Alluvial Fans in the Death Valley Region California and Nevada

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By CHARLES S. DENNY

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A survey and interpretation of some aspects of desert geomorphology

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ALLUVIAL FANS IN THE DEATH VALLEY REGION, CALIFORNIA AND NEVADA

By Charles S. Denny

ABSTRACT

Two alluvial fans in the Amargosa Valley near the California-Nevada State line were mapped in detail; a more cursory examination was made of several fans in Greenwater and Death Valleys, the study of which was based on maps prepared by Harald Drewes and C. B. Hunt. Measurements of such characteristics of a fan as areal extent, width and slope of washes, and size of material on the surface were made on the ground and on topographic maps. The size measurements are based on samples selected by means of a grid.

The massive quartzites of Shadow Mountain, east of Death Valley Junction, yield coarse debris that forms a complex alluvial fan having a pronounced upward concavity in longitudinal profile. In common with most of the large fans in the region, the Shadow Mountain fan has a complex surface, a mosaic of desert pavements and washes; the washes can be classified into the modern washes, floored with unweathered gravel, and others now abandoned, where the fragments on the surface have a coating of desert varnish.

Bare braided channels and gravel bars having a microrelief ranging from 1 to 3 feet form the modern washes. They are not uniformly distributed over the fan but occur chiefly near the mountain front, in midfan downstream from mouths of small meandering washes heading in areas of desert pavement, and near the toe, where shallow washes are cut in fine-grained arid-basin deposits (sand, silt, and gravel).

Abandoned washes containing scattered shrubs are the most extensive type of surface on the fan. They resemble the modern washes, but the surface material, coated with desert varnish, is slightly coarser grained, and the local relief is slightly greater.

Stones overturned during the construction of a long-abandoned road across the fan have not acquired a coating of desert varnish in a period of more than 50 years. The erosion of the roadbed suggests that at least a third of the area of wash crossed by the road has been subjected to overflow during this interval. The abandoned washes record an episode of more extensive flooding, perhaps of greater discharge than at present, but whether this episode was a few hundred or a few thousand years ago is uncertain.

Desert pavements are smooth, gently sloping surfaces composed of closely packed angular fragments of rock, commonly coated with desert varnish or faceted by solution and ranging in size from a fraction of an inch to several feet in diameter. The pavement is an armor that promotes runoff and protects the underlying silty material from removal by water or by wind. This silty material is formed apparently by both chemical and mechanical weathering of gravel similar to the gravel that lies below it.

Few pavements are completely smooth; most are broken by miniature terraces having risers less than an inch high. Apparently these terraces form when the underlying silt is saturated with water to depths of an inch or two. Because the silt tends to flow downslope, it is placed under tension, and cracks—the risers of the miniature terraces—form at right angles to the pavement slope. Such downslope movement, aided by surface wash and by wind action, gradually transforms the channels and bars of an abandoned wash into a smooth pavement.

All pavements are traversed by meandering washes that head in them; these washes are gullies cut well below the surface of the pavement and below the floor of the adjacent braided washes. The meandering washes have finer-grained bed material and a lower gradient than do braided washes heading in the mountains. The bed material in a meandering wash seems to come largely from the pavement and underlying silty material. Thus a pavement and the gullies that appear to be dissecting it may be in balance. The proportion of pavement and of gully may remain constant for some time while the surface of the pavement is gradually lowered.

Most fans consist of segments of modern and of abandoned washes whose areal extent is related to that of their source areas in the mountains. For the 60 fans studied in the Death Valley region, the area of disposition on a fan or that of an abandoned depositional segment is equal to one-third to one-half the size of the source area.

In this region a fan-building wash from the mountains has coarse-grained bed material and a steep gradient, whereas one that heads on the fan has a gentler gradient and a bed that may lie many feet below that of the adjacent fan-building wash. Flow in a fan-building wash from the mountains may in time be diverted into a low-lying channel that heads on the fan; the diversion causes the wash to be cut down into the head of the fan and the load to be deposited in the lower channel. Such diversions, described some years ago by J. L. Rich, are responsible for the complex surface form of most large fans.

The pronounced upward concavity in the longitudinal profile of the Shadow Mountain fan is due to the fact that the detritus from the mountain is deposited on a steep slope near the mountain, where it remains until weathered into smaller fragments that the local runoff is then able to move farther downfan on a somewhat lower gradient.

Fans built of detritus from the volcanic rocks of the region are longer, more gently sloping, and built of finer grained debris than those derived from quartzite or other massive bedrock. Some hills composed of monzonite yield fine-grained detritus that has formed small fans having a pronounced upward concavity in longitudinal profile. Elsewhere monzonitic debris mantles long, gently sloping piedmonts.

Fans on the west side of Death Valley at the east foot of the lofty Panamint Range are built of coarse debris but have

straight slopes for long distances; apparently the canyons above these fans carry larger floods than washes on other fans because the mountains reach up into a zone of higher precipitation. The fans east of the valley are small relative to their source in the Black Mountains because the valley floor has been tilted eastward in Quaternary time; the tilting caused the lower parts of the fans to be buried under fine-grained playa deposits.

Compared with stream channels in humid regions, the desert washes are generally steeper; perhaps they are also wider, but the data are inconclusive.

The material on the floor of the washes ranges from boulders to clay and is not well sorted; the proportion of clay and silt is small. No consistent relation was found between the slope of a wash and the size of the bed material. Changes in grain size downwash vary from fan to fan. The bed material in the desert washes is finer grained than the bedload of some streams in more humid regions having comparable drainage basins.

INTRODUCTION

The mountains surrounding Death Valley and nearby basins are bordered by sloping plains that are largely coalescing alluvial fans. Only a small fraction of these sloping plains is a surface of erosion, or a pediment. No one term is in common usage to describe these sloping desert plains that lie between the mountain front and the central or axial playa or river flood plain. For convenience in this report, the term "piedmont" is used to refer to the entire surface of such a sloping plain, whether it be a fan, a pediment, or any combination thereof. "Pediment," as used here, is an erosional segment of a piedmont, whether a surface that bevels the rocks of the mountain or those of the basin fill (Bryan, 1922; Tuan, 1959). An alluvial fan is a depositional segment of a piedmont regardless of whether or not its surface is distinctly fan shaped either in plan or in profile.

Pediments and fans are produced during the degradation of a mountain and the transport of the detritus to an adjacent basin. Erosion and deposition operate on different segments of a piedmont at the same time. I believe that an alluvial fan is related to some sort of balance or interaction between mountain degradation and valley alluviation—perhaps to a condition of dynamic equilibrium between a fan-building wash and its surroundings—rather than to the fan's stage of development in some evolutionary sequence. This paper attempts to explain the complex morphology of a fan as much as possible in terms of the processes that appear to be operative at present. Only in this way can any reasonable evaluation be made of the widely held view that many characteristics of a desert fan are inherited, that they are the result of processes that are either no longer active under the climate that exists today or were probably more active in the past.

In 1956–58, as part of a study of the geology of a segment of the Amargosa Valley a few miles east of Death Valley near the California-Nevada State line (fig. 1), two fans were mapped in detail, and various aspects of their characteristic features were measured both in the field and on topographic maps. During 1958 about a month was devoted to an examination of fans in adjacent valleys.

The fieldwork was carried on with the able assistance of H. F. Barnett, Jack Rachlin, and J. P. D'Agostino. I am indebted to Alice and Charles Hunt and to Harald Drewes for agreeably profitable field conferences and for helpful criticism of this report. John T. Hack spent a week in the field experimenting with various sampling techniques and was a constant source of guidance and encouragement. The report has also benefited from the criticism of L. B. Leopold, the late J. P. Miller, and C. C. Nikiforoff.

METHOD OF STUDY

The study of alluvial fans is based on two kinds of evidence: (1) maps showing a fan's surface geology and geomorphology and (2) measurements of some of the surface features of a fan made on the ground in the field and obtained from topographic maps. Because the surface of most fans is a mosaic of desert pavements and washes, some of which are covered by unweathered gravel and others by fragments coated with desert varnish, it is essential first to map the fan in order to make certain that the samples used to obtain measurements of such features as grain size are from comparable deposits.

Although one of the obvious characteristics of any fan is the size of the detrital material, systematic measurements of grain size have seldom been published (Eckis, 1928, 1934; Blissenbach, 1954; Emery, 1955). In this study estimates were made of the size of the material on the surface of a fan rather than of the size of material in bulk samples excavated from a bank or bed. Because the washes floored with unweathered gravel are the loci of streamflow at the present time, they were sampled in detail, not only on the fan but also at several points along the principal tributary in the mountains upstream from the apex. At most sample sites the following data were recorded: (1) width of wash, (2) height of banks, (3) slope as measured with an Abney level, and (4) an estimated mean size and lithologic composition of the gravel on the surface.

The size of material on the surface of a fan was estimated by the use of a slight modification of the grid method described by Wolman (1954). A 100-foot steel

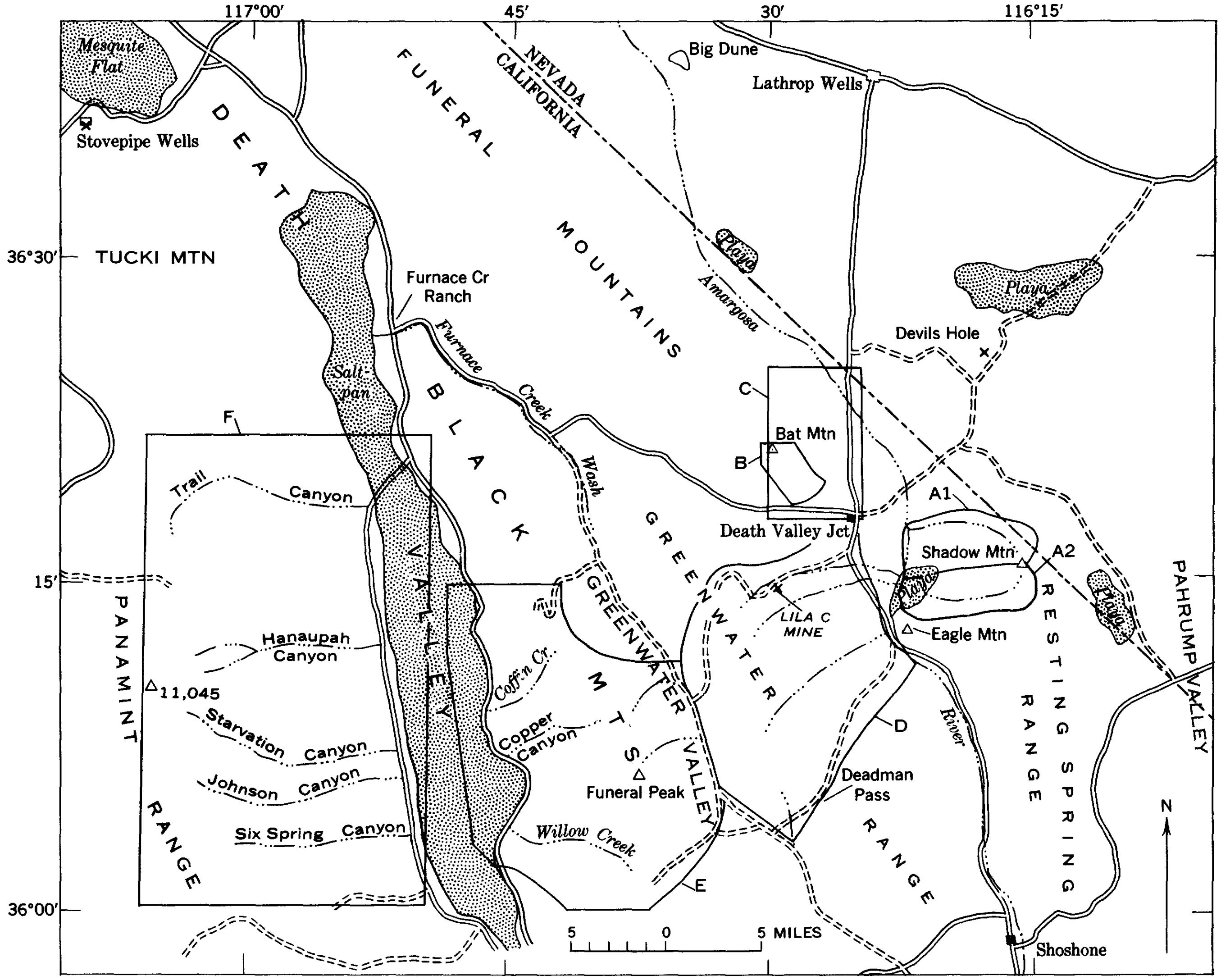

FIGURE 1.—Map of the Death Valley region, California and Nevada, showing the location of more detailed maps included in this paper. A1, plate 1; A2, plate 1 insert; B, plate 2; C, figure 13; D, plate 3; E, plate 4; F, plate 5.

tape was laid across the wash or pavement; whatever material lay beneath each 4-foot mark (4, 8, 12, 16, etc.) was picked up, and the length of the intermediate axis of the particle was tallied within a size class. A sample of 25 particles was obtained in this manner.

The Wentworth size classes denoted by the phi notation are used. Experience has shown that the sizes of the particles on a streambed or fan surface form a population that has approximately a log normal distribution. In order to apply statistical methods to the figures obtained, therefore, the sizes must be expressed in units on a logarithmic scale. This conversion is most conveniently done by using the phi units of Krumbein based on logarithms to the base 2 ($\phi = -\log_2 n$, where n = grain size, in millimeters). The size classes increase in a geometric progression as follows:

Phi unit	*size (mm)*
−1	2
−2	4
−3	8
−4	16
−5	32

The actual particles picked up were tallied in size classes by means of a scale graduated as follows:

Size class (φ)	*Size range (mm)*	*Size class (φ)*	*Size range (mm)*
−1	0.00–2.83	−6	45.2–90.5
−2	2.83–5.7	−7	90.5–181.0
−3	5.7–11.3	−8	181.0–361.8
−4	11.3–22.6	−9	361.8–723.8
−5	22.6–45.2		

The number of particles in each size class was plotted as a cumulative curve (fig. 2), and an estimated mean size, in phi units, was determined by inspection as follows:

$$\text{Estimated mean size} = \frac{Q_1 + Q_3}{2},$$

where Q_1 is the first quartile, or the 25 percentile, and Q_3 is the third quartile, or the 75 percentile (both in phi units). The estimated mean size was then converted into millimeters.

The values of mean size obtained by this method refer only to the surface of the material sampled. They are not directly comparable to the sieve analysis of a bulk sample. Such a grid method is usable provided that the material on the surface does not include too many particles in phi size class −1 (less than about 3 mm).

Not all the individual measurements may be representative of the surface material, but the values for the entire length of a wash—from mountain crest to toe of fan—when plotted on a graph group about a trend line that seems to be representative of the surface of the wash and can be compared with similar curves for the washes on other fans. These estimates suggest the size of the material of which a fan may be built and indicate how the size of the material on one fan may differ from that on a neighboring fan.

The accuracy of the grid sampling method can be determined on the basis of well-known statistical principles. If the individual particles measured are assumed to be selected randomly, then the error in any estimate of the mean size of all the particles within the sampled area or transect depends, first, on the actual variation in size of all the particles within the area and, second, on the number of particles actually measured. Thus if the deposit on the surface is poorly sorted and contains a wide range of sizes, the estimate of the mean size obtained by the grid sampling method is apt to be much further from the true mean than it would be if the deposit at the surface were well sorted. The error involved may be reduced by measuring a larger number of pebbles. Experience as well as statistical theory shows, however, that with increasing number of measurements accuracy increases at a gradually decreasing rate. The improvement in accuracy from a count of 2 particles to one of 25 particles, for example, is much greater than that from 25 to 100. The probability that a certain accuracy has been attained can be estimated by simple statistical methods and is expressed as the confidence limit. An estimate of the confidence limit can be obtained as follows:

$$\text{Estimated confidence limit, in } \phi \text{ units} = \bar{x} - u = \frac{ts}{\sqrt{n}},$$

where $\bar{x}$=estimated means, u=true means, s=estimated standard deviation (all in phi units); n is the number of individuals in the sample, and t is a statistic (Dixon and Massey, 1951, app., table 5, p. 307). The estimated standard deviation, which is a measure of the sorting or range in size of the sample, can be obtained from the cumulative curve of size classes (fig. 2) as follows:

$$\text{Estimated standard deviation} = \frac{P_{84} - P_{16}}{2},$$

where P_{84} is the 84 percentile and P_{16} is the 16 percentile (both in phi units).

The Trask sorting coefficient, another measure of sorting, can be obtained from the cumulative curve of range in size (fig. 2) as follows:

$$\text{Trask sorting coefficient} = \sqrt{\frac{P_{75}}{P_{25}}},$$

where P_{75} is the 75 percentile and P_{25} is the 25 percentile (both in millimeters).

To illustrate the use and accuracy of the method, counts at three localities in subgroups are shown on figure 2 and table 1. As shown in the table, sample AM 38 has a standard deviation of 2.18 phi. The estimated confidence limit or maximum difference that can be expected between the mean of the sample and the mean of the deposit as a whole (9 times out of 10) is 0.6 phi. For sample AM 35, which has a lower standard deviation and a larger number in the count, the confidence limit is 0.2 phi. For a pavement (sample AM 39) where the sorting is very good (estimated standard deviation 1.6 phi), the confidence limit is low compared with that of other samples having a similar number of individuals.

In practice it was deemed advisable to sample the fans at many places using a count of 25 individuals at each place rather than to measure many particles at a small number of places. On the average the mean values obtained at most sample sites can be expected to be within 0.5 phi unit of the true values.

The values of estimated mean size used in this report are true geometric means because the original measurements and the calculations were in phi units. These values are comparable with those measured by Hack in streams in the Appalachian region (Hack, 1957). Since the size distribution of such alluvial deposits is approximately log normal, Hack's median grain sizes are estimated geometeric means and thus are comparable with those from the Death Valley region. Measurements of size bed material in streams in the southern Rocky Mountains made by Miller (1958) yielded values that also appear to be comparable. The estimates from all three regions are based on a grid method of sampling of the surface of the deposits.

For each locality sampled in the field, one or more of the following measurements were made from topographic maps in the laboratory: (1) altitude, (2) distance to divide, (3) fall or difference in altitude between drainage divide and sample locality, (4) slope, and (5) drainage area above the sample locality. Most sample sites were selected along a main fan-building wash, and the distance to divide was measured along the wash. For sample sites on areas of desert pavement and on fans or parts of fans where no single, well-defined wash occurs, distance to divide was measured along a radius from the apex. In this paper all slope

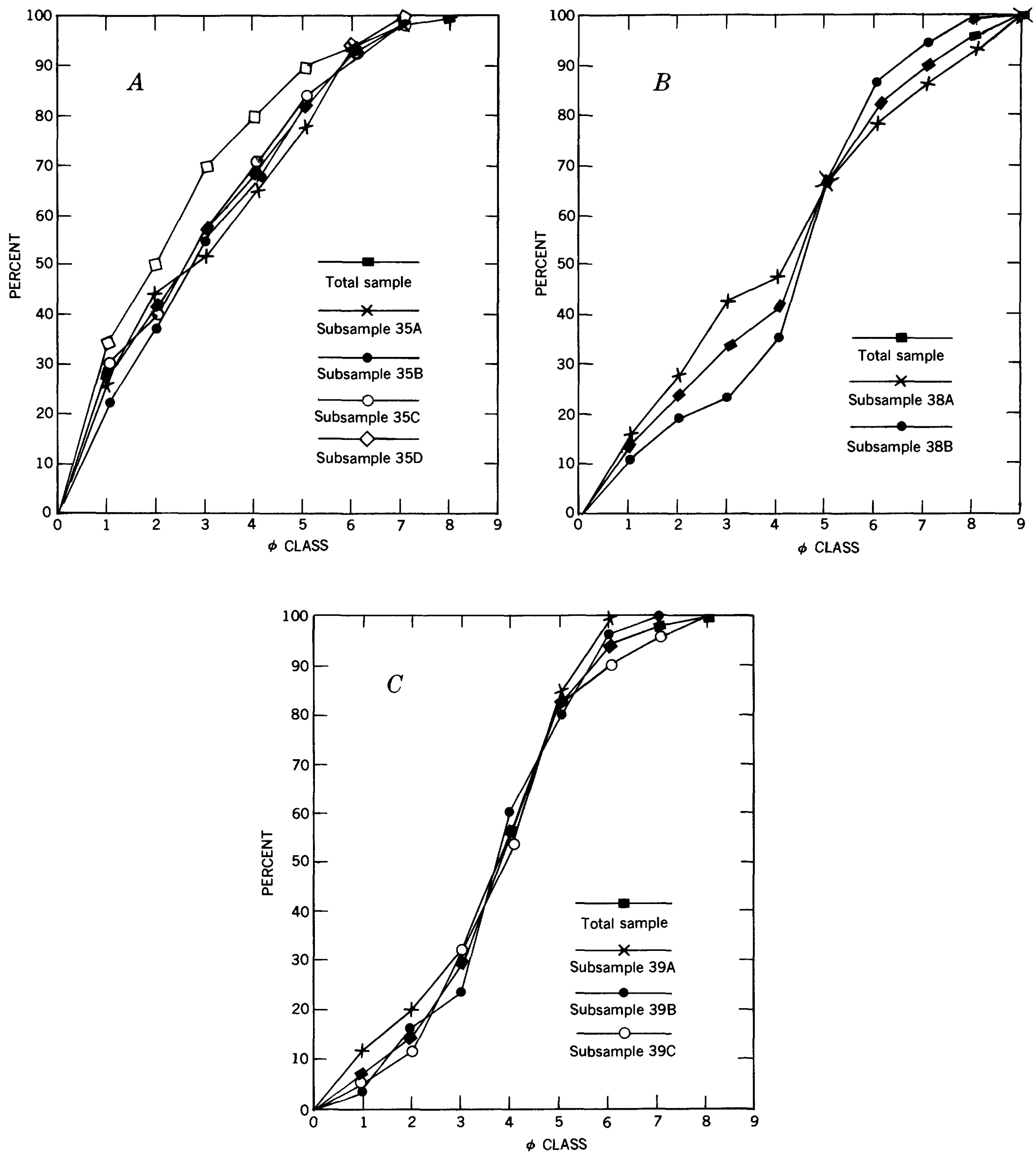

FIGURE 2.—Cumulative curves of samples from surface of washes floored with unweathered gravel and from weathered gravel of desert pavement, Ash Meadows quadrangle, Nevada-California. *A*, wash, sample AM 35; *B*, wash, sample AM 38; *C*, pavement, sample AM 39.

TABLE 1.—*Size analyses of samples of unweathered gravel on the surface of washes and of the weathered gravel of desert pavement, Ash Meadows quadrangle, Nevada-California*

Sample	Subsample	Number of individuals in sample	Mean size		Difference between mean of whole sample and means of subsamples		Estimated standard deviation	Standard deviation	Estimated confidence limit (90 percent of the time)
			ϕ	Millimeters	ϕ	Error (percent)	ϕ	ϕ	ϕ
AM38 (Wash)		50	−3. 8	14. 0			2. 5	2. 18	0. 60
	38A	25	−3. 7	13. 0	0. 1	2	2. 6	2. 44	. 80
	B	25	−4. 2	18. 5	. 4	10	2. 2	1. 95	. 70
AM35 (Wash)		350	−2. 7	6. 5			2. 3	1. 98	. 20
	35A	100	−3. 0	8. 0	. 3	11	2. 4	2. 06	. 35
	B	100	−2. 9	7. 4	. 2	7	2. 2	1. 95	. 35
	C	100	−2. 5	5. 6	. 2	7	2. 3		
	D	50	−2. 1	4. 2	. 6	22	2. 0	1. 84	. 40
AM39 (Pavement)		100	−3. 7	13. 0			1. 6	1. 57	. 30
	39A	25	−3. 6	12. 0	. 1	2	1. 8	1. 59	. 60
	B	25	−3. 9	15. 0	. 2	5	1. 7	2. 09	. 60
	C	50	−3. 7	13. 0	. 0	0	2. 1	1. 65	. 50

data are taken from a topographic map, unless otherwise stated, because experience shows that measurements of slopes over a long distance from a topographic map give more consistent results than do measurements over a short distance in the field. All the field and laboratory measurements used in this report are presented in table 7 (p. 43).

DEFINITIONS AND SYMBOLS

The following definitions and symbols are used in the text unless otherwise specified:

The area of fan or fan segment (Af) is measured by planimeter on a map, in square miles.

The drainage or source area (Am) is the area of the basin above sample locality measured by planimeter on a map, in square miles.

Width (W) is the width of a wash at a sample locality, in feet.

GEOGRAPHY

The fans discussed in detail are in the Amargosa Valley east of the Greenwater Range and east of the southeast end of the Funeral Mountains (fig. 1). This segment of the valley is a broad area of sloping alluvial plains bordered by low moutains that rise about 3,000 feet above the river and are bordered by piedmonts 1 to about 6 miles long, measured at right angles to the mountain front. The foot slopes are largely alluvial fans, and the total area of pediment is small. The Shadow Mountain fan, east of Death Valley Junction, is part of the alluvial apron at the northwest end of the Resting Spring Range. The Bat Mountain fan, northwest of Death Valley Junction, is close to the southeast end of the Funeral Moutains. These two fans, and the others briefly described, are listed in table 2, and their approximate location is shown on figure 1. Two of the other fans are in Greenwater Valley, which lies between the Amargosa River and Death Valley. One, perhaps in part a pediment, is north of Funeral Peak; the second, a small one, is on the east side of the valley southwest of Deadman Pass. Five fans in Death Valley are discussed briefly: three are on the west side of the valley east of the Panamint Range, at the mouths of Trail, Hanaupah, and Johnson Canyons; and two, Copper Canyon fan and Willow Creek fan, are at the foot of the Black Mountains east of the valley floor.

The climate of the region is warm and dry. Trees are absent except in the higher parts of the Panamint Range. Climatological data are given in the following table:

Summary of climatological data

[U.S. Weather Bur., 1932, 1935; Troxell and Hofmann, 1954; C. B. Hunt, written commun., 1960]

Area	Average annual precipitation (inches)	Temperature (°F)	
		Summer	Winter
Floor of Amargosa Valley.	3–4; snow rare.	Average maximum for July, >100.	Minimum for for December and January, <32.
Mountains adjacent to Amargosa Valley.	Slightly more than 4; occasional snow.		
Floor of Death Valley.	1.65	Average for July, >100.	Minimum rarely below freezing.
Higher parts of Panamint Range.	12–15 (estimated); snow common.		

TABLE 2.—*Fans and washes described in this report*

Regional subdivision	Name and location (fig. 1)	Source area				Piedmont						
		Bedrock	Altitude of summit (feet)	Relief apex to divide (feet)	Drainage area (sq mi)	Approximate length (miles)	Relief toe to apex (feet)	Areas in square miles (values in parenthesis are in percent.)				
								Total area	Area of desert pavement	Area of varnished gravel	Area of unweathered gravel	Area of varnished and unweathered gravel
East side of Amargosa Valley, west of Shadow Mountain	Shadow Mountain fan, east of Death Valley Junction, Ash Meadows quadrangle	Quartzite and subordinate shale, limestone, and dolomite	5,071	1,591	2.73	6.0	1,450	[1] 8.95 (100)	3.26 (36.4)	3.65 (40.8)	1.71 (19.1)	5.36 (59.9)
	Fan east of Alkalai Flat, southeast of Death Valley Junction, Ash Meadows quadrangle	Quartzite and subordinate shale	5,071	1,721	1.10	4.0	1,350	3.68 (100)	.73 (19.6)			2.95 (80.2)
West side of Amargosa Valley, east of Funeral Mountains	Bat Mountain fan, northwest of Death Valley Junction, Ash Meadows quadrangle	Limestone, dolomite, fanglomerate, and subordinate sandstone, and shale	4,963	2,123	1.14	4.5	750	3.93 (100)	0.78 (19.8)	[2] 2.39 (60.8)	0.76 (19.4)	3.15 (80.2)
West side of Amargosa Valley, east of Greenwater Range	Wash northwest of Lila C mine, Funeral Peak quadrangle	Volcanic and sedimentary rocks, chiefly basalt, rhyolite, vitrophyre, tuff, sandstone, and conglomerate	4,006	786	.23	8.5	1,000	Individual fans merge on lower half of piedmont.				
	Wash southeast of Lila C mine, Funeral Peak and Eagle Mountain quadrangles		4,276	1,476	2.80	6.0	800					
	Wash west of Eagle Mountain, Funeral Peak and Eagle Mountain quadrangles		4,982	1,742	4.11	7.0	1,240					
	Segment of piedmont between Lila C mine and Deadman Pass, Funeral Peak, Ash Meadows and Eagle Mountain quadrangles		4,982	about 2,000	16.31	4.7–7.0	1,250 (max)	19.96 (100)	8.85 (44.3)	-------	-------	11.11 (55.7)
Greenwater Valley	Wash southwest of Deadman Pass, Eagle Mountain quadrangle	Monzonite	4,056	696	.14	2.0	530	Fan merges with adjacent ones on lower half of piedmont.				
	Wash north of Funeral Peak, Funeral Peak quadrangle		6,287	1,087	.50	3.0	1,240	Fan merges with adjacent ones. May be thin mantle over pediment.				
East side of Death Valley, west of Black Mountains	Willow Creek fan, Funeral Peak quadrangle	Metadiorite, monzonite, and volcanic rocks	6,317	6,417	22.35	.6	150	0.41 (100)	0.03 (7)	0.00 (0)	0.38 (93)	0.38 (93)
	Copper Canyon fan, Funeral Peak and Bennetts Well quadrangles	Sandstone, siltstone, fanglomerate, and metadiorite	6,160	5,980	22.26	1.5	440	2.28 (100)	.20 (9)	.72 (32)	1.36 (59)	2.08 (91)
West side of Death Valley, east of Panamint Range	Trail Canyon fan, Emigrant Canyon and Furnace Creek quadrangles	Quartzite, argillite, and dolomite	9,064	7,504	23.76	5.0	1,810	11.47 (100)	3.14 (27)	4.68 (41)	3.65 (32)	8.33 (73)
	Hanaupah Canyon fan, Telescope Peak and Bennetts Well quadrangles	Quartzite, argillite, and granitic rocks	11,049	9,009	25.68	5.5	2,290	13.12 (100)	6.47 (49)	3.18 (24)	3.47 (27)	6.65 (51)
	Johnson Canyon fan, Telescope Peak and Bennetts Well quadrangles	Quartzite and argillite	9,636	7,336	17.88	6.5	2,550	14.53 (100)	8.76 (60)	2.67 (18)	3.10 (21)	5.77 (40)

[1] Includes 0.32 sq mi (3.7 percent) underlain by fine-grained beds of Quaternary age.

[2] Includes areas where individual patches of pavement, varnished gravel, or unweathered gravel are too small to be mapped separately.

The maximum air temperature recorded in Death Valley at Furnace Creek Ranch is 134°F (U.S. Weather Bur., 1935). In the Amargosa Valley the highest recorded temperature, at Clay Camp in the Ash Meadows quadrangle, is 118° F in July; the lowest is 3°F in December. On the floor of Death Valley, ground temperatures as high as 190°F have been reported (C. B. Hunt, written commun., 1960). During the summer of 1957, a reading of 162°F was recorded on a desert pavement in Amargosa Valley.

SHADOW MOUNTAIN FAN

Shadow Mountain, rising about 3,000 feet above the Amargosa River, is bordered by a sloping piedmont 3–6 miles wide underlain by Quaternary alluvial deposits. In the area mapped (pl. 1), this piedmont is a complex alluvial fan bordered by small areas of older rocks that have been beveled by erosion and form pediments. Near the mountain front where the fan has a maximum slope of 700 feet per mile (fig. 3), the fan is a complex of narrow ridges and washes as much as 50 feet in

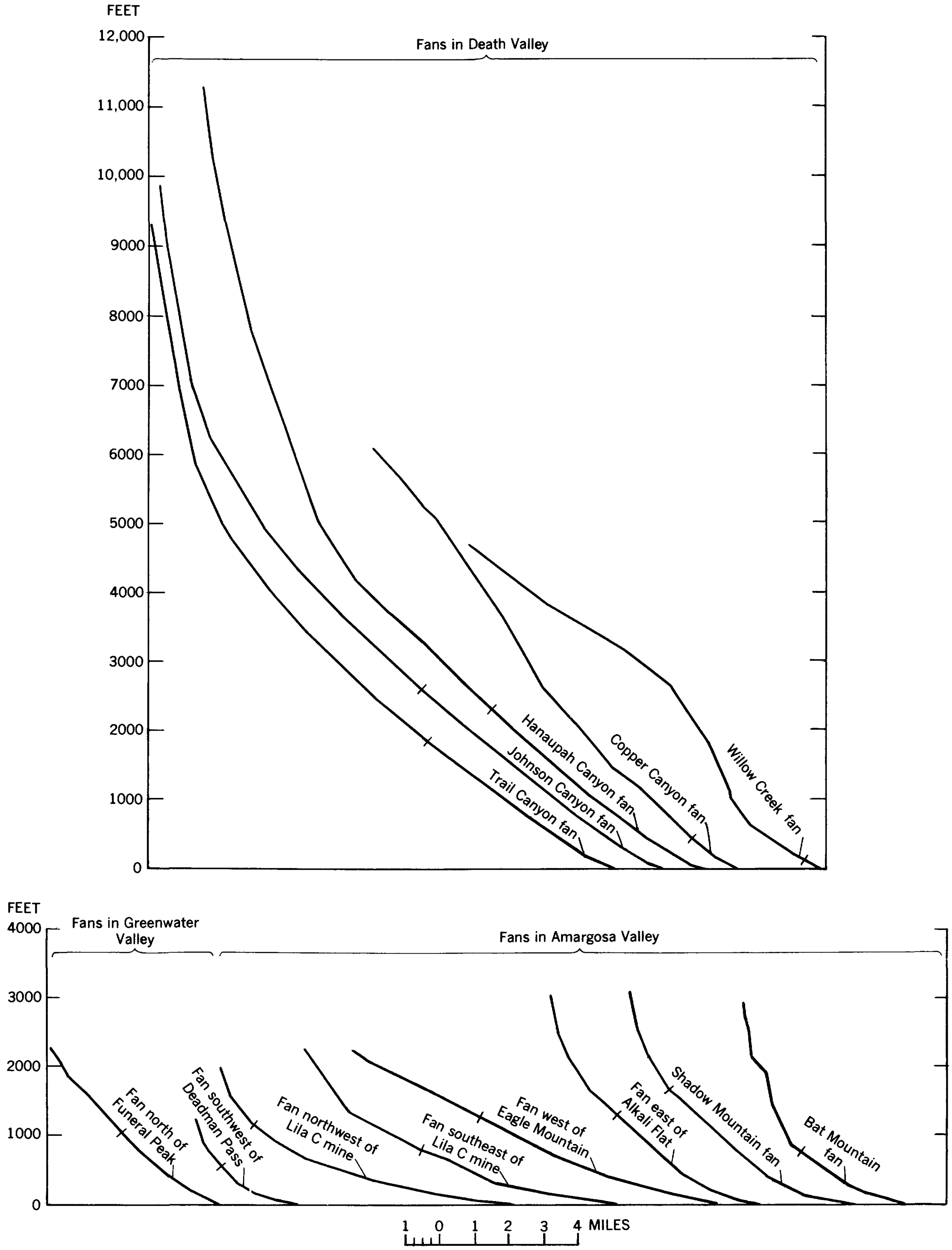

FIGURE 3.—Longitudinal profiles of fan-building washes in the Death Valley region. Profiles extend along the main wash from the drainage divide in the mountains to the toe of the fan. Position of the apex of a fan is shown by tick mark. The vertical exaggeration is about ×10.

depth. Broad washes separated by extensive areas of desert pavement appear a short distance down the fan, but the pavements narrow and come to an end before reaching a point half way between the apex and the toe. An expanse of braided channels and gravel bars dotted by small areas of pavement, especially near the toe, extends westward to the flood plain of Carson Slough.

The geoloy of the fan was mapped on a scale of about 4 inches per mile (pl. 1), and the size of material at the surface was measured at sample sites along a traverse from the toe of the fan to the summit of Shadow Mountain and at other localities. The sample sites are shown by number on plate 1, and the data from the measurements are recorded in table 7. In some places the boundary between wash and pavement is arbitrary. The determination of the boundary is especially difficult on the western part of the fan, where both the local relief between pavement and wash and the size of the individual areas decrease toward the toe.

GEOLOGY

Shadow Mountain is underlain by east-dipping beds of probable Cambrian age, which are composed of gray and brownish quartzite and subordinate micaceous shale and quartzite-pebble conglomerate. Along the west base of the mountain is a narrow band of limestone and dolomite, probably also of Cambrian age, that is faulted against the quartzite. Low hills north of Shadow Mountain consist largely of fanglomerates of late Cenozoic age that rest unconformably on the Paleozoic rocks and are themselves somewhat tilted and faulted.

The Quaternary deposits that form most of the piedmont west of Shadow Mountain are a little-deformed accumulation of arid-basin sediments that rest unconformably on the older rocks. The fragments are composed largely of quartzite and, near the mountain front, range in size from silt to boulders. Away from the mountain the proportions of the larger sizes decrease, and silt, sand, and clay are dominant near the toe. Most of the deposits are cemented by caliche. At the north and south edges of the fan (pl. 1) are small outcrops of eastward-dipping beds of sandstone and clay, veneered with gravel, and low hills of fanglomerate. The flood plain of Carson Slough and Alkali Flat, west of the fan, are floored with unconsolidated silt, sand, and clay.

GEOMORPHOLOGY

The surface of the Shadow Mountain piedmont can be divided into four geomorphic units (pl. 1)—modern washes, abandoned washes, desert pavement, and pediment (fig. 4)—which differ in topographic form and in the nature of the material at the surface. The modern washes are those segments of the piedmont that appear to be areas of active erosion or deposition at the present time. Desert shrubs are absent. The material that floors these washes is unweathered and lacks the coating of desert varnish characteristic of much of the surface of the fans in this region. The modern washes constitute only a small portion of the surface of any fan, a fact suggesting that most of them have a complex history.

The abandoned washes support a growth of desert shrubs and are floored with stones that have a coating of desert varnish. They are stream channels in which shrubs have grown and whose floor has acquired a coating of varnish since the last time they were flooded. Unforunately, it is not known how long ago such a flood took place. Nevertheless, the greater extent of the abandoned washes as compared with that of the modern ones suggest that the regimen of the modern streams may differ from that represented by the abandoned washes. The size of the bed material in these two types of wash also differs.

Desert pavements are armors of rock fragments that rest on and protect a layer of silty material apparently weathered from the gravel below. The fragments have a coating of desert varnish and are tightly packed together. A pavement is dark colored, gently sloping, and smooth surfaced and lacks the channels and bars of a wash. The areas of pavement on the Shadow Mountain fan show as a dark stippled pattern on an aerial photograph (fig. 4). A pavement is a segment of a fan on which no new sediment has been deposited for a long time. The range in size of the constituents of the pavements depends not only on the size of the gravel from which the pavement is derived but also on the weathering, mass movements, and erosion that have combined to transform the channeled surface of a wash into a smooth pavement.

The pediments on the piedmont northwest of Shadow Mountain occupy small areas marginal to the fan, where deformed rocks largely of Tertiary age have been beveled and mantled by gravel and are now dissected to expose the buried pediment.

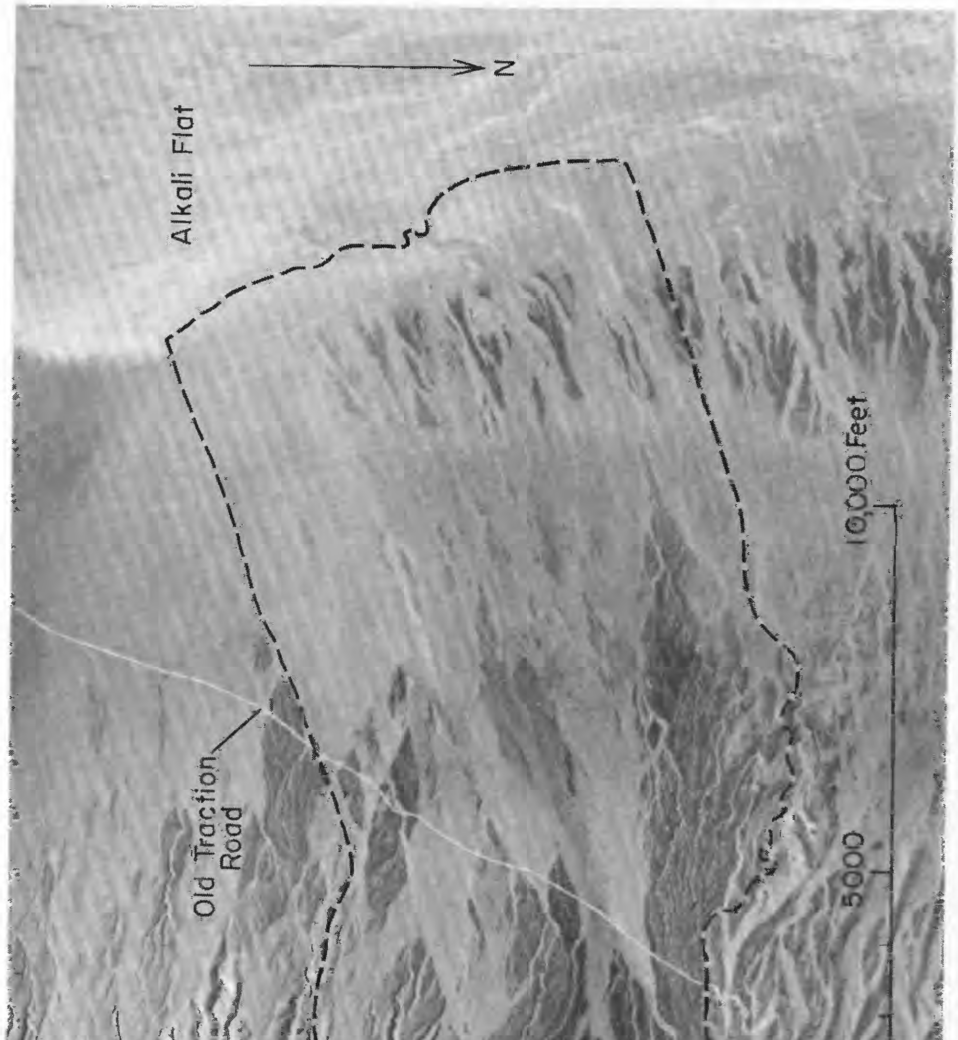

FIGURE 4.—Aerial photograph of the Shadow Mountain fan. Area outlined is that shown in plate 1.

MODERN WASHES

Braided channels and gravel bars with a microrelief ranging from 1 to 3 feet constitute the modern washes. Those mapped range in width from 50 to several hundred feet. The channels and bars, generally lacking vegetation, are underlain by bouldery to pebbly gravel and sand; the coarse fragments are angular to subangular blocks and slabs that are almost unweathered, and the exposed fragments are not coated with desert varnish.

The modern washes are not uniformly distributed over the fan but are most extensive near the mountain front, in midfan downstream from the mouths of washes heading in pavements, and near the toe. On the lower part of the fan, on plate 1 in the vicinity of the 2,200-foot contour, a broad indefinite zone occurs where the modern washes divide into many channels that narrow westward. Some of the channels finger out and end in a broad area of abandoned washes, whereas others continue westward as narrow channels too small to map at the scale of plate 1. Where small pavements and fine-grained arid-basin sediments occur near the toe, modern washes are also present, but near the southern part of the toe of the fan, the fine-grained beds are absent and the surface is a mosaic of abandoned washes.

The mean size of the gravel that floors the modern washes—that is, the surface layer—ranges from about 20 mm near the mountain front to less than 5 mm near the toe (fig. 5). The microrelief of the surface also decreases downfan. These values of mean size are smaller than those of the gravel on the surface of the abandoned washes or the pavements, although the rate of decrease in size downfan is about the same as that for the gravel in the abandoned washes.

A very rough estimate of the effects produced by present-day runoff in the modern washes is afforded by measurements of erosion of the Old Traction Road. Built about 1905 but not maintained, the road is a continuous 15-foot-wide embankment whose top is about at the level of the highest part of the adjacent wash. Part of this embankment has been washed out, and the amount of material removed is a measure of the total erosion on the Shadow Mountain fan during the last 50 years. Near the Old Traction Road, about a third of the area mapped as modern or abandoned washes has been subject to overflow during this time, and of the third, about half shows evidence of erosion. The evidence comprises 24 cuts through the roadway; the cuts range in depth from 6 inches to about 3 feet and in width from 4 feet to as much as 180 feet.

The direction of flow of the stream in a modern wash on the northeast edge of the Shadow Mountain fan has recently changed. Such diversion or piracy is an important element in the history of this fan and doubtless of many others (Rich, 1935; Hunt and others, 1953). The modern wash running westward just south of the State line (pl. 1) narrows abruptly and then passes as a single channel through as mall area of fanglomerate (near loc. 74) into an extensive pavement. The floor of the modern wash is only 5–10 feet below the smooth surface of the fanglomerate and only a foot or two below the surface of the large area of abandoned washes just north of locality 74 that extends northwestward beyond the mapped area. Clearly, the stream in the

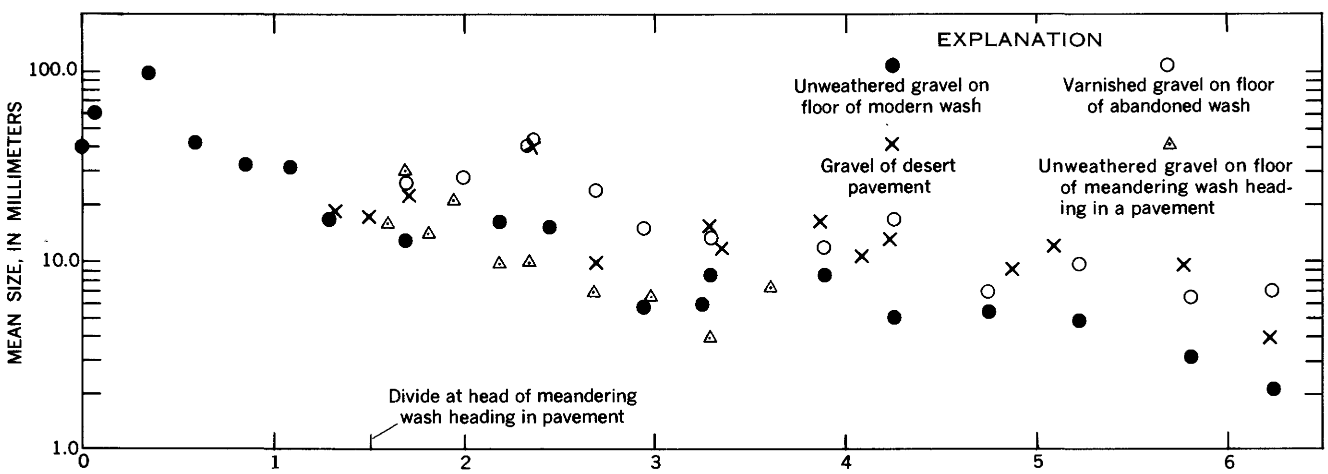

FIGURE 5.—Semilogarithmic scatter diagram showing the relation between the mean size of material at sample sites on the surface of the Shadow Mountain fan and the distance of these sites from the divide (pl. 1). The diagram includes size measurements of fragments forming the desert pavement and of the gravels that floor both modern and abandoned washes. Data are also shown for unweathered gravel on the floor of a meandering wash heading in a pavement.

modern wash once flowed northwestward. The present course of the wash through the fanglomerate probably resulted from overflow or from lateral cutting by the stream, which thus spilled into the head of a west-flowing gully whose floor was at a lower level than that of the wash. This diversion could have taken place during the last few hundred years, and a cloudburst might even now send water and debris down channels in both directions.

ABANDONED WASHES

Abandoned washes, the most extensive geomorphic unit on the fan, are the somewhat subdued remnants of braided stream channels in which water has not flowed for a long time. The channels contain faint broad ridges and swales having a relief of several feet and spaced 5–20 feet apart. The ridges and swales are covered by gravel and boulders; commonly, the ridges are more bouldery than the swales. Desert shrubs a few feet to as much as 15 feet apart are scattered over the surface. Abandoned washes are floored with gravel whose exposed stones are varnished but otherwise not greatly weathered. The intensity of the varnish varies: in some places the pebbles have only a faint coating, and in other places the floor of the wash appears dark colored because the exposed fragments are thickly coated.

The estimated mean size of the gravel on the surface of abandoned washes from near the apex to the toe of the fan (pl. 1; table 7, varnished gravel in abandoned washes) generally ranges from 7 to 25 mm (fig. 5). These means are slightly larger than those for the unweathered gravel of the modern washes at the same distance down the fan. Presumably, when the abandoned washes carried water, the flood discharges were greater than they are today. The fragments are slightly rounded, and in general are distinct from the angular fragments of a pavement. The surface of an abandoned wash has a slightly greater relief than does a modern one. An abandoned wash may lie as much as 2 feet above the level of an adjacent modern one, or their positions may be reversed, the modern wash being either built out over the adjacent abandoned wash or separated from it by a higher-standing area of desert pavement.

The character of the abandoned washes changes to some extent from the apex to the toe of the fan. Although the spacing between the individual ridges and swales is constant, the relief between them decreases from as much as 5 feet near the apex to a maximum of about 2 feet on the lower half of the fan. The local relief near the toe is seldom more than a few inches. The color of the varnish that coats the fragments at the surface changes from place to place, being slightly lighter colored near the apex and the toe than elsewhere on the fan.

The varnish that coats quartzite fragments flooring the abandoned washes is evidence that these washes have not carried water for many years. If the time when the stones were coated could be determined, a minimum age for these abandoned water courses could be estimated. Engle and Sharp (1958) described a locality where desert varnish has formed on fragments of rhyolite in 25 years, and C. B. Hunt (1954) and A. P. Hunt (1960) cited abundant archaeological evidence that most varnish coatings are at least 2,000 years old. During the building of the Old Traction Road about 1905, pavements were disturbed and the varnished stones removed from areas adjacent to the road (a situation not unlike that described by Engel and Sharp (1958) at the South Stoddard locality near Barstow). The road was never maintained, and the areas of moved stones and of bare ground adjacent to it probably have not been disturbed for more than 50 years. These quartzite fragments, moved or disturbed during road construction, have not acquired a visible coating of varnish in about 50 years. Thus the time since the last water flowed down these abandoned channels is in excess of 50 years and doubtless is much more, perhaps more than 2,000 years.

Other considerations, however, suggest that an estimate of thousands of years is too large. On the lower part of the fan, the floor of a modern wash is in many places less than a foot below the surface of the adjacent abandoned one. Therefore, water deeper than 1 foot has not flowed down a modern wash on the lower part of the fan. The magnitude of the occasional floods that have occurred in the Death Valley region during the last century make it seem likely that during the last 2,000 years many floods reached the toe of the Shadow Mountain fan with depths of more than a foot. Thus, I believe that the last flows down the abandoned washes are more likely to have occurred within the last few hundred years than prior to the beginning of the Christian era.

ORIGIN OF WASHES

The modern and abandoned washes are those parts of the fan where erosion and sedimentation have taken places during the last few hundred to few thousand years. The distribution of the modern washes suggests that at present these processes are vigorous on only a small part of the fan—namely, at the moutain front, downfan from areas of pavement, and near the toe. These areas are the areas of more rapid runoff—the bedrock slope of the mountain and the smooth surface of a pavement—compared with the broad areas of abandoned washes, where little erosion or deposition have occurred for a long time.

The abandoned washes, on the other hand, record a time when flooding of the fan was more extensive than at present, and presumably a time of more active erosion and deposition. This condition is suggested both by the coarse debris on the floors of the abandoned washes (fig. 5) and by the much greater areal extent of the washes as compared with the modern ones. Although a gradual lateral shift of the modern washes would cover some of the areas of abandoned wash, large areas of abandoned wash on the lower part of the fan are not traversed by mappable areas of modern wash. When the abandoned washes were active areas of erosion and deposition, floods must have spread downfan much further than they do at the present time.

When these large areas of abandoned washes were flooded, the total discharge presumably was greater, because of either greater yearly or summer rainfall, less evaporation, or a combination of both. Such flooding may have occurred at various times, from only a few hundred years ago to as far back as the beginning of the Christian era, when Death Valley contained a shallow lake (C. B. Hunt, written commun. 1960).

Both erosion and deposition take place along a wash, and it is difficult to be certain whether during some time interval the net result has been to build up or to lower the surface of the wash. The surfaces of some areas of wash, however, have the form of the segment of a very low cone, suggesting that these washes are areas where deposition has been dominant. A good example is the circular area of abandoned washes near the apex of the Shadow Mountain fan, between localities 430 and 426 (pl. 1). On a map, the contours crossing this area are convex downfan. This depositional segment, shown on figure 6*A* as area 2d, was built up by debris carried to it from a small area on the northwest slope of Shadow Mountain (area 2s, fig. 6*A*) and can be described informally as a "fan on a fan." Just north of locality 78, varnished gravel of an abandoned wash laps over the edge of the adjacent pavement. Some water was lost by percolation and evaporation in this depositional segment; the remainder flowed westward between pavements in channels where erosion and transportation were the dominant processes.

Three additional areas of washes whose surfaces are cone shaped are present on the Shadow Mountain fan, and their locations are shown on figure 6*A* as depositional areas 1d, 3d, and 4d. These three depositional segments and their source areas are briefly described in the following paragraphs. Their conical surface form is too subdued to be shown by the 200-foot contours on plate 1, but the reader will find that the conical form is suggested by the 40-foot contours on the topographic map of the Ash Meadows quadrangle, Nevada-California, published by the U.S. Geological Survey.

The first area is west of the segment of the Old Traction Road that lies between sample localities 73 and 69 and south of the extensive pavement along the north edge of the fan (pl. 1)). This is a large area of abandoned washes with a faintly cone shaped surface (area 1d, fig. 6*A*) whose western limit is about midway between altitudes of 2,200 and 2,400-feet. This depositional segment received sediment from much of the eastern half of the pavement along the north edge of the fan (area 1s). The depositional segment previously mentioned near the apex of the fan (area 2d) is also a part of the area that drained to the larger segment 1d. The smaller segment, however, is not considered a source of sediment for the larger one because it was itself an area of deposition.

The source area of depositional segment 1d is drawn on figure 6*A* to exclude a large area, near the State line, that now drains to it (roughly the same as area 5s, fig. 6*B*). We can assume that the source area of depositional segment 1d did not include area 5s because, as mentioned on page 11, the diversion of drainage that caused area 5s to drain into area 1s took place only a short time ago, probably after much of the gravel in area 1d had acquired its coating of desert varnish. When the gravel of area 1d was being deposited, area 5s was supplying sediment to areas of wash north of the fan.

Two other areas of wash with slightly cone-shaped surfaces are shown on figure 6. Area 3d is a small diamond-shaped segment of abandoned washes south of area 1d, between it and the Old Traction Road, that was fed by drainage from source area 3s, the long narrow pavement just to the east (pl. 1, locs. 69–78). Area 4d includes two areas of deposition: one just north of the area of pediment near the southern edge of the map and the other farther north separated from the first area by a large diamond-shaped pavement. Area 4d received sediment from the west slope Shadow Mountain and adjacent areas of pavement (source area 4s).

In order to show the significance of these three areas as well as other depositional segments in the formation of the Shadow Mountain fan, one of the conclusions of this paper (p. 38) must be mentioned in advance of the presentation of all of the facts on which it is based. Plate 1 shows that the Shadow Mountain fan consists of segments of modern and abandoned washes and of areas of desert pavement. The analysis of the data of several fans in the Death Valley region demonstrates that the areal extent of the segments of a fan is related to that of their source areas in the mountains. The size of the depositional segments of which the fans are com-

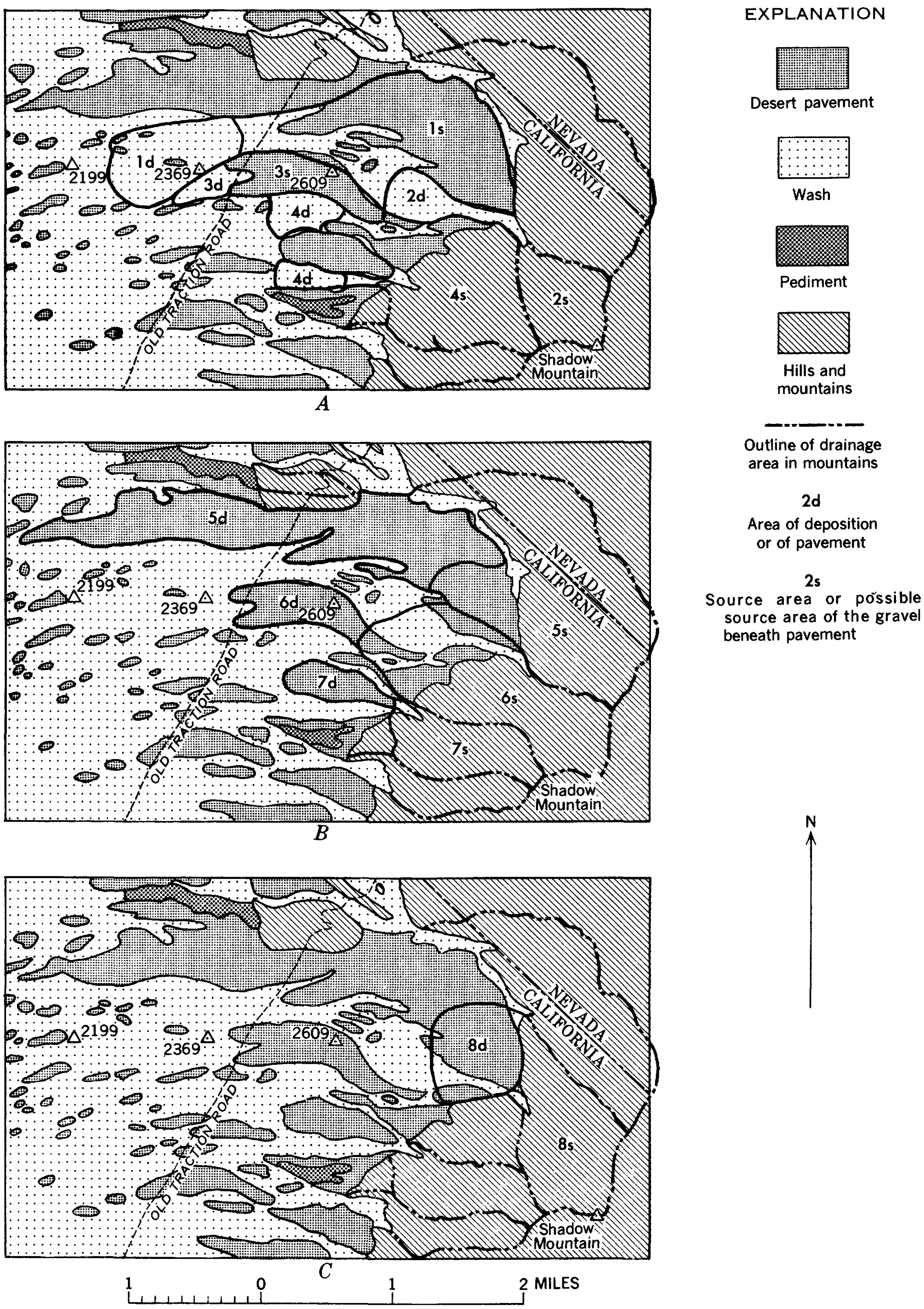

FIGURE 6.—Areas of deposition on the Shadow Mountain fan and their possible source regions. *A*, Areas of deposition in washes—areas with faintly cone-shaped surface—and their possible source areas that supplied water and sediment; *B*, three pavements and the possible source areas of the gravel that underlies them; *C*, one pavement and possible source area of the gravel that underlies it. Related source and depositional areas shown by same number. Maps generalized from plate 1.

posed is roughly equal to one-third to one-half the size of their source areas.

On the Shadow Mountain fan, the four areas of deposition having slightly cone-shaped surfaces range in areal extent from 0.08 square mile to 0.46 square mile whereas their source regions range from 0.27 square mile to 1.26 square miles, as given in the following table:

Segment (fig. 6)	*Depositional segment (sq mi)*	*Source area (sq mi)*
1	0.46	1.26
2	.16	.43
3	.08	.27
4	.23	.95

A logarithmic plot of these values (fig. 7) shows that they fall about a line, drawn by inspection, that in-

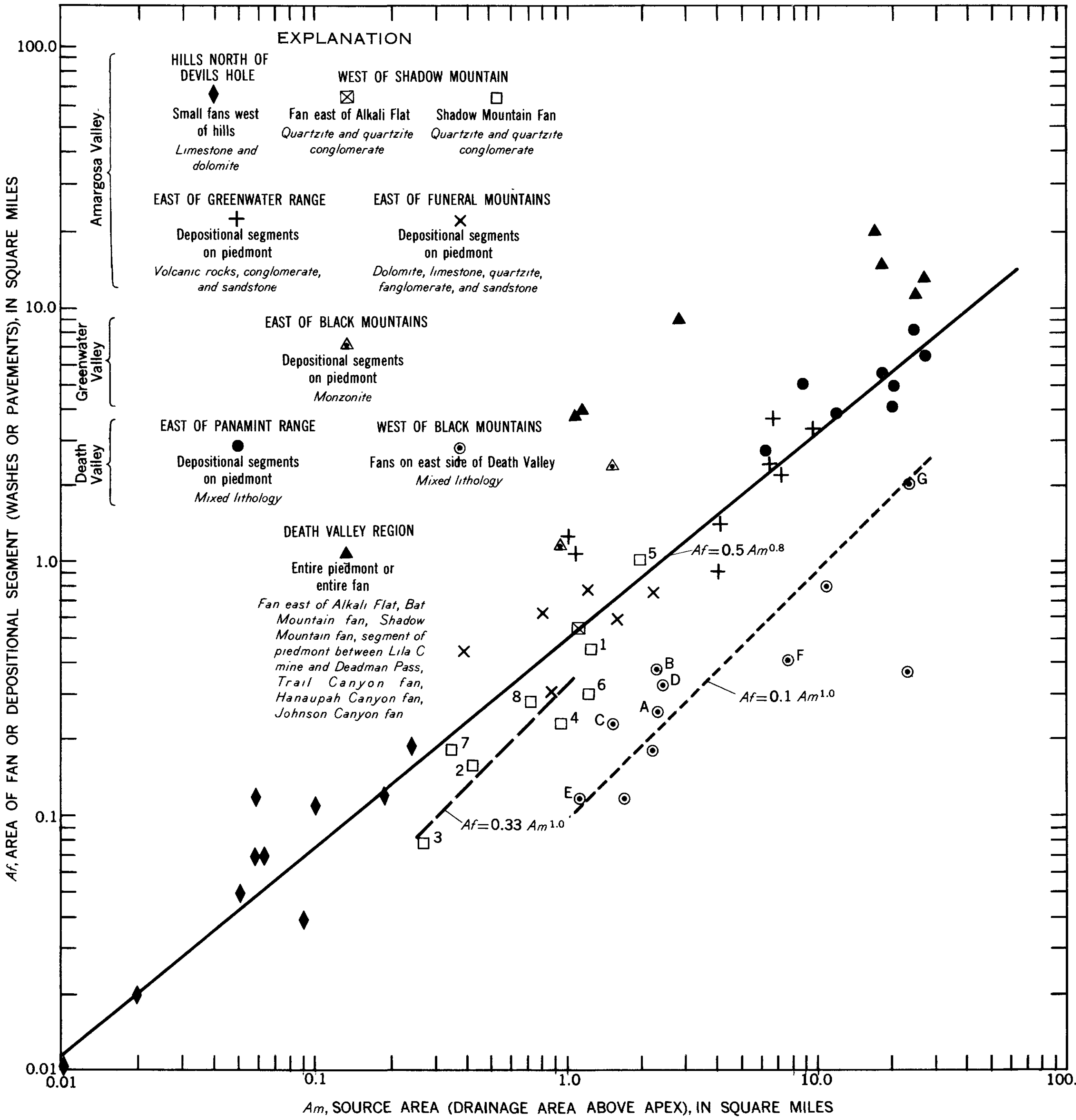

Figure 7.—Logarithmic graph showing the relation between the area of a fan or depositional segment on a fan and its source area in adjacent mountains. Points for about 60 fans are shown and are grouped with the highland from which they are derived. Data used in construction of the graph are given in tables 2 and 7. Numbers for areas on the Shadow Mountain fan are shown on figure 6. Letters for fans west of the Black Mountains are shown on plate 4. Fans west of the hills near Devils Hole were mapped by C. S. Denny and Harald Drewes (unpub. data).

dicates that these four depositional segments are roughly equal to one third of the area that drains to them ($Af=0.33Am$). Their size and also apparently their location appear to be independent of the position of the toe of the fan. This plot shows four other points representing areas on the Shadow Mountain fan. These are segments of desert pavement and are discussed on page 22.

The graph on figure 7 confirms the view that the piracy believed to have taken place near the north edge of the Shadow Mountain fan is a recent event. If in the graph on figure 7 the source area of desposi-tional segment 1d is assumed to include the area near the State line that now drains to it—that is, to include area 1s plus most of area 5s (fig. 6), or about 3.18 square miles—then the point on the graph representing depositional segment 1d would fall to the right of the three other points for the Shadow Mountain fan and would also fall outside of the cluster of points for most of the other fans described in this paper. Thus the graph on figure 7 supports the assumption that the diversion of most of the drainage from area 5s into depositional area 1d took place so recently that it has not yet caused an enlargement of depositional area 1d.

DESERT PAVEMENT

Desert pavements, common to most fans in the Death Valley region, are smooth, gently sloping surfaces composed of closely packed rock fragments ranging in diameter from a fraction of an inch to several feet. The fragments of a desert pavement constitute an armor that promotes rapid runoff and protects the underlying silty material from removal by water or wind.

Desert pavements occur on all parts of the Shadow Mountain fan but are most extensive near the bordering highlands. The largest single area of pavement, along the northern edge of the map (pl. 1; fig. 4), is about 1,000–3,000 feet wide and more than 4 miles long. The east end of this pavement, forming the embayment in the northwest face of Shadow Mountain, is broken into narrow ridges separated by gullies as much as 50 feet deep. Only the tops of the narrow ridges are typical pavement; most of the land is steeply sloping. The western part of the pavement, however, consists of extensive fan-shaped surfaces trenched by narrow gullies; probably 90 percent of the area is pavement, and only 10 percent is gully. In the eastern half of the map area, most pavements stand a few feet to several tens of feet above adjacent washes. West of the Old Traction Road, pavements are close to or even slightly below the level of the adjacent washes; the streams in the washes may have either scoured the pavement or deposited material on top of it. Near the toe of the fan are many small pavements and narrow outcrops of fine-grained arid-basin sediments. Both the pavements and the fine sediments are absent near the southern edge of the mapped area.

The fragments forming pavements are largely varnished pieces of quartzite and quartzite conglomerate and range in size from pebbles to boulders a foot or more in diameter. Near the west base of the mountain, etched fragments of limestone and dolomite are abundant. The fragments rest on several inches of silty material, which is transitional downward into weathered gravel cemented by caliche. Presumably at greater depth the gravel is little weathered. The armor and underlying silty material probably constitute a weathered mantle developed in the coarse detritus of the arid-basin sediments.

The stones forming the pavements are the weathered relics of the coarse gravelly part on the arid-basin sediments. Many stones are angular fragments, and in some places, adjacent pieces can be fitted together to form the parent cobble or boulder. Most fragments of quartzite and of quartzite conglomerate have weathering rinds a quarter to half an inch thick. The tops of the stones have a dark coating of desert varnish, but the undersides are brown or reddish brown. Some stones have little varnish except for a dark-brown band close to ground level, and still others appear as if they had lost most of an older film of varnish or had recently been overturned or otherwise dislodged from the pavement. Adjacent fragments whose shape and position suggest that they were once part of a single boulder are commonly varnished on all exposed surfaces. The limestone and dolomite fragments of a pavement generally have flat, rough and pitted upper surfaces and rounded undersides coated with caliche. They are unvarnished, except for chert nodules in them. Clearly the limestone fragments have acquired their form by solution while part of a pavement.

Estimates of the mean size of fragments on pavements were made at several localities along a traverse down the fan from the apex (loc. 424–447, pl. 1). The results are given in table 7 and are shown graphically on figure 5. These means generally range from 10 to 20 mm, except near the toe (loc. 447), where the mean is about 4 mm. Size does not markedly decrease downfan, as is true for the gravel in adjacent washes, where the estimated mean sizes are smaller than those of the pavement. The difference is expectable because the fragments on the pavement are part of a weathering profile, whereas those of the washes reflect their mode of transport.

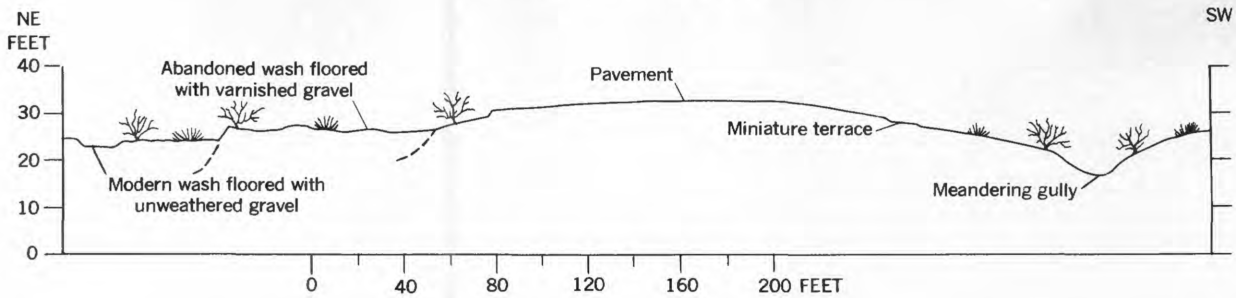

FIGURE 8.—Profile across a pavement and a wash on the Bat Mountain fan, Ash Meadows quadrangle in California. Profile trends roughly northeastward at right angles to the regional slope. At the southwest end, the profile crosses a meandering wash that heads in pavement; the northeast segment of the profile intersects abandoned and modern washes. The profile is drawn to scale; the datum is assumed. For location see plate 2.

In surface form, the Shadow Mountain pavements resemble those found throughout the Death Valley region. The typical pavement is virtually a plain surface that slopes downfan, whereas in a transverse profile, a pavement is commonly slightly convex upward with steeper slopes along its lateral margins (fig. 8). Pavements are relatively smooth near the lower end of the fan; farther upfan, the pavement surface becomes more irregular, apparently as the number and size of the large fragments increase.

Most of the pavements in the Death Valley region are traversed by meandering washes that head on the pavement. From a shallow swale in a pavement, marked by a line of shrubs, a gully descends abruptly to a level that is commonly slightly below that of an adjacent wash (fig. 8) and follows a meandering course downfan to the lower end of the pavement, where it joins a modern wash. Commonly, the gradient of the meandering gully is less steep and the grain size of the material on its bed (fig. 5) is smaller than in neighboring washes. In the embayment at the head of the Shadow Mountan fan are several such steep-walled gullies—for example, the one that begins near locality 465.

FIGURE 9.—Desert pavement composed of angular fragments of varnished quartzite. A few unvarnished pieces are visible in upper left hand corner of photograph. Stones touch or overlap and generally range from 1 to 12 inches in diameter. The larger stones in the middle distance form a curving line, concave to the camera, that extends from the pick handle to the slate. The smaller stones in the background are piled up against the larger ones and form the tread of a miniature terrace. The locality is on Shadow Mountain fan, Ash Meadows quadrangle, California and Nevada.

Few pavements are completely smooth; rather, when examined in detail, miniature steps or terraces less than an inch high can be seen (fig. 9). These miniature breaks are generally only a few feet long and range from 1 to several feet in width (fig 10). Near the edge of a meandering gully or of an adjacent wash, a terrace riser may run parallel to the regional slope of the fan (fig. 8), and near the center of an area of pavement, the miniature terraces commonly trend across the fan at right angles to the regional slope.

Details of several such miniature terraces are shown in plan and profile view on figure 10. Although these examples are on the Bat Mountain fan, similar features are found on the Shadow Mountain fan. The plan view shown on this figure is diagrammatic, but the larger fragments and bands of unusually small fragments are shown in their true positions on the pavement. Actually, the fragments which are generally 1 or 2 inches in diameter touch each other or overlap (fig. 9). The overall slope of the profile is about 4° (375 feet per mile). Only the terraces of small fragments are easily seen; the others are indistinguishable in surface material and are conspicuous only when they cast a shadow. In some places the terrace scarp is a single large fragment of rock, and rarely a continuous band of large fragments marks the riser. Elsewhere, the risers can be traced for 10 feet or more as faint topographic breaks in material of similar size. Most of the stones are uniformly varnished and no variation in extent or appearance of varnished fragments is apparent in either terraced or unterraced pavements.

Desert shrubs grow generally 20–30 feet apart on pavements; but in some places shrub-free areas measure

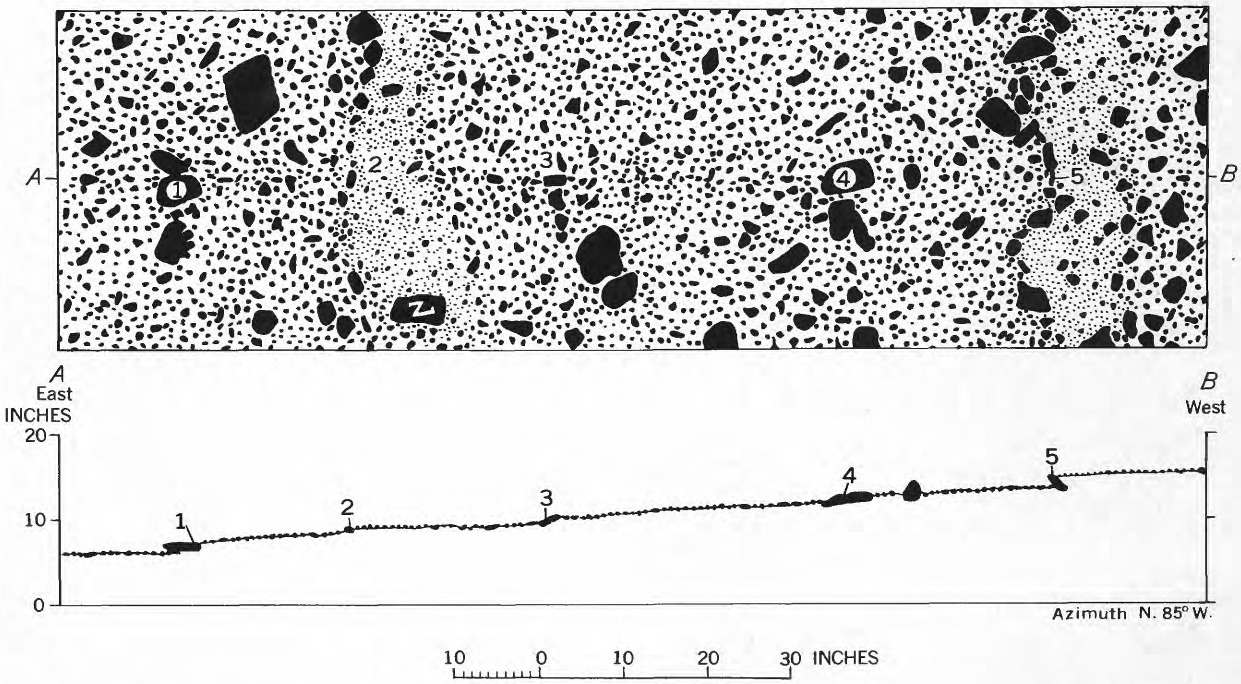

FIGURE 10.—Diagrammatic plan and profile of small area of pavement showing miniature terraces, Bat Mountain fan, Ash Meadows quadrangle in California (loc. 255, pl. 2).

hundreds of feet in diameter, and in other places these plants are spaced every few feet. The ground around a shrub is commonly bare of stones and, in some places, forms a pedestal an inch or so in height on which the plant grows.

Small areas of pavement near the toe of the Shadow Mountain fan adjacent to fine-grained Quaternary deposits (pl. 1) are the top of a thin bed of gravel, a few inches thick, that overlies unconsolidated silt, sand, and clay. The mean size of the fragments is small, and many of them lack desert varnish; the quartzitic fragments have rough exteriors, and the few pieces of carbonate rock are well-formed rillensteine. Between pavements the surface of the Quaternary deposits has abundant surface efflorescences of salt. The ground beneath these pavements is soft, even in dry weather.

The rain that falls on a pavement runs off much more rapidly than that falling elsewhere on a fan (C. B. Hunt, written communication, 1960). Runoff moves not only small particles across a pavement but larger fragments as well. For example, the desert shrubs common to most pavements are surrounded by animal burrows, and the surface is strewn with small white pieces of the caliche that cements the underlying gravel. In some places the pavement downslope from a bush is strewn for distances as great as 8 feet with these fragments carried across the pavement by surface wash.

The extensive pavement along the north edge of the Shadow Mountain fan was studied in a small area just east of the Old Traction Road (loc. 435, pl. 1). Observations were made following a heavy rain, and a trench was dug across the pavement to expose the material below the armor of stones. The material exposed in the trench is shown diagrammatically on figure 11 and is described in table 3.

The cross section on figure 11 shows that the pavement cut by the trench slopes to the southwest. The surface is not smooth but is interrupted by miniature steps a few inches wide whose risers are formed by boulders. All but the largest stones under the pavement rest on a thin layer of loose silt (unit 2), which in turn lies on a porous friable silt (unit 3) that is transitional downward (unit 4) into weathered gravel (unit 5). Many of the openings in the porous silt are lined with secondary material, a fact suggesting repeating solution during rains and redeposition when drying. This condition is perhaps caused by the capillary rise of vadose water. The silty material exposed in the trench between the layer of stones under the pavement and the weathered gravel resembles that found throughout this part of the Amargosa Valley, except that the silt generally has a vesicular structure throughout, the fragments beneath the pavement resting directly on firm porous silt (unit 3) and not on loose silt (unit 2), as in

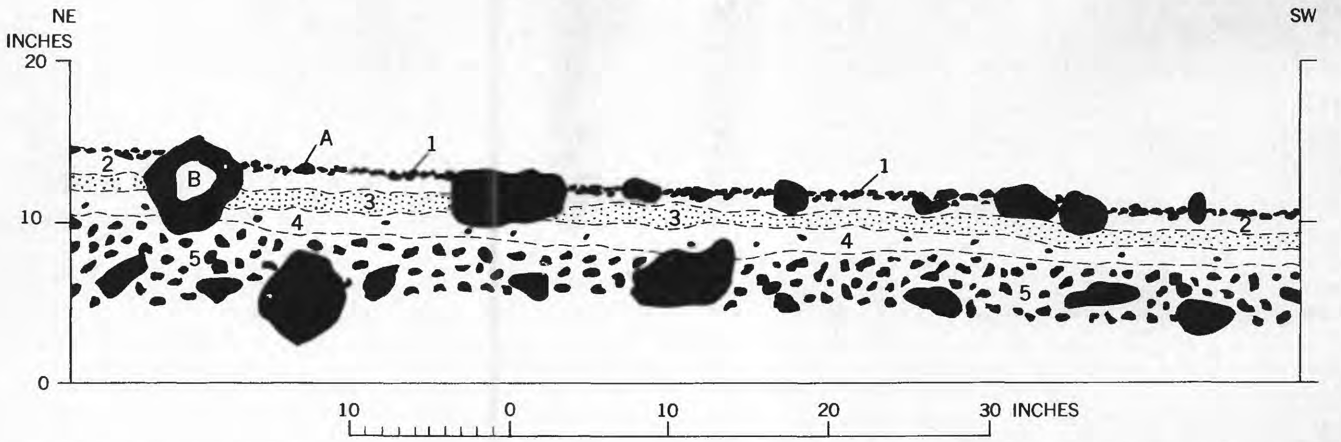

FIGURE 11.—Section of material exposed in trench dug beneath pavement on Shadow Mountain fan, Ash Meadows quadrangle, California and Nevada. Units are described in table 3 (loc. 435, pl. 1). Fragments A and B are referred to in text.

the trench. Scattered observations suggest that the silt beneath the stone armor tends to be thicker where the underlying gravel is finer grained and to be thinner where the gravel is more bouldery. On fans where the gravel contains many fragments of limestone and dolomite, such as the Bat Mountain fan (p. 25), the silt appears to be thicker than on the Shadow Mountain fan, at least in those places where the grain sizes in the underlying gravel are comparable.

Observations made on the pavement at the site of the trench following a heavy rain suggest that some of the silt beneath the armor of stones became saturated with water and tended to flow downslope, carrying the smaller stones with it. Meanwhile the larger stones, imbedded in firm dry silt, did not move; they impeded the lateral flow of the silt and caused the stone-covered surface of the silt to remain slightly higher on the upslope side of the boulder than just downslope from it.

When the pavement at the site of the trench was first reached on the afternoon of April 7, 1958, following about 24 hours of intermittent rain, a faint tinkling sound was heard which continued for about 20 minutes. The pavement was not firm; the jeep tires had made shallow ruts. When one of the smaller fragments of the pavement, such as fragment A shown on figure 11, was pushed horizontally, all the stones within a radius of 3–4 inches jiggled. The material beneath the pavement had the consistency of jelly, and when a stone was removed from the pavement, the surrounding silt tended to flow into the depression left by the stone. If, however, a large fragment set deeper in the underlying silt, such as fragment B shown on figure 11, was pushed horizontally, it did not move. The silt beneath the pavement was saturated with water to depths ranging from 1 to 2 inches; below, the ground was dry. The fact that the large stable fragments form the risers of miniature steps indicates that such steps probably form when the water-saturated surface layer moves in small increments downslope, carrying along the small fragments of the pavement. Such movement is checked where it meets a boulder firmly embedded in the underlying dry silt.

ORIGIN OF PAVEMENT

The pavements on the Shadow Mountain fan are the floors of very old abandoned washes where no deposition has taken place for a long time. The fragments on the surface of these washes have been broken into smaller pieces by mechanical processes such as expansion and contraction due to temperature changes or to freezing of water and by chemical decay. The fine material has been removed from the surface by running water and by wind, and a concentrate of closely packed fragments—the pavement—has been left. Such a mechanism, however, does not seem adequate to transform a rough surface of channels and gravel bars into a smooth pavement. For this transformation some kind of lateral redistribution of material seems required.

A lateral movement of the fragments of a pavement is indicated by the miniature terraces, and this movement appears to be caused by the flowage of the silt on which the fragments rest. When saturated with water, the silt becomes plastic and tends to flow downslope, either toward an adjacent wash or downfan. Expansion of the silt due to wetting also has a small horizontal component that increases with increase in slope and may result, after many cycles of wetting and drying, in a slight net movement of the silt downslope. When the paement and underlying silt creep down the steep banks of a wash, the downslope support of the gently inclined surface layer of saturated silt is removed farther up the pavement. The saturated silt tends to flow, and tension cracks tend to form in the wet silt, displacing the pavement. The risers of the miniature terraces are the surface expression of these tension cracks. This mechanism seems adequate to form long and evenly spaced terraces. In other places, where a pavement includes boulders that are anchored in firm dry ground, the saturated material creeps downslope and either piles up behind the boulders or flows by them. In either occurrence, the segment of pavement behind a boulder stands slightly above the surface in front of it.

TABLE 3.—*Material exposed in trench dug beneath pavement on Shadow Mountain fan, Ash Meadows quadrangle, Nevada-California*

[Units shown in section of figure 11. Trench dug on May 1, 1958. Material dry to depth of about 5 in. Locality 435, pl. 1]

	Range in thickness (inches)	*Average depth (inches)*
Unit 1. Pavement. Pebbles and angular fragments of quartzite; 1 in. or less is a common size but includes a few larger fragments; form a single layer of fragments resting directly on or in the underlying silt.		
2. Silt or clayey silt, light gray (10*YR* 7/2), loose; basal contact sharp, wavy; microrelief about 0.5 inch	1.0–1.75	0.0–1.5
3. Silt or clayey silt; contains a few sand grains; light gray (10*YR* 7/2); very firm in place; very friable, porous, has vesicular structure; openings commonly 0.05 in. in diameter, a few are 0.1 in. in diameter; locally openings are larger near base. Some openings contain skins of silt or clay that under the hand lens resemble tallow that has run down the side of a candle and hardened. Lower contact gradational	1.0–2.0	1.5–3.0
4. Silt or clayey silt; contains a few small pebbles; light yellowish-brown (10*YR* 6/4) to very pale brown (10*YR* 7/4); firm in place, very friable, porous; has vesicular structure and silt or clay skins similar to those of unit 3. Some openings are lined with brown crystalline material (caliche?). Distribution of openings gives this unit a faint thin wavy horizontal banding. Lower contact gradational	0.75–2.0	3.0–4.5
5. Gravel, silty, yellowish-brown (10*YR* 5/4), loose to slightly firm, very friable; contains angular fragments of rock as much as 4 in. in diameter. Caliche on underside of many fragments is in the form of small lath-shaped crystals as much as 0.1 in. long. At depth of 10 in. below the pavement, the silt is brown (7.5*YR* 5/4) and contains thin flakes of caliche. Below depths of 15–20 in. the material is loose and faintly stratified and contains angular and very slightly rounded pebbles as much as 7 in. in diameter; 0.25–2 in. is a common size. Base not exposed	15+	4.5–20+

The presence of the silt beneath the pavement requires further explanation. The pavement acts as an armor that protects the underlying fine material from removal by water and wind. This armor is the top of a weathering profile; the material beneath it has been formed by the weathering of the gravel of which the fan is made. Perhaps the silt is formed largely by mechanical weathering, because the fragments scattered through it are not greatly weathered. The mechanism might involve the loosening and breaking up of the parent gravel by wetting and drying, and the resulting expansion and contraction of a surface layer causes the larger fragments to be raised to the surface in the same way that stones are raised by repeated freeze and thaw. As explained by this theory, the silt beneath the pavement is the matrix of the parent gravel and, as a corollary, gravel having abundant matrix should form a thicker layer of silt than one having little interstitial material. Gravels derived from the volcanic rocks of this region contain much fine material, and the pavements on such fans do in fact rest on thick silt layers. On the other hand, the silt is thicker where the underlying gravel is composed of fragments of easily weathered carbonate rocks than where resistant quartzite is its principal constituent; this fact suggests that chemical weathering is also a factor.

The origin of the vesicular structure of the silt beneath a pavement is not entirely clear. Thorough wetting apparently destroys the structure; therefore, its occurrence not only under all pavements but throughout the surface layer of most silty deposits in this region suggests that it forms rapidly after wetting. The openings may contain air or carbon dioxide trapped in the saturated silt by some sort of crust. Perhaps some of the irregular openings resulted from solution and redeposition rather than the entrapment of gas. Nikiforoff (oral commun., 1961) suggested, on the basis of personal observation, that during rains a curtain of moisture descends through the dry silt, trapping air in pockets. On drying, the air is warmed, expands, and rises toward the surface where it is held in by a crust composed of a very thin layer of micaceous mineral flakes.

Although on the Shadow Mountain fan are found many typical pavements and abandoned washes, many areas also occur where the surface of this fan has charateristics both of pavements and of washes. These areas, intermediate between the two types, can be grouped to represent a continuous series of steps in the process of transforming a wash into a pavement.

Dissection of a pavement by washes heading on it has apparently gone on hand in hand with its formation. No large "undissected" pavements occur on this fan or elsewhere in the region. Thus the tendency for the surface of an abandoned segment of the fan to be transformed into a pavement is opposed by the local runoff, which carves gullies in the surface. In many places the two forces—smoothing and dissection—appear to be in balance. The amount of pavement and underlying silt that creeps down into the wash is balanced against the ability of ephemeral streams to transport this material down the fan.

A pavement, once formed, may persist for a long time. All well-formed pavements, under conditions of this theory, need not have been in existence for the same period of time, nor are the many small pavements on one part of a fan necessarily part of a single once more extensive pavement. For example, the many small pavements on the central part of the Shadow Mountain fan, near locality 453, could have come into existence long after the large pavement on the north edge of the fan.

The area of narrow flat-topped ridges separated by deep washes that forms the eastern end of the Shadow Mountain fan is perhaps its oldest segment (p. 22). The gravel beneath this segment, whose western limit is approximately at an altitude of 2,800 feet, is probably slightly older than that beneath the rest of the pavement to the west. Dissection of the surrounding parts of the fan has permitted the surface runoff on this segment to carve deep gullies, thereby greatly decreasing the area of pavement.

PEDIMENT

Along the northern and southern sides of the fan are small areas of pediment (fig. 6) underlain by Tertiary sandstone and clay and a younger fanglomerate (pl. 1). These weakly cemented but deformed rocks are exposed in shallow gullies and are overlain unconformably by a few feet of gravel, which is not shown on plate 1. The unconformity at the base of the gravel is an erosion surface that bevels the deformed rocks—in other words, a pediment that has been mantled by a younger gravel and has subsequently been dissected. Other areas of pediment not shown on figure 6 are the small outcrops of Tertiary fanglomerate and of Cambrian(?) Quartzite that are situated along the northeast edge of the fan east of locality 74 (pl. 1).

The two areas of pediment north and south of the fan (fig. 6*B*) are places where erosion has dominated over deposition to the extent that rocks of early Pleistocene(?) and older age are exposed beneath only a few feet of gravel. While on the fan itself extensive bodies of detritus have been deposited, weathered, and eroded, slightly consolidated and tilted beds have been beveled by weathering and erosion in these small areas to either side. These two small segments of the piedmont receive water and sediment from only small drainage areas in the adjacent highland. Even this small amount of runoff has removed all the local detritus and has eroded these weak rocks to the level of the adjacent fan.

ORIGIN OF THE SHADOW MOUNTAIN FAN

Although detritus from the mountain is transported down the fan and ultimately reaches the toe, the history of any given particle of quartzite from its bedrock source to the toe is clearly not one of continuous movement. Sediment is not now being deposited uniformly over the entire surface, nor can deposition be assumed to have ever been uniform over the entire fan. Instead, the surface of the fan has probably always been a mosaic of pavements and washes. The following discussion attempts to decipher the history of the fan from its present configuration.

The relative ages of some parts of the surface of the fan are obvious. The modern washes are the youngest unit; in times of flood they carry water that erodes, transports, and deposits the material on their beds. The abandoned washes are older; they have not been flooded, nor has their bed material been moved for a long time. Many of the pavements are on deposits that are older than the gravel that floors the abandoned washes.

Inspection of plate 1 and figure 6*B* will show three areas of pavement that have the relations common to most pavements; the areas are (1) the large pavement (No. 5d) that extends about 4 miles along the north edge of the fan, (2) the two-pronged pavement near the center of the fan (No. 6d) that extends eastward from the Old Traction Road for about a mile and includes localities 69 and 78, and (3) the oval-shaped pavement (No. 7d) just west of the belt of limestone and dolomite at the foot of Shadow Mountain. The gravels beneath these three pavements were deposited prior to those in the adjacent washes, although the pavements themselves may be younger. The gravels of the washes lie in channels cut generally below the pavements; in a few places however, as north of locality 78, gravel in a wash laps over the edge of the adjacent pavement.

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The large pavement along the north edge of the fan appears to be developed on parts of two adjacent fan segments. One segment (No. 8d, fig. 6*C*) had its apex near that of the modern fan, near locality 424 (pl. 1), and sloped rather steeply northward and westward for a distance of almost a mile to the place where the slope of the existing pavement decreases a little and changes in direction from northwest to slightly south of west. This change in amount and direction of slope is only suggested by the 200-foot contour lines on plate 1; it coincides roughly with the arc of a circle passing through locality 440 whose center is at locality 424. When segment 8d was receiving sediment from Shadow Mountain, of course, no gully occurred east of it, as is there today. The second segment of the large pavement (No. 5d) had its apex about a mile north of and about 500 feet lower than the first one—that is, at a point about half a mile east of locality 74. This segment sloped westward. The first segment (No. 8d) has its source on a part of the northwest slope of Shadow Mountain (segment 8s), perhaps in a somewhat larger area than now drains to the apex (to loc. 298). The second segment (No. 5d) received its detritus from the hills of quartzite and fanglomerate shown in the northeast corner of the map (segment 5s).

The reconstructions (figs. 6*B*, *C*) of segments 5d and 8d show an overlap of their source areas, which indicates that deposition of segment 8d preceded that of 5d. An age difference between these two segments is reasonable also because the surface of segment 8d now stands much higher above the surrounding washes than does segment 5d and because segment 5d is much more extensive. Because the area of deposition on a fan is proportional to the source area (fig. 7), the large size of segment 5d suggests that its source area was much larger than that of segment 8d. Within the framework of the existing highlands such a difference can be understood only by assuming a diversion of drainage, such as described on page 11.

The two-pronged pavement near the center of the fan (No. 6d, fig. 6*B*) extends eastward from the Old Traction Road nearly to the mountain front. The gravel beneath this pavement was probably derived in part from the northwest face of Shadow Mountain and partly from the gravel of area 8d (fig. 6*C*). The sediment on which the oval-shaped pavement (No. 7d) formed west of the gap in the belt of carbonate rock probably came from a small area (No. 7s) on the west slope of Shadow Mountain.

The four areas of pavement just defined were loci of deposition at some time in the past. Because the extent of deposition in the washes bears a fairly constant relation to the size of their source areas, perhaps the size of the four pavements is similarly related to the size of the areas that may have supplied the sediment that underlies them. The size of each of these four segments of pavement and of the possible source areas of the gravel beneath them are given in the following table:

Pavement segment (fig. 6)	*Area of pavement segment (sq mi)*	*Source area (sq mi)*
5d	1.04	1.92
6d	.30	1.22
7d	.18	.35
8d	.28	.72

A logarithmic plot of these values (fig. 7) shows that they fall near the points for the areas of deposition in the washes (Nos. 1, 2, 3, and 4), suggesting that these pavements were, in fact, once areas of deposition.

A part of the history of the Shadow Mountain fan may be reconstructed by an analysis of these four pavements; the history started with the deposition of the gravel beneath segment 8d (fig. 6*C*). This gravel was deposited by a stream heading on the northwest slope of Shadow Mountain. Assume that the stream flowed northward on the east edge of segment 8d in a channel that was below the top of the gravel near the south edge of the segment. A west-flowing stream in a small wash heading in the southern part of the segment eroded its bed to a level below that of the fan-building wash to the east (the small wash is analogous to those that head in pavements). Ultimately the divide of gravel between these two washes was breached, probably by a lateral swing of the larger northward-flowing stream, which was thus diverted westward and cut down; fan segment 8 was thereby abandoned.

The west-flowing stream from the mountain cut a gorge through segment 8d (fig. 6*C*) and began to deposit its load farther downfan in the area of pavement 6d (fig. 6*B*). At the same time, the gravel beneath pavement 5d was laid down by a stream heading in area 5s. Another stream, flowing down the east edge of the abandoned segment 8d carved a valley in the underlying bedrock, diverting some of the drainage off the quartzite from segment 6d to 5d. Most of the remainder of segment 8d also drained to segment 5d. Meanwhile, the gravel beneath the oval-shaped pavement (No. 7d, fig. 6*B*) was laid down by a stream that drained a part of the west slope of Shadow Mountain and flowed northwestward through the belt of limestone and dolomite.

While the alluvian beneath pavements 5d, 6d, and 7d was being laid down, streams in washes heading in reentrants on the fan between these segments deepened their beds and set the stage for additional diversions of drainage. In time the stream that carried sediment to 5d was diverted northward into a wash that flowed to the northwest through the hills of fanglomerate that are traversed by the Old Traction Road. In like manner the fan-building washes on segments 6d and 7d were diverted to the north or to the south. These diversions brought to an end the deposition of gravel in segments 5d, 6d, and 7d. Weathering and erosion then became the dominant processes on these segments of the fan and transformed an irregular surface of channels and gravel bars into the smooth pavements of the present day.

With the close of deposition in segments 5d, 6d, and 7d, the modern and abandoned washes became the principal places of transportation and deposition on the fan. Deposition, however, has not been equal in amount over all the washes but has been concentrated either in areas near the mountain front, such as depositional area 2d (fig. 6*A*), or downstream from pavements, such as areas 1d, 3d, and 4d. Sedimentation continues at the present time although the amount deposited during perhaps the last few thousand years is small in comparison with the total volume of material now exposed on the fan. Only a short time ago the northwest-trending wash that carried the drainage from the hills along the State line was diverted southwestward. Water from these hills now flows in a narrow wash through the eastern part of pavement 5d (fig. 6*B*) to depositional area 1d west of the Old Traction Road.

The small areas of exposed pediment on the north and south sides of the Shadow Mountain fan (fig. 6) are now areas where erosion is dominant over deposition. These gravel-capped ridges are probably younger than the gravel beneath the adjacent pavements; at least the uncovering of these buried erosion surfaces was coincident with formation of the adjacent abandoned washes. These pediments may in time be buried again. The pediment along the southern edge of the fan, for example, is traversed by a very small wash heading in a small area on the bedrock slope to the east. The floor of this small wash is more than 40 feet below the adjacent broad wash to the north and is separated from it by a low ridge of gravel on which is a pavement. At some time in the not too distant future, the stream in the large wash may cut through the gravel ridge, spill over into the small wash, and bury it with many feet of gravel to form a new fan segment.

This partial history of the Shadow Mountain fan does not deal with areas near its toe, because the events just described are conditioned by changes that have taken place on the upper part of the fan or on the adjacent highlands. The position of the toe is controlled primarily by the level of the alluvium along Carson Slough and is largely unaffected by changes that may have taken place near the apex. The overall size and shape of the Shadow Mountain fan and perhaps, in part, its downfan gradient are dependent primarily on the kind of rock that forms the highlands and the structural history of this part of the Amargosa Valley. Although the highlands clearly owe their elevation primarily to faulting, no convincing evidence exists that faulting has disrupted the fan's surface since deposition of the oldest gravel now exposed on it (beneath pavement 8d, fig. 6*C*).

A gradual rise of as much as 200 feet in the level of Carson Slough would have little effect on the formation of the upper part of the fan because such a change would not affect either the discharge of the streams in the fan-building washes or the size of their load. However a rise of several hundred feet would obviously cause radical changes on the Shadow Mountain piedmont. Gradual lowering of the broad flood plain of Carson Slough might lead to deposition of detritus from the mountains along the east side of the plain, thereby moving the position of the toe westward. Carson Slough could lower its bed several tens of feet without noticeable changes taking place on most of Shadow Mountain fan.

As a further illustration of the way in which the Shadow Mountain fan has been formed—a sequence of events that is doubtless common to many fans in this region—consider the history of a particle of detritus, from its source in the bedrock of Shadow Mountain to its lodgement at the toe. The particle in question is a boulder of quartzite in the gravel beneath pavement number 8d at the head of the fan. The boulder was once part of the bedrock on the northwest slope of the mountain. It was produced by weathering on the bedrock slope; it moved down to the wash and ultimately was carried to its present position in segment 8d. Erosion, lowering the surface of the deposit, will in time bring the boulder into the weathered zone where it may break into angular fragments of pebble size that in time may reach the surface as part of the pavement. Creep and wash will move these pebbles to the adjacent narrow gully where flood waters will carry them down a gentle gradient to the end of the pavement near the Old Traction Road and deposit them in area 1d (fig. 6*A*). Here the pebbles may in time weather to still smaller fragments, perhaps once again becoming part of a pavement armor. Ultimately, these small particles may be carried to the toe.

The movement of detritus downfan thus takes place during short periods separated by long intervals during which the material is comminuted by weathering. Boulders near the apex are reduced to pebbles and sand before they reach the toe. This change in size from place to place, rather than along a single wash from apex to toe, produces the marked concavity in the longitudinal profile of the fan. Such a concavity is a common feature where boulders are abundant near the apex of a fan but are not carried by floods to the toe.

The processes of erosion, transportation, deposition, and weathering are operating on the Shadow Mountain fan, but their intensity varies from place to place. Erosion and sedimentation are dominant in the washes, while weathering is more important in areas of pavements. During the life of the fan, these processes have been in operation at more or less constant rates. The mode of fan formation presented here does not require that these processes were much more active during the last glacial age than they have been since that time. Rather, the location of the places where one or another of these processes are dominant shifts from time to time (Eckis, 1934, p. 101–104). That is not to say that changes in the activity of these processes may not have taken place. Perhaps weathering and erosion were more active during the last glacial age than they have been since that time. Such increased activity may have permitted the transformation of an abandoned wash into a pavement in a shorter period of time than it does at present. But once formed, the pavement will persist for a long time because of the tendency for the processes that produce it to balance the erosive activity of the local runoff that is tending to destroy it.

The existence of narrow pavements and washes near part of the toe of the Shadow Mountain fan indicates that the net result of the processes active near that part of the toe has been erosion, not deposition. Such erosion is easily explained by assuming a slight lowering of the level of Carson Slough. However, the presence of narrow washes and pavements where the underlying arid-basin sediments are fine-grained and the absence near the southern part of the toe of the fan (pl. 1), where the surface material is entirely gravel, suggests a causal relationship. Perhaps channels and ridges are the result where streams in the washes are eroding sand and silt, whereas a broad plain is produced where the streams are flowing on gravel (Thomas Maddock, Jr., oral commun., 1960). Where the bank of a wash is composed of gravel, the impinging of the current against the bank may undermine it and cause the pebbles to fall to the floor of the wash but not move down the fan any great distance. The stream is more effective in eroding the bank of the wash than in moving

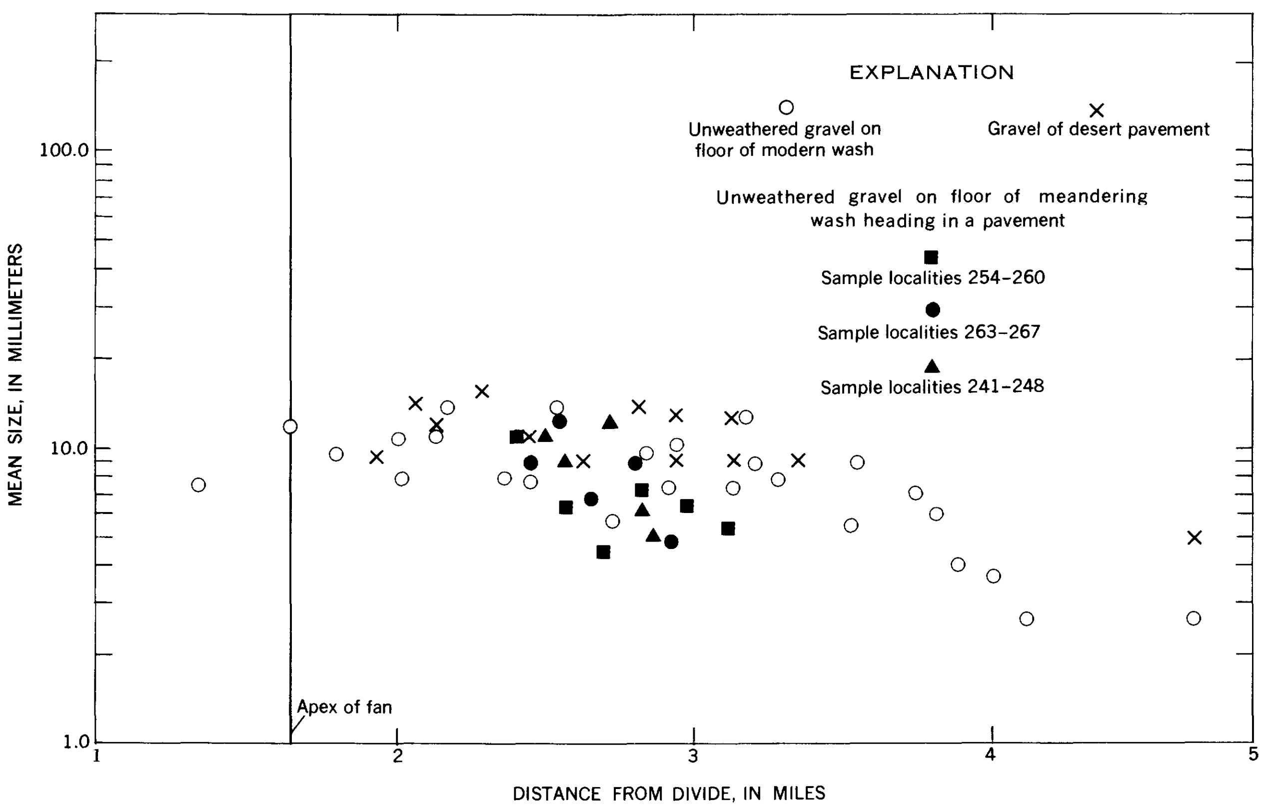

FIGURE 12.—Semilogarithmic scatter diagram showing the relation between the mean size of material at sample sites on the surface of Bat Mountain fan and the distance of these sites from the divide. The diagram includes size measurements of fragments forming desert pavement and of gravel that floors the modern washes. Data also shown for unweathered gravel on floors of meandering washes heading in a pavement.

coarse material on the bed of the wash; it cuts laterally until it meets adjacent washes, thus producing a wide gravel-covered plain. On the other hand, where the bank is sand and silt, the stream can move the bedload more easily and tends to remain in a distinct channel.

FAN EAST OF ALKALI FLAT

This fan built of detritus carried by the wash that drains the south slope of Shadow Mountain (pl. 1) lies just to the south of the Shadow Mountain fan, which it closely resembles. The fan is not described in detail, but measurements made on it (table 7) are included in the general discussion of fans in a later section of this paper (p. 38).

FANS SURROUNDING HILLS NEAR DEVILS HOLE

In the northeast part of the Ash Meadows quadrangle east of the Amargosa River, steep-sided hills composed of massive limestone and dolomite (Bonanza King Formation) near Devils Hole (fig. 1) rise 400–800 feet above an encircling apron of small alluvial fans composed of bouldery to pebbly gravel and sand. These fans are mentioned here only because measurements on some of them are used in the development of a general relation between a fan and its source (p. 38).

BAT MOUNTAIN FAN

The symmetric Bat Mountain fan, measuring 4½ miles from apex to toe (pl. 2), lies about 5 miles northwest of Death Valley Junction (fig. 1) near the southeastern terminus of the Funeral Mountains. Although the fan is much like that northwest of Shadow Mountain, the total relief from apex to toe (table 2), the local relief, and the size of the source region of the Bat Mountain fan are about half those of the Shadow Mountain fan. These differences reflect diverse geologic histories. The presence of abundant fragments of carbonate rock—both limestone and dolomite—in the gravels of the Bat Mountain fan causes some difference in the response of the gravels to weathering, as reflected by changes in size of sediment on the fan and in the nature of the desert pavements.

The Bat Mountain fan heads in an area of eastward dipping massive beds of boulder fanglomerate, limestone, and dolomite cut by high-angle faults. The surface of the fan (pl. 2) is divided into four geomorphic units, three of which—modern washes, abandoned washes, and desert pavement—resemble their counterparts on the Shadow Mountain fan. The fourth is a combination of all three types that forms a mosaic in which the individual areas are too small to be mapped at the scale of plate 2. The fan has a longitudinal profile that is concave upward (fig. 3) and is not broken by fault scarps. It is younger than the emplacement of a landslide (Denny, 1961) that terminates just northeast of the fan's apex and is in sharp relief when viewed from State Route 190. The slide rests on an older gravel that probably formed the apex of an earlier fan.

The modern washes are floored with some sand and silt, but the material is largely gravel composed of fragments of limestone, dolomite, quartzite, sandstone, and conglomerate (table 4). No mudflow deposits were noted either on the surface of the fan or in the deposits beneath the pavements. Mean size of material in the modern washes ranges from 7 to 14 mm, except within about a mile of the toe, where size decreases abruptly to less than 3 mm (fig. 12). The ratio of carbonate to quartz-rich rocks is 2.57 at a sample locality near the apex and decreases to 0.66 near the toe. The gravel on the floor of the abandoned washes resembles the material in the modern ones, except that the surfaces of quartzitic rocks are varnished and those of limestone and dolomite are solution faceted.

The desert pavements are composed of the same rock types that are found in the washes; but the fragments of a pavement have a slightly larger mean size (fig.

TABLE 4.—*Lithology of gravel on Bat Mountain fan, Ash Meadows quadrangle, Nevada-California*

[For location of samples see pl. 2]

Distance from apex (miles)	Sample locality	Unweathered gravel in wash							Desert pavement						
		Lithology (percent)				Ratio of carbonate to quartz-rich rocks	Mean size (millimeters)	Number of fragments	Lithology (percent)				Ratio of carbonate to quartz-rich rocks	Mean size (millimeters)	Number of fragments
		Limestone and dolomite	Quartzite and sandstone	Conglomerate	Other [1]				Limestone and dolomite	Quartzite and sandstone	Conglomerate	Other [1]			
0.49	24	59	12	11	18	2.57	11.2	100	44	28	9	19	1.19	12.0	100
1.29	25	50	27	8	15	1.43	10.5	100	40	38	3	19	.98	13.0	100
1.50	27	46	36	5	13	1.12	7.4	100	----	----	----	----	----	----	----
3.07	26	19	29	2	50	.66	2.6	108	25	46	0	29	.54	4.9	105

[1] Includes many fragments less than 2.8 mm in diameter (pebbles, sand, and silt).

12 and table 4), and the proportion of quartz-rich rocks is greater because of the destruction of some fragments of carbonate rocks by solution during pavement formation. Near the toe, however, the proportion of carbonate to quartz-rich rocks is about the same on both pavement and wash, a fact suggesting that the pavements near the toe are not formed in quite the same manner or are not as old as those on the upper part of the fan. Near the toe the materials beneath both pavement and wash are probably derived from a common source—the pavements on the middle of the fan—and thus the parent gravels of a pavement near the toe resemble the material in an adjacent wash. The fact that even after the parent gravels have been transformed into a pavement, the proportion of carbonate to quartz-rich rock in pavement and adjacent wash remains about the same indicates that less weathering is involved in the formation of the pavements near the toe than in the formation of those on the upper part of the fan. Perhaps the pavements upfan are older.

The surface of the northwest part of the large southern pavement on Bat Mountain fan—that is, roughly between the altitudes of 2,500 and 2,600 feet (pl. 2)—consists of two segments, one sloping southeast and the other south, which meet along a meandering gully (loc. 254–258). The gully is apparently localized along the contact between these two segments of pavement, one of which has developed on the surface of washes flowing southeastward and the other, on washes flowing from the north. This observation supports the idea, presented on page 21, that meandering gullies form in pavements while these surfaces themselves are being fashioned. The common toe between these two abandoned depositional segments, now transformed into pavements, localized the meandering wash, which now traverses the area of pavement in a gully that has a maximum depth of 14 feet.

On the lower part of the fan, the relief is commonly less than a foot, and the surface is a mosaic of small areas of pavement and of wash floored with both varnished and unweathered gravel. The individual areas are so small or so interlocked that it is not feasible to map them on the scale of plate 2. Only about one quarter of the surface is modern wash. During a 2-year interval, the amount of erosion or deposition near the toe of the fan was virtually zero. Tracks made by tanks that crossed the lower part of the fan in 1955 were nearly undisturbed 2 years later.

The size of the major geomorphic units on the upper part of the Bat Mountain fan and of three other depositional segments on neighboring fans, shown on figure 13, were measured for comparison with those of other fans in the region. The measurements are given in the following table and are discussed on page 38, together with data from all the other fans:

Size of depositional segments and of their source areas at eastern end of Funeral Mountains

Segment (fig. 13)	*Depositional segment (sq mi)*	*Source area (sq mi)*
1	0.60	1.61
2	.78	1.20
3	.76	2.18
4	.31	.88
5	.45	.39
6	.64	.79

The history of the Bat Mountain fan is much like that of its neighbor across the valley and involves deposition in one segment and diversion of drainage into and sedimentation in an adjacent area while the channels and bars of the first segment are transformed into a pavement. When the old gravels—those beneath the large pavements—were being deposited, streams in washes on the north side of the fan, presumably heading in it or on the toe of the landslide, carved a valley below the level of the area of deposition to the south. Ultimately drainage from the mountain was diverted northward into this lower valley which was buried by the gravel that now underlies the long tongues of abandoned washes near the north edge of the fan. These gravels, like those in the abandoned washes on the Shadow Mountain fan, are coarser grained than any deposited since that time. While this deposition was going on, streams in washes heading in the pavements to the south deepened their channels, and ultimately, drainage from the apex was diverted to its present courses between pavements.

Sediment is apparently now being deposited chiefly near the apex and in the middle of the fan. The slope of the modern washes steepens a short distance below the apex, a fact suggesting that deposition is taking place—for example, between localities 252 and 253 (pl. 2). Large areas of unweathered gravel downfan from pavements or segments of abandoned washes are probably also areas of deposition. Apparently, the modern floods move coarse debris from the mountain to within about a mile of the toe. The finer-grained debris close to the toe, as mentioned earlier, is perhaps derived by local runoff largely from the pavements in midfan.

There are no time markers with which to correlate the events in the history of the Bat Mountain fan with those that have taken place on its neighbor on the opposite side of the Amargosa Valley. On both fans, abandoned washes floored with coarse gravel suggest that flood discharges were greater at some time in the past than at present. The timing of the drainage diversions and the resultant shifts in areas of dominant

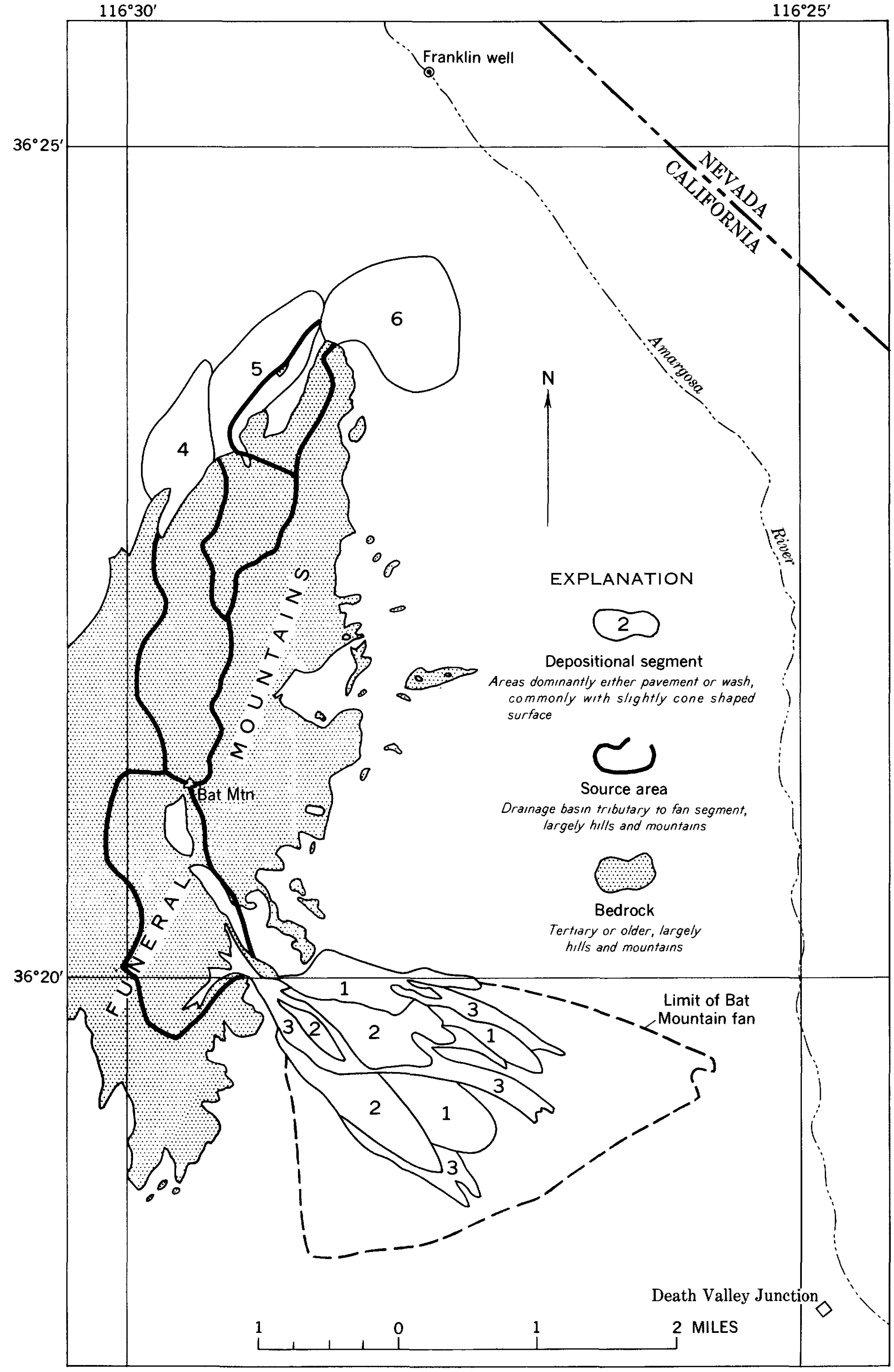

FIGURE 13.—Distribution and source areas of fans near the eastern end of the Funeral Mountains, California. Size measurements of the numbered geomorphic units are listed in the table showing size of depositional segments and of their source areas (p. 26) and are plotted on figure 7.

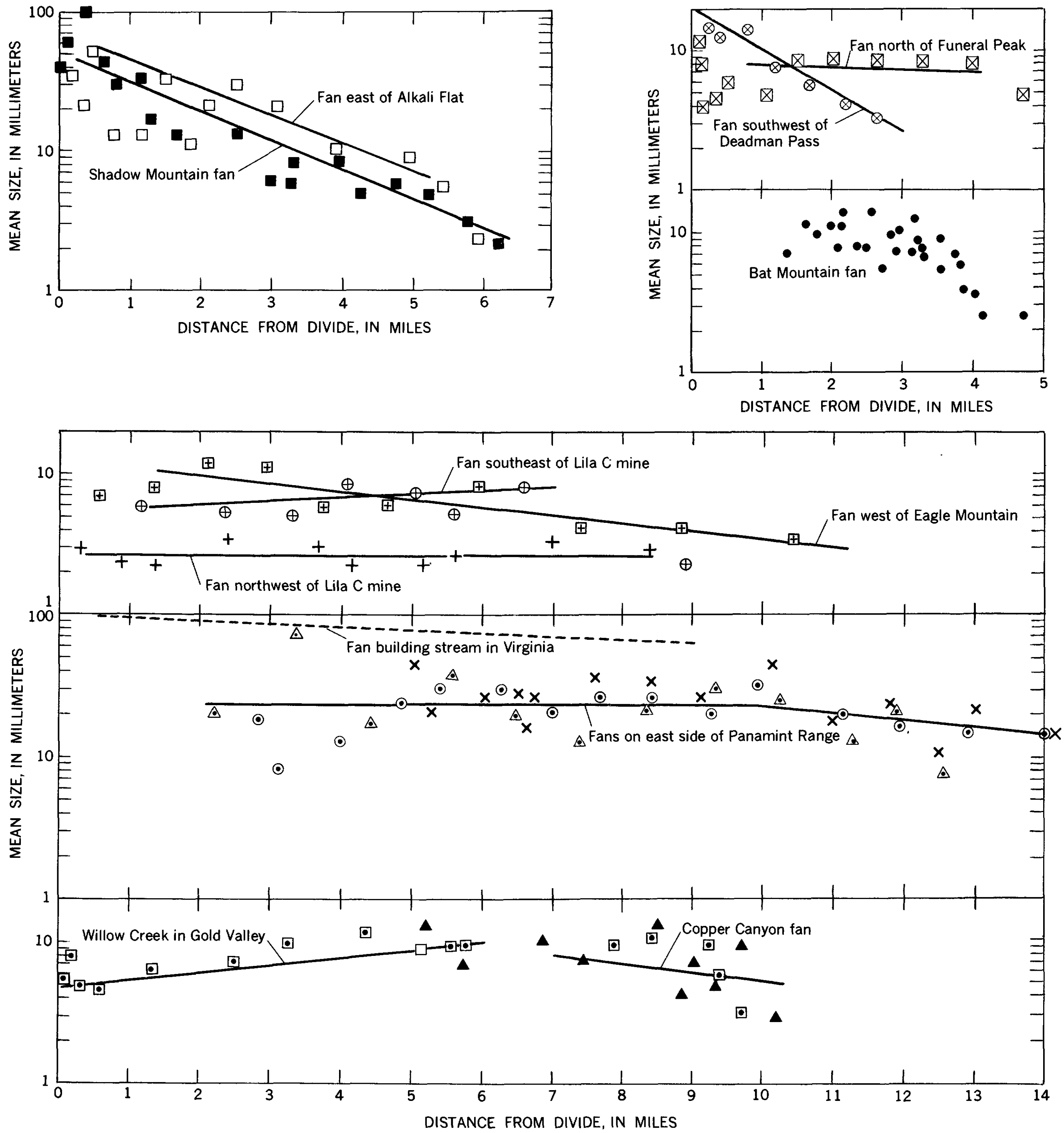

FIGURE 14.—Semilogarithmic scatter diagrams showing the relation between the mean size of material on floor of wash and the distance from the divide, at sample sites along fan-building washes in the Death Valley region. For comparison, the median size of bed material at sample sites along East Dry Branch of Middle River, Va., a fan-building stream on the west side of Shenandoah Valley (Hack, 1957) is shown by a dashed line.

EXPLANATION

Sample locality and principal lithologic types comprising the bed material on the surface of the main fan-building washes

Death Valley

EAST OF PANAMINT RANGE

◬ Trail Canyon fan
Quartzite, argillite, and dolomite

× Hanaupah Canyon fan
Quartzite, argillite, and granitic rocks

⊙ Johnson Canyon fan
Quartzite and argillite

WEST OF BLACK MOUNTAINS

▣ Willow Creek fan
Metadiorite, monzonite, and volcanic rocks

▲ Copper Canyon fan
Sandstone, siltstone, fanglomerate, and metadiorite

Greenwater Valley

EAST OF BLACK MOUNTAINS

⊠ Fan north of Funeral Peak
Monzonite

⊗ Fan southwest of Deadman Pass
Monzonite

Amargosa Valley

EAST OF GREENWATER RANGE

+ Fan northwest of Lila C mine
Volcanic rocks, conglomerate, and sandstone

⊕ Fan southeast of Lila C mine
Volcanic rocks, conglomerate, and sandstone

⊞ Fan west of Eagle Mountain
Volcanic rocks, conglomerate, and sandstone

WEST OF SHADOW MOUNTAIN

■ Shadow Mountain fan
Quartzite and quartzite conglomerate

□ Fan east of Alkali Flat
Quartzite and quartzite conglomerate

EAST OF FUNERAL MOUNTAINS

● Bat Mountain fan
Dolomite, limestone, quartzite, fanglomerate, and sandstone

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erosion or pavement formation depend on the spatial relations of mountain and basin—that is, on the structural history—and thus may differ from range to range.

FANS EAST OF GREENWATER RANGE

The volcanic rocks of the Greenwater Range yield a relatively fine grained detritus, which has been deposited by east-flowing streams, in the form of a broad piedmont 4–8 miles wide that slopes gently toward the Amargosa River (fig. 1). In comparison with the Bat Mountain and Shadow Mountain fans, previously described, those fans east of the Greenwater Range are longer from apex to toe and have a finer grained bed material. On no other of the fans studied in the Death Valley region are the pavements more extensive (pl. 3). The fine size of the bed material and the gentle slope may be a function of the bedrock, but the structural history of mountain and basin probably determines the length of the fans and the extent of the areas of pavement.

The Greenwater Range from Greenwater Canyon southward to Deadman Pass is made up dominantly of late Tertiary and early Pleistocene volcanic rocks and associated sediments; andesite and basalt, rhyolite and rhyodacite, vitrophyre, tuff, sandstone, and conglomerate are the principal lithologic types (Drewes, 1963). The piedmont east of the range is underlain almost exclusively by an unkown thickness of Quaternary deposits—largely bouldery to pebbly gravel, sand, and silt. The several small outcrops of Tertiary rock in the embayment west of the Lila C mine suggest that the embayment may be in part a pediment thinly veneered with gravel.

The piedmont has a gentle slope, from about 250 feet per mile near the mountain front to less than 100 feet per mile near the Amargosa River. Estimates of mean size and of slope were made at sample localities (pl. 3) along three washes from the crest of the Greenwater Range to the Amargosa River (table 7). Both within the range and on the piedmont, the slope of these washes is virtually constant for long distances (fig. 3), and the mean size of the material on the surface is small and decreases downwash at a low rate (fig. 14). The extensive areas of desert pavement show that on much of the surface of the piedmont, weathering and erosion are the dominant processes. The pavements resemble those on the Shadow Mountain fan, except that the coating of varnish on the stones is darker and the silty layer beneath the pavement is thicker—about 10 inches in some places. Boulders resting on an otherwise smooth surface are characteristic of the pavements east of the Greenwater Range (fig. 15).

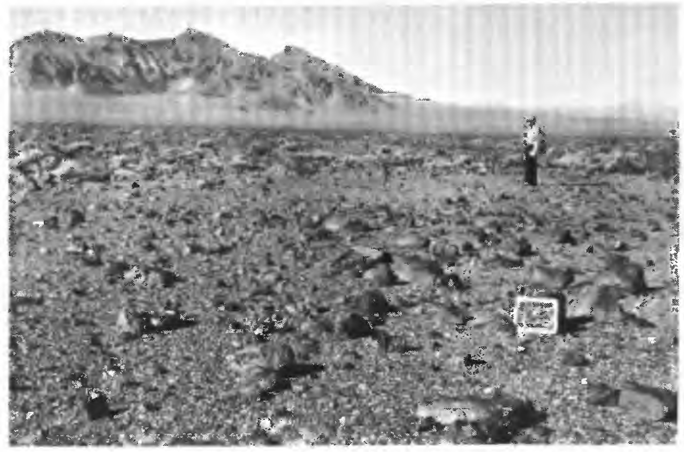

FIGURE 15.—Desert pavement on gravel derived from volcanic rocks of the Greenwater Range. The desert shrubs beyond the man are along a wash. The view is northward toward the east end of the Funeral Mountains from a point about 2 miles north of Lila C mine (loc. 133, pl. 3). The slope is eastward at about 140 feet per mile. The estimated mean size of the stones forming the pavement is about 10 mm.

Only three segments of wash on the piedmont have slightly cone-shaped surfaces, a fact suggesting that they are areas of deposition. However, the several large areas of pavement are also slightly cone shaped surfaces, a fact suggesting that they too were once areas of deposition. The extent of these pavements and segments of wash and the location of the source areas that may have supplied the gravel of which they are composed are shown on figure 16, and their extent is given in the following table (these measurements are discussed on page 38):

Size of depositional segments and of their source areas on the east side of the Greenwater Range

Segment (fig. 16)	*Depositional segment (sq mi)*	*Source area (sq mi)*
1	0. 90	3. 88
2	1. 41	4. 04
3	3. 34	9. 46
4	3. 70	6. 50
5	2. 43	6. 14
6	1. 27	1. 00
7	1. 08	1. 05
8	2. 20	6. 99

Although the overall configuration of the piedmont is related to the structural history, the location of pavement and wash near the mountain front is the result of diversions of drainage similar to those that have taken place on the Shadow Mountain fan. On figure 16, for example, fan segment 3 appears to have been deposited by the stream that had previously built fan segment 8, and fan segment 4, where material is now being deposited, came into being when drainage was diverted northward from segment 3. Near the Amargosa River, on the other hand, the extensive pavements doubtless owe their formation to downcutting by the river.

The fans west of the river are about 2 miles longer and slope more gently than the Shadow Mountain fan to the east (fig. 3); perhaps these differences are entirely due to an eastward tilting of the valley, which is clearly the explanation for a similar contrast between the east and west sides of Death Valley. On the other hand, the differences in lithology and in size of fragments between the Amargosa Valley fans may account for the asymmetry of the valley—a short fan having markedly concave-upward profile on the east side of the valley and a long slightly concave profile on the west. The Shadow Mountain fan east of the Amargosa River is built of bouldery material, and its profiles is markedly concave. This concavity, as mentioned on page 23, may be due to the bouldery detritus from the quartzite mountain; the detritus is deposited high up on the piedmont

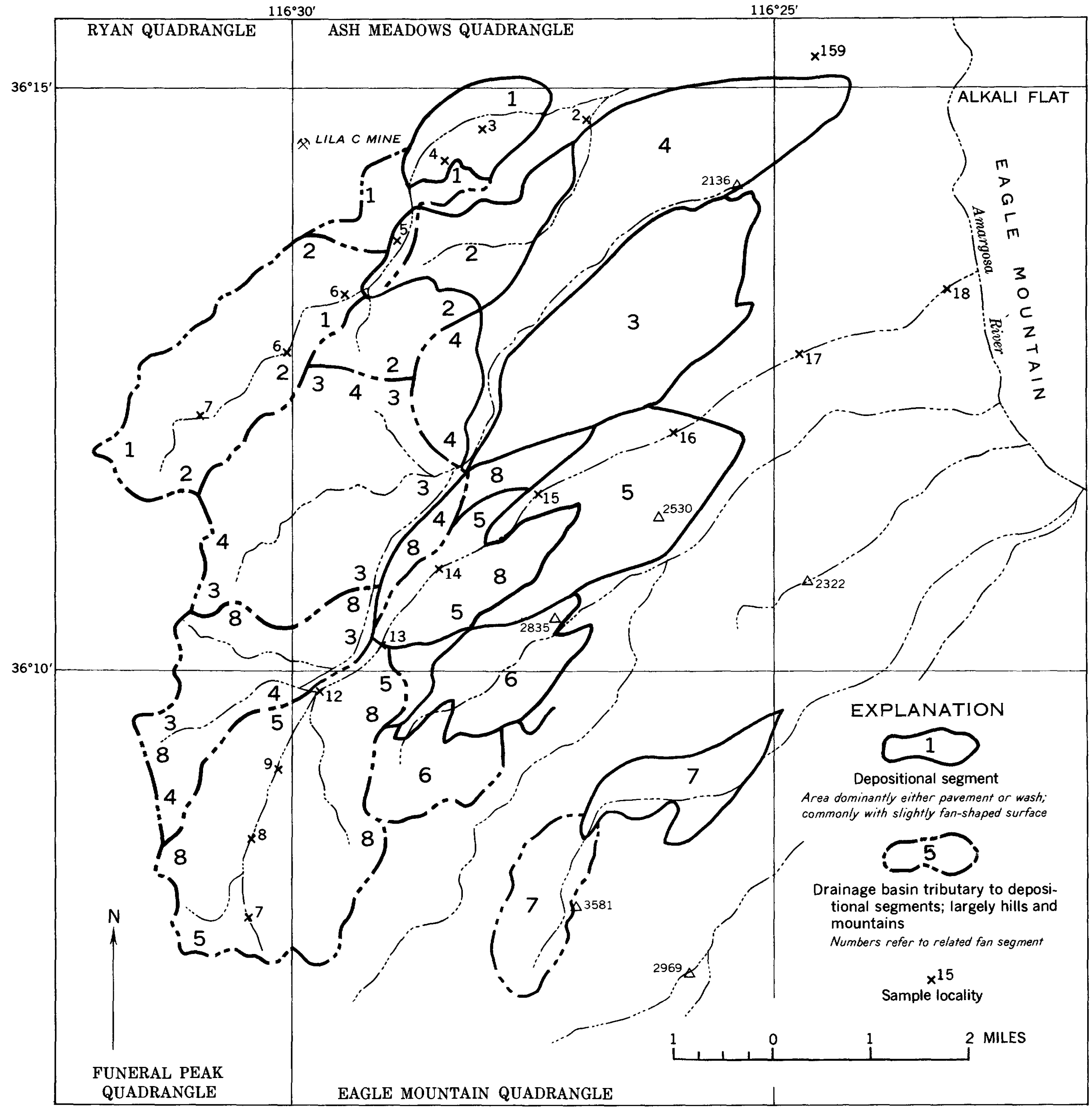

FIGURE 16.—Map of the piedmont east of the Greenwater Range showing depositional segments and related drainage basins in adjacent mountains. Related segments and basins as shown by the same number.

and does not move farther downfan until it is comminuted by weathering. The contrasted fans adjacent to the Greenwater Range west of the river are composed of pebbly material including cobbles of vesicular volcanic rocks; the low density of the rocks doubtless permits their transport a longer distance downfan than that of the quartzite cobbles on the opposite side of the river.

FANS IN GREENWATER VALLEY

Two fan-shaped segments of piedmont mantled by detritus from hills composed of granitic rocks were investigated in Greenwater Valley (fig. 1). These round-topped hills, in common with many other areas of granitic rocks in the Southwestern United States, have a high drainage density—many closely spaced washes—and are partly mantled by gruss (Sharp, 1954, p. 7). The longitudinal profile of one of the segments is nearly straight, whereas that of the other is marked concave upward. Both are floored with fine-grained debris (table 7). The floor of Greenwater Valley ranges between 3,500 and 4,000 feet in altitude and has a luxuriant growth of desert shrubs. The valley is asymmetric; the axial wash runs close to the base of Greenwater Range (pl. 4) and, to the west, a piedmont mantled by Quaternary gravel and sand extends 2–3 miles into an embayed mountain front. The Black Mountains tower more than 6,000 feet above the floor of Death Valley (fig. 1), whereas Greenwater Valley, east of the mountains, lies only about 2,000 feet below their summit.

One of the two washes studied has a steep slope and a long narrow drainage basin in an area of monzonite north of Funeral Peak (fig. 3; locs. 41–36, pl. 4). The wash can be traced for about half a mile east of the mountain front (to loc. 35), where it is lost on a slightly cone shaped segment of the piedmont (segment M, pl. 4) that is grooved by many small and discontinuous washes only a few feet in depth and width. The size of material in the wash changes little, except near the toe (fig. 14). The second wash, southwest of Deadman Pass (pl. 3), rises in low hills composed of monzonite surrounded on three sides by a sloping piedmont underlain by Quaternary gravel and sand. The longitudinal profile of the fan shows a pronounced concavity, and the material underlying it decreases in size toward the toe. Near the apex, the wash is incised and slopes more steeply (between locs. 9 and 8) than farther south, where no individual channel is continuous.

The wash north of Funeral Peak owes its steepness perhaps to an eastward tilting of the Black Mountains that may be still in progress (Drewes, 1963). In plate 4, depositional segment M and a part of the larger area of pavement just to the south, labeled segment N, have cone-shaped surfaces, a fact suggesting that the gravels beneath them are segments of fans that had their sources in the granitic and volcanic rocks north of the peak. The size of these two segments and of their source areas are given in the following table:

Size of depositional segments and of their source areas on east side of Black Mountains

Segment (pl. 4)	Depositional segment (sq mi)	Source area (sq mi)
M	2.38	1.49
N	1.16	.94

Both segments are slightly larger than most other fans or fan segments having a comparable source area (fig. 7). Perhaps the deposits on the surface of these segments are veneers over broad pediments. (See p. 38.) Several small bedrock hills rising above the piedmont northeast of Funeral Peak also suggest that the alluvial cover is thin.

The decrease in grain size and the pronounced upward concavity in longitudinal profile of the fan southwest of Deadman Pass are related to the spatial relations of this fan. The fan is compound. Near the apex it receives sediment from only a small area in the adjacent hills, but the lower part of the fan, which has no continuous channel, is part of a broad piedmont whose source includes a much larger segment of the Greenwater Range. This difference in size of source area between those of sample localities 8 and 7 results in a marked decrease in slope and in size of material.

DEATH VALLEY FANS

The Death Valley fans clearly show how continuing structural deformation influences the size of the individual fan or of an entire piedmont. Death Valley is bounded by high mountains (fig. 1) and, in the area near Badwater, is asymmetric. The precipitous west front of the Black Mountains is fringed by small semicircular fans, which contrast with the broad apron of coalescing fans that spreads eastward from the base of the Panamint Range. The Black Mountains (pl. 4) are built of sedimentary, igneous, and metamorphic rocks, and their dominant structural feature is a fault zone at the west front of the range. The mountains have been elevated several thousand feet relative to the valley floor; perhaps more than 100 feet of the displacement has taken place during the last few thousand years. The surface of the fans west of the mountains consists of modern or abandoned washes and of a few small ribbon-shaped areas of desert pavement. The size of 12 fans between Badwater and Mormon Point and the extent of their source areas are presented in table 5.

Copper Canyon has a straight and steep gradient from divide to mountain front (fig. 3), where the

TABLE 5.—*Size of fans or depositional segments in Death Valley and of their source areas in the Black Mountains and the Panamint Range*

Fan or fan segment (Letters refer to pls. 4 and 5)	Fan or fan segment washes only (sq mi)	Source area (sq mi)
Eastside:		
A	0.26	2.28
B	.38	2.23
C	.23	1.50
D	.33	2.37
E	.12	1.13
Coffin Canyon (F)	.41	7.47
Copper Canyon (G)	2.08	22.26
Sheep Canyon (H)	.82	10.60
Willow Creek (J)	.38	22.35
K	.12	1.65
L	.18	2.13
West side:		
Trail Canyon (O)	8.33	23.76
Death Valley Canyon (P)	3.92	11.76
Q	2.72	5.94
Hanaupah Canyon (R)	6.65	25.68
S	5.04	8.37
Starvation Canyon (T)	4.99	19.48
Johnson Canyon (U)	5.77	17.88
Six Spring Canyon (V)	4.24	19.03

ephermeral stream has built a symmetrical fan with a radius of a little more than a mile (table 2). The local relief on the fan is only a few feet except near the apex, where a small terrace underlain by weathered gravel rises 10 feet above the canyon floor. The upper half of Willow Creek flows down a gentle slope within capacious Gold Valley, which is carved in granitic rocks. To the west beyond Willow Spring, the creek enters a deep canyon and descends over several dry falls to emerge on a small fan (table 2). The Willow Creek fan (Segment J, pl. 4) is cut by low fault scarps that displace both unweathered gravel and desert pavement. Measurements of the size of bed material were made along Copper Canyon, Willow Creek, and on their fans.

The lofty Panamint Range, whose crest lies between altitudes of 9,000 and 11,000 feet, is composed of sedimentary and metasedimentary rocks of late Precambrian and early Paleozoic ages and, near Telescope Peak, of granitic rocks. Alluvial fans 3–6 miles long (pl. 5 and table 2) form the piedmont east of the range from Trail Canyon southward to Six Spring Canyon. In the mountains the floors of the main washes are several hundred feet wide along their lower courses and, at their mouths, are as much as 200 feet below the surface of the fan. These high banks commonly persist downfan and gradually decrease in height over a distance equal to one-half or two-thirds of the fan's radius.

The piedmont east of the Panamint Range is underlain by alluvial deposits of Pleistocene age that are divided into three geomorphic units on plate 5: unweathered gravel in the modern washes, varnished gravel in the abandoned washes, and weathered gravel generally forming a desert pavement. Pavements cover from one-quarter to two-thirds of the piedmont (table 2) and, near the mountain front, cap mesas that rise as much as 200 feet above the modern washes. Both the modern and abandoned washes are cut in the older gravel and are floored with similar material. Gravel is now deposited on only small parts of the fans (table 2), chiefly near their toes, and is finer grained than the varnished gravel in the abandoned washes. Historical and archaeological evidence gathered by A. P. Hunt (1960) and by C. B. Hunt (written commun., 1960) indicate that only a small amount of material has been moved down the Death Valley fans during the Recent epoch. These workers believed that the varnished gravel dates from a pluvial period that immediately preceded the Christian era or from a still earlier period.

Trail Canyon fan, the smallest of the Panamint Range fans studied in the field, has about three-quarters of its surface covered by either modern or abandoned washes (table 2), and the flat-bottomed canyon at its head is more than 500 feet wide throughout its lower 3½ miles. The chief lithologic types either in the fan gravel or exposed in the source area are quartzite, argillite, and dolomite, but, in addition, granitic rocks are present near the headwaters.

The surface of the Hanaupah Canyon fan is about equally divided between wash and pavement (table 2). The canyon heads on the east slope of Telescope Peak, the highest point on the Panamint Range, and the fan is built chiefly of fragments of quartzite and argillite and a subordinate amount of granitic material. The main wash leaves the mountains as a channel nearly 1,000 feet wide whose banks decrease in height from almost 200 feet near the apex to only a few feet in the middle of the fan (pl. 5; fig. 17). Elongate areas of desert pavement extend from near the apex of the fan to a point about four-fifths of the distance to the toe; areas north of the main wash end in an east-facing fault scarp about 50 feet high.

Desert pavement mantles three-fifths of the surface of the fan at the mouth of Johnson Canyon; the rest, chiefly in the northern part and near the toe, is about equally divided between modern and abandoned washes. The fan gravels are composed largely of fragments of quartzite, argillite, and dolomite.

The broad gravel-floored washes that head in the Panamint Range have smooth longitudinal profiles that are slightly concave upward (fig. 3). No change in gradient occurs at the mountain front or at the head of the fan-shaped areas of modern or abandoned washes (pl. 5). Although the washes are hundreds of feet wide in their lower courses, they are not wider in proportion to the size of their catchment areas than are

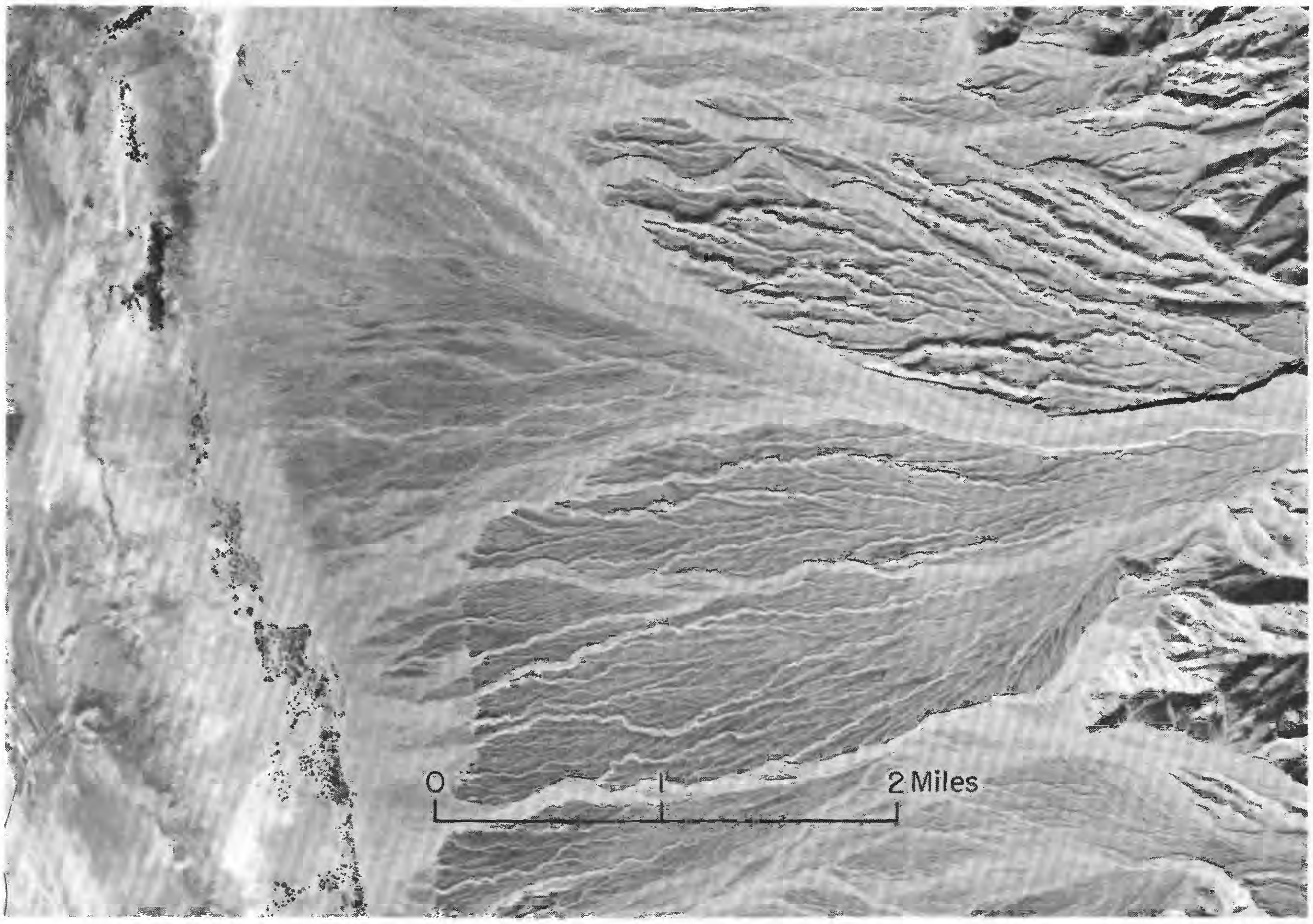

FIGURE 17.—Aerial photograph of the Hanaupah Canyon fan on the west side of Death Valley. Note the meandering washes heading in areas of desert pavement. For location, see outline on plate 5.

other washes in this region (fig. 18). The material on their beds is coarse grained (fig. 14) and is comparable in size only with that near the apex of the fans west of Shadow Mountain (fig. 19). The rate of decrease in size downfan is small; this low rate of decrease is equaled only by that in the washes east of Greenwater Range and in the wash north of Funeral Peak.

The large areas of pavement on the Panamint Range piedmont are cone-shaped surfaces that were probably inherited from the original depositional form of the gravels that underlie them. Some time ago the streams in the fan-building washes were diverted from these areas into new channels. The streams in the new washes cut down, abandoning the old depositional segments, which have since been transformed into pavements. Changes of this sort have occurred on many parts of the piedmont. The pavements on the Hanaupah Canyon fan are described in the following paragraphs to illustrate these changes.

Inspection of plate 5 shows that about halfway down the Hanaupah Canyon fan, near locality 6, is the apex of a fan-shaped area of washes that extends to the edge of the saltpan and, in the following discussion, is called the "modern fan." The modern fan has a slightly cone-shaped surface and is the place where deposition has gone on during the last few thousand years. The reader will find that the form of the modern fan is well shown by the topographic map of the Bennetts Well quadrangle, California, published by the U.S. Geological Survey. North of the main wash, a segment of pavement, labeled Z (pl. 5), has its apex near locality 8, and another such segment of pavement south of the main wash, shown as Y, has an apex near locality 51. The arithmetic plot on figure 20 shows that the eastward slope of segment Z is slightly less than that of segment Y and that both are a little steeper than the modern fan.

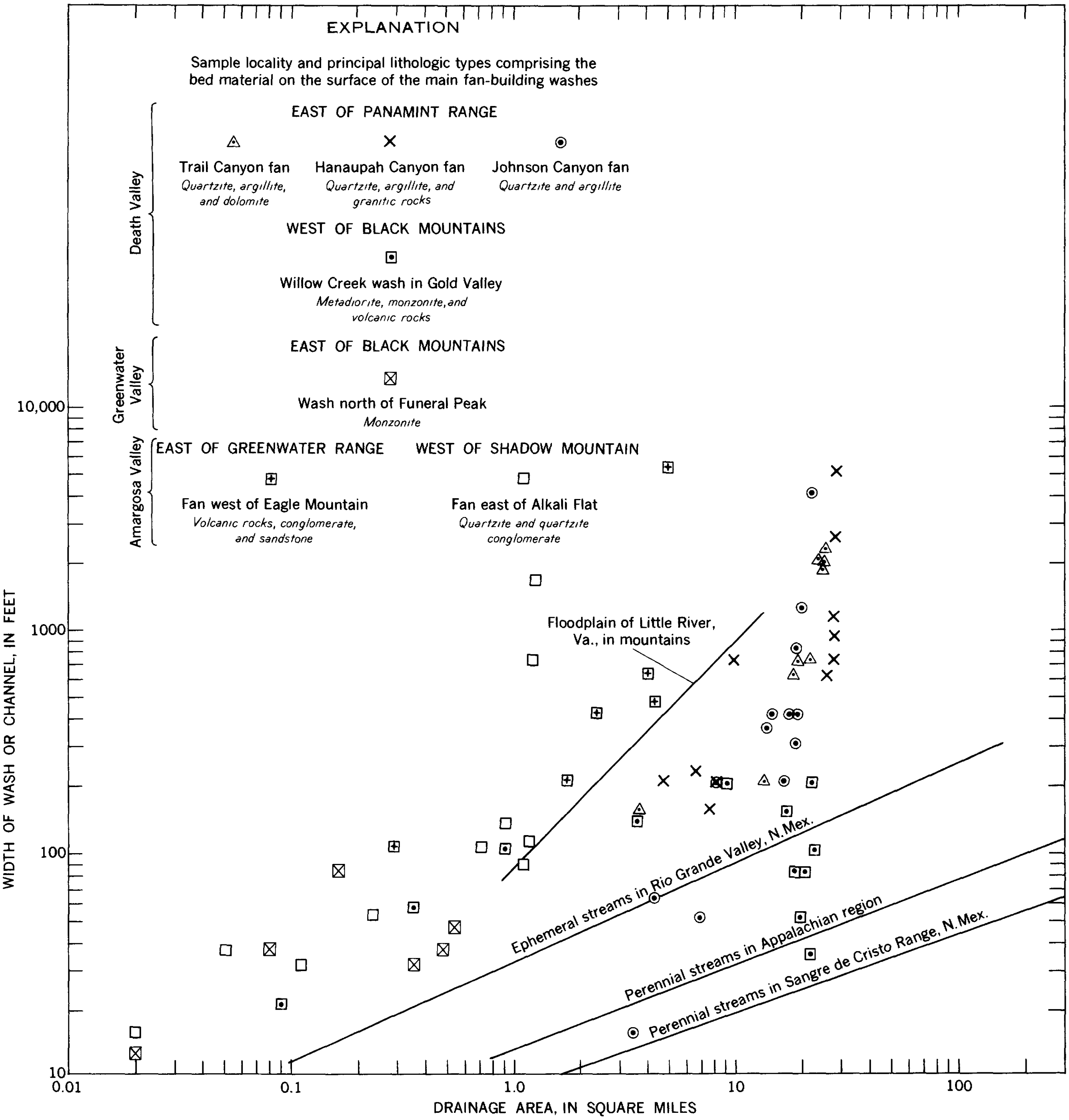

FIGURE 18.—Logarithmic scatter diagram showing the relation between width of wash and drainage area at sample sites along seven washes in the Death Valley region. Lines representing generalizations from similar data for channels in N. Mex. (Leopold and Miller, 1956; Miller, 1958) and in the Appalachian region (Hack, 1957; Hack and Goodlett, 1960) are shown for comparison.

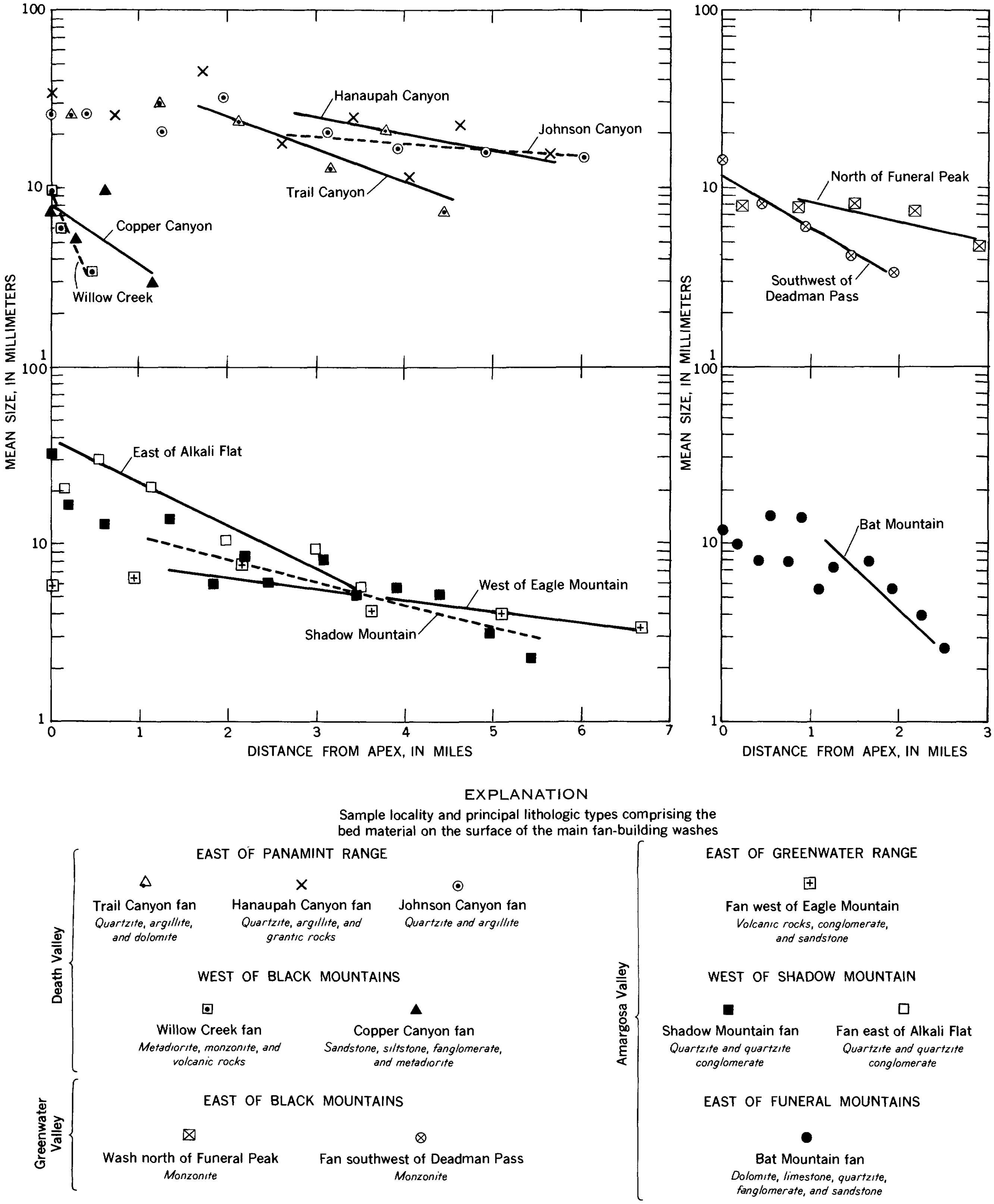

FIGURE 19.—Semilogarithmic scatter diagram showing the relation between the mean size of material on the surface of the wash and the distance from the apex at sample sites on 11 fans. The apexes of the fans are at the mountain front. Lines, drawn by inspection, show depositional areas where a wash has the form of the segment of a very low cone—commonly the areas where wash is wide.

These two pavement segments on the Hanaupah Canyon fan are old; when they were the loci of deposition, the modern fan was not in existence. Pavement Y has a steeeper slope and is more deeply dissected than pavement Z a fact suggesting that the gravel beneath Y is perhaps older than that below Z. The two gravels, however, could be parts of the same fan, because the area of the modern fan is about equal to that of pavement segment Y plus segment Z. The gravels

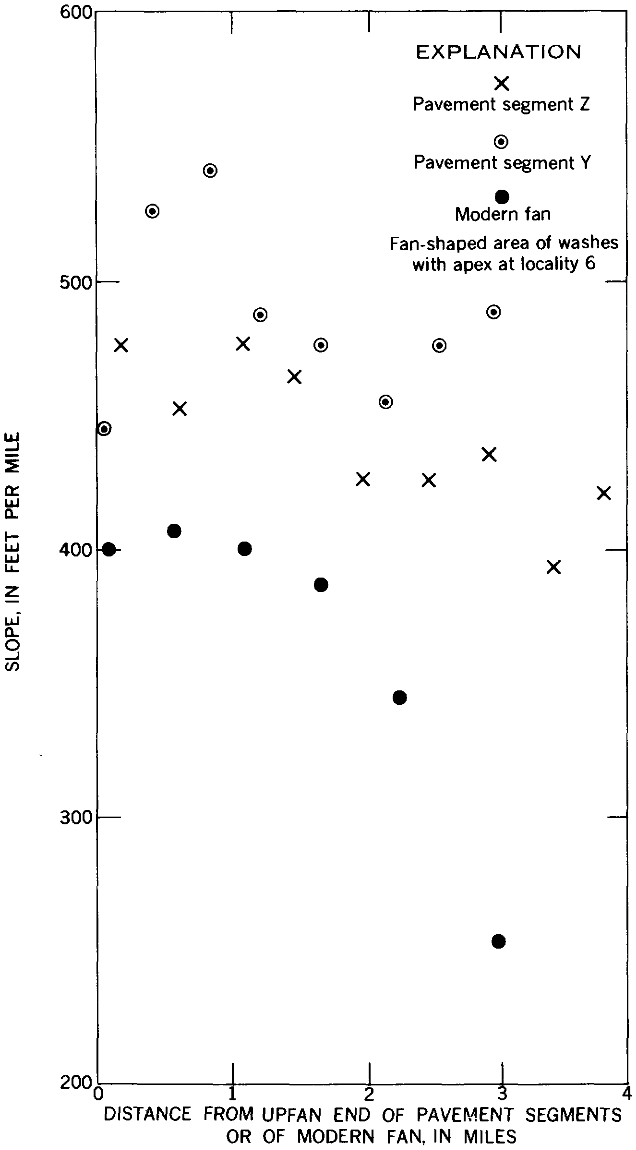

FIGURE 20.—Slope of pavement segments and of a part of the main wash on the Hanaupah Canyon fan. Locality 6 is at the apex of a fan-shaped area of washes—the modern fan—that extends to the edge of the saltpan. Pavement segments Y and Z are shown on plate 5. Arithmetic scatter diagram showing the relation between slope and distance from upfan end of pavement segments or of the modern fan.

under the pavements pass downfan beneath the gravels of the adjacent washes. Presumably the toe of the old gravel fan is now buried at an altitude lower than the surface of the saltpan, but whether it is east or west of the toe of the modern fan is unknown. Pavement segments Y and Z perhaps include most of the area of an earlier fan whose toe was about half a mile west of the toe of the modern one. At the toe of Starvation Canyon fan, however, weathered boulder gravel of Quaternary age exposed in a small fault block (C. B. Hunt, written commun., 1960) is part of an ancient fan that must have extended further eastward than the edge of the saltpan.

The contrast between the east and west sides of Death Valley reflects, in large part, its structural history and is influenced to only a small extent by the difference in altitude between the two opposing highlands. The Black Mountain fans are small in comparison with those west of Death Valley and even with all the other fans studied (fig. 7). Copper Canyon fan, for example, with an area of about 2 square miles, would have to be about three times its present size to bring it in accord with other fans in this region. On figure 7, the average trend line of the graph lies above the point that represents the Copper Canyon fan. During the Quaternary period, the floor of Death Valley was depressed relative to the west front of the Black Mountains and tilted eastward (C. B. Hunt, written commun., 1960). This deformation lowered the Black Mountain fans and caused most of the sedimentation on the saltpan to be localized along its eastern edge at the foot of the mountains. The surface of the saltpan has risen faster than the surface of the Black Mountain fans. Deformation and eastward tilting of the Black Mountains themselves are suggested by the steep easterly slope of their piedmont in Greenwater Valley (p. 30). The mouths of the canyons in the Panamint Range have been the sites alternately of erosion and of deposition. After the mouths of the canyons were eroded at least to their present depth, they were filled with gravel to a height 200 feet above their present floors.

It is reasonable to suppose that the greater rainfall intercepted by the lofty Panamint Range results in more frequent flooding and more rapid erosion or deposition on its fans. From this supposition we might infer that the fans east of the range should be exceptionally large ones. However, the areal extent of the washes on the piedmont east of the range compared with that of their source areas (fig. 7) follows the general relation for all fans in the region. The areas of these washes is proportional to the size of their source areas. The entire piedmont east of the range has probably never been at one time an area of wash but has always included large areas of pavement. This probability is supported by data shown on figure 7. When the total areas—pavement plus wash (table 2)—of the Trail Canyon, Hanaupah Canyon, and Johnson Canyon fans are plotted on the graph, these points fall well above the general line, and slightly above the field of scatter of all other points.

CHARACTERISTICS OF FANS

SIZE AND RELATION TO PEDIMENTS

The size of an alluvial fan is related to the size of the source area. The description of the several fans presented in the first part of this paper has shown that if values for the area of a fan or of the area of deposition on a fan is plotted on a logarithmic graph against the size of the drainage area above the apex, the field of scatter of many of the points (fig. 7) is restricted; a line can be drawn through the points by inspection and may be expressed by the relation

$$Af=0.5\ Am^{0.8},$$

which states that the size of a fan or fan segment is equal to half of the eight tenths power of the size of its source area. This graph includes values for fans of varying size and material—from the small fans ringing the isolated hills near Devils Hole to the Trail Canyon fan having an area of 8 square miles—and clearly represents a valid relation. Nevertheless the data are not precise, and it is perhaps more meaningful to say that in the Death Valley region the area of deposition on a fan is roughly one-third to one-half that of its source area in the desert mountain.

This relation, however, does not hold if the entire fan or entire piedmont is considered and either one includes extensive areas of desert pavement. Values for several entire piedmonts are also plotted on figure 7, and the points lie well above the trend line. The explanation for this divergence appears to lie partly in the structural history of mountain and basin and partly in drainage changes. On the large piedmont east of the Panamint Range, for example, the local runoff carves lowlands in part of a fan while deposition takes place on a higher segment near by. Drainage diversions cause the stream in the fan-building wash to leave the higher segment and flow down into the lowland incising a channel across the breached divide and depositing sediment in the lowland. Thus the loci of deposition shift whereas, on the contrary, the size of the area of deposition remains the same.

The fans west of the Black Mountains, on the other hand, are notably small in relation to the size of their source regions (fig. 7). These fans do not follow the equilibrium relation of size to source area that is general for fans in the Death Valley region. Clearly this lack of adjustment is related to the recent eastward tilting of the floor of Death Valley and the resultant overlap of the playa beds onto the fans (C. B. Hunt, written communication, 1960). This evidence does not necessarily imply, however, that the volume of fan debris at the base of the Black Mountains is of a smaller order of magnitude than the debris which underlies the fans on the west side of the valley. A large volume of fan debris from the Black Mountains may lie beneath the valley floor.

The arrangement on the graph of sizes of the fans west of the Black Mountains from Badwater south to Copper Canyon (fans A to G in fig. 7 and pl. 4) is not haphazard but is orderly, a fact suggesting that these fans follow a different equilibrium relation of size to source area than is represented by the other fans studied. Inspection of figure 7 shows that these seven fans are roughly equal to one-tenth the size of their source areas in the Black Mountains ($Af=0.1\ Am^{1.0}$). These fan-building washes, therefore, are maintained in some sort of equilibrium with their surroundings in spite of continuing deformation.

A third example is the entire Shadow Mountain fan, which is about three times larger in proportion to its source area than called for by the general relation. Only the valves for the many depositional segments of which the fan is composed plot close to the trend line shown on figure 7.

On many piedmonts distinguishing alluvial fans from pediments either by field observation or from map study is difficult at best. It would be of considerable practical value if one could distinguish a fan underlain by many hundreds of feet of alluvium from a pediment thinly veneered with gravel. Conical segments of the alluvial fans that have been studied show a consistent relation between size of depositional segment and extent of source area. This relation implies that all conical segments are in fact depositional and, therefore, that a piedmont made up largely of conical segments is a constructional landform. Such a generalization should be used with caution, but in its support, note that the Panamint Range piedmont, clearly built up of thick alluvial deposits, consists of cone-shaped segments of pavement and of wash.

Only parts of the Shadow Mountain fan, on the other hand, are cone shaped, and a considerable part of its surface (pl. 1) is either a more or less sloping plain or actually scoop shaped. The same is true also of the fans that slope southwestward from the Funeral Mountains (fig. 1) near Chloride Cliff to the north end of the saltpan (C. B. Hunt, written commun., 1960). Whether or not these scoop-shaped areas are pediments cannot be answered with certainty. On the Shadow Mountain fan, however, the pavements near the toe and the small segments of pediment along its north and south borders are areas where erosion has dominated over deposition in the recent past. It is not unreasonable, therefore, to suppose that the gravels that now crop out on the western half of the fan are not more than a few tens of feet thick, whereas to the east the thickness may reach several hundred feet.

The total area of the Bat Mountain fan (fig. 13) and of the fan-shaped segment of the piedmont traversed by the wash north of Funeral Peak (segment M, pl. 4) is several times larger than that indicated by the general relation of fan area to source area (fig. 7). Perhaps parts of these two fans are actually veneers on a pediment, for small bedrock hills rise within them and suggest that the alluvium is thin.

In regions where the mountains are small relative to their piedmonts, as in southeastern Arizona, the areas demonstrable as pediment are much larger in proportion to the areas that drain to them than are the Death Valley fans (Tuan, 1959, fig. 47). At best, once a considerable number of observations on the relation of area of fan to source area are available for a given region, a plot of size of fan against size of drainage area, such as figure 7, may aid in guessing which segments of a piedmont are fan and which are buried pediment.

FAN-BUILDING WASHES

The desert washes, both modern and abandoned, are broad, flat-floored troughs with or without distinct banks and consist of channels and gravel bars. They are generally steeper and wider than stream channels in humid regions; these differences are related perhaps to the regimen of the ephemeral streams and the absence of a protective blanket of vegetation. The material on the floor of the desert washes is finer grained than that on the beds of perennial-streams, but the actual sizes present depend primarily on the local geology.

The slopes of the larger washes in desert mountains—those having drainage areas greater than about 1 square mile—are generally steeper than stream channels in humid regions, although both commonly have concave-upward longitudinal profiles and, along both, the slope decreases with increasing drainage area, as is illustrated by the diagram on figure 21. If drainage area is a factor directly affecting discharge, then this diagram shows that at the same discharge, the slope of a desert wash in the mountains is steeper than that of stream channels in more humid regions, perhaps because water is lost by evaporation and by flow into the gravel beneath the bed of the desert wash.

Although most desert washes are wider than are stream channels in humid regions, both increase in width in a downstream direction at roughly the same rate as drainage area increases (fig. 18). Many of the desert washes vary widely in width with little or no corresponding change in slope (fig. 22), but where a stream channel has the same width as a desert wash, the gradient of the perennial stream is much lower. This apparent greater width of the desert washes may be related to the nature of their banks. The stabilizing effect of vegetation is absent and perhaps in a desert wash, as mentioned on page 24, gravel banks are more easily eroded than are those built of finer materials.

The difference in width between channels in humid and those in arid regions, however, may be more apparent than real because most washes whose widths are represented in these diagrams actually consist of several braided channels separated by gravel bars. Because we do not know which part of the floor of a wash was covered with water at any one time, the width of a wash is possibly more comparable to flood-plain width in a humid region than to channel width. For example, the flood plain of the Little River in the mountains west of the Shenandoah Valley, Va. (Hack and Goodlett, 1960) has widths and slopes that are comparable to those of washes in the California desert (figs. 18 and 22). This segment of the Little River flood plain includes both bare channels and forested areas and forms the entire floor of a narrow valley in the mountains.

The material on the surface of the fan-building washes ranges in size from boulders to clay, but the amount of silt or finer sediment is small. The range in estimated mean size for 115 samples of material at sites on the surface of washes from headwaters to toe of fan, is shown as a cumulative curve on figure 23. The mean value for all samples is 8.5 mm (table 6). No estimates

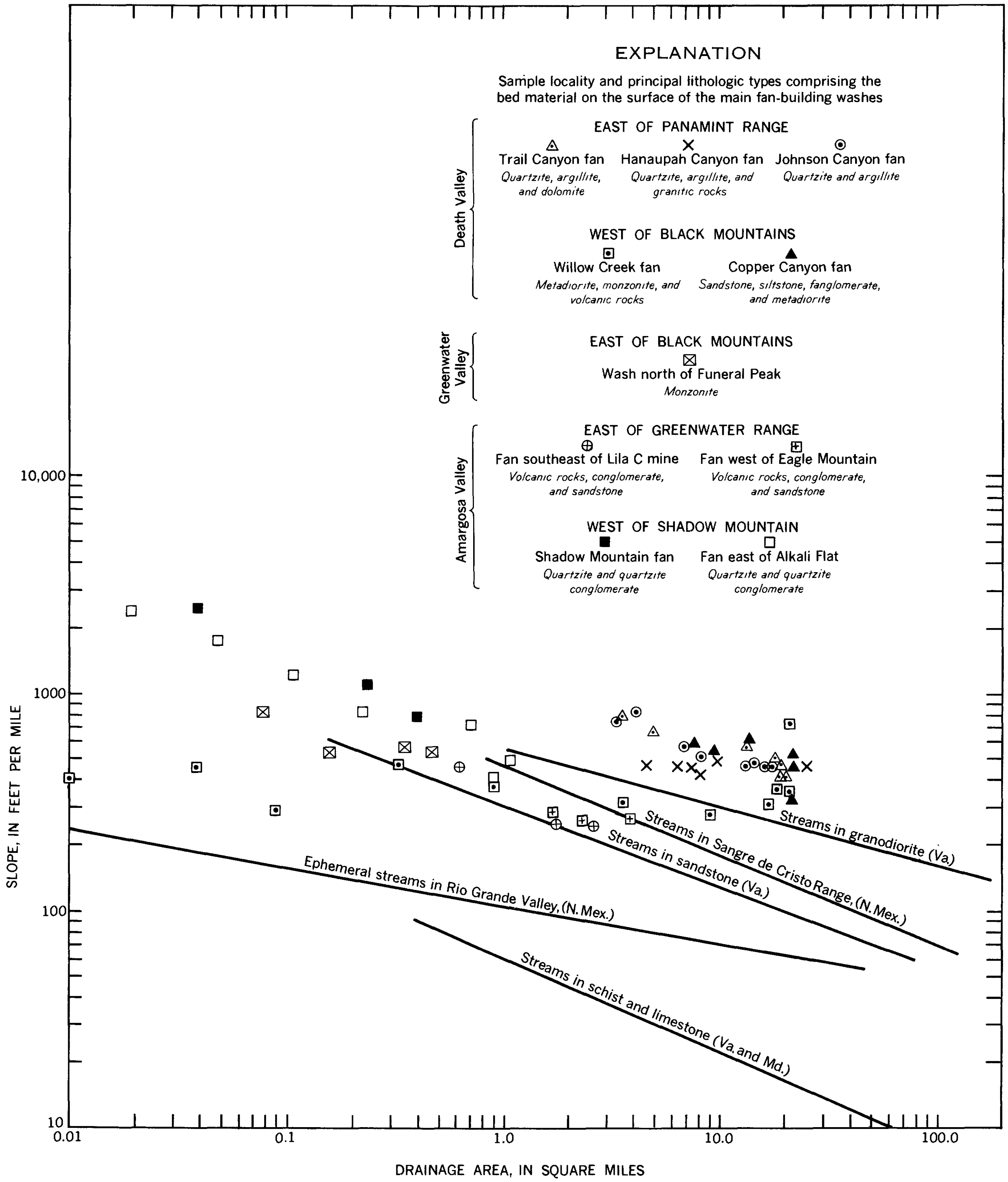

FIGURE 21.—Logarithmic scatter diagram showing the relation between slope and drainage area at sample sites along 10 washes in the mountains of the Death Valley region. For comparison, lines on the diagram show the generalized slope-drainage area relation for stream channels in other regions. Those in Maryland and Virginia are from Hack (1957, fig. 16) ; those in the Sangre de Cristo Range, N. Mex., are based on data collected by Miller (1958, fig. 20), and those for ephemeral streams in the Rio Grande Valley are from Leopold and Miller (1956, fig. 24).

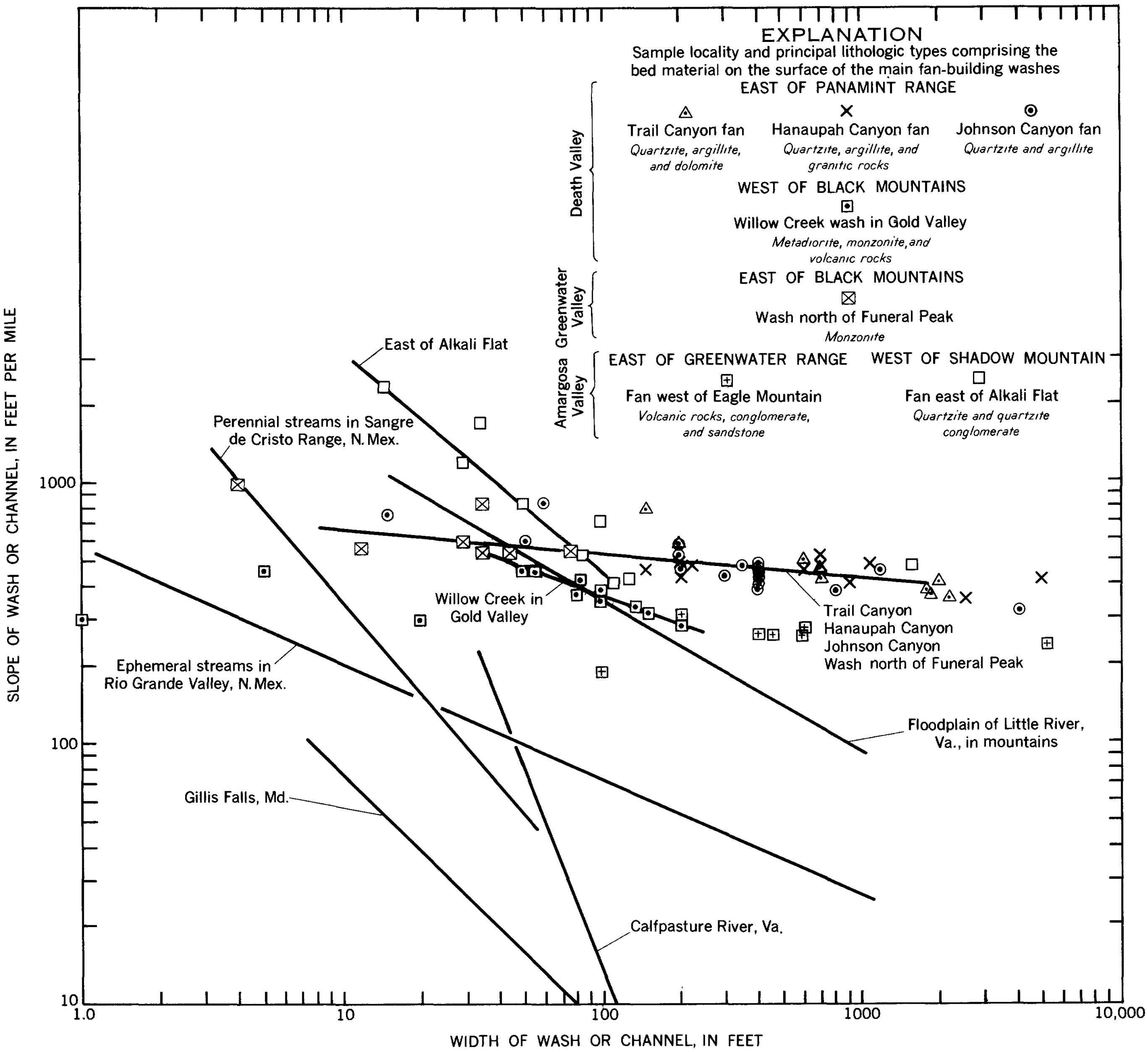

FIGURE 22.—Logarithmic scatter diagram showing the relation between slope and width at sample sites along seven washes in the Death Valley region. Lines representing generalizations from similar data for channels in N. Mex. (Leopold and Miller, 1956; Miller, 1958) and in the Appalachian region (Hack, 1957; Hack and Goodlett, 1960) are shown for comparison.

TABLE 6.—*Particle size and sorting coefficients for bed material from various regions*

[All samples were selected by use of a grid. Values for the Appalachian region are from Hack (1957, table 8); values for the Southern Rocky Mountain region are from Miller (1958, tables 15-18)]

Region	Mean diameter (millimeters)			Trask sorting coefficient		
	Mean of all samples	Minimum value	Maximum value	Mean of all samples	Minimum value	Maximum value
Death Valley	8.5	2.4	74.0	1.9	1.25	4.00
Appalachian	[1] 47.0	5.0	630.0	1.95	1.1	21.0
Southern Rocky Mountain	105.0	48.0	312.0	1.6	1.29	2.05

[1] Median diameter.

were made of maximum size, but the 90 percentile size of the material at the sample localities is given in table 7. These values generally are 3–5 times larger than the mean diameters. Of 115 analyses from the Death Valley region, about two-thirds are unimodal, the most abundant modal class being 4 phi units. The remainder are bimidal; 6 phi units is the most common primary mode, and 1 phi unit is a secondary mode. Washes draining areas of granitic rock are floored with unimodal gravel; on the other hand the high Panamint Range, which has a diverse lithology, furnishes a detritus that is bimodal at two-thirds of the sample localities.

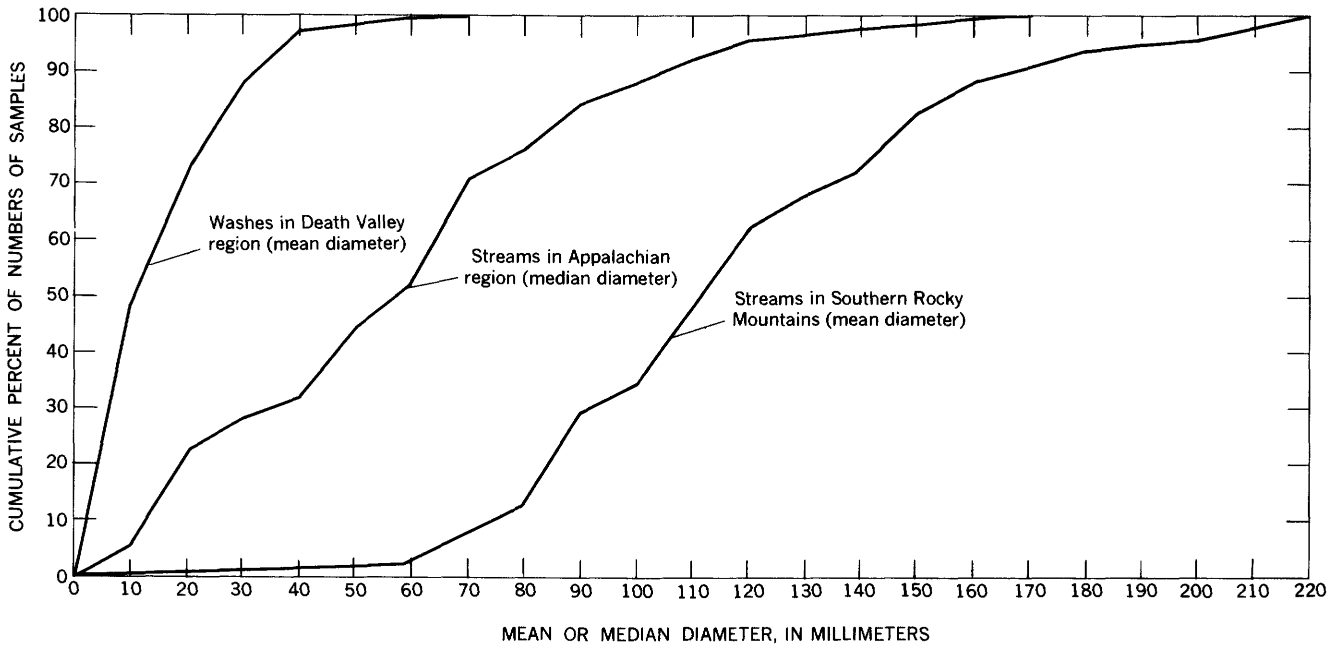

FIGURE 23.—Cumulative curves showing the range in mean or median diameter of material on the floors of washes in the Death Valley region and in streams in the Appalachian region (Hack, 1957, table 8), and the southern Rocky Mountains (Miller, 1958, tables 15–18). Numerical values are given in table 6.

The samples from the floors of the desert washes are not well sorted. The standard deviation ranges from 0.45 to 2.85 phi units and is slightly higher for samples from fans compared with those from washes in the adjacent mountains. Sorting is nearly independent of mean size of material. The range of standard deviation varies slightly from fan to fan.

The change in size of bed material downwash does not seem to follow any general law but varies from fan to fan (fig. 14). On the east side of the Panamint Range, for example, the changes in size of bed material from one sample site to the next are considerably greater than any overall decrease in size from headwaters to toe of fan. No clear explanation can be given for this lack of order. In part, the debris supplied to the Panamint Range washes may vary in size from place to place because of bedrock differences. The explanation may lie in the regimen of the washes. The high altitude of the range induce occasional great floods that move coarse debris nearly to the saltpan, but floods of lesser magnitude or covering only a part of the source area merely cause deposition along washes in the mountains. Thus the material on the floor of the washes results from varying combinations of formative processes. The quartzite debris of the washes west of Shadow Mountain, decreases markedly in size downfan because the floods from this low mountain carry coarse debris only a short distance down the fan, where it remains until comminuted by weathering.

No overall change in the slope of a wash occurs with change in the size of bed material, as indicated on figure 24; however, the plot of values suggests that at less than a slope of about 500 feet per mile and where size is not more than about 15 millimeters, there is a slight tendency for slope to increase with increasing size of bed material.

TABLE 7.—*Principal measurements at sample localities*

[Data used in constructing graphs presented in this paper are included in this table. The location of each sample locality is shown on the plate indicated. Slope, calculated, was measured on a topographic map between sample localities; slope, measured, was determined in the field by use of an Abney level. Distance to apex, at head of cone-shaped area of wash is to the head of the area where the wash has a cone-shaped surface (on a topographic map the area where the contours crossing the wash are convex downslope)]

Quadrangle and locality No.	Altitude (feet)	Distance to divide (miles)	Drainage area (square miles)	Slope (feet per mile)	Mean grain size (mm)	Width (feet)	Distance to apex (miles)		90 percentile size	
							At mountain front	At head of cone-shaped area of wash	ø	Millimeters
EAST OF PANAMINT RANGE										
Trail Canyon fan (pl. 5)										
Emigrant Canyon				*Calculated*						
2	4,640	2.22	3.61	800	21.0	150	--------	--------	5.9	60.0
14	3,840	3.37	5.00	696	74.0	--------	--------	--------	7.7	105.0
1	3,240	4.40	13.45	583	17.0	200	--------	--------	6.3	79.0
13	2,680	5.52	18.38	500	37.0	600	--------	--------	6.9	120.0
11	2,240	6.44	19.72	478	20.0	700	--------	--------	6.1	69.0
Furnace Creek										
8	1,840	7.39	20.89	421	13.0	700	--------	--------	5.9	60.0
16	1,440	8.35	23.81	417	26.0	2,000	0.25	--------	6.2	74.0
5	1,060	9.33	24.84	388	30.0	1,800	1.23	--------	7.1	140.0
14	720	10.22	25.03	382	24.0	1,900	2.12	0.45	6.8	112.0
3	340	11.27	25.33	362	13.0	2,200	3.17	1.50	5.5	45.0
12	120	11.89	26.06	355	21.0	--------	3.79	2.12	6.9	120.0
10	−110	12.55	26.23	348	7.4	--------	4.45	2.78	6.2	74.0
Hanaupah Canyon fan (pl. 5)										
Telescope Peak				*Calculated*						
6	3,670	5.01	4.64	485	45.0	200	--------	--------	6.8	112.0
7	3,550	5.26	6.58	480	22.5	225	--------	--------	7.5	185.0
1	3,200	6.01	7.68	467	26.0	150	--------	--------	6.2	74.0
Bennetts Well										
44	2,940	6.60	8.24	441	17.0	200	--------	--------	5.8	56.0
9	2,420	7.63	9.77	505	37.0	700	--------	--------	6.7	105.0
45	2,040	8.44	25.68	469	34.5	600	0.00	--------	6.7	105.0
8	1,680	9.17	27.54	493	26.0	1,100	.73	--------	6.8	112.0
46	1,220	10.16	27.79	465	45.0	700	1.72	--------	6.8	112.0
6	840	11.07	27.96	418	18.5	900	2.63	--------	7.2	150.0
48	560	11.86	28.05	354	24.0	2,500	3.42	0.50	7.1	140.0
47	280	12.53	28.11	418	11.2	5,000	4.09	1.37	5.2	37.0
4	100	13.05	29.27	346	22.5	--------	4.61	1.89	7.2	150.0
1	−220	14.08	30.38	311	15.0	--------	5.64	2.92	5.9	60.0

TABLE 7.—*Principal measurements at sample localities*—Continued

Quadrangle and locality No.	Altitude (feet)	Distance to divide (miles)	Drainage area (square miles)	Slope (feet per mile)	Mean grain size (mm)	Width (feet)	Distance to apex (miles)		90 percentile size	
							At mountain front	At head of cone-shaped area of wash	ø	Millimeters
Johnson Canyon fan (pl. 5)										
Unweathered gravel on floor of modern wash										
Telescope Peak				*Calculated*						
2	4,880	2.80	3.40	762	18.5	15	--------	--------	7.5	185.0
3	4,640	3.09	4.21	828	8.5	60	--------	--------	6.2	74.0
4	4,130	3.95	6.92	593	13.0	50	--------	--------	5.8	56.0
5	3,670	4.81	8.23	535	24.0	200	--------	--------	6.6	98.0
Bennetts Well										
10	3,360	5.46	13.78	477	34.5	350	--------	--------	6.5	91.0
36	2,990	6.21	14.41	493	30.0	400	--------	--------	6.8	112.0
37	2,660	6.91	16.59	471	21.0	200	--------	--------	5.9	60.0
11	2,300	7.67	17.88	474	26.0	400	0.00	--------	6.8	112.0
39	1,980	8.41	18.68	432	26.0	400	.41	--------	6.9	120.0
40	1,600	9.27	18.88	442	21.0	300	1.27	--------	6.4	85.0
13	1,340	9.94	18.99	388	32.0	800	1.94	--------	6.9	120.0
42	860	11.11	19.25	410	20.0	400	3.11	0.50	5.9	60.0
15	540	11.93	19.52	390	17.0	400	3.93	1.32	6.7	105.0
43	180	12.90	19.95	464	16.0	1,200	4.90	2.29	6.4	85.0
16	−180	14.02	22.01	321	15.0	4,000	6.02	3.41	6.2	74.0
Wash heading on the fan (pl. 5)										
Bennetts Well				*Calculated*						
19	2,000	0.21	0.01	571	49.0	2	--------	--------	------	--------
20	1,920	.34	.02	615	18.5	8	--------	--------	------	--------
21	1,680	.83	.06	490	37.0	23	--------	--------	------	--------
22	1,200	1.87	.18	462	28.0	30	--------	--------	------	--------
23	700	3.15	.98	391	10.5	160	--------	--------	------	--------
24	120	4.90	1.83	331	14.0	400	--------	--------	------	--------
WEST OF BLACK MOUNTAINS										
Willow Creek fan (pl. 4)										
Funeral Peak				*Calculated*						
21	4,435	0.05	0.01	300	5.2	1	--------	--------	3.9	15.0
22	4,370	.19	.04	464	8.0	5	--------	--------	4.7	26.0
23	4,340	.29	.09	300	4.9	20	--------	--------	3.6	12.0
24	4,210	.57	.35	464	4.9	55	--------	--------	3.6	12.0
25	3,910	1.34	.91	390	6.5	100	--------	--------	3.9	15.0
26	3,520	2.50	3.55	336	7.0	135	--------	--------	3.8	14.0
27	3,300	3.28	9.07	282	9.8	200	--------	--------	5.3	39.0
28	2,960	4.36	16.87	315	12.0	150	--------	--------	5.6	49.0
29	2,660	5.15	18.70	380	9.2	80	--------	--------	4.9	30.0
31	2,480	5.57	19.47	429	9.8	80	--------	--------	4.9	30.0
30	2,400	5.74	19.65	470	9.8	50	--------	--------	5.9	60.0
17	390	7.88	21.32	778	9.8	35	--------	--------	6.2	74.0
18	200	8.41	21.73	358	11.2	200	--------	--------	5.6	49.0
16	−100	9.26	22.35	353	9.8	100	0.00	--------	5.7	52.0
19	−130	9.39	22.36	231	6.0	500	.13	--------	5.8	56.0
20	−230	9.70	22.38	326	3.4	2,000	.44	--------	6.3	79.0

TABLE 7.—*Principal measurements at sample localities*—Continued

Quadrangle and locality No.	Altitude (feet)	Distance to divide (miles)	Drainage area (square miles)	Slope (feet per mile)	Mean grain size (mm)	Width (feet)	Distance to apex (miles): At mountain front	Distance to apex (miles): At head of cone-shaped area of wash	90 percentile size: φ	90 percentile size: Millimeters
Copper Canyon fan (pl. 4)										
Funeral Peak				*Calculated*						
10	2,160	5.21	7.76	600	13.0				5.5	45.0
11	1,870	5.74	9.45	547	7.0				4.9	30.0
12	1,180	6.88	13.76	605	10.5				5.9	60.0
13	990	7.45	21.48	333	8.0				4.8	28.0
14	460	8.51	22.04	321	13.0				5.3	39.0
15	280	8.85	22.21	529	4.5				4.6	24.0
Bennetts Well										
25	180	9.06	22.26	476	7.4		0.00		4.7	26.0
31	60	9.34	22.29	429	5.2		.28		3.9	15.0
33	−100	9.72	22.33	421	9.8		.66		6.1	69.0
32	−240	10.21	22.36	286	3.0		1.15		4.5	22.5
EAST OF BLACK MOUNTAINS										
Wash north of Funeral Peak (pl. 4)										
Funeral Peak				*Measured*						
42	6,240	0.04	0.01	1,452	12.0				6.3	79.0
43	6,200	.09	.01	1,000	8.0	4			5.2	37.0
44	6,120	.16	.02	554	4.0	12			3.8	14.0
				Calculated						
40	6,000	.34	.08	823	4.5	35			3.4	10.5
39	5,840	.63	.16	552	6.0	80			3.9	15.0
38	5,580	1.06	.35	590	4.9	30			3.7	13.0
37	5,320	1.53	.48	550	8.0	35			4.2	18.5
36	5,040	2.03	.53	560	8.0	45	0.25		4.7	26.0
35	4,710	2.63	.58	550	8.0		.85	0.00	4.1	17.0
34	4,440	3.26	.62	429	8.0		1.48	.63	4.1	17.0
33	4,170	3.94	.67	397	7.4		2.16	1.31	3.8	14.0
32	3,980	4.68	.73	257	4.9		2.90	2.05	3.9	15.0
Wash southwest of Deadman Pass (pl. 3)										
Eagle Mountain				*Calculated*						
11	3,720	0.25	0.03	1,320	15.0				6.8	112.0
10	3,580	.41	.05	875	13.0				5.6	49.0
9	3,360	.76	.14	629	14.0		0.00		6.2	74.0
8	3,120	1.19	.18	558	8.0		.43		4.5	22.5
7	2,980	1.69	.39	280	6.0		.93		5.2	37.0
19	2,890	2.19	.63	180	4.2		1.43		3.8	14.0
20	2,830	2.68	.70	122	3.4		1.92		3.9	15.0

TABLE 7.—*Principal measurements at sample localities*—Continued

Quadrangle and locality No.	Altitude (feet)	Distance to divide (miles)	Drainage area (square miles)	Slope (feet per mile)	Mean grain size (mm)	Width (feet)	Distance to apex (miles)		90 percentile size	
							At mountain front	At head of cone-shaped area of wash	ϕ	Millimeter
EAST OF GREENWATER RANGE										
Fan west of Eagle Mountain (pl. 3)										
Funeral Peak				*Calculated*						
7	4,065	0.55	0.29	188	7.0	100	--------	--------	3.9	15.0
8	3,870	1.32	1.72	294	8.0	200	--------	--------	4.9	30.0
9	3,680	2.11	2.33	267	12.0	400	--------	--------	5.2	37.0
Eagle Mountain										
12	3,450	2.95	4.00	274	11.2	600	--------	--------	4.1	17.0
13	3,240	3.74	4.11	266	6.0	600	0.00	--------	4.2	18.5
14	2,990	4.70	4.28	260	6.5	450	.96	--------	4.2	18.5
15	2,700	5.93	4.68	236	8.0	5,200	2.19	0.90	4.8	28.0
16	2,420	7.39	4.77	192	4.2	--------	3.65	2.36	4.5	22.5
17	2,200	8.86	4.85	150	4.0	--------	5.12	3.83	4.9	30.0
18	2,020	10.43	4.93	117	3.4	--------	6.69	5.40	3.5	11.2
Wash northwest of Lila C mine (pl. 3)										
Funeral Peak				*Calculated*						
1	3,580	0.29	0.04	1,448	3.0	--------	--------	--------	--------	--------
2	3,220	.87	.23	620	2.4	--------	--------	--------	--------	--------
4	3,020	1.35	.41	417	2.3	--------	--------	--------	--------	--------
5	2,710	2.38	.49	300	3.4	--------	--------	--------	--------	--------
Ash Meadows										
123	2,490	3.66	--------	--------	3.0	--------	--------	--------	--------	--------
124	2,420	4.12	--------	--------	2.3	--------	--------	--------	--------	--------
126	2,300	5.11	--------	--------	2.3	--------	--------	--------	--------	--------
127	2,240	5.63	--------	--------	2.6	--------	--------	--------	--------	--------
155	2,110	6.98	--------	--------	3.2	--------	--------	--------	--------	--------
158	2,035	8.35	--------	--------	2.8	--------	--------	--------	--------	--------
Wash southeast of Lila C mine (pl. 3)										
Funeral Peak				*Calculated*						
7	3,380	1.17	0.63	479	6.0	--------	--------	--------	--------	--------
6	3,070	2.34	1.79	265	5.6	--------	--------	--------	--------	--------
Eagle Mountain										
6	2,830	3.29	2.71	253	4.9	--------	--------	--------	--------	--------
5	2,660	4.08	3.24	215	8.0	--------	--------	--------	--------	--------
4	2,420	5.07	3.65	242	7.0	--------	--------	--------	--------	--------
3	2,320	5.56	3.68	204	5.2	--------	--------	--------	--------	--------
2	2,200	6.59	3.77	117	8.0	--------	--------	--------	--------	--------
Ash Meadows										
159	2,030	8.90	3.96	74	2.3	--------	--------	--------	--------	--------

TABLE 7.—*Principal measurements at sample localities*—Continued

Quadrangle and locality No.	Altitude (feet)	Distance to divide (miles)	Drainage area (square miles)	Slope (feet per mile)	Mean grain size (mm)	Width (feet)	Distance to apex (miles)		90 percentile size	
							At mountain front	At head of cone-shaped area of wash	ϕ	Millimeters
WEST OF SHADOW MOUNTAIN										
Fan east of Alkali Flat (pl. 1)										
Ash Meadows				*Calculated*						
485	4, 640	0. 18	0. 02	2, 394	34. 5	15	--	--	--	--
486	4, 360	. 34	. 05	1, 750	21. 0	35	--	--	--	--
487	4, 160	. 50	. 11	1, 250	52. 0	30	--	--	7. 7	214. 0
488	3, 920	. 78	. 23	857	13. 0	50	--	--	6. 2	74. 0
489	3, 640	1. 16	. 71	737	13. 0	100	--	--	5. 4	42. 0
Eagle Mountain										
108	3, 500	1. 49	. 91	424	34. 5	130	--	--	7. 2	150. 0
109	3, 310	1. 86	1. 09	514	11. 2	85	--	--	5. 2	37. 0
490	3, 220	2. 07	1. 16	429	21. 0	110	0. 14	--	6. 5	91. 0
110	3, 030	2. 47	1. 19	475	30. 0	700	. 54	0. 44	7. 1	140. 0
112	2, 740	3. 07	1. 23	483	21. 0	1, 600	1. 14	1. 04	5. 8	56. 0
Ash Meadows										
113	2, 380	3. 92	1. 28	423	10. 5	--	1. 99	1. 89	5. 7	52. 0
50	2, 110	4. 93	1. 35	267	9. 2	--	3. 00	2. 90	5. 3	39. 0
51	2, 040	5. 44	1. 39	137	5. 6	--	3. 51	3. 41	4. 6	24. 0
52	2, 000	5. 92	1. 43	83	2. 4	--	--	--	3. 5	11. 2
Shadow Mountain Fan										
Unweathered gravel on floor of modern wash (pl. 1, Qg)										
Ash Meadows				*Calculated*						
302	5, 040	0. 00	--	--	39. 0	--	--	--	6. 7	105. 0
303	5, 040	. 06	--	--	60. 0	--	--	--	6. 8	112. 0
301	4, 340	. 35	0. 04	2, 470	98. 0	--	--	--	7. 7	214. 0
300	3, 980	. 58	--	1, 567	42. 0	100	--	--	7. 1	140. 0
299	3, 680	. 85	. 24	1, 111	32. 0	50	--	--	7. 5	185. 0
298	3, 480	1. 10	. 40	800	32. 0	--	0. 00	--	6. 9	120. 0
423	3, 380	1. 30	. 42	500	17. 0	80	. 20	--	6. 6	98. 0
426	3, 120	1. 70	. 45	650	13. 0	30	. 60	--	6. 2	74. 0
431	2, 665	2. 47	. 53	592	14. 0	8	1. 37	--	5. 8	56. 0
434	2, 545	2. 96	1. 11	245	6. 0	100	1. 86	--	4. 9	30. 0
461	2, 475	3. 28	1. 15	218	8. 5	10	2. 18	--	5. 5	45. 0
463	2, 480	3. 25	3. 29	224	6. 0	80	2. 47	--	5. 4	42. 0
458	2, 370	3. 88	3. 29	183	8. 5	50	3. 07	--	5. 3	39. 0
457	2, 280	4. 25	3. 29	243	5. 2	--	3. 44	--	4. 9	30. 0
453	2, 200	4. 74	3. 29	163	5. 6	16	3. 93	--	5. 2	37. 0
452	2, 130	5. 22	3. 29	146	4. 9	--	4. 41	--	5. 8	56. 0
53	2, 066	5. 80	3. 29	111	3. 2	10	4. 99	--	4. 2	18. 5
448	2, 035	6. 24	3. 30	70	2. 3	20	5. 43	--	2. 7	6. 5
Varnished gravel in abandoned wash (pl. 1, Qgv)										
Ash Meadows				*Calculated*						
426	3, 120	1. 70	0. 45	--	26. 0	--	--	--	--	--
428	2, 940	2. 00	. 47	600	28. 0	--	--	--	--	--
430	2, 670	2. 45	. 53	600	21. 0	--	--	--	--	--
432	2, 610	2. 69	. 66	250	22. 5	--	--	--	--	--
433	2, 550	2. 94	. 67	240	15. 0	--	--	--	--	--
462	2, 475	3. 30	1. 15	208	13. 0	--	--	--	--	--
459	2, 370	3. 88	3. 29	181	12. 0	--	--	--	--	--
455	2, 280	4. 25	3. 29	243	16. 0	--	--	--	--	--
63	2, 199	4. 74	3. 29	165	7. 0	--	--	--	--	--
451	2, 130	5. 22	3. 29	144	9. 8	--	--	--	--	--
53	2, 066	5. 80	3. 29	110	6. 5	--	--	--	--	--
449 [1]	2, 035	6. 24	3. 30	70	7. 0	--	--	--	--	--

[1] Small unmapped area of varnished gravel.

TABLE 7.—*Principal measurements at sample localities*—Continued

Quadrangle and locality No.	Altitude (feet)	Distance to divide (miles)	Drainage area (square miles)	Slope (feet per mile)	Mean grain size (mm)	Width (feet)	Distance to apex (miles)		90 percentile size	
							At mountain front	At head of cone-shaped area of wash	ϕ	Millimeters
Desert pavement (pl. 1, Qgp)										
Ash Meadows				*Calculated*						
424	3, 380	1. 31	------	------	18. 5	------	------	------	------	------
427	3, 100	1. 72	------	------	22. 5	------	------	------	------	------
78	2, 720	2. 46	------	------	22. 0	------	------	------	------	------
429	2, 650	2. 69	------	------	9. 8	------	------	------	------	------
73	2, 520	3. 30	------	------	15. 0	------	------	------	------	------
69	2, 460	3. 34	------	------	12. 0	------	------	------	------	------
72	2, 360	4. 08	------	------	10. 5	------	------	------	------	------
460	2, 350	3. 87	------	------	16. 0	------	------	------	------	------
456	2, 280	4. 23	------	------	13. 0	------	------	------	------	------
454	2, 180	4. 87	------	------	9. 2	------	------	------	------	------
71	2, 185	5. 08	------	------	12. 0	------	------	------	------	------
53	2, 066	5. 76	------	------	9. 8	------	------	------	------	------
447	2, 035	6. 23	------	------	4. 0	------	------	------	------	------
Wash heading on the fan (pl. 1)										
Ash Meadows				*Measured*						
464	3, 240	0. 000	0. 0000	------	17. 0	------	------	------	------	------
465	3, 190	. 085	. 0024	660	16. 0	4	------	------	------	------
466	3, 110	. 180	. 0072	582	30. 0	16	------	------	------	------
467	3, 040	. 303	. 0167	740	14. 0	15	------	------	------	------
469	2, 980	. 437	. 0262	365	21. 0	14	------	------	------	------
468	2, 910	. 682	. 0428	343	9. 8	45	------	------	------	------
440	2, 840	. 833	. 0618	290	9. 8	45	------	------	------	------
439	2, 760	1. 174	. 1428	238	7. 0	25	------	------	------	------
438	2, 690	1. 477	. 2332	211	6. 5	50	------	------	------	------
437	2, 640	1. 780	. 3592	185	4. 0	35	------	------	------	------
436	2, 560	2. 102	. 3782	158	7. 4	90	------	------	------	------
EAST OF FUNERAL MOUNTAINS										
Bat Mountain fan										
Unweathered gravel (pl. 2, Qg)										
Ash Meadows				*Calculated*						
279	2, 940	1. 35	0. 63	------	7. 4	------	------	------	7. 5	185. 0
276	2, 840	1. 64	1. 14	345	12. 0	------	0. 00	------	4. 9	30. 0
280	2, 780	1. 79	1. 14	400	9. 8	------	. 15	------	5. 2	37. 0
484	2, 700	2. 02	1. 15	348	8. 0	------	. 38	------	4. 9	30. 0
483	2, 640	2. 17	1. 15	400	14. 0	------	. 53	------	5. 7	52. 0
482	2, 560	2. 37	1. 17	400	8. 0	------	. 73	------	4. 4	21. 0
481	2, 510	2. 53	1. 17	313	14. 0	------	. 89	------	4. 9	30. 0
480	2, 440	2. 72	1. 18	368	5. 6	------	1. 08	------	4. 6	24. 0
479	2, 380	2. 91	1. 21	316	7. 4	------	1. 27	0. 19	4. 2	18. 5
478	2, 290	3. 29	1. 23	237	8. 0	------	1. 65	. 57	4. 9	30. 0
475	2, 230	3. 54	1. 42	240	5. 6	------	1. 90	. 82	3. 9	15. 0
473	2, 170	3. 89	1. 43	171	4. 0	------	2. 25	1. 17	3. 4	10. 5
471	2, 130	4. 12	1. 43	174	2. 6	------	2. 48	1. 40	2. 9	7. 4
252	2, 720	2. 00	------	------	11. 0	------	------	------	5. 6	49. 0
253	2, 550	2. 45	------	------	8. 0	------	------	------	5. 1	34. 5
261	2, 455	2. 84	------	------	9. 8	------	------	------	4. 8	28. 0
262	2, 370	3. 16	------	------	13. 0	------	------	------	5. 9	60. 0
273	2, 360	3. 21	------	------	9. 0	------	------	------	4. 5	22. 5
250	2, 285	3. 53	------	------	9. 0	------	------	------	5. 9	60. 0
274	2, 230	3. 74	------	------	7. 0	------	------	------	4. 9	30. 0
275	2, 225	3. 81	------	------	6. 0	------	------	------	5. 1	34. 5
296	2, 140	4. 02	------	------	3. 7	------	------	------	5. 4	42. 0
24	2, 660	2. 13	------	------	11. 2	------	0. 49	------	------	------
25	2, 385	2. 93	------	------	10. 5	------	1. 29	------	------	------
27	2, 340	3. 14	------	------	7. 4	------	1. 50	------	------	------
26	2, 075	4. 71	------	------	2. 6	------	3. 07	------	------	------

TABLE 7.—*Principal measurements at sample localities*—Continued

Quadrangle and locality No.	Altitude (feet)	Distance to divide (miles)	Drainage area (square miles)	Slope (feet per mile)	Mean grain size (mm)	Width (feet)	Distance to apex (miles)		90 percentile size	
							At mountain front	At head of cone-shaped area of wash	ϕ	Millimeters
Desert pavement (pl. 2, Qgp)										
Ash Meadows				*Calculated*						
441	2,640	2.07	-----	-----	14.0	-----	-----	-----	-----	-----
255	2,545	2.45	-----	-----	11.0	-----	-----	-----	-----	-----
444	2,430	2.94	-----	-----	9.2	-----	-----	-----	-----	-----
443	2,380	3.14	-----	-----	9.2	-----	-----	-----	-----	-----
442	2,330	3.35	-----	-----	9.2	-----	-----	-----	-----	-----
292	2,700	1.93	-----	-----	9.2	-----	-----	-----	-----	-----
240	2,600	2.28	-----	-----	16.0	-----	-----	-----	-----	-----
285	2,470	2.62	-----	-----	9.2	-----	-----	-----	-----	-----
247	2,400	2.82	-----	-----	14.0	-----	-----	-----	-----	-----
284	2,330	3.12	-----	-----	13.0	-----	-----	-----	-----	-----
24	2,665	2.13	-----	-----	12.0	-----	-----	-----	-----	-----
25	2,385	2.93	-----	-----	13.0	-----	-----	-----	-----	-----
26	2,075	4.71	-----	-----	4.9	-----	-----	-----	-----	-----
Washes heading on the fan (pl. 2)										
Ash Meadows				*Measured*						
254	2,529	0.189	0.007	290	11.0	8	-----	-----	-----	-----
256	2,501	.313	.020	343	6.5	16	-----	-----	-----	-----
257	2,476	.445	.029	238	4.6	22	-----	-----	-----	-----
258	2,451	.568	.039	211	7.4	26	-----	-----	-----	-----
259	2,413	.720	.056	211	6.5	34	-----	-----	-----	-----
260	2,385	.871	.062	290	5.6	-----	-----	-----	-----	-----
264	2,461	.189	.006	317	9.2	9	-----	-----	-----	-----
263	2,430	.294	.011	343	13.0	8	-----	-----	-----	-----
265	2,394	.417	.023	264	6.9	15	-----	-----	-----	-----
266	2,371	.540	.034	238	9.2	19	-----	-----	-----	-----
267	2,351	.653	.037	185	4.9	-----	-----	-----	-----	-----
241	2,532	.189	.006	448	11.0	8	-----	-----	-----	-----
242	2,485	.284	.011	396	9.0	6	-----	-----	-----	-----
244	-----	.436	.018	365	12.0	14	-----	-----	-----	-----
245	-----	.540	.021	211	6.0	20	-----	-----	-----	-----
248	-----	.587	.026	-----	5.0	18	-----	-----	-----	-----

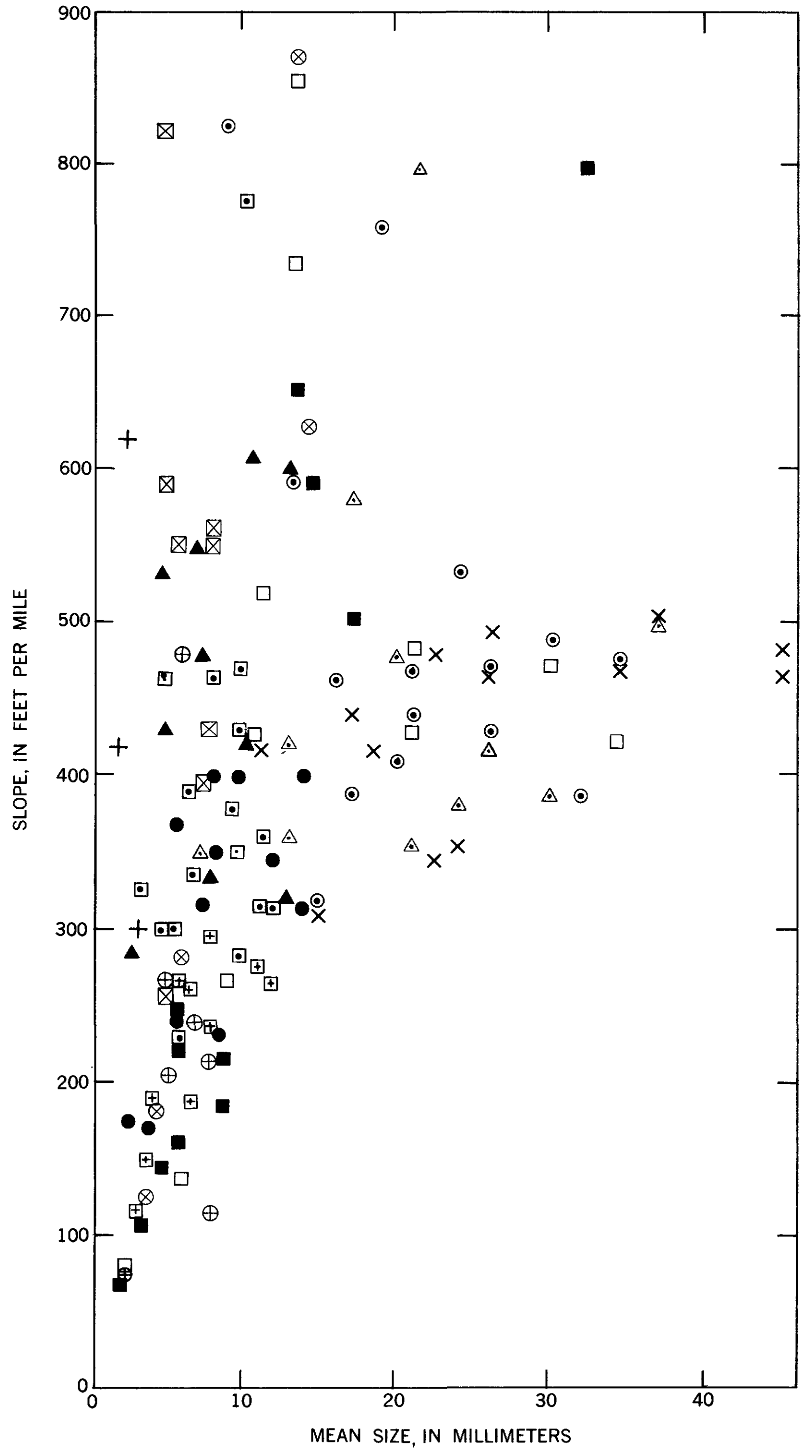

FIGURE 24.—Arithmetic scatter diagram showing the relation between size of material

EXPLANATION

Sample locality and principal lithologic types comprising the bed material on the surface of the main fan-building washes

Death Valley

EAST OF PANAMINT RANGE

- ◬ Trail Canyon fan — *Quartzite, argillite, and dolomite*
- × Hanaupah Canyon fan — *Quartzite, argillite, and granitic rocks*
- ⊙ Johnson Canyon fan — *Quartzite and argillite*

WEST OF BLACK MOUNTAINS

- ⊡ Willow Creek fan — *Metadiorite, monzonite, and volcanic rocks*
- ▲ Copper Canyon fan — *Sandstone, siltstone, fanglomerate, and metadiorite*

Greenwater Valley

EAST OF BLACK MOUNTAINS

- ⊠ Wash north of Funeral Peak — *Monzonite*
- ⊗ Fan southwest of Deadman Pass — *Monzonite*

Amargosa Valley

EAST OF GREENWATER RANGE

- + Fan northwest of Lila C mine — *Volcanic rocks, conglomerate, and sandstone*
- ⊕ Fan southeast of Lila C mine — *Volcanic rocks, conglomerate, and sandstone*
- ⊞ Fan west of Eagle Mountain — *Volcanic rocks, conglomerate, and sandstone*

WEST OF SHADOW MOUNTAIN

- ■ Shadow Mountain fan — *Quartzite and quartzite conglomerate*
- □ Fan east of Alkali Flat — *Quartzite and quartzite conglomerate*

EAST OF FUNERAL MOUNTAINS

- ● Bat Mountain fan — *Dolomite, limestone, quartzite, fanglomerate, and sandstone*

on surface of wash and slope at sample sites along washes in the Death Valley region.

A relation between size of load, slope of wash, and drainage area, such as Hack (1957, fig. 19) demonstrated for streams in the Appalachian region, does not appear to hold true in the desert. For his sample sites Hack plotted channel slope against the ratio of the size of bed material to drainage area and found that the points of the resulting scatter diagram cluster about a line that may be expressed by the relation

$$S=18\frac{M^{0.6}}{A},$$

where S is channel slope, M is median particle size of bed material, and A is drainage area. A similar diagram for sample sites along the desert washes, not included in this paper, shows a large field of scatter and indicates that for a wide range of values of M/A, slope remains nearly constant. Geological differences appear to have more effect on the form of the individual desert wash than any equilibrium relation between size, slope, and drainage area. Perhaps the streams in Shenandoah Valley, for example, constitute a single system in equilibrium, whereas in the desert, each wash represents a different system.

The material that floors the desert washes is apparently finer grained than the bedload of some streams in more humid regions (table 6). Fan-building streams on the west side of the Shenandoah Valley have a bedload that is slightly coarser than the bed material in the fan-building washes from the Panamint Range (fig. 14). The Appalachian streams, in turn, have a finer grained bedload than do the streams in the southern Rocky Mountains described by Miller (1958). It is not clear why these differences in size of bed material occur. Perhaps a sample selected by means of a grid on the bed of a perennial stream is not closely comparable to one selected in the same way from the dry bed of a desert wash. Fine material remains on the bed of a dry wash, whereas it is removed from the bed of a perennial stream by the low flow. The size differences shown by the samples may be related to differences in channel characteristics, in vegetation and in weathering on adjacent slopes, or in the amount and frequency of precipitation.

WASHES HEADING ON A FAN

Areas of desert pavement in the Death Valley region are traversed by meandering washes that are both narrow and steep-sided (fig. 17). Near the upper end of an area of pavement, a shallow channel marked by a line of shrubs descends steeply and becomes a few to several tens of feet deep. Thence to the downfan end of the pavement the channel has a meandering course and a downvalley gradient less than that of the adjacent pavement or of a neighboring wash heading in the mountains. As mentioned on page 21, the erosion in these meandering washes appears to work in opposition to the processes forming pavements. Indeed, the two processes may be part of an open system that at times approaches a steady state of balance.

The meandering washes that head in pavements differ in some respects from fan-building washes that head in the mountains. The meandering washes have drainage basins that are long and narrow compared with those of the fan-building washes. At a point about 1 mile from the headwaters of a meandering wash, the area draining to that point is about 0.1 square mile, but 1 mile from the headwaters of a fan-building wash, the drainage area is about 0.5 square mile. The width of a meandering wash increases with an increase in drainage area (fig. 25) at the same rate as does the width of a main wash (fig. 18). On the Bat and Shadow Mountain fans, meander lengths range from about 150 to 450 feet, and radius of curvature ranges from about 50 to 250 feet. These size parameters conform to the empirical relations of meander length to channel width or to radius of curvature determined by Leopold and Wolman (1960).

At its headwaters a meandering wash has coarse bed material and a steep slope. Both size of bed material and slope decrease downwash and become a little smaller than those of the adjacent wash or pavement (figs. 26 and 27). Perhaps a meandering wash has a gentle slope because its bed material is fine grained; the fine material comes to it from the weathered gravel beneath the adjacent pavement or underlying silt. A meandering wash on the Johnson Canyon fan has coarser bed material (fig. 28) and a steeper gradient than do those on the other two fans, probably because the surface of the Panamint Range fan is covered by much coarser material than are either the Bat or the Shadow Mountain fans. On the Johnson Canyon fan, however, the rate of decrease in size of bed material downwash is for some reason much less rapid than is that in meandering washes on the other fans. The slope of a meandering wash is comparable with that of ephemeral-stream channels in the Tertiary rocks of the Rio Grande Valley, near Santa Fe, N. Mex. (Leopold and Miller, 1950, fig. 24).

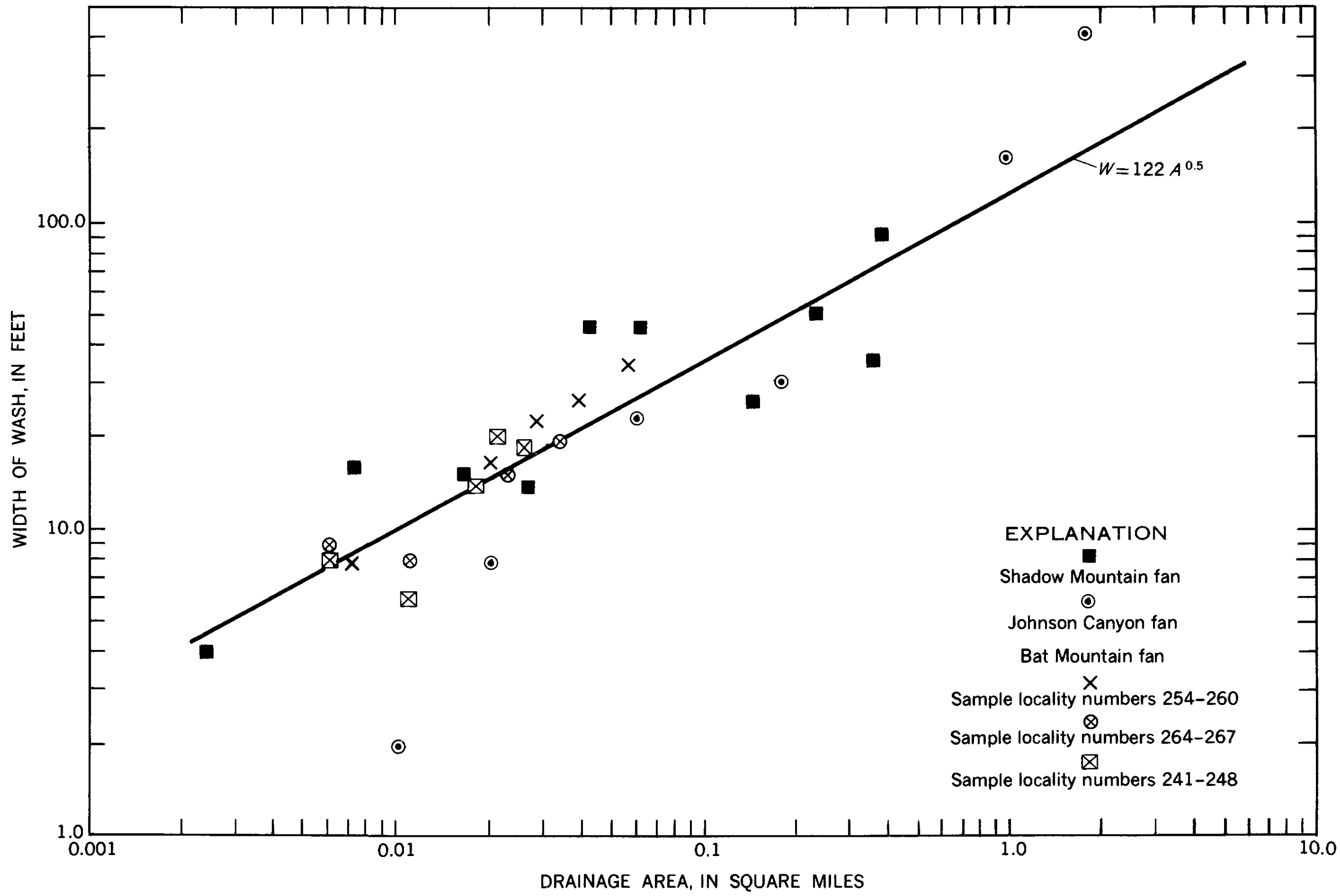

FIGURE 25.—Logarithmic scatter diagram showing the relation between the drainage area and the width at sample sites along five meandering washes that head in pavements on fans in the Death Valley region.

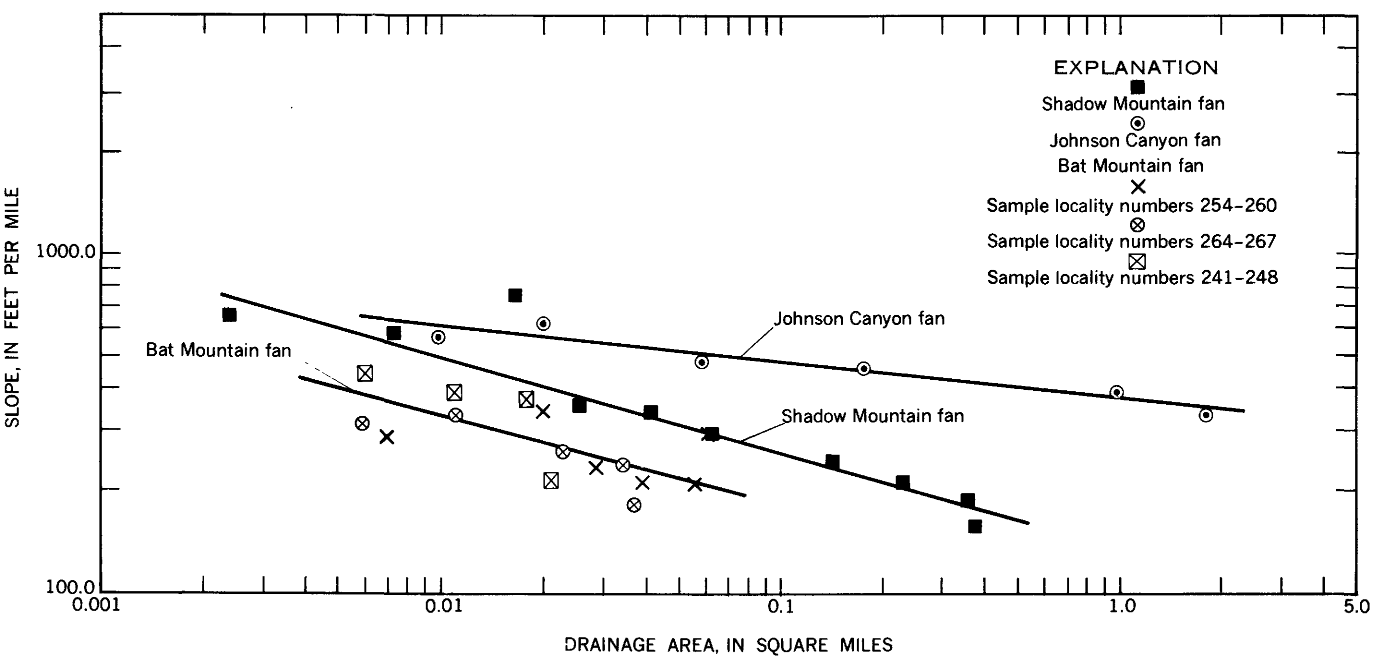

FIGURE 26.—Logarithmic scatter diagram showing the relation between the drainage area and the slope at sample sites along five meandering washes that head in pavements on fans in the Death Valley region.

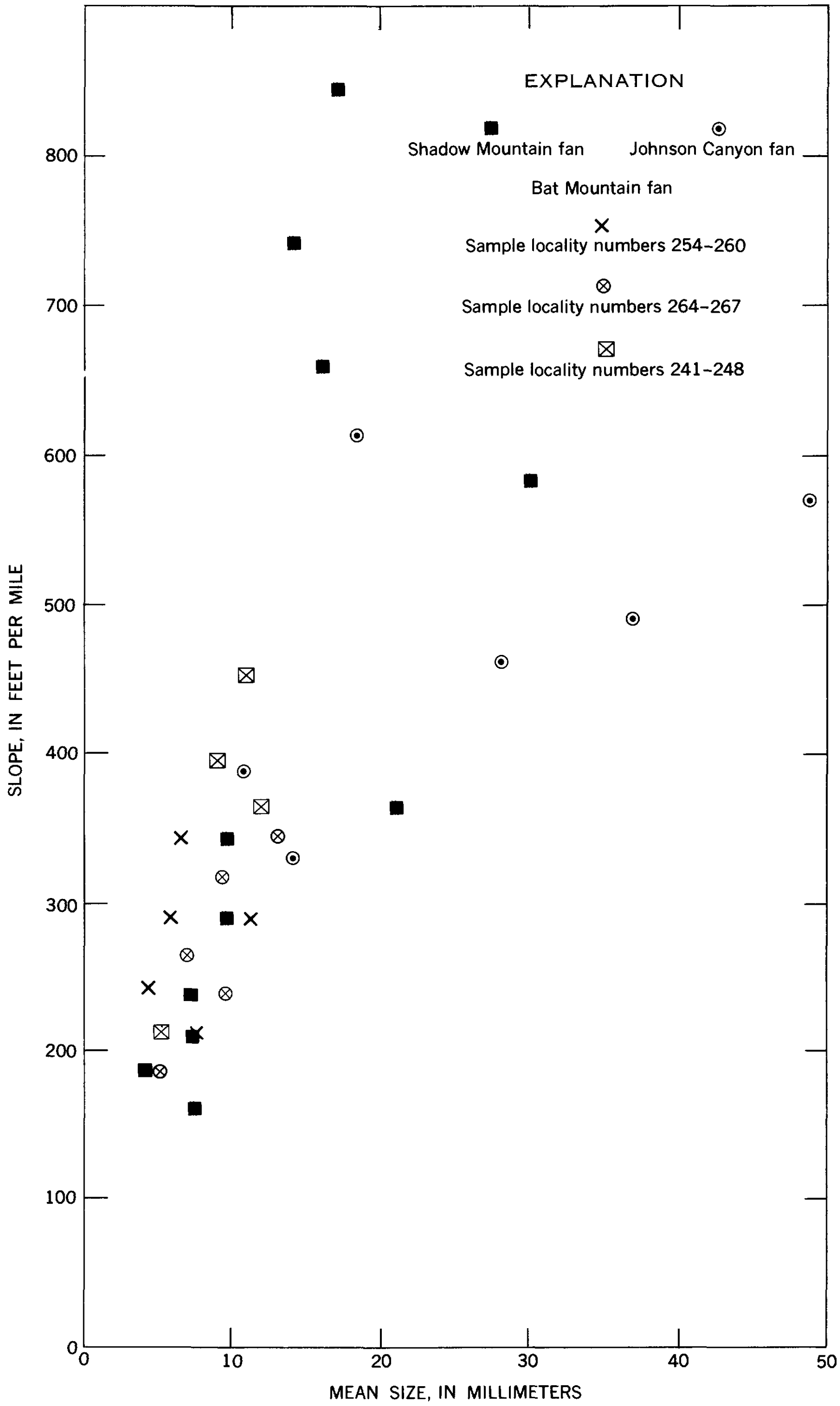

FIGURE 27.—Arithmetic scatter diagram showing the relation between the size of bed material and the slope at sample sites along five meandering washes that head in pavements on fans in the Death Valley region.

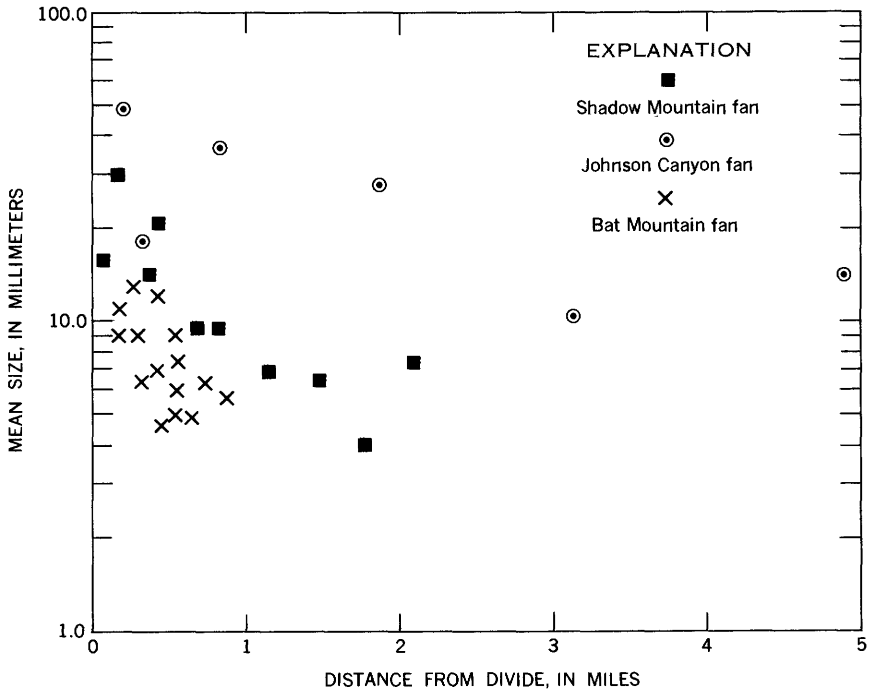

FIGURE 28.—Semilogarithmic scatter diagram showing the relation between the mean size of material on floor of washes and the distance from the divide at sample sites along meandering washes that head in pavements on fans in the Death Valley region.

CONCLUSIONS

Alluvial fans are accumulations of detritus at the point where a debris-carrying stream from a highland leaves a confined channel and enters a place where it is free to migrate from side to side. In the Death Valley region the highland may be 10 feet or 10,000 feet high. The fan-building wash has a smooth profile and passes without a break in slope from the highland out onto the fan. Compared with stream channels in more humid regions, the desert washes are generally steeper and their bed materials appear to be finer grained; perhaps they are also wider, but the data on comparative widths are inconclusive. The gradient and cross section of a desert wash are probably adjusted to the available discharge and load. The wash is more or less in equilibrium—in quasi-equilibrium, to use the less controversial term of Leopold and Maddock (1953)—although hydrologic data and measurements of bedload are not numerous enough to demonstrate that this is so. The stream in a fan-building wash forms and maintains its gradient by erosion and deposition. In order for the wash to acquire a smooth profile from the headwaters to the toe of the fan, deposition may take place both in the confined channel and where the stream is than the gradient upstream. The fan-building wash channel is unconfined if the gradient at that place is less free to migrate. Deposition will take place where the acquires a profile whose form can best be discribed as graded, much as a highway is graded. The point of termination of the confined channel varies from fan to fan and, doubtless, from time to time. On some fans it is at the mountain front; on others, it is more than half way down to the toe. The location of the point of termination is related to the structural history of the area and to drainage diversions that have taken place on the fan.

The slope of a fan or fan segment depends in some degree on the size of the debris of which it is built, although a comparison of the measurements of size and slope recorded on figure 29 lends only moderate support to this view. Nevertheless, a relation of size to slope appears to be part of the explanation of why some fans are markedly concave upward in longitudinal profile. Although all fans have concave profiles, on many the concavity is slight, and these fans have nearly uniform slopes for long distances. Fans having only slight concavity include those that are largely without areas of desert pavement. Such fans are small. Some large fans with extensive areas of pavement, such as those in longitudinal profile, whereas others, such as those east of the Panamint Range, are only slightly concave west of Shadow Mountain, are markedly so. The tion of the size of the material deposited on different explanation for these differences may lie in a consideraparts of a fan. If steeply sloping pavements on coarse detritus high on a fan are the source of fine debris deposited on a gently sloping segment lower down, as on the Shadow Mountain piedmont, the fan is markedly concave upward in longitudinal profile. In contrast, if the fan is built of coarse debris and pavements contribute fine sediment only to points near the toe, as on the piedmont east of the Panamint Range, the longitudinal profile of the fan is only slightly concave.

The piedmonts adjacent to the Panamint Range and Shadow Mountain are approximately the same size. Both have lengths, measured at right angles to the mountain front, of 5–6 miles (table 2). The two piedmonts have contrasting source areas and differ also in the size of their fan-shaped segments of wash—that is, in the size of their areas of deposition. The areas of deposition on the Panamint Range fans are larger perhaps in part because washes from the range drain an area of high rainfall but principally for the reason that the source areas are many times greater than those on Shadow Mountain.

The surface features of a piedmont are to a large extent independent of the position of the toes of the fans. On the piedmont east of the Panamint Range, for example, the fan-shaped segments where deposition has taken place during the last few thousand years are large enough to extend from the mouth of the main fan-building wash to the edge of the saltpan, whereas on the Shadow Mountain piedmont, the depositional segments are not large enough to extend from the mouth of the main fan-building wash to the edge of Alkali Flat. Coarse detritus from the mountain is deposited on the upper part of the Shadow Mountain fan. Farther from the mountain front, the finer gravel on the surface comes from the erosion of areas of pavement upfan. If Eagle Mountain should be elevated, damming the Amargosa River and causing the level of Alkali Flat to rise so that the lower half of the Shadow Mountain fan were buried, the exposed upper part would still have a relatively straight slope. The longitudinal profile of the fan would resemble those of fans east of the Panamint Range and would probably maintain such a slope because a rise of the surface of Alkali Flat, unaccompanied by any change on Shadow Mountain, would not alter the load or flood regimen of the fan-building wash.

It is a commonplace that the size of a fan is related to the size of the source region. Measurements of the size of many fans, or of some segments of their washes or pavements, compared with the size of their source areas, indicate that the size of a fan is roughly equal to one-third to one-half of the size of the source area. The data presented on figure 7 can be expressed by the relation

$$Af=0.5\ Am^{0.8},$$

which states that the area of a fan or fan segment is equal to half the eight-tenths power of its source area (all measurements are in square miles). This relation is only a first approximation, for the delineation of the individual segment is not always easy, the number measured is not large, and the field of scatter is considerable. The relation, also, seems to vary slightly from range to range. If it is restricted to include only the data from the Shadow Mountain piedmont, the size of these fans or fan segments more closely approximates the 1 : 3 relation than if all the measurements are included. Because the relation holds good for fans that are composed of various rock types and have diverse geologic histories, the probability is high that a general relation exists. It follows that the confiuration of a fan depends upon some functional relation between the bedrock and the processes acting upon it and not upon a fan's stage of development in an evolutionary sequence.

The height of the source area above a fan may be as important as its extent in determining the size of a fan. The piedmont east of the Greenwater Range, for example, is slightly larger in relation to its source area in the neighboring hills than are the fans east of the lofty Panamint Range. The size measurements suggest that the Panamint Range supplies much coarser grained bed material than is found on the floor of the washes west of the Amargosa River. The bedrock of the Panamint Range is not more massive than that elsewhere, for it includes extensive areas underlain by argillite, thin-bedded quartzite, and granitic rocks. The coarseness of the material is probably explained by the effects of the height of the Panamints, which reach up into a zone of relatively great precipitation and of deep canyons having precipitous walls where runoff is rapid. The coarse debris on the floor of the Panamint Range washes seems to be clearly related to the adjacent steep slopes and to the large discharge as compared with those in the washes of the Amargosa Valley.

The type of rock that makes up the highland source plays a part in alluvial-fan formation. Shale hills may be bordered by very small fans—commonly the adjacent piedmont is largely pediment—whereas hills of massive bedrock may have extensive aprons composed of coarse detritus (Hunt and others 1953, p. 189–204). The long gently sloping fans west of the Amargosa Valley contrast with the shorter, steeper fans east of the river; the fans differ perhaps because of bedrock differences in their source areas. The mountains on either side of the valley are more or less the same height, although the source areas on Shadow Mountain are a little smaller than those in the Greenwater Range. The grain-size measurements suggest that the volcanic rocks of the Greenwater Range supply a finer-grained bed material to the washes that traverse them than does the quartzite of Shadow Mountain. If one assumes that the occasional discharges in the washes on both sides of the valley are of the same order of magnitude, the difference in length of these fans possibly reflects the size of the debris supplied by the highlands. Fine debris from the western highlands may be carried a longer distance and down a gentler gradient than is the coarse debris from the mountains to the east. The asymmetry of the Amargosa Valley, as explained by this theory, reflects the mechanism of fan formation. Casual inspection of many piedmonts in this region suggests that many of the longer ones, as measured at right angles to the mountain front, adjoin highlands composed of volcanic rock.

The structural history determines the capacity of the depositional basin relative to the amount of debris supplied, and thereby, in large measure, fixes the outline of the piedmont—the extent of fan and of pediment. The continual deformation of many of the highlands and basins of the Death Valley region promotes the maintenance of large alluvial fans and retards the erosion of broad pediments. On the Shadow Mountain fan, for example, the areas of demonstrable pediment are small and are restricted to small segments between the large fan-building washes. These small segments are traversed by washes that drain correspondingly small areas on the mountain front. Within certain limits, the form of a large complex fan depends upon the size, elevation, and lithology of its source and not upon the position of its toe or the floor of the adjacent basin.

I believe that the complex of wash, pavement, and pediment that constitutes many piedmonts is not a cyclic phenomena related to an evolutionary sequence but is the result of present-day processes. Hack (1960, p. 81) stated that a piedmont "and the processes molding it are considered a part of an open system in a steady state of balance in which every slope and every form [every area of pavement, wash, or pediment] is adjusted to every other." The form of the piedmont is explainable in terms of the bedrock and the processes acting on it, and the differences between one piedmont and another are accounted for by differences in the spatial relations of mountain and basin. As long as Shadow Mountain and the adjacent segment of the Amargosa Valley had or continues to have about the same spatial relations, one to another, the general configuration of the piedmont has been and will continue to be much as it is today. The location of pavement, wash, or pediment on the piedmont will change from time to time, but the proportion of pavement, wash, and pediment will remain roughly constant.

A change in the proportion of pavement, wash, and pediment on a piedmont will take place when the erosional or depositional processes or the spatial relations of mountain and basin change. The great extent of varnished bouldery gravel on many fans as compared to the area of unweathered more pebbly gravel in the active washes indicates greater flooding of the fans in the past, perhaps more than 2,000 years ago. Such a change in process—an increase in flood discharge—doubtless also took place during the pluvial periods of the Pleistocene. The small size of the fans at the west base of the Black Mountains and the irregular longitudinal profiles of their fan-building washes show that along this mountain front erosion and deposition have not been able to keep pace with changes in the relative position of highland and basin floor. Eastward tilting of the floor of Death Valley during the Recent Epoch has resulted in the burial of an unknown volume of fan debris beneath the saltpan. If no further deformation takes place, however, the Black Mountain-fans will probably grow in surface area until they are two or three times their present size.

The ubiquitous desert pavement dissected by meandering washes is a part of the system of alluvial-fan formation. The processes of weathering and of erosion that flatten an area of braided channels and gravel bars into a smooth desert pavement are opposed by surface runoff, which collects in channels and is continually dissecting the pavement. The processes of pavement formation and destruction tend to balance each other. A pavement once formed may persist for some time and adjacent pavements are, for this reason, not necessarily of equal age. A general lowering of the piedmont by erosion because of structural changes or because of general mountain degradation ultimately causes pavement dissection to proceed more rapidly than pavement formation, and the pavement is consumed. Meanwhile new areas of pavement are developed elsewhere on the fan. Thus the maximum life expectancy of one pavement is probably much less than that of the mosaic of pavements and washes on the entire piedmont.

Pediments are segments of a piedmont where erosion dominates over deposition. The areas of pediment in this region are very small; most of them are bed rock surfaces veneered with gravel and are exposed only where gullies dissect the gravel veneer. Pediments are, of course, limited because the mountains are high and extensive relative to the valleys; deformation is probably a continuing process in much of the region. Pediments occur between fans either where the adjacent highland is low or where the streams traversing the pediment have small source areas.

The pediments north and south of the Shadow Mountain fan, for example, are small areas of desert pavement traversed by small meandering washes that have dissected a gravel veneer 5–10 feet thick and exposed deformed Tertiary rocks. The pediment is the planed top of these weakly cemented sands and clays. The small wash has a lower gradient than adjacent fan-building washes and is floored with fine debris (Hunt and others, 1953, fig. 106). The pediment was cut by a wash similar to that which now exposes it and ends downfan, where it descends beneath the floor of the wash. The planed surface now visible is the floor of such a wash; the pediment was perhaps "born dissected" (Gilluly, 1946, p. 65) and was never a smooth plain but was always ridged as at present. Clearly, the activity of the stream in the small wash that exposes the pediment is a part of the equilibrium of the entire piedmont, for the floor of the small wash cannot be eroded below the level at which it meets the adjacent fan. The bed of the small wash up stream from its mouth may lie 10–20 feet below the bed of the adjacent fan-building wash and may be separated from it by a low gravel ridge. In time, the stream in the larger wash may breach the ridge and empty into the small one, filling the wash with gravel and burying the pediment beneath a new fan segment. In the meantime, erosion elsewhere on the piedmont may expose or erode another segment of pediment.

As long as Shadow Mountain and the Amargosa Valley maintain about their present size and shape, no extensive pediments will form on the piedmont. But if, in time, mountain degradation exceeds uplift of the range, then the amount of debris deposited on the piedmont will decrease with respect to the amount removed by erosion. The general level of the piedmont will be gradually lowered, and the areas of pediment will increase. Parenthetically, a pediment may be difficult to recognize where carved in undeformed alluvial-fan deposits. The mountain that was once surrounded in large part by sloping alluvial fans is in time reduced to hills bordered by a wide pediment that at some distance from the hills passes beneath an alluvial cover. Many such pediments are areas where shallow gullies expose bedrock veneered with gravel.

This study offers no new criteria for the identification of alluvial-fan deposits—fanglomerate—in the geologic column. It merely emphasizes how many different combinations of geomorphic factors could be postulated on the basis of what can be seen in outcrop or inferred from geologic relations. Size estimates based on point counts on the surface of a wash are not closely comparable to similar counts on the surface of an outcrop, although further study might make such a comparison possible. The trace of a desert pavement might perhaps be preserved in a cross section through a fanglomerate. In one exposure near Devils Hole (fig. 1), a band of solution-faceted pebbles of carbonate rock that suggests a buried pavement was observed in a cut through a small alluvial cone. However, pavements are easily disturbed by running water and are probably destroyed in the process of burial. The weathered zone beneath a pavement stands a much better chance of being partly preserved (Eckis, 1934). The presence of a thick sequence of fanglomerate in the geologic column indicates that deformation and sedimentation were concurrent processes. If deformation slows down, the area of pediment increases, and the alluvial deposits are removed.

This theory of alluvial-fan formation postulates that when a steady state of balance is reached, such a state will be maintained as long as the spatial relations of mountain and basin are maintained. Let us assume that material is supplied by a recently elevated highland at a constant rate. A fan at the base of the highland will grow in surface area year by year. In time drainage diversions will take place, however, and the area of deposition may be displaced downfan. Abandoned segments of the fan near the apex are continually being eroded while they are transformed into pavements. Pediments may be eroded in areas between fans. The area of the piedmont being eroded—that is, the amount of material being removed—will increase, until it equals the amount supplied. The system will thereafter be in a steady state of balance and will remain so as long as the topographic position of mountain and basin and the geologic processes remain the same (Nikiforoff, 1942). The total volume of detrital material on the piedmont will not change; the volume of fine material reaching the adjacent playa or floodplain is balanced by the amount of coarse detritus supplied by the highlands.

The hills and mountains in much of arid southern California and adjacent States are surrounded by broad, sloping, gravel-covered piedmonts. Where the mountains are recently elevated, as in much of the Death Valley region, the piedmonts consist largely of fans. Where the mountains are small compared with the adjacent basin, as in parts of the Mojave Desert, the piedmonts include extensive areas of exposed pediment, especially near the highlands. These mountains in the Mojave may always have stood above their sloping piedmonts, much as they do today rather than having been once surrounded by broad alluvial plains. The debris on the piedmonts is carried to them by mountain floods and dropped where the banks of the washes terminate. Once deposited the debris is not easily moved by local runoff on the piedmont until it has weathered to smaller-sized particles. A sloping apron of waste will gradually encroach more and more onto the mountain block until equilibrium is reached and the transport of debris out onto the fan equals the rate at which the material on the fan is weathered into a size transportable further downfan. The mountain will appear as if it was resting on top of a very broad and very low pyramid. However, as the mountain is reduced in size, it will supply less and less debris to the washes. Erosion will become the dominant process on a large segment of the piedmont and will cause the area of pediment to increase. Near the mountain front, more and more bedrock will be exposed, whereas further away from the highlands the fan deposits will be eroded.

Tuan (1959, p. 120) suggested that the pediments in southeastern Arizona are exhumed erosion surfaces that were once buried under a vast sheet of waste whose gradual removal is now exposing an extensive bedrock surface, the pediment. However, some of his maps (Tuan, 1959, fig. 8) appear to show a contrast in gradient and position between washes having large drainage basins in the mountains and those having small catchment basins, and several localities occur where drainage diversions similar to those described in the Death Valley region can be reasonably inferred to have taken place. I believe that the pediments in Arizona have probably formed in the manner just outlined for the California region and to postulate their burial beneath a thick alluvial cover is unnecessary.

REFERENCES CITED

Blissenbach, Erich, 1954, Geology of alluvial fans in semiarid regions: Geol. Soc. America Bull., v. 65, no. 2, p. 175–190.

Bryan, Kirk, 1922, Erosion and sedimentation in the Papago Country, Arizona: U.S. Geol. Survey Bull. 730, p. 19–90.

Denny, C. S., 1961, Landslides east of Funeral Mountains, near Death Valley Junction, California, *in* U.S. Geological Survey, Short papers in the Geologic and Hydrologic Sciences, Art. 293–435: U.S. Geol. Survey Prof. Paper 424–D, p. D85–D89.

Dixon, W. J., and Massey, F. J., Jr., 1951, Introduction to statistical analysis: New York, McGraw-Hill, 370 p.

Drewes, Harald, 1963, Geology of the Funeral Peak quadrangle, California: U.S. Geol. Survey Prof. Paper 413, 78 p.

Eckis, Rollin, 1928, Alluvial fans of the Cucamonga district, southern California: Jour. Geology, v. 36, no. 3, p. 225–247.

———1934, South coastal-basin investigation; Geology and ground-water storage capacity of valley fill: California Water Res. Div. Bull. 45, 279 p.

Emery, K. O., 1955, Grain size of marine beach gravels: Jour. Geology, v. 63, no. 1, p. 39–49.

Engel, C. G., and Sharp, R. P., 1958, Chemical data on desert varnish: Geol. Soc. America Bull., v. 69, no. 5, p. 487–518.

Gilluly, James, 1946, The Ajo mining district, Arizona: U.S. Geol. Survey Prof. Paper 209, 112 p.

Hack, J. T., 1957, Studies of longitudinal stream profiles in Virginia and Maryland: U.S. Geol. Survey Prof. Paper 294–B, p. 45–97.

———1960, Interpretation of erosional topography in humid temperate regions: Am. Jour. Sci., Bradley Volume, v. 258–A, p. 80–97.

Hack, J. T., and Goodlett, J. C., 1960, Geomorphology and forest ecology of a mountain region in the central Appalachians: U.S. Geol. Survey Prof. Paper 347, 66 p.

Hunt, A. P., 1960, Archeology of the Death Valley salt pan, California: Utah Univ. Anthropol. Papers, no. 47, 313 p.

Hunt, C. B., 1954, Desert varnish: Science, v. 120, p. 183–184.

Hunt, C. B., Averitt, Paul, and Miller, R. L., 1953, Geology and geography of the Henry Mountains region, Utah: U.S. Geol. Survey Prof. Paper 228, 234 p.

Leopold, L. B., and Maddock, Thomas, Jr., 1953, The hydraulic geometry of stream channels and some physiographic implications: U.S. Geol. Survey Prof. Paper 252, 57 p.

Leopold, L. B., and Miller, J. P., 1956, Ephemeral streams—Hydraulic factors and their relation to the drainage net: U.S. Geol. Survey Prof. Paper 282-A, p. 1–37.

Leopold, L. B., and Wolman, M. G., 1960, River meanders: Geol. Soc. America Bull., v. 71, p. 769–794.

Miller, J. P., 1958, High mountain streams: effects of geology on channel characteristics and bed material: New Mexico Bur. Mines and Mineral Resources, Mem. 4, 53 p.

Nikiforoff, C. C., 1942, Fundamental formula of soil formation: Am. Jour. Sci., v. 240, p. 847–866.

Rich, J. L., 1935, Origin and evolution of rock fans and pediments: Geol. Soc. America Bull., v. 46, no. 6, p. 999–1024.

Sharp, R. P., 1954, Some physiographic aspects of southern California, pt. 1 *of* chapter 5 *of* Jahns, R. H. ed., Geology of southern California: California, Div. Mines Bull. 170, p. 5–10.

Troxell, H. C., and Hofmann, Walter, 1954, Hydrology of the Mojave Desert, pt. 2 *of* chapter 6 *of* Jahns, R. H., ed., Geology of southern California: California, Div. Mines Bull. 170, p. 13–17.

Tuan, Yi-Fu. 1959, Pediments in southeastern Arizona: California Univ. Pub. Geography, v. 13, 163 p.

U.S. Weather Bureau, 1932, Nevada sec. 19 *of* Climatic summary of the United States, climatic data to 1930 inclusive: 34 p.

——— 1935, Southern California and Owens Valley, sec. 18 *of* Climatic summary of the United States, climatic data to 1930 inclusive: 38 p.

Wolman, M. G., 1954, A method of sampling coarse river-bed material: Am. Geophys. Union Trans., v. 35, p. 951–956.

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