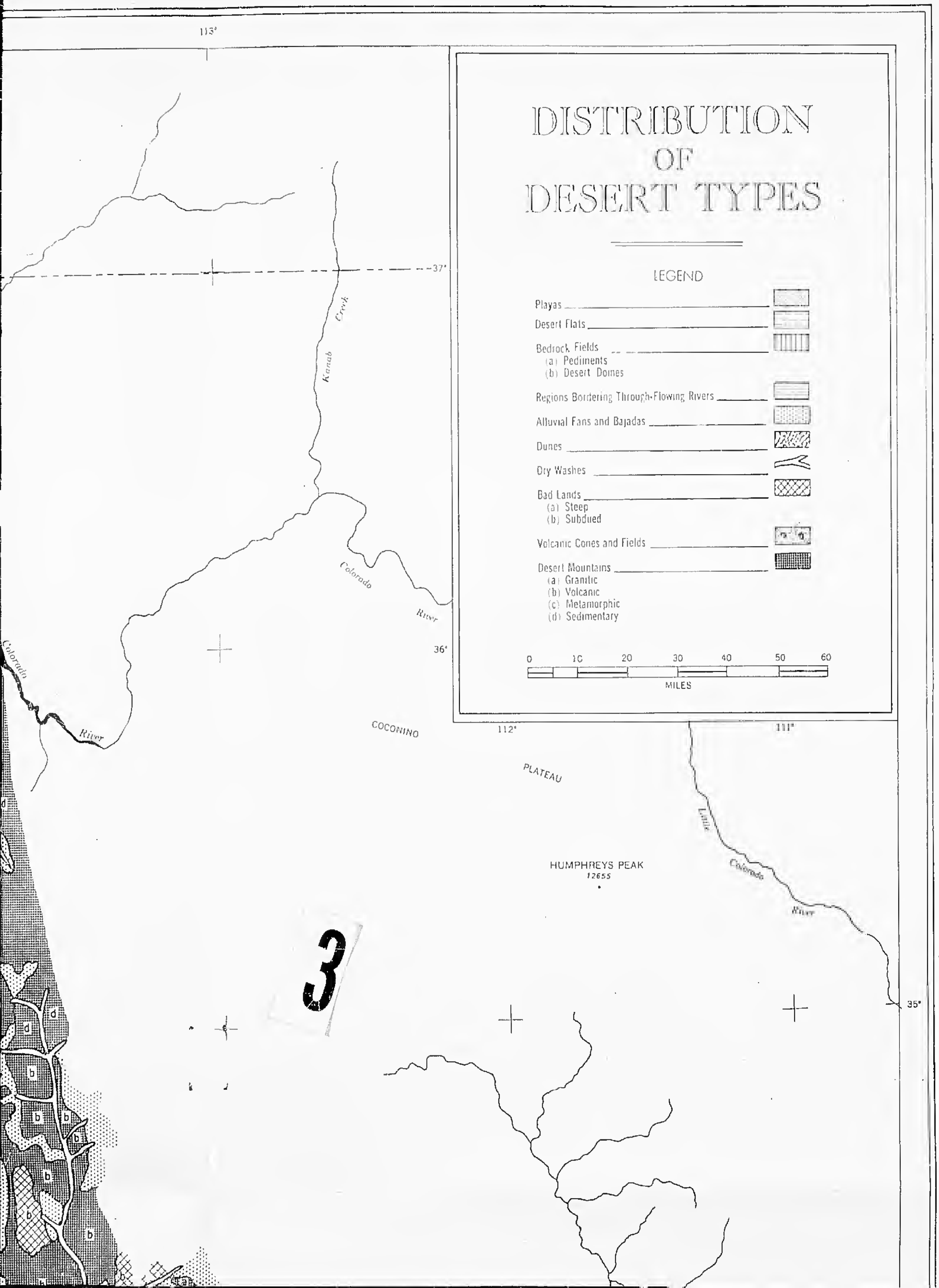
Ludlow
Essex
Bagdad
Amboy
Chubbuck
Twentynine Palms
SHEEPHOLE MOUNTAINS
COXCOMB MOUNTAINS
PINTO BASIN
COTTONWOOD MOUNTAINS
Desert Center
Rice
MOJAVE
CHEMEHUEVIS
MOUNTAINS
MOUNTAINS
Parker Dam
Earp
Vidal
Parker
Kingman
Prescott
Morristown
Salome
Quartzsite
Blythe
Colorado
River
OROCOPIA MOUNTAINS
CHOCOLATE
MOUNTAINS
COLORADO DESERT
CALIFORNIA
ARIZONA
Hassayampa River
Hassayampa
Gillespie
Montezuma
Picacho
Imperial Dam
Yuma Test Station
Gila River
Sentinel
Gila Bend
Mohawk
Dome
Brawley
IMPERIAL
VALLEY
Yuma Sand Hills
El Centro
Calexico
Mexicali
CALIFORNIA
Yuma
UNITED STATES
MEXICO
ARIZONA
Ajo
Rio Hardy
Colorado River
5
116°
115°
114°
113°



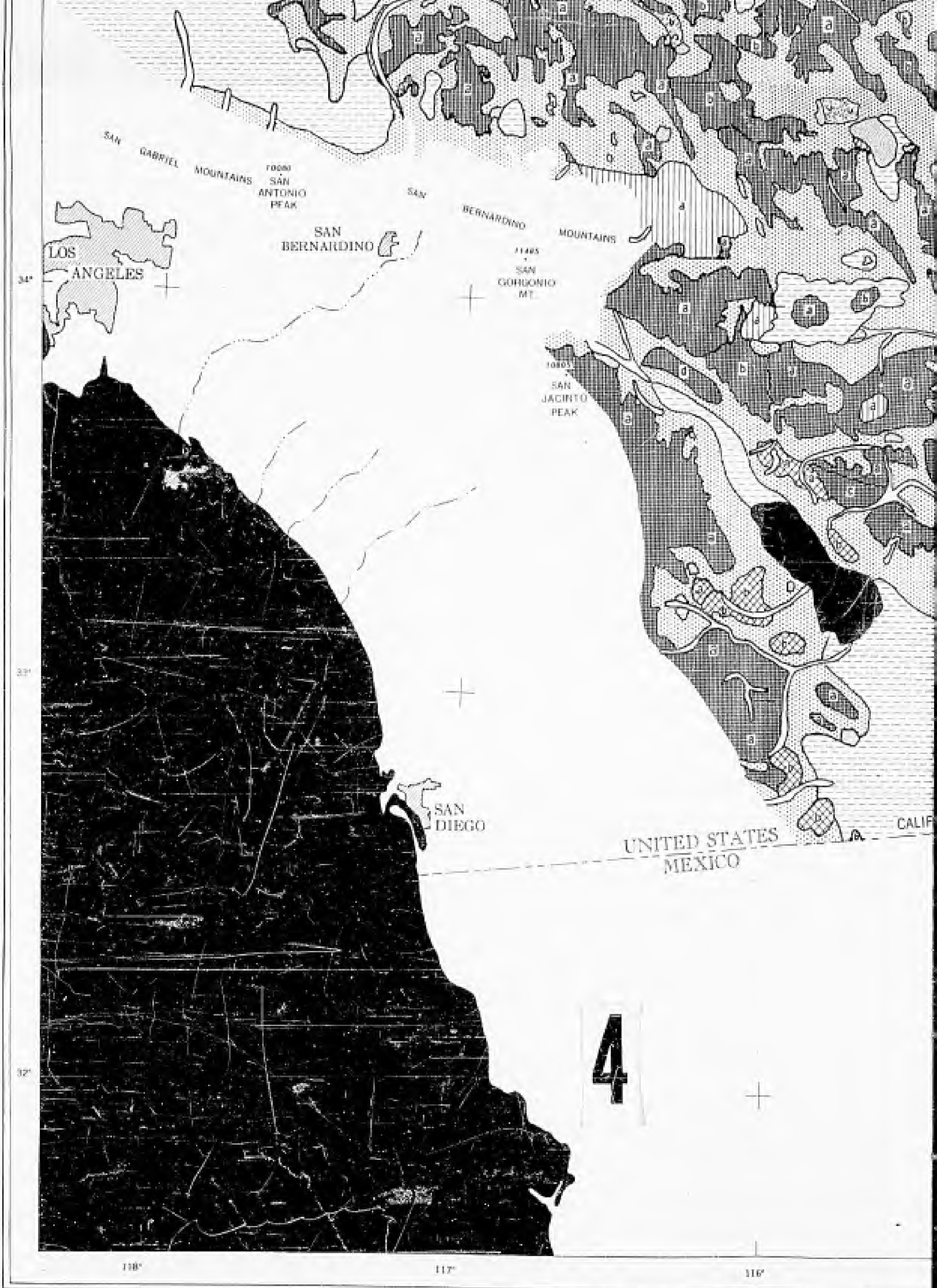
Amy-Lorell, Inc., Boston, Mass.

1
118°
117°
116°
37°
36°
35°
Owens River
NEVADA
CALIFORNIA
MOUNT WHITNEY
14495
SIERRA
NEVADA
LOS ANGELES AQUEDUCT
SIRRETTA PEAK
COSO RANGE
ARGUS RANGE
PANAMINT MOUNTAINS
BLACK MTS
Cima Dome
SAN GABRIEL MOUNTAINS


NEVADA
UTAH
ARIZONA
LAS VEGAS
Virgin River
Kanab Creek
Colorado River
BLACK MOUNTAINS
2



DISTRIBUTION
OF
DESERT TYPES
LEGEND
Playas
Desert Flats
Bedrock Fields
(a) Pediments
(b) Desert Domes
Regions Bordering Through-Flowing Rivers
Alluvial Fans and Bajadas
Dunes
Dry Washes
Bad Lands
(a) Steep
(b) Subdued
Volcanic Cones and Fields
Desert Mountains
(a) Granitic
(b) Volcanic
(c) Metamorphic
(d) Sedimentary
0
10
20
30
40
50
60
MILES
113°
37°
36°
35°
112°
111°
Kanab Creek
Colorado River
COCONINO
PLATEAU
HUMPHREYS PEAK
12655
Little Colorado River
3



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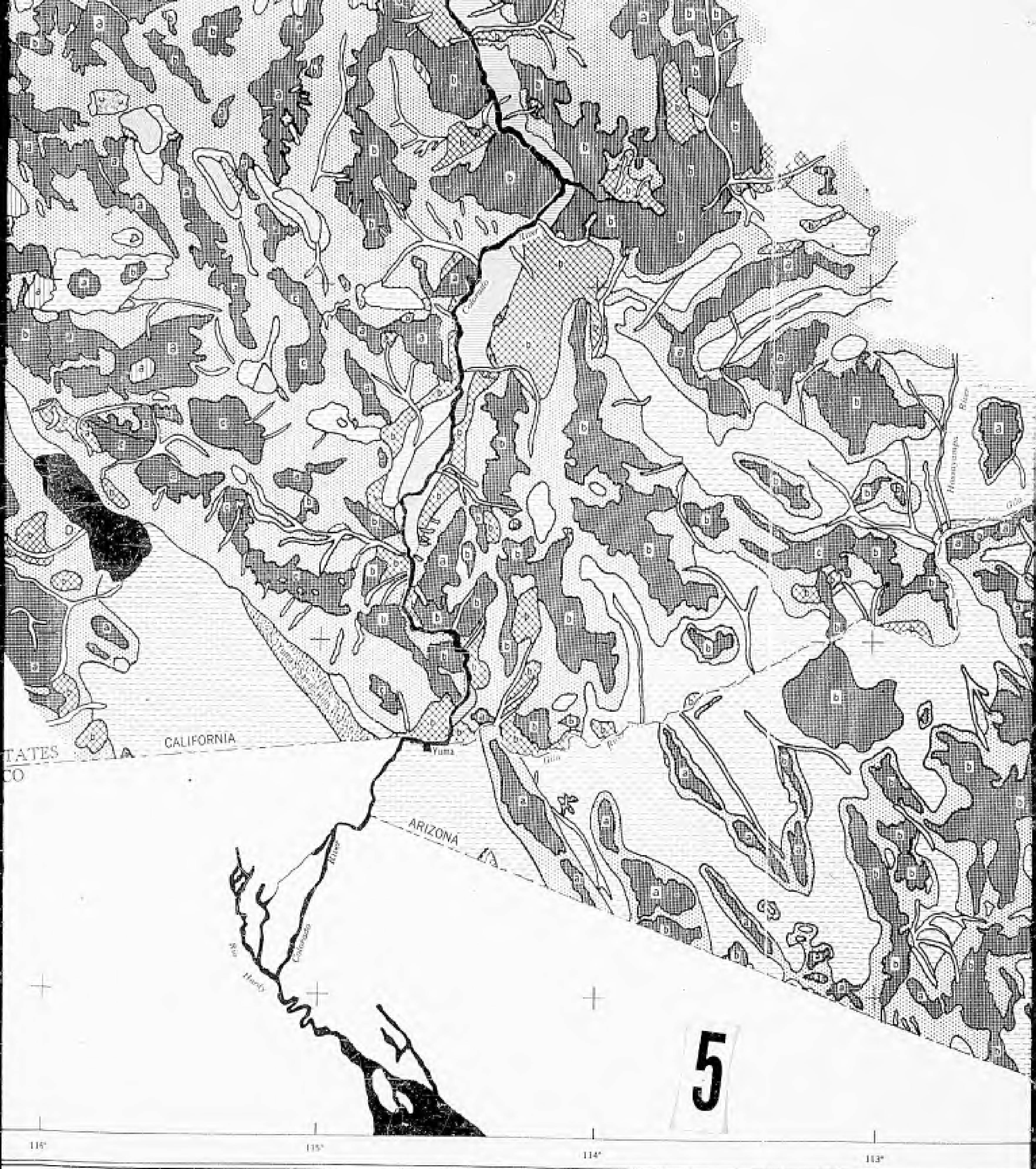

CALIFORNIA
ARIZONA
Yuma
Colorado River
Gila River
Rio Hardy
Hassayampa River
116°
115°
114°
113°
5

Army-Lorell, Inc., Boston, Mass.

UNCLASSIFIED

UNCLASSIFIED