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Soils, geomorphology, and multiple displacements along the Organ Mountains fault in southern New Mexico

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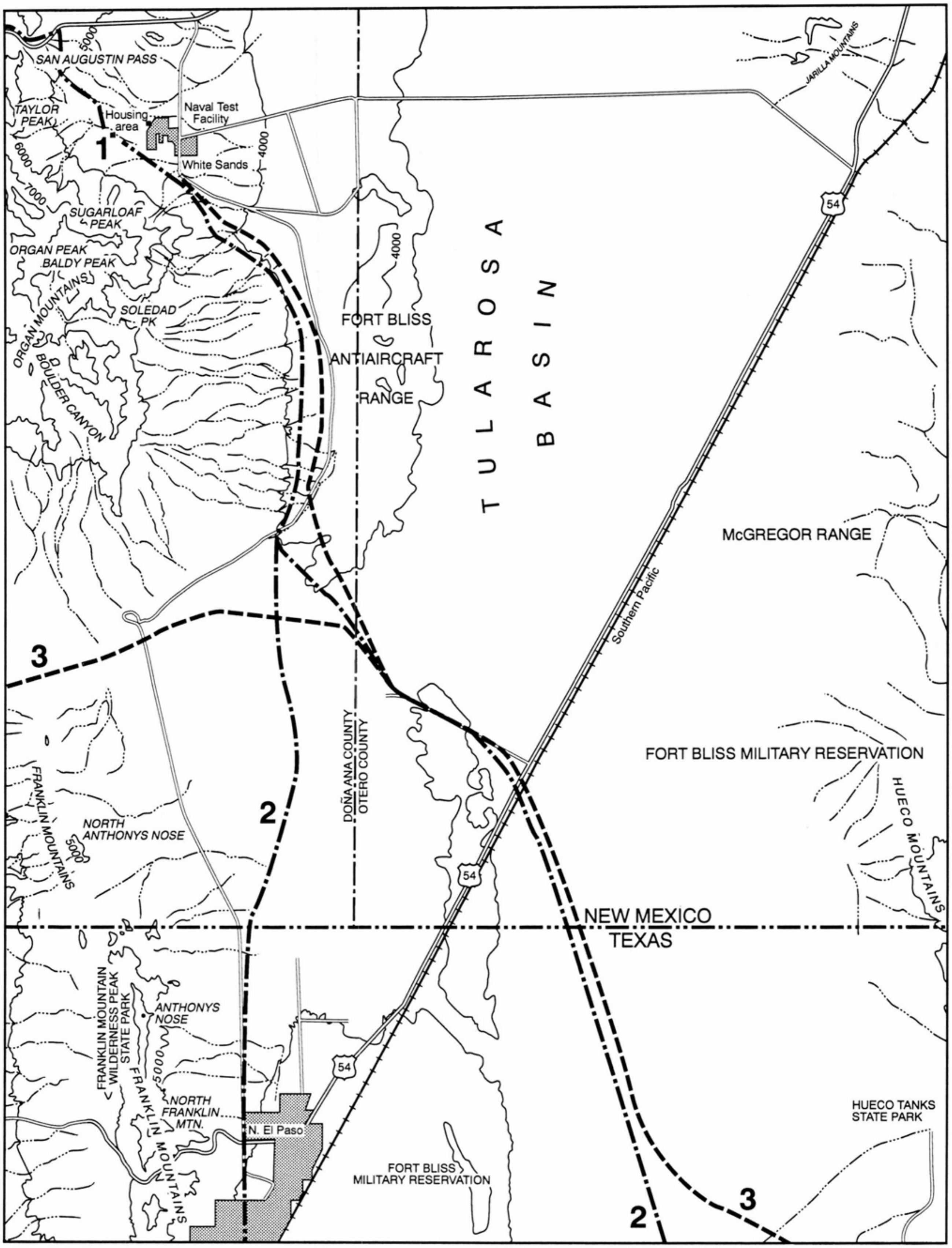
CONTENTS

Note: Capital letters in parentheses identify the map units in the soil map (Fig. 18).

FIGURES

TABLES



FRONTISPIECE—Position of the study area in the Tularosa Basin, east of the Organ Mountains. Approximate location of early trails that led by the study area is also shown: (1) study area; (2) Aguirre Merchant Mule Train Trail; (3) Salt Trail. Trail location by courtesy of Anthony Aguirre (see Early trails section).

Acknowledgments

Grateful acknowledgment is made to Rob Cox for expediting access to the research area, for precipitation data, and for on-the-spot observations of the flash flood on August 19, 1978. Louis Buescher, Bob Myers and Fritz Weber provided valuable assistance in obtaining the 1963 and 1983 aerial photography. I thank the Bureau of Mines and Mineral Resources, Socorro, for financial support of the study, and former Director Frank Kottlowski for his interest and support. I am grateful to John Hawley, Bill Seager, LeRoy Daugherty, and Frank Kottlowski for reviewing the manuscript. Karl Laumbach, Pat Beckett, and Dave Kirkpatrick provided archeological information near the study area. Austin Hoover, Anthony Aguirre, Herman Weisner, Mary Taylor, Lee Priestly, Keith Humphries, Gloria Ikard, and Gloria Clayshulte provided historical information and suggestions. I am indebted to Anthony Aguirre for information about old trails in the area, and for the map showing some of them (frontispiece). I thank Susie Welch for helpful editorial comments. Special acknowledgment is made to my wife, Dora, for typing drafts of this report, and to Yvonne Flores for typing most of the manuscript.

Abstract

A previous study along the Organ Mountains fault in southern New Mexico found evidence of a displacement estimated to have taken place about 1,000 yrs ago. The late Holocene fault scarp associated with the displacement represents one of the youngest if not the youngest fault in New Mexico. In this study, examination of an older scarp adjacent to the late Holocene scarp revealed buried evidence of late Holocene faulting below the base of the older scarp. This evidence consists of displaced sediments and soils of late Pleistocene age, and post-faulting sediments and soils similar to those at the late Holocene scarp. Prominent soils on large parts of the older scarp indicate that, as a general landscape feature, the scarp must date from the Pleistocene.

The discovery of such masking of faults below an ancient scarp indicates that the late Holocene faulting previously reported could be much more extensive than suggested by the downfaulted late Holocene sediments alone. Total displacement of the late middle Pleistocene sediments along the ancient scarp must be more than the minimum of 80 to 82 ft (24 to 24.6 m) shown by the present scarp. Below the ancient scarp, late Holocene displacement at the fault plane is estimated to be about 3 ft (0.9m); if nearby downwarping also reflects late Holocene faulting then the total displacement for the late Holocene would be considerably greater.

Two depositional zones that differ considerably in particle size are characteristic of the late Holocene faulting at both scarps, and are useful criteria that reflect episodes of faulting in these materials. One zone, termed the *skeletal zone*, is dominated by rock fragments and is emplaced almost immediately after faulting as an erosional response to the downdropped materials below the fault. The *fine-earth zone* is deposited later by small streams that cross the scarp and by overland flow, and commonly buries the skeletal zone in part. Soils formed in one or both of these two zones constitute major chronological markers for the study of displacement times. Below the base of the ancient scarp, the displaced soil of late Pleistocene age has formed in a fine-earth zone that reflects an episode of faulting older than the late Holocene displacement. Although this soil needs further study, its prominent horizons of clay and carbonate accumulation could indicate, at some locations along the fault, a time of stability and soil formation that would be longer than the current estimate of about 5,000 yrs for the maximum interval of time between faulting episodes.

Studies of soils and geomorphic surfaces adjacent to the scarps show that soil development (e.g., accumulation of silicate clay) increases with increasing age of surface and soil. Carbonate, clay, silt, very fine sand and a lesser amount of fine sand derived from dustfall and in some instances from overlying water-laid materials have moved downward and accumulated in debris flows. The maximum particle size for such downward movement appears to be about 0.2 mm.

Away from the ancient scarp, no carbonate horizons at all have formed in soils less than about 2,100 yrs old. This is due to the pervious parent materials, precipitation (13.95 inches, 35.43 cm annually), and to the deeply penetrating wetting fronts of these soils. Weak stage I carbonate horizons have formed in soils about 2,200–7,000 yrs old. Even in soils of late Pleistocene age, only strong stage I carbonate horizons have developed in these materials. The most prominent carbonate horizons were found on lower slopes of the ancient scarp. A strong leaching regime on upper and middle slopes of the scarp has moved carbonate to lower slopes, where a combination of lateral and vertical leaching has formed stage III (calcic) horizons in drainageways and stage IV (petrocalcic) horizons in older areas between drainageways. These horizons furnish calcarous parent materials for the downslope late Holocene soils formed in the skeletal and fine-earth zones of the latest displacement, and these soils do have stage I carbonate horizons.

Colluviation is a major process of alteration along both the late Holocene and ancient scarps, but the degree of alteration of the two scarps is very different because of their great difference in age. Colluviation along the late Holocene scarp is relatively simple and appears to represent one major period of colluviation that took place immediately after the late Holocene displacement. In contrast, colluvia of multiple ages are evident in many places along the ancient scarp, and may involve deposits caused by changes in climate as well as by faulting. Large drainageways in the scarp illustrate gigantic desert pavements that apparently are moving slowly downslope across the top of older colluvia. Fines of eolian and colluvial origin appear to be moving from the surface to beneath the desert pavement, and appear to be an important factor in keeping the desert pavement at the surface. Prominent soil horizons beneath the pavement indicate that some of the older colluvia either are not moving or are moving so slowly that soil morphology is virtually undisturbed. Long-term monitoring and studies of colluviation and chronology (including recurrence intervals) are suggested for the fault, which is very close to the Headquarters of the White Sands Missile Range and not far from major population centers.

Introduction

The Organ Mountains fault occurs along the eastern side of the Organ and San Andres Mountains in Doña Ana County, New Mexico (Seager, 1981; Fig. 1). The study area is located just east of the Desert Soil—Geomorphology Project, an area of detailed pedologic and geologic investigations discussed later. The fault is one of the youngest if not the youngest in New Mexico, and is of particular local interest and significance because 1) episodes of faulting are accompanied by severe earthquake activity, 2) major centers of population are nearby, and 3) the fault is very close to the Headquarters of the White Sands Missile Range (WSMR; cover). Evidence of a late Holocene displacement estimated to have taken place about 1,000 yrs B.P. was presented in previous reports (Gile, 1986, 1987). This report presents a study of soils, geomorphology, and evidence of both late Holocene and pre-Holocene displacements along the fault.

Elevation of the study area is about 4,500 ft (1,372 m). Alluvial fans are common along the mountain front, and fans of several ages have been displaced by the fault. Soil parent materials are dominantly monzonite sediments derived from soils and sediments upslope and from bedrock of the Organ Mountains (Dunham, 1935; Seager, 1981). Smaller amounts of andesite are also present. Most of the materials are debris flows with abundant rock fragments that range in size from pebbles to boulders. Smaller amounts of water-laid materials also occur, generally as surficial deposits that bury the debris flows. Carbonate, clay, silt, fine sand, and very fine sand from dustfall have been added to the soils at various times during their development (Gile, 1987).

Background and cultural setting

Pre-history

The Clovis culture, which existed from about 11,500 to 11,000 yr B.P., is one of the oldest in North America (Lewin, 1987). Three Clovis sites have been documented in the Tularosa Basin (Beckett, 1983), none of them near the study area at the fault. Younger prehistoric sites are more numerous; many were found in an archaeological survey of the WSMR Headquarters (David Kirkpatrick, pers. comm. June 1989). The sites range in age from Early Archaic through the El Paso phase of the Jornada Mogollon, or from about 5,500 B.C. to 1,350 A.D.

Early trails

A number of trails led by the study area because of the nearby springs and scarcity of water in this desert region. The frontispiece shows routes of a salt trail and the Aguirre Merchant Mule Train Trail. The following statements about these trails are based on personal communications from Anthony Aguirre (February and March, 1989), who has observed the trails both from the air and on the ground. The Aguirre Merchant Trail began about 1750 and was used until about 1850 or possibly as late as 1870. The salt trail (which was originally an Indian trail) was a different trail for the most part, but in places the two trails converged. Southward the salt trail branched east to Salt Flat, Texas, where salt beds were located (Ward, 1932; Sonnichsen, 1961).

Stoes (1957a) gives information about another, older salt trail:

> In the early days of sparse settlement this trail was known as "El Camino de Sal"—the Salt Road. El Camino de Sal got itself a name when, more than a century ago, small pack burros out of Paso del Norte—the Pass—Juarez, Mexico, padded a trail that ribboned the eastern slopes of the Franklin and Organ Mountains north to the salt and soda beds that lie white and unveiled, void of spring or shrub, on the lonely stretches east of the San Andres range.
>
> To the Mexican salt traders these surface deposits were the substance of trade. Trade was cambalache-barter—one primitive necessity for another. Salt in exchange for foodstuffs; salt in trade for hides and clothing; salt a savor for man and beast; salt a preservative; and salt for a score of varied utilities.

Sonnichsen (1961) mentions both trails, and reasons for development of the salt beds at Salt Flat, Texas:

> A hundred miles east of the Valley towns Guadalupe Peak lifted its sheer limestone wall nine thousand feet above the level plain and low foothills. In its shadow was a thing of great value—a vast deposit of salt lying under a thin skim of water in a chain of lakes which glistened against the dusty tans and greens of the desert.
>
> The Valley Mexicans must have known about these deposits from the earliest times, but until the outbreak of the American Civil War they left them alone. Custom and a good road had led them from time immemorial to the Tularosa or San Andres *salinas* a long two-days' journey to the north in New Mexico.
>
> In 1862 they made up their minds to open up the beds under Guadalupe Peak. The quality of the salt was better, and there was a rumor that private owners might cut off the Tularosa supply.

The San Augustine Ranch

Livestock concentrations can be significant in erosion because of the potential for overgrazing and reduction of vegetative protection. The study area was once a part of the Cox Ranch, also known as the San Augustine Ranch. Newspaper articles by Stoes (1957 a,b) and Humphries (1976) discuss early history of the Ranch and livestock. Humphries (1976) states:

> Ranching earliest roots in the Dona Ana County area reach back to 1598 when Juan de Oñate brought cattle with him on a trek north from Mexico.
>
> It was a long time after de Onate's activity, though, that a link to the present sparse ranching activity in the valley can be found. The famous Cox ranch, located a mile west of what is now the White Sands Missile Range, is rooted in a sheep ranch which passing priests wrote about in the early 1800s.
>
> The sheep ranch, protected by rock walls of Spanish origin which can still be seen, was located just east of the Organs at San Augustin Springs. The ranchers survived until about 1815 when they were killed or starved out by Apaches, according to the priests' accounts.

Priests' accounts of those early days should be highly interesting, so I asked Mr. Humphries if he knew where they were. Mr. Humphries said (personal communication, December 1988) that he did not, that he heard about them by word-of-mouth. After checking with other local historians it appears that the location of such accounts, if they exist, is unknown.

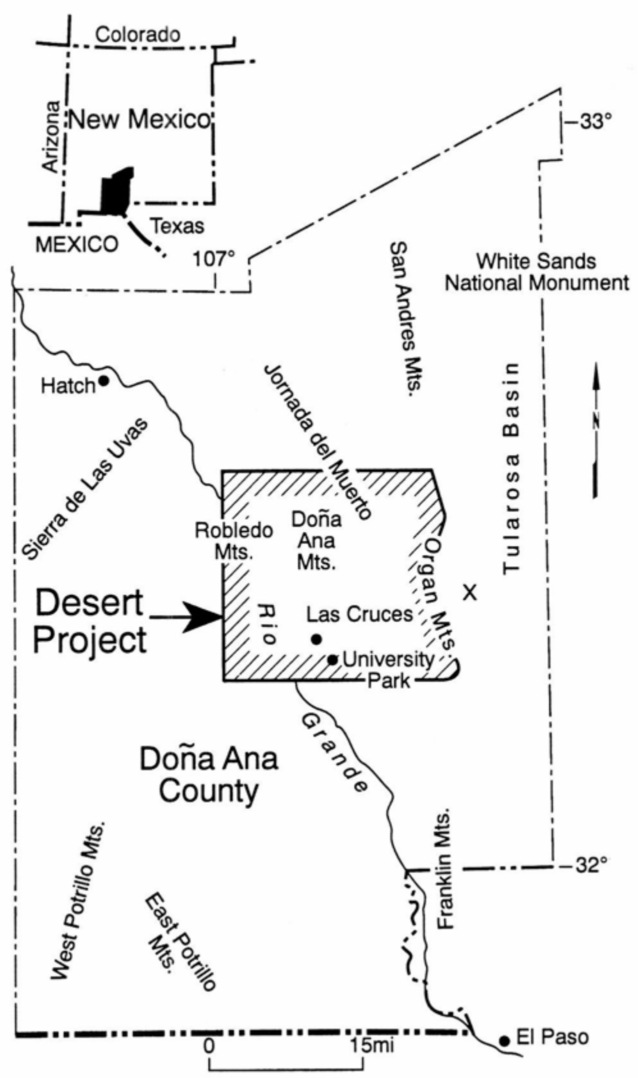


FIGURE 1—Location of the Desert Soil-Geomorphology Project and the studied part of the Organ Mountains fault (marked by x) (Gile, 1987).

Stoes (1957a,b) provides details about the early development of the Ranch. The first owner of record was Thomas J. Bull from Indiana, who was a civilian clerk with the American Army on its 1846 march to Mexico City. In 1851 Bull cut lumber for the American Army for the construction of Fort Fillmore, south of Las Cruces. Later, Bull purchased lots in Las Cruces, established a store in Mesilla, moved to the valley and sold his holdings on the San Augustine Ranch to Warren T. Shedd. Figure 2, one of the oldest photographs known to be taken near the study area, shows Shedd at Devil's Tooth in December, 1892. Figure 3 is a December, 1988 photograph of Devil's Tooth and Rob Cox, present owner of the Ranch. The 1892 photograph was not at hand when the recent photograph was taken, but the two scenes are fairly close. Little change is evident in the landscape and vegetation in the vicinity of Devil's Tooth.

Shedd, who had moved to the El Paso-Juarez area before the Mexican War, made a trip up the Old Salt Trail, admired the area at San Augustine Spring, and purchased Bull's holdings. During his ownership Shedd built a hotel, stage station, corrals and the main adobe house now occupied by Mr. and Mrs. Rob Cox. Although Shedd was not a stockman, livestock did use the area at times. Stoes (1957a) writes:

> "Here at Shedd's men and animals found food, forage and rest. Uncle Sam's soldiers, cowboys and the traveling public made Shedd's a customary stopping place . . . Mining booms in nearby mountains shifted men of all classes, their pack trains and remudas . . . to Shedd's
> • ••

Stoes (1957) further quotes the July, 1877, issue of the *Mesilla Independent:*

> The Shedd Ranch at San Augustine Spring . . . has the reputation of being the headquarters and rendezvous of the worst gang of horse thieves and cutthroats that ever cursed a community . . . Mountains and canyons offer hiding places for stolen stock, and lurking places for bandits that have plundered Dona Ana County and Lincoln . . .

These accounts indicate that livestock grazed at the ranch at times during Shedd's ownership. In 1875 Shedd sold the Ranch to Benjamin B. Davies, a neighboring sheep-man to the south.

In contrast to Shedd, Davies was a stockman and had large herds of sheep and cattle. The *Mesilla Independent News* (cited in Stoes, 1957a) stated that Davies shipped 30,000 pounds of wool in 1877. Davies died in the late 1880s and John H. Wilde, his son-in-law, became manager and administrator. After a devastating drought took a heavy toll of livestock, Wilde moved the cattle to Texas where he was fatally injured under a falling horse. Davies' widow remarried and the family moved to Kansas. In 1893 the San Augustine Ranch was purchased by W.W. Cox.

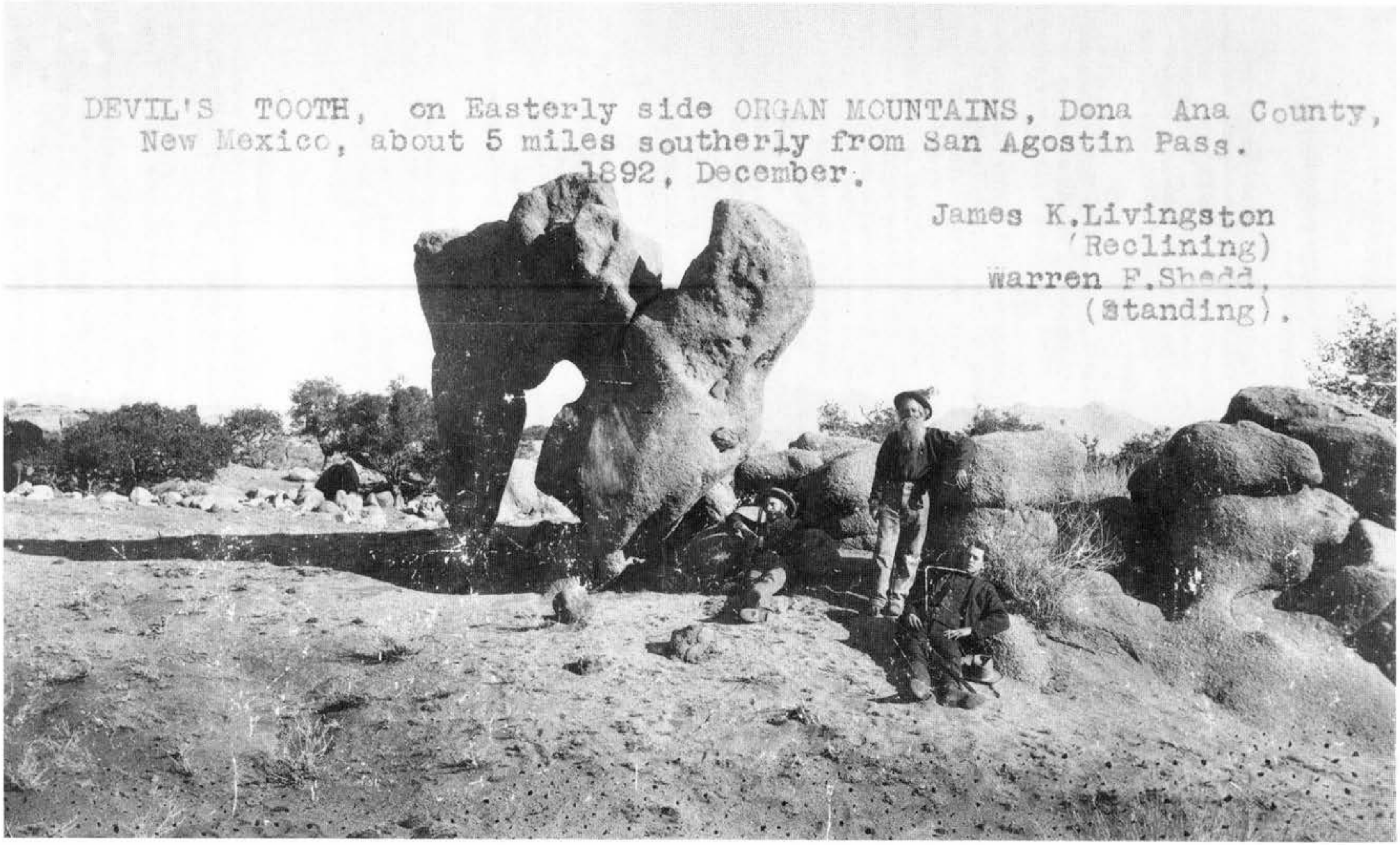
At first Cox stocked the ranch with sheep but later sold them and restocked with Hereford cattle (Stoes, 1957b). As time passed Cox acquired various lands and in all controlled some 150,000 acres. A severe drought occurred in 1906 and some of the cattle were moved to a location between the Jarilla and Sacramento Mountains. Shortly after 1920 another drought dried the pastures. A large portion of the stock, including 4,000 cows and heifers, 100 bulls, and 2,700 calves were moved to the Corralitos Ranch west of Las Cruces. The cattle did not do well and Cox began moving the cattle back to the San Augustine Ranch before the six-month permit expired. Since an unknown number of cattle were not included in the move to Corralitos, a total in excess of 6,800 head of cattle must have been grazing on the ranch at the time of the move.

In 1945 the U.S Government filed a condemnation suit for military purposes and took over 91 percent of the ranch. Today Rob Cox, grandson of W.W. Cox, and his wife operate the remainder of the ranch. They raise Hereford cattle, as did Rob's grandfather, and had about 300 head in 1988 (personal communication, Rob Cox, 1988).

Climate

Precipitation data in the vicinity of the fault are available from two nearby locations. One is the Cox Ranch house (elevation 4,520 ft; 1,378 m) and the other is the WSMR Headquarters weather station (elevation 4,238 ft; 1,292 m). Table 1 summarizes precipitation data from the two stations for the years 1950-1977.

Precipitation at the Cox Ranch house is slightly greater than at the Headquarters station; this would be expected because the Cox Ranch house is closer to the mountains. The precipitation record at the Cox Ranch house (Table 2) is the longest known precipitation record in or adjacent to the Organ Mountains. Mean annual precipitation for the years 1923-1988 is 13.95 inches (35.43 cm). Mean annual temperature at the WSMR Headquarters averages 64° for the years 1950-1976 (Novlan, 1977).



DEVIL'S TOOTH, on Easterly side ORGAN MOUNTAINS, Dona Ana County,
New Mexico, about 5 miles southerly from San Agostin Pass.
1892, December.

James K.Livingston
(Reclining)
Warren F.Shedd,
(Standing).

FIGURE 2—Warren F. Shedd, standing, one of the early owners of the San Augustine Ranch, photographed at Devil's Tooth in December, 1892. Devil's Tooth is located southwest of the Cox Ranch house, just beyond the west edge of the cover photograph. Photograph courtesy of Rio Grande Historical Collections, New Mexico State University Library; enlargement made by Tim Blevins.

FIGURE 3—Devil's Tooth, photographed in December, 1988. Rob Cox, present owner of the Ranch, is at right. Part of Devil's Tooth fell down shortly after this photograph was taken (Rob Cox, personal communication, March, 1989).

TABLE 1. Precipitation (in inches) at the Cox Ranch house and WSMR Headquarters, 1950–1977. Data for the Cox Ranch house are from Table 2; data for the WSMR Headquarters are from Novlan (1977).

Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Ann
Cox Ranch house												
.71	.62	.63	.34	.30	.86	2.74	2.05	1.52	1.30	.51	.79	12.37 (31.39 cm)
WSMR Headquarters												
.53	.53	.49	.25	.25	.84	2.22	1.84	1.48	1.16	.44	.74	10.77 (27.36 cm)

Flash flood of August 19, 1978

A severe rainstorm and flash flood occurred in the vicinity of the fault on August 19, 1978. WSMR officials did not record the rain that fell on the base (*El Paso Times*, Aug. 22, 1978), because the rain gauge was in the process of being moved when the storm struck (David Novlan, personal communication, 1978). According to the *Las Cruces Sun-News* dated August 21, 1978, high winds began shortly after noon on August 19, and increased considerably by 2 p.m. Heavy rains began at 5 p.m. and lasted through the night. The storm killed five people caught in the flood waters. Much damage was done to roads, to the WSMR golf course and to some of the nearby buildings. Power was out for several hours at the base, and there were also reports of trees being uprooted.

Although the amount of rain was not recorded at WSMR Headquarters, 10 inches (25.4 cm) of rain were recorded by Rob Cox at the Cox Ranch house, on the upthrown side of the fault (Fig. 4). Severity of the storm in the Ranch area is indicated by the following comments from Rob Cox (personal communication, Rob Cox, 1985):

1) The first 5 inches (12.7 cm) of rain were the most intense, falling within ^{1}/2 to 2 hours just before dark. The second 5 inches (12.7 cm) were less intense and fell between dark and sunrise.
2) The heaviest part of the storm appeared to occupy an area radiating about 1 mi (1.6 km) from the ranch house. A gauge about 2 mi (3.2 km) northwest of the ranch house recorded 2.6 inches (6.6 cm) of rain and another gauge about 3 mi (4.8 km) north recorded 5 inches (12.7 cm).
3) The 10 inches (25.4 cm) of rain were by far the most for a single storm during the memory of Rob's father, Jim, who was born on the ranch in 1895.
4) Hundreds of snakes and rabbits were killed. The snakes were hung up on bushes and fences. Some of the rabbits were found on the crests of ridges and may have been killed by hail (diameter about the size of a fingernail) that fell with torrential force.

Extensive areas of fresh alluvium were deposited in Cox Arroyo, below the Cox Ranch house (Fig. 4). Effects of the storm on the stream system in the vicinity of the fault are well illustrated by aerial photographs discussed later.

Vegetation

Vegetation observed in the study area is summarized in Table 3. Vegetation observed in each map unit is listed in the discussion of the unit. The intent is not to list all vegetation in the units but only some of the more common kinds of perennial vegetation.

TABLE 2. Precipitation (in inches) at the Cox Ranch house for the years 1923–1988.

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual
1923	.25	1.94	1.63	.95	—	—	.36	3.80	.92	.23	2.45	1.39	13.92
1924	.10	.41	1.16	.94	—	.16	3.54	—	.60	—	—	—	6.91
1925	—	—	—	—	.99	.97	1.36	3.37	1.31	1.92	—	.48	11.00
1926	1.23	.05	3.22	.98	1.87	.68	1.98	.81	4.25	2.76	.12	2.13	20.08
1927	—	.76	2.96	—	—	.39	2.46	2.62	1.40	—	—	1.01	11.60
1928	.11	1.41	—	.52	1.00	—	.54	4.12	1.36	2.85	2.28	.17	14.36
1929	.70	.63	.30	.11	2.66	—	4.04	4.00	.49	2.61	1.27	.35	17.16
1930	.35	.17	.68	.27	.32	1.44	2.06	1.75	.38	1.20	1.94	.49	11.05
1931	1.48	1.90	.72	1.91	.08	.81	3.27	6.03	.90	.61	1.82	.99	20.52
1932	1.12	1.67	.32	—	1.57	1.00	.31	3.07	4.02	1.37	—	1.31	15.76
1933	.84	.62	—	.12	.17	3.03	1.01	1.69	.12	.61	.98	—	9.19
1934	—	.50	.28	.04	.86	.13	.64	1.47	—	.92	.37	.60	5.81
1935	.70	.33	.07	.15	.86	.05	.87	4.77	1.80	—	1.44	.85	11.89
1936	2.24	1.07	.42	.12	1.57	.52	2.30	.57	4.74	.65	.70	.73	15.63
1937	.13	1.30	2.17	—	.32	.75	.27	1.20	3.60	1.60	—	.91	12.25
1938	.89	1.51	.76	—	.12	2.84	5.24	2.63	3.30	.20	.51	1.12	19.12
1939	1.03	.06	1.03	.26	—	.54	4.71	2.18	2.28	1.86	1.07	.75	15.77
1940	.85	1.44	.17	.13	.74	1.36	1.29	2.54	1.71	2.48	1.46	.93	15.10
1941	1.47	.97	1.91	1.99	1.31	.35	1.05	2.74	7.61	2.03	.36	.64	22.43
1942	.40	1.18	.04	1.86	—	2.37	1.02	3.76	2.17	1.97	—	1.51	16.28
1943	.38	—	1.51	—	.15	3.20	2.85	1.34	1.39	.27	.75	2.11	13.95
1944	.72	1.03	.12	.31	.83	.10	1.99	2.35	2.06	2.29	2.09	.90	14.79
1945	.51	—	1.05	—	—	—	.95	.73	.19	2.33	—	.11	5.87
1946	1.92	.10	—	.09	.66	1.15	1.25	1.07	1.94	.35	.37	.96	9.86
1947	1.06	.33	.47	.07	.33	.65	1.19	4.14	—	.08	.97	.75	10.04
1948	.21	1.68	.46	—	.32	1.32	.31	2.03	.22	.75	—	1.79	9.09
1949	3.27	1.08	.10	.37	.88	.75	1.65	2.81	3.14	1.84	—	1.45	17.34
1950	.70	.50	—	—	.07	—	4.61	.01	1.09	1.02	—	—	8.00
1951	.62	.75	.75	.96	.20	—	.05	1.06	.94	.85	.37	1.98	8.53
	23.28	23.39	22.30	12.15	17.88	24.56	53.77	68.66	53.93	35.65	21.32	26.41	383.30

Table 2, *continued*

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual
1952	.33	1.05	1.78	1.36	.39	1.99	2.60	1.00	.37	—	.77	.32	11.96
1953	—	2.19	.22	.82	.17	.94	.44	.31	.20	.70	.06	.29	6.34
1954	.30	—	.62	—	.39	.18	1.58	2.92	1.47	1.79	—	.05	9.30
1955	1.28	.03	.94	—	.14	.16	4.29	.72	—	2.99	.05	—	10.60
1956	.21	.17	—	.05	—	.59	2.80	1.40	.15	.73	—	.58	6.68
1957	.38	1.21	1.10	.68	.80	—	2.58	1.31	.38	4.33	.90	.04	13.71
1958	1.74	1.20	3.11	.48	.22	1.21	2.33	2.38	5.08	2.13	.35	—	20.23
1959	.06	1.25	.10	.03	.66	.68	1.37	7.90	—	.51	.16	.36	13.08
1960	1.87	.12	.44	—	.28	.86	4.21	.51	.06	1.48	.04	1.81	11.68
1961	.83	—	.61	—	—	.79	2.87	1.20	1.57	.06	2.25	1.57	11.75
1962	1.36	.41	.38	.64	—	.11	4.22	.34	2.70	1.29	.42	1.25	13.12
1963	.18	.69	—	.21	—	.48	.90	1.98	4.00	.70	.85	—	9.99
1964	.13	.19	1.17	.08	.22	—	.57	4.20	3.37	—	—	.81	10.74
1965	.83	.90	.44	.37	.42	1.47	.68	2.42	1.55	.36	.27	2.19	11.90
1966	.47	.65	.18	.74	—	6.42	3.57	1.38	2.05	.28	.63	.14	16.51
1967	—	.30	.07	—	.18	2.67	.52	.46	2.16	—	.62	1.52	8.50
1968	.69	1.11	1.08	.07	—	.66	6.66	1.23	.29	.29	1.37	.85	14.30
1969	.38	.24	.23	—	.50	.46	2.31	5.80	.89	2.29	.19	1.34	14.63
1970	.03	.34	.86	—	.19	.56	3.02	1.53	.19	.43	—	.46	7.61
1971	.30	.12	—	.42	—	.28	3.91	.54	.69	2.07	1.45	1.44	11.22
1972	1.13	—	.01	—	.19	1.98	2.29	5.85	2.62	4.21	.88	2.46	21.62
1973	1.35	2.18	1.69	.02	.79	.23	7.49	1.85	.26	—	.27	—	16.13
1974	1.91	—	.67	.95	—	.07	2.42	3.02	4.53	4.32	.30	1.91	20.10
1975	1.29	.62	.59	.04	.34	—	2.20	2.39	3.56	.13	.82	.44	12.42
1976	.81	1.00	.12	.58	1.84	.06	3.36	1.49	.76	1.83	1.30	.02	13.17
1977	.80	—	.58	.99	.31	1.23	2.84	2.19	1.49	1.48	—	.38	12.34
1978	1.56	1.30	.89	—	.83	2.19	1.37	11.83	7.47	2.92	4.64	2.29	37.29
1979	2.43	.32	.22	—	.38	.35	1.08	5.91	1.41	—	—	1.92	14.02
1980	1.14	1.03	.82	.76	.88	—	1.11	2.15	5.54	.94	.47	—	14.84
1981	1.33	.50	.69	.55	.56	.15	1.89	5.74	1.53	1.52	1.03	.87	16.36
1982	3.38	.37	.10	—	.33	.41	1.33	.09	3.42	—	.63	4.24	14.30
1983	.48	1.00	.68	1.14	—	.32	.74	1.24	1.36	1.79	1.42	.94	11.11
1984	.98	—	.38	—	.76	2.18	.36	8.57	.89	4.77	.64	4.48	24.01
1985	2.15	.41	.51	.59	.19	.15	2.57	1.87	2.05	4.30	.30	—	15.09
1986	.14	.35	.94	—	.22	4.67	1.02	3.03	2.86	2.11	3.77	3.27	22.38
1987	.37	.87	.66	1.20	—	1.27	1.37	9.38	.65	.39	.74	2.04	18.94
1988	.67	1.38	.10	.85	—	.84	3.36	6.56	.95	.94	.74	2.91	19.30
Total	56.57	46.89	45.28	25.77	30.06	61.22	142.00	181.35	122.45	89.73	49.65	69.60	920.57
Average	.86	.71	.69	.39	.46	.93	2.15	2.74	1.86	1.36	.75	1.05	13.95

The amount and kind of vegetation are strongly affected by the number of rock fragments at the surface. Rock fragments tend to concentrate moisture so the plants are larger and more numerous; in many places, certain plants would not otherwise occur. Thus in some areas black grama was found where high concentrations of rock fragments occurred, but not in adjacent areas that lacked them. The sandy soils of map unit A are also generally lacking perennial grasses. These soils, which have formed in terrace sediments deposited by Cox Arroyo, not only tend to lack rock fragments but also have little clay.

Some areas have evidence of vegetation changes within the last few decades, and some of the changes may be associated with man's introduction of livestock. Shrub increase is indicated by aerial photographs discussed later. A considerable increase in mesquite was also noted in a ground observation by Rob Cox and his father Jim (Rob Cox, personal communication, March, 1989). A rapid increase in mesquite as well as other shrubs was observed in the Jornada Experimental Range (Buffington and Herbel, 1965). Cattle can disseminate mesquite seed since it passes through their digestive tracts without damage. Seed dispersal, accompanied by heavy grazing and periodic droughts, appeared to be the major factor affecting the rapid increase in shrubs in the Experimental Range (Buffington and Herbel, 1965). These factors may also have been important in the rapid increase in shrubs at the fault.

The chronological model

Piedmont-slope geomorphic surfaces in the vicinity of the fault (Fig. 5A) are similar to those at the Desert Soil-Geomorphology Project (informally termed the Desert Project) on the west side of the Organ Mountains (Fig. 1; Table 4). The Desert Project, a 400—square-mile study of desert soil and landscape evolution, was conducted from 19571972 by Soil Survey Investigations, USDA—SCS (Rube, 1967; Hawley, 1975b; Gile and Grossman, 1979; Gile et al., 1981). All of the piedmont-slope geomorphic surfaces at the Desert Project except Dona Ana have been recognized in the fault area. Two phases of the Organ III surface, early and late, have also been recognized (Gile, 1987). Figure 5B locates the study sites.

Figure 6 shows part of the study area at larger scale. Among other things the enlargement shows the roads used to reach the late Holocene and the Holocene—Pleistocene scarps. The road to the late Holocene scarp was initially constructed by hand to minimize erosion. Later, more prominent tracks were made by excavation equipment. Use of these roads for any future work along the fault is encouraged. Permission for such work must be obtained from Rob Cox, whose land must be crossed to reach the fault, and from WSMR, in which the study area is located.

As in the Desert Project, the geomorphic surfaces were mapped using morphostratigraphic units, in which sedi-

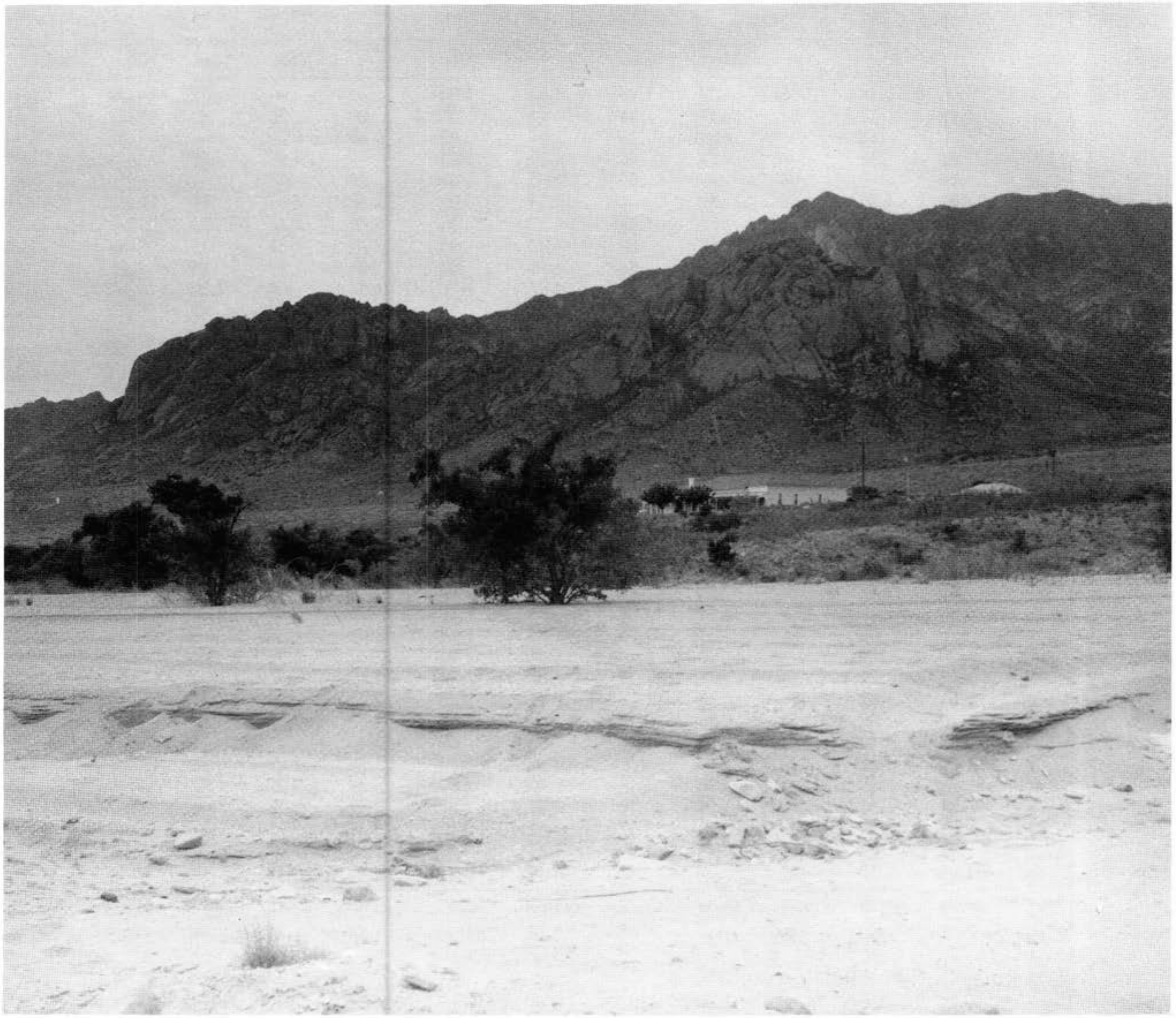


FIGURE 4—Thick alluvium deposited by the flood of August 19, 1978, in Cox Arroyo. The Cox Ranch house is in the middle ground beyond the arroyo. The study area (not shown) is beyond the left margin of the photograph. The Organ Mountains are on the skyline. Photographed April, 1979.

ments associated with constructional surfaces are the mapping units (Hawley and Kottlowski, 1969; Hawley, 1975a, Gile et al., 1981; Table 4). Sediments associated with the surfaces are designated by the geomorphic surface name (e.g., late Organ III sediments).

Historical sediments (1850 A.D. to present)

Historical sediments are sediments deposited since about 1850 (Table 4). The most extensive Historical sediments were deposited in the 1978 flood. The 1978 deposits are common in and adjacent to arroyos and below the three major drains that descend the Pleistocene scarp (Fig. 6). Figure 4 shows a large deposit of 1978 sediments in Cox Arroyo, east of the Cox Ranch house.

Organ III surface and sediments, (100-1,100 yrs B.P.)

The two phases of Organ III have not been distinguished on the geomorphic map because of their highly complex occurrence along the late Holocene scarp, on terraces above the scarp, and on the large Organ fan below the scarp. The two phases occur as narrow bands along the late Holocene scarp (see Fig. 14 in Gile, 1987). Late Organ HI sediments are illustrated by site 16 (Figs. 7, 8), where the deposits occur as a small terrace inset against an early Organ HI fan.

Figures 9 and 10 show the early Organ HI surface and its soil at site 9, photographed before it was accidentally obliterated in construction of a large trench at the Beehner site (Fig. 6). However, the early Organ III ridge is still preserved east of site 9 (see site 20).

Figure 6 (J—M) locates four earlier positions of Cox Arroyo. Presence of sediments characteristic of Cox Arroyo (see map unit A of soils section) in these former channels shows that the arroyo was the main cause of the former channels and associated sediments. Sediments of Historical and late Organ HI age extend towards Cox Arroyo from both the Holocene—Pleistocene scarp and the Organ fan. After the latest displacement (in late Holocene time; Gile, 1987) swung Cox Arroyo against the fault zone, continued sedimentation from the scarp and the Organ fan deposits must have forced the arroyo eastward to its present position.

Only very small areas of the older post-faulting deposits of Cox Arroyo are evident at the surface because of later Organ III and Historical sedimentation. One of those

TABLE 3. Scientific and common names of perennial grasses, shrubs and trees observed in the study area.

Scientific name	Common name
	Perennial grasses
Bouteloua gracilis	Blue grama
Aristida sp.	Three-awn
Bouteloua curtipendula	Sideoats grama
Bouteloua eriopoda	Black grama
Eragrostis lehmanniana	Lehmann lovegrass
Muhlenbergia porteri	Bush muhly
Tridens pulchellus	Fluffgrass
Digitaria californica	Arizona cottontop
Bothriochloa barbinodis	Cane bluestem
Elymus elymoides	Squirrel tail
	Shrubs and trees
Acacia constricta	Whitethorn
Acacia Greggii	Catclaw
Celtis sp.	Hackberry
Atriplex canescens	Four-wing saltbush
Brickellia laciniata	Brickellbush
Chilopsis linearis	Desert willow
Condalia lycioides	Buckthorn
Dasylirion Wheeleri	Sotol
Ephredra torreyana	Mormon tea
Eriogonum Wrightii	Buckwheat
Gutierrezia sarothrae	Snakeweed
Haplopappus laricifolius	Turpentine bush
Lippia Wrightii	Lippia
Opuntia spp.	Cholla, prickly pear
Prosopis juliflora	Mesquite
Quercus sp.	Oak
Trixis californica	Trixis
Morus microphylla	Mulberry
Fallugia paradoxa	Apache plume
Yucca elata	yucca
Lyceum Berlandieri	Desert thorn
Hymenoclea monogyra	Burro brush

areas is below the abrupt north end of the Organ fan at location K (Fig. 6), where a small area of ancestral sediments is still preserved. The abrupt end of the fan and the deposits below it appear to represent an early post-faulting channel of Cox Arroyo. West of this cut, the watershed increases in size, and analogous terrace sediments, if they are present, are buried by late Organ III alluvium from the fan just south.

At position J (Figs. 5B, 6; site 27), alluvium of Cox Arroyo grades into fault-caused skeletal colluvium of early Organ III age. This indicates early Organ III age for these ancestral deposits of Cox Arroyo, which must be the oldest Cox Arroyo deposits that postdate the late Holocene fault (see discussion at site 27).

Organ II surface and sediments (1,100-2,100 yrs B.P.)

The Organ II surface and sediments are most extensive above the late Holocene scarp (Figs. 5A, 6). The topographic relation of Organ II to Organ I and HI surfaces above the fault has been shown in cross section (see Fig. 5 in Gile, 1987). At least three remnants of the Organ II surface also occur below the scarp (Figs. 5A, 6).

Organ I surface and sediments (2,200-7,000 yrs B.P.)

The Organ I surface and sediments, although well preserved in scattered areas, have been eroded away in others, and also have been buried in many places. The Organ I surface occurs in a complex of Organ I, II, and III (Fig. 5A).

Isaacks' Ranch surface and sediments (8,000-15,000 yrs B.P.)

As a fan surface, the Isaacks' Ranch surface has been observed only in buried position in the vicinity of the fault (see site 26). Isaacks' Ranch sediments were also identified at the Holocene-Pleistocene scarp (see sites 31 and 32).

TABLE 4—Geomorphic surfaces and soil ages of the upper piedmont slope at the Desert Project. The age of a geomorphic surface and its soils is considered to be the same. On a constructional surface, for example, all would date from the approximate time that sedimentation stopped and soil development started. All surfaces except Doña Ana have been observed in the vicinity of the study area. Years B.P. = years before 1950, following the custom for reporting radiocarbon ages (from Table 1 in Gile, 1987).

Geomorphic surface	Soil age (years B.P. or epoch)
Arroyo channels	Historical (since 1850)
Organ	100–7,000
III	100(?)–1,100
II	1,100–2,100
I	2,100–7,000
Isaacks' Ranch	Earliest Holocene-latest Pleistocene (8,000–15,000)
Jornada II	Late Pleistocene (25,000–150,000)
Jornada I	Late middle Pleistocene (250,000–400,000)
Doña Ana	Early to middle Pleistocene (>400,000)

Jomada II surface and sediments (25,000-150,000 yrs BP.)

The Jornada II surface occurs both as a terrace surface and as part of the Holocene-Pleistocene scarp that cuts the Jornada I surface (Figs. 5A, 6, 11).

The Jornada II terrace surface is a single surface of Jornada II, but the scarp has arroyo channels and Historical, Organ, Isaacks' Ranch and Jornada II sediments. The scarp landscape consists of two general parts—drainageways and areas between them. Because the drainageways are cut into and below areas between them, the drainageways are younger. Despite relative youth of the drainageways, they have soils of Jornada II as well as Organ and Isaacks' Ranch age. Thus the oldest parts of areas between the drainageways would occupy the oldest parts of the Jornada II age range (Table 4).

Jornada I surface and sediments (250,000-400,000 yrs B.P.)

The Jornada I surface and associated fan deposits of the Camp Rice Formation (Seager, 1981) occur above the Holocene-Pleistocene scarp (Figs. 5A, 12). The fan has occasional broad drainageways, three of which empty into major drainageways of the scarp at sites 30-32 (Figs. 5B, 6).

A photographic record of changes along the **fault**

Aerial photography

Figures 13-16 are aerial photographs of the study area taken in 1936, 1942, 1963 and 1983. 1941 was a year of record precipitation throughout much of the Southwest. In that year 22.43 inches fell at the Cox Ranch house (Table 2). Aerial photographs taken in 1942 showed that only a few changes occurred in depositional patterns between 1936 and 1942 (Figs. 13, 14). Effects of the 1978 flood were much greater than the 1942 wet year; many arroyos in the study area were considerably enlarged by the 1978 storm, which made fresh exposures for study and sampling in a number of places. For example, the south bank of North Arroyo at site 15 (Fig. 5B), discussed later, was examined for exposures before the storm and none were available; the sloping

FIGURE 5A—Geomorphic map of the study area. OA = dominantly Organ III surface (sediments deposited primarily to wholly by Cox Arroyo), with small areas of arroyo channel surface; OB = dominantly Organ III surface (sediments deposited by arroyos that head in the scarp or upslope of it), with small areas of arroyo channel surface and very minor areas of Organ II surface; OC = dominantly Organ II surface, with small areas of Organ I, Organ III and arroyo channel surfaces; OD = complex of Organ I, II, and III surfaces, with small areas of arroyo channel surface; JA = Jornada II and younger surfaces; JB = Jornada II surface; JC = Jornada I surface. 1983 aerial photograph.

bank was thickly covered with large rock fragments. After the storm an excellent exposure was available at the same place (Fig. 17). Long, fresh exposures at sites 25 and 26 were made by the same storm.

The aerial photographs also show effects of vegetation changes. Shrubs (primarily mesquite) have increased considerably in density and size as shown by the increased density of the dark spotted pattern on the Jornada I fan surface from 1936 to 1983 (Figs. 13-16). The period between 1963 and 1983 was a time of particularly rapid growth in the density and size of shrubs (Figs. 15, 16).

The 1978 flood caused a reversal of the general eastward post-faulting trend of Cox Arroyo, previously discussed; east of relict channel M, a former channel was reexcavated and enlarged (see Figs. 6, 15 and 16). Traces of relict channels K, L and M were still evident in 1983 but much less so than they were in 1936 (Figs. 13-16).

Potential of repeat photography on the ground

Repeat photography is the practice of finding the site of a previous photograph, reoccupying the original camera

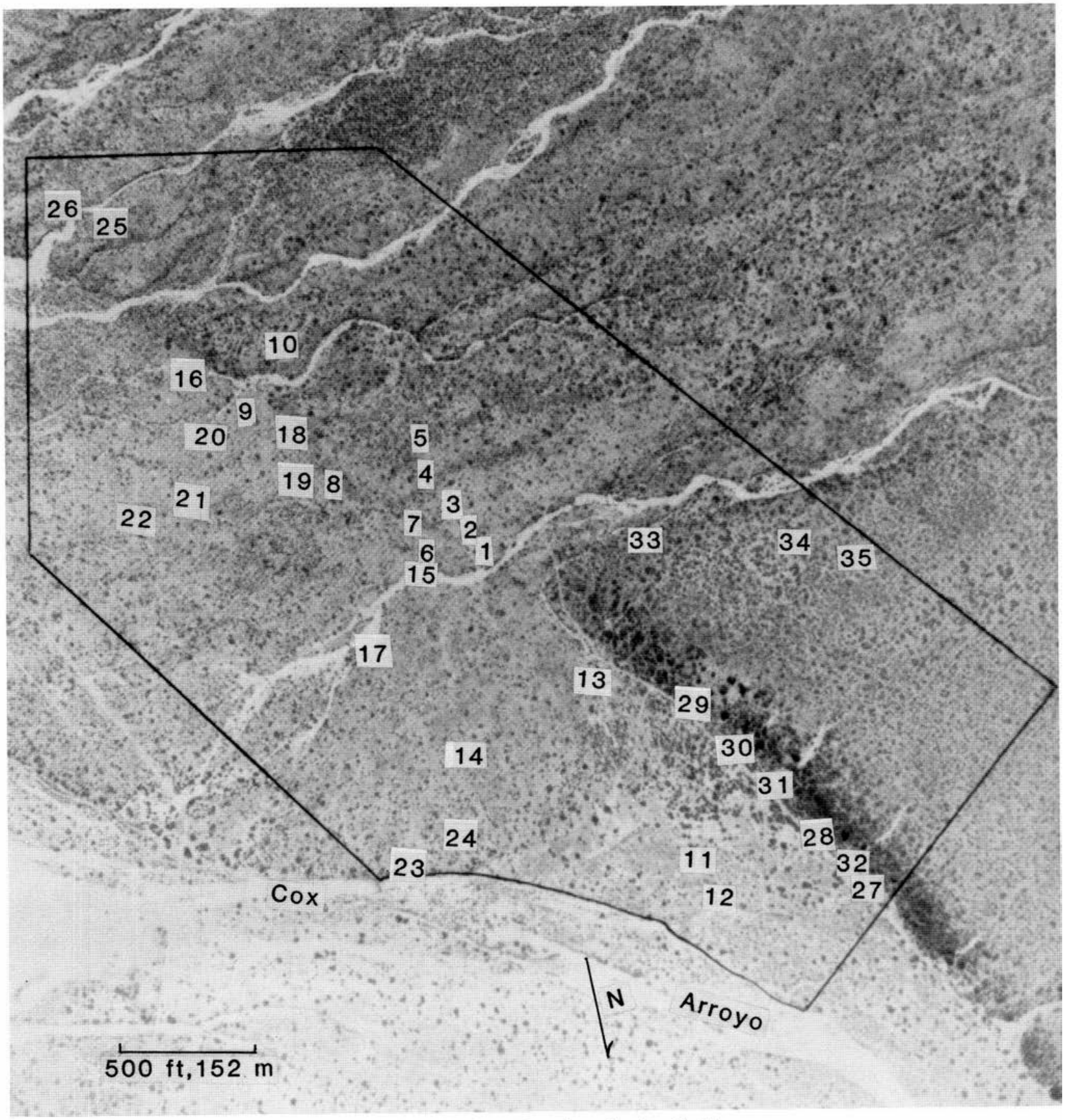


FIGURE 5B—Location of study sites 1–35.

position, and making a new photograph of the same scene (Rogers et al., 1984, p. ix). Three illustrative volumes on repeat photography in the Southwest are Hastings and Turner (1966), Rogers (1982), and Stevens and Shoemaker (1987).

The study area at the fault is a good area to photographically document long-term effects of erosion on arroyo banks and the exposed soils because numerous photographs were taken of them not long after the 1978 flood (mostly from March through June, 1979; see individual sites for specific month of photography). At the time of photography the arroyo bank exposures were still quite fresh and vertical or nearly so. The photographs should also be useful in assessing the chronology of colluviation (including soil creep) down the steep Holocene—Pleistocene scarp.

Soil taxonomy, mapping, and conventions

Table 5 lists soils of the study area and their classification (Soil Survey Staff, 1975). The study area is in a transition zone between Mollisols, which are more common next to the mountains, and Aridisols, which are dominant downslope. Entisols are also present, and occurrence of a specific order at a particular place is determined by such factors as soil age, particle size and landscape stability.

A number of changes have been made (Guthrie and Witty, 1982) in the long-standing horizon designations used in the 1951 Soil Survey Manual (Soil Survey Staff, 1951) and its 1962 Supplement. However, the **K horizon** nomenclature (Gile et al., 1965) continues to be used in Desert Project and other publications because, as noted by Birkeland (1984),

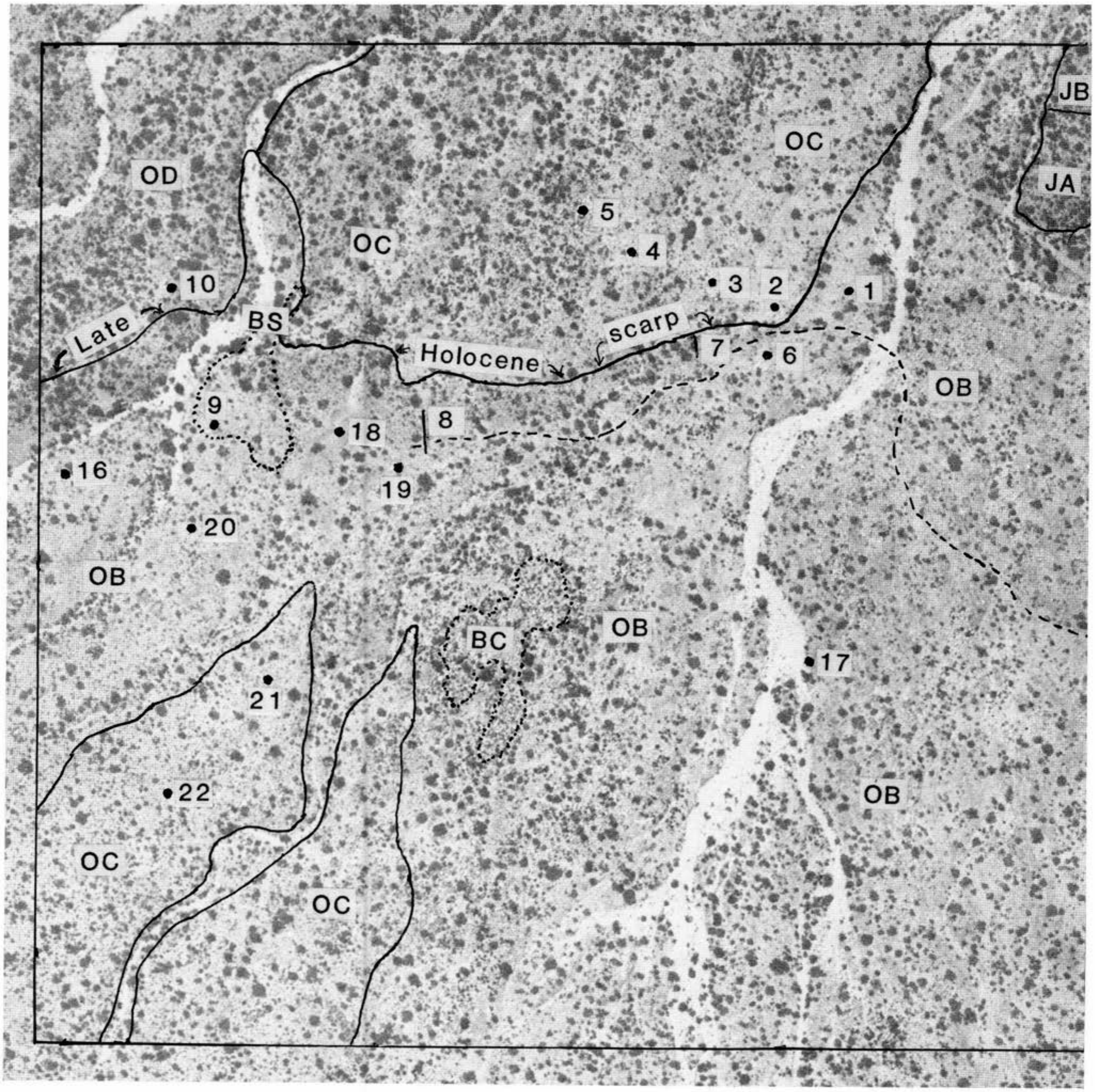


FIGURE 6—Enlargement of part of Fig. 5A. Numbers 1–24 locate study sites. The symbols OA, OB, OC, JA, JB, and JC designate geomorphic surfaces (see Fig. 5A for identification). Dashed lines are access roads to the late Holocene and the Holocene-Pleistocene scarps. Letters J, K, L and M locate former positions of Cox Arroyo. Dotted delineation BS = disturbed area at Beehner (1989) site. Dotted delineation BC = boulder and stone concentration. 1983 aerial photograph (above and at right).

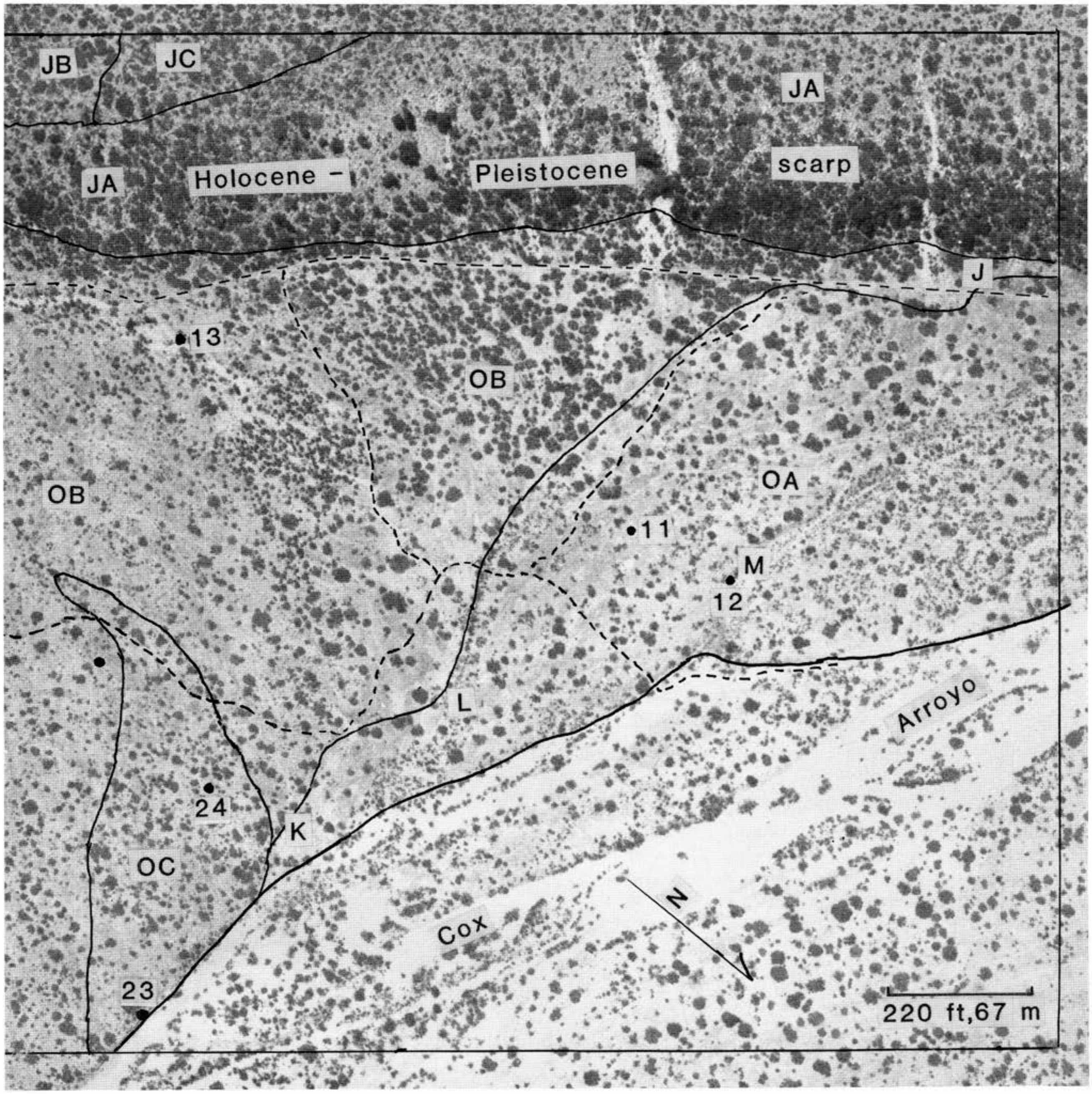
"most pedologists and geologists working in arid lands find it a very useful term."

Only shallow trenches could be dug by hand in most places because of numerous large rock fragments. However, some of the soils were well shown in fresh arroyo exposures made by the 1978 flood. Other exposures were made by backhoe.

Organic carbon was measured by the Walkley—Black method. Particle-size analyses by the Soil and Water Testing Laboratory at New Mexico State University were done by the hydrometer method, using a 6—hour reading for clay. Particle-size analyses by Carol Taschek were done by the pipette method. The hydrometer method with a 6—hour reading for clay gives values very similar to those obtained by the pipette method (personal communication, B.L. Allen, 1983). Particle size and organic carbon values at sites 2-6 and 9 were determined by Carol Taschek; for all other sites by the Soil and Water Testing Laboratory at New Mexico State University.

The soil map (Fig. 18) has eight map units, which are designated as texture phases and soil complexes. Texture phases (e.g., Roswell sand) indicate the average texture of the surface layer (as used here, the upper 15 cm). In soil complexes, the soils occur in such intricate patterns that they cannot be mapped separately at a scale of 1:15,840.

The 35 study sites (Fig. 5B) consist of a backhoe trench or an arroyo exposure. The study sites are designated in two ways, depending upon the number of studied areas at



a given site. Each site is designated first of all by a number (e.g., site 27). Some sites consist of more than one part; the components are designated by an added lower case letter (e.g., site 27a). Individual pedons are similarly designated (e.g., pedon 27a) for the purpose of specific reference to the small section of soil containing the horizons that were sampled. Abbreviations in tables are explained in Table 6.

Miscellaneous areas (Soil Survey Staff, 1990b) are areas having little or no identifiable soils as defined in *Soil Taxonomy* (Soil Survey Staff, 1975). Two kinds of miscellaneous areas occur in this study. (1) *Rubble land* consists of areas with more than 90 percent of the surface occupied by stones or boulders. Voids are free of soil material and vegetation is sparse or absent (see Fig. 19 for an example). (2) *Stream-wash* designates unstabilized areas of sandy, gravelly, cobbly, stony or bouldery materials that are flooded and reworked by streams so frequently that they have no pedogenic horizons and little or no vegetation. These areas occupy the prominent white linear patterns that are distinct on aerial photographs taken after 1978 (see cover). These patterns were established by the 1978 flood and have changed little since that time. Streamwash is similar to Riverwash (Soil Survey Staff, 1990b), but is used instead of Riverwash because the streams of this study are not rivers.

The Ustollic Haplargid Coxranch (Table 5) is similar to the Caralampi series in upper horizons, but lower horizons are so tightly packed with fine earth that the horizons could not be excavated by backhoe. No calcic or petrocalcic horizon was found in the two study trenches (sites 34 and 35), but one or the other could be present below the excavated depths (42 and 47 inches, 107 and 119 cm). Occurring in complex association with Coxranch is an unnamed Aridic Argiustoll that is similar to Coxranch but has a mollic epipedon and occurs at stablest sites. Both soils are distinguished in Table 5 by the designation "compact substratum."

Concentrations of boulders and stones

Concentrations of boulders and stones occur in places. The largest concentration observed is in an area of Organ III deposits (Fig. 19); smaller concentrations occur on the

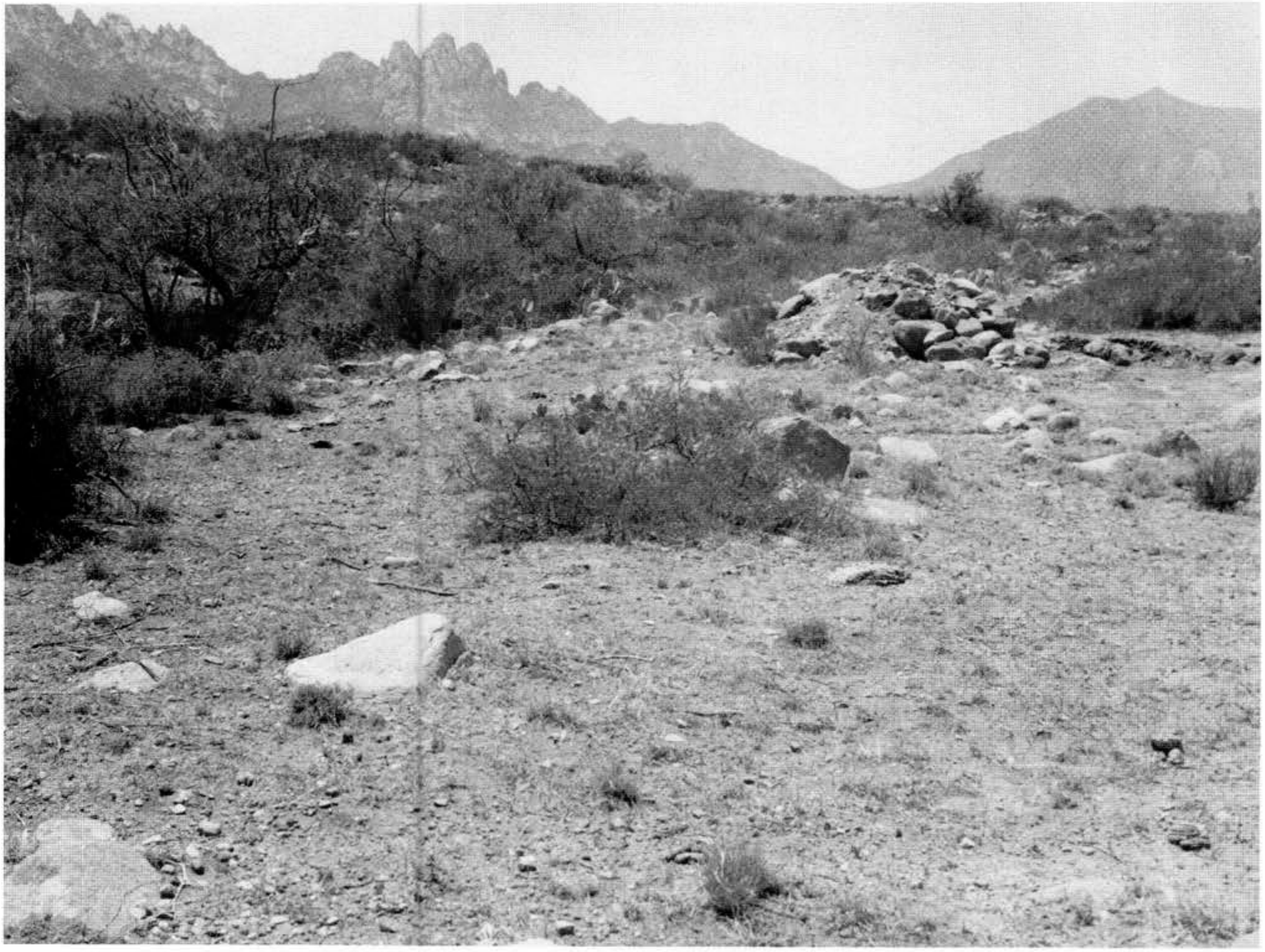


FIGURE 7—Landscape at site 16 looking to the west. The south fork of South Arroyo is at left. Spoil of the site 16 trench is at right center; the late Organ III terrace extends from the foreground to slightly beyond the trench. The stony upper horizons of the soil can be seen in the trench. The late Holocene scarp is in middle ground at left and right. The Organ Mountains are on the skyline.

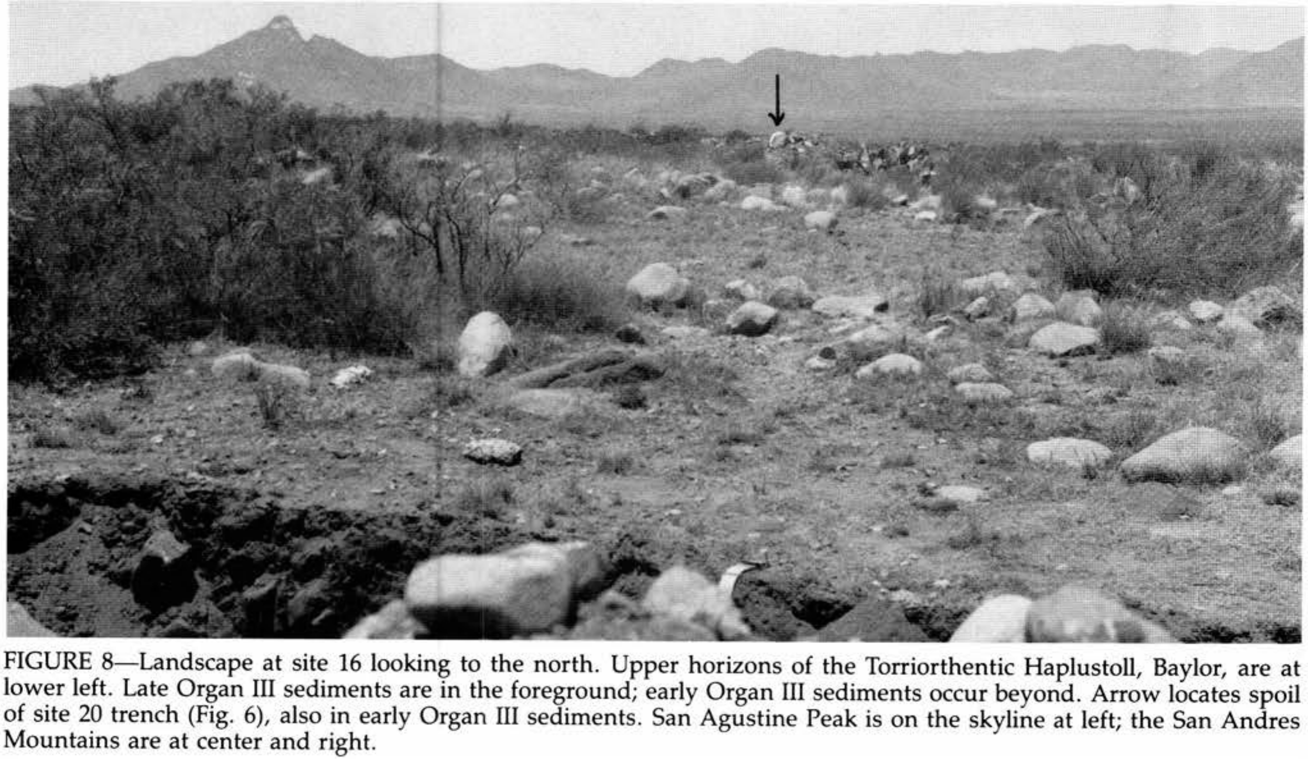


FIGURE 8—Landscape at site 16 looking to the north. Upper horizons of the Torriorthentic Haplustoll, Baylor, are at lower left. Late Organ III sediments are in the foreground; early Organ III sediments occur beyond. Arrow locates spoil of site 20 trench (Fig. 6), also in early Organ III sediments. San Agustine Peak is on the skyline at left; the San Andres Mountains are at center and right.

FIGURE 9—Landscape at site 9, looking west. Site 9 was accidentally obliterated during filling of the long trench at the Beehner site (Fig. 6). The Beehner trench was in the south end of the scarp where it was cut by South Arroyo, at right center.

Organ II surface and in arroyos. Boulders and stones in the Organ III concentration appear fresher and have fewer cracks and spalls than do those of Organ **II** age at site 5 (see Fig. 10 in Gile, 1987). This supports the boulders and stones shown in Fig. 19 as being of Organ III age.

In places the deposit of stones and boulders is thick enough (at least 7 ft, 2.1 m) that fine earth cannot be seen from the surface of the deposit. Many of the boulders range from 3 to 5 ft (0.9 to 1.5 m) in diameter and some are as much as 6 ft (1.8 m) across. The deposit appears to have been emplaced as a debris flow during migration of North Arroyo from a large channel east of site 8 northward to its present position (see Gile, 1987, for further discussion of the channel east of site 8). There is no vegetation except for occasional shrubs, which consist mainly of Lippia, desert willow, turpentine bush, and hackberry.

Sites **1-10**

Sites 1-10 were discussed in connection with the time of latest displacement along the fault (Gile, 1987). Data for soils at sites 1-10 have been included in this report (see tables that follow) so that data for both studies will be available in one place.

Historical sediments (1850 A.D. to present)

Sediments of Historical age are not extensive enough in any unit to dominate it. Materials of several ages are present. Streamwash in active arroyo channels is so young and reworked so frequently that plants cannot grow and that soil horizons cannot form. Slightly older deposits along channel margins have well developed perennial vegetation but no A horizon. Some of the latter deposits have surficial accumulations of organic matter such as twigs and bits of grass, but darkening by organic carbon is not evident. Older deposits lack a dark A horizon but do have scattered bits of organic carbon that mark the beginning of A horizon development.

Some surface or near-surface layers are quite dark but are interstratified with light-colored layers that are so fresh and undisturbed that they are obviously very young. This indicates that the dark-colored material was dark when it was deposited, and that it was derived from dark surficial horizons upslope (see site 25).

Historical deposits are underlain by buried soils in many places. These deposits are usually too thin (less than 50 cm thick) to be considered in the classification system (Soil Survey Staff, 1975) and classification is based on underlying soils.

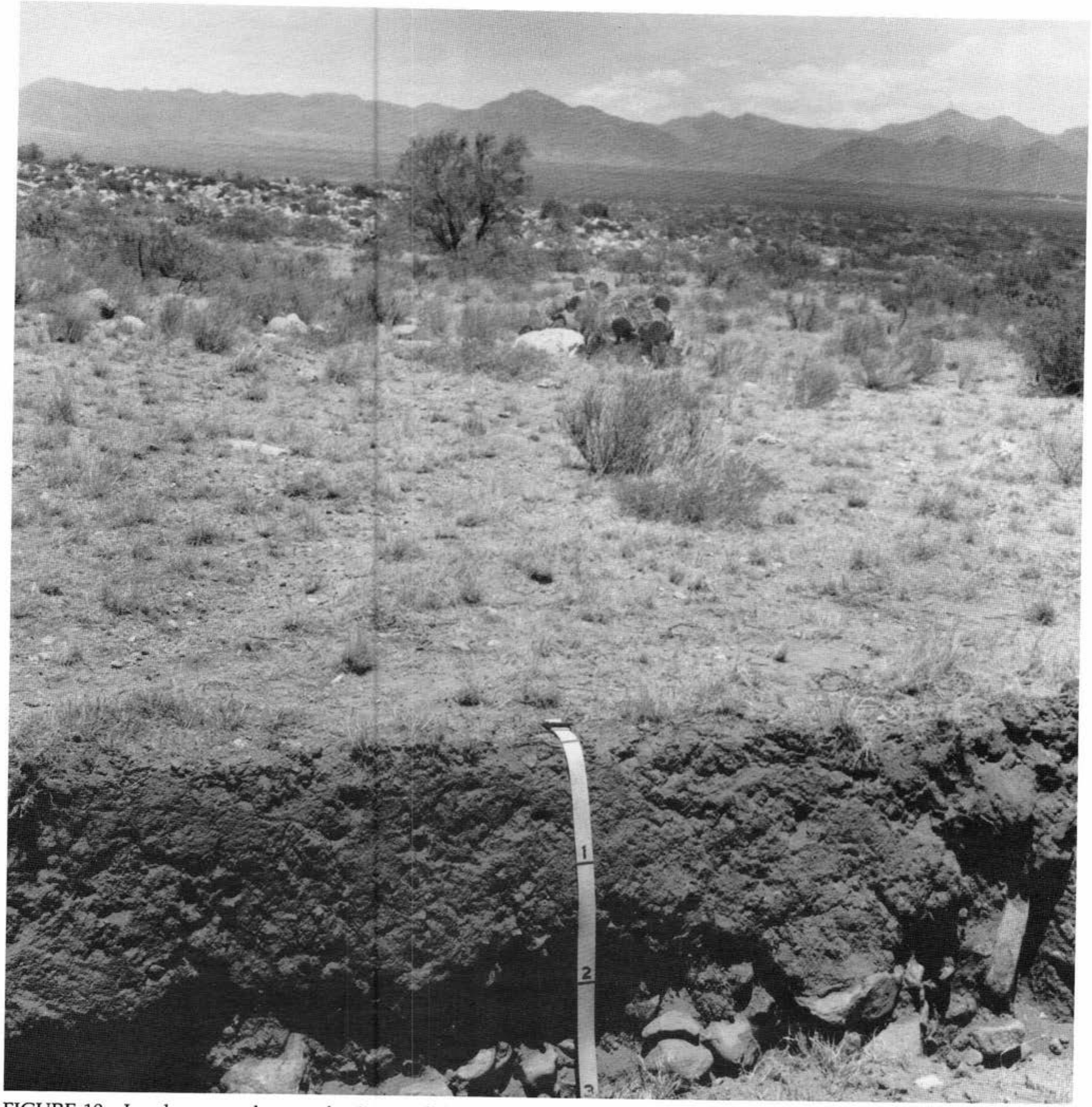


FIGURE 10—Landscape and upper horizons of the Ustollic Camborthid in early Organ III sediments at site 9, looking north. In about the upper 2 ft the sediments contain few rock fragments and are water-laid. Sediments below that depth contain abundant rock fragments and are interpreted as a debris flow. The San Andres Mountains are on the skyline. Scale is in feet.

Soils of the Organ III surface (100-1,100 yrs *B.P.)*

Soils of Organ III age illustrate initial development of the mollic epipedon, the cambic horizon, and (at certain sites at the base of the Holocene—Pleistocene scarp) the argillic horizon. Organic carbon data are not available for all soils thought to have mollic epipedons. Judging from analyses of soils of this study and of soils in the nearby Desert Project, in this study Mollisols with mollic epipedons that are 50 cm or more thick would generally qualify as Pachic but not Cumulic (Soil Survey Staff, 1975, 1990a).

Soils with too little organic carbon for a mollic epipedon either tend to occur on the more arid sites, such as the crests of narrow ridges, or have formed in sediments with few or no rock fragments.

The Organ III soils are highly significant to the chronology of faulting because they extend across the fault zone without displacement (Gile, 1987). The chronological and geomorphic background indicating a time in the late Holocene (estimated to be about 1,000 yrs B.P.) for the latest displacement has been presented (Gile, 1987) and is not further discussed here.

Soils of a terrace along Cox Arroyo: Roswell sand (A, Fig. 18)

Landscape, soil occurrence, unit boundaries, vegetation

Soils of map unit A occur in deposits of a terrace bordering Cox Arroyo on the west (Fig. 18). The terrace slopes

FIGURE 11—Landscape at site 27 looking west up the Holocene–Pleistocene scarp. The study trench is at left.

2% to the south. The Torripsamment, Roswell sand, dominates the map unit. Small areas of a Torrifluvent occur where sandy upper horizons are underlain by a finer horizon that occurs below 25 cm depth.

The eastern boundary of unit A (Fig. 18) is part of the eastern boundary of the study area, and extends along the eastern edge of a low terrace that borders a channel cut by the 1978 flood (see Fig. 6). Boundaries between unit A and units B and C involve interactions between Cox Arroyo and the Organ fan that borders the terraces on the south, and the Holocene—Pleistocene scarp to the west. The eastern end of the boundary to unit B is particularly significant because, as discussed previously, the abrupt north end of the Organ fan appears to represent an early post-faulting contact of ancestral Cox Arroyo against the Organ fan. Westward the Organ ridges extend northward and no evidence of the early channel of Cox Arroyo can be seen.

The boundary between units A and B is marked by prominent differences in slope. Soils of unit B (on the Organ fan to the south) slope 4% to the **north** whereas the soils of the unit A (on the terrace of Cox Arroyo) slope 2% to the **south.** Another surficial difference between the two map units is that the large fan has many more of the larger rock fragments on the surface than does the Cox Arroyo terrace. Near the Holocene—Pleistocene scarp, the boundary to unit B is commonly marked by a change from the grayish surface of the terrace (unit A) to the reddish, rockier surface of sediments derived from the scarp (unit B). The boundary is very close to the scarp at the north end of the study area but to the south veers eastward where sediments derived from the scarp have forced Cox Arroyo to the east.

Vegetation consists of scattered mesquite, Mormon tea, Yucca elata, and prickly pear. Many areas between shrubs have no perennial vegetation.

Ustic Torripsamment at site 11

The Roswell soils (Fig. 20, Table 6) usually contain sedimentary strata at shallow depth and show little evidence of pedogenesis except for organic carbon accumulation and some pedogenic mixing by soil biota. The soil surface is smooth, grayish, and has very few or no large rock fragments (Fig. 20). Typically the Roswell soils have a thin, soft and loose Al horizon, an underlying A2 horizon that is harder than the Al, and a soft C horizon. **In** some pedons a dark A horizon is buried at shallow depth; in others, the dark A horizon is at the surface. The C horizon is typically sand, but in places contains lenses of loamy sand.

Ustic Torrifluvent at site 12

Site 12 (Figs. 21, 22; Table 6) illustrates the Ustic Torrifluvents, which also occur in map unit A (Fig. 18). The finer subsurface horizon (Table 6), which causes an irregular decrease in organic carbon with depth and a change to the Fluvents, apparently represents a thin slack-water deposit.

FIGURE 12—The Jornada I surface and soil at site 34, looking northwest. The Cox Ranch house is in the middle ground; San Agustin Peak is at top center. Scale is in feet.

The Torrifluvent at site 12 is of particular interest because it was photographed in April, 1979, soon after the 1978 flood. Examination of post-1978 aerial photographs and study on the ground in 1979 indicate that the 1978 flood had relatively little effect on this terrace, apparently because it is a relict terrace, which was bypassed by Cox Arroyo at some time prior to 1936 (Fig. 13). When the terrace was viewed in 1989, the top of the exposure had been rounded by erosion and additional sediments had accumulated at the foot of the bank. Position of a key marker stone (Fig. 22) indicated that bank erosion had not been great.

Soils along and below the late Holocene scarp, and on narrow terraces above it: Baylor complex (B, Fig. 18)

Landscape, soil occurrence, unit boundaries, vegetation

Soils of map unit B occur on the large fan that debouches across the late Holocene scarp (Fig. 18); along the scarp; and on narrow terraces along arroyos that extend above the scarp. Slopes range from 4% to 7% with the gentler slopes occurring along and near the lower margins of the fan. Concentrations of rock fragments ranging in size from pebbles to boulders are common on the surface. In many places the concentrations alternate with surfaces that are free or nearly free of rock fragments.

Torriorthentic Haplustolls (Baylor soils) are dominant, and occur almost continuously on terraces adjacent to arroyos above the scarp. Parts of these terraces were eroded away during the 1978 flood; this is evident from present exposures and from a comparison of aerial photographs taken before and after the flood. Baylor soils also occur below the scarp, but generally do not occur at lowest elevations in the unit. The Torriorthentic Haplustolls (Aladdin and Hawkeye soils) occur in a few areas where the volume of rock fragments is too low for the skeletal families. Baylor

TABLE 5. Classification and diagnostic horizons and features of soils in the study area. See Soil Taxonomy (Soil Survey Staff, 1975) for detailed definitions of the listed orders, suborders, great groups and subgroups. All soils are in the thermic temperature class and the mixed mineralogy class (see glossary for definitions of these terms and for explanations of diagnostic soil horizons and features). Aladdin, Earp, Caralampi, Hawkeye, Minneosa, Santo Tomas, and Vado are established series. Baylor, Coxranch, Holliday, Soledad, and Summerford are proposed series. Rockspring is an informal series name. The Thapto-Calciorthidic and Thapto-Haplargidic subgroups are informal subgroup names. Yana variant, as used in this report, includes both sandy and coarse-loamy families. Soils classified at the subgroup level only are not included in this table.

Order	Suborder	Great group	Subgroup	Particle-size class	Series or variant and illustrative pedon
Entisols Lack diagnostic horizons	Fluvents	Torrifluvents	Ustic	Sandy	Minneosa Variant (12)
	Orthents	Torriorthents	Ustic	Sandy-skeletal	Rockspring (17, 25c)
				Sandy coarse-loamy	Yana Variant (7b, 8d, 18)
	Psamments	Torripsamments	Ustic	Coarse-loamy	Roswell (11)
Aridisols Cambic, argillic or calcic horizon	Argids Argillic horizon	Haplargids	Typic	Loamy skeletal	Soledad (21, 22)
			Ustollic	Loamy-skeletal	Holliday (2, 3, 4, 7a, 10a, 10b, 23, 25a, 26a) Unnamed (steep) (30b) Caralampi Coxranch (compact substratum) (34, 35)
				Coarse-loamy	Summerford (29b)
				Fine	Unnamed (32c)
	Orthids	Camborthids Cambic horizon	Typic	Loamy-skeletal	Unnamed (24)
			Ustollic	Loamy-skeletal	Vado Variant (9, 19, 20)
				Coarse-loamy	Unnamed (28b, 31a)
		Calciorthids Calcic horizon	Ustollic	Sandy	Unnamed (32a)
Mollisols Mollic epipedon	Ustolls	Argiustolls Argillic horizon	Aridic	Loamy-skeletal	Earp (Beehner site, 26b, 33) Unnamed (compact substratum) Unnamed (steep) (32b)
				Fine-loamy	Unnamed (31b, 32d, 32e)
			Pachic	Loamy-skeletal	Earp Variant (5, 29a)
		Haplustolls	Torriorthentic	Sandy-skeletal	Baylor (1, 6, 8a, 13–16)
				Coarse-loamy	Aladdin
				Sandy	Hawkeye
			Thapto-Calciorthidic	Coarse-loamy	Unnamed (27a)
			Pachic	Loamy-skeletal	Santo Tomas (8b, 25b, 25d)
				Sandy-skeletal	Santo Tomas Variant (8c)
				Coarse-loamy	Unnamed (27b)
			Thapto-Haplargidic	Coarse-loamy	Unnamed (28a)
			Typic	Coarse-loamy	Unnamed (30a)

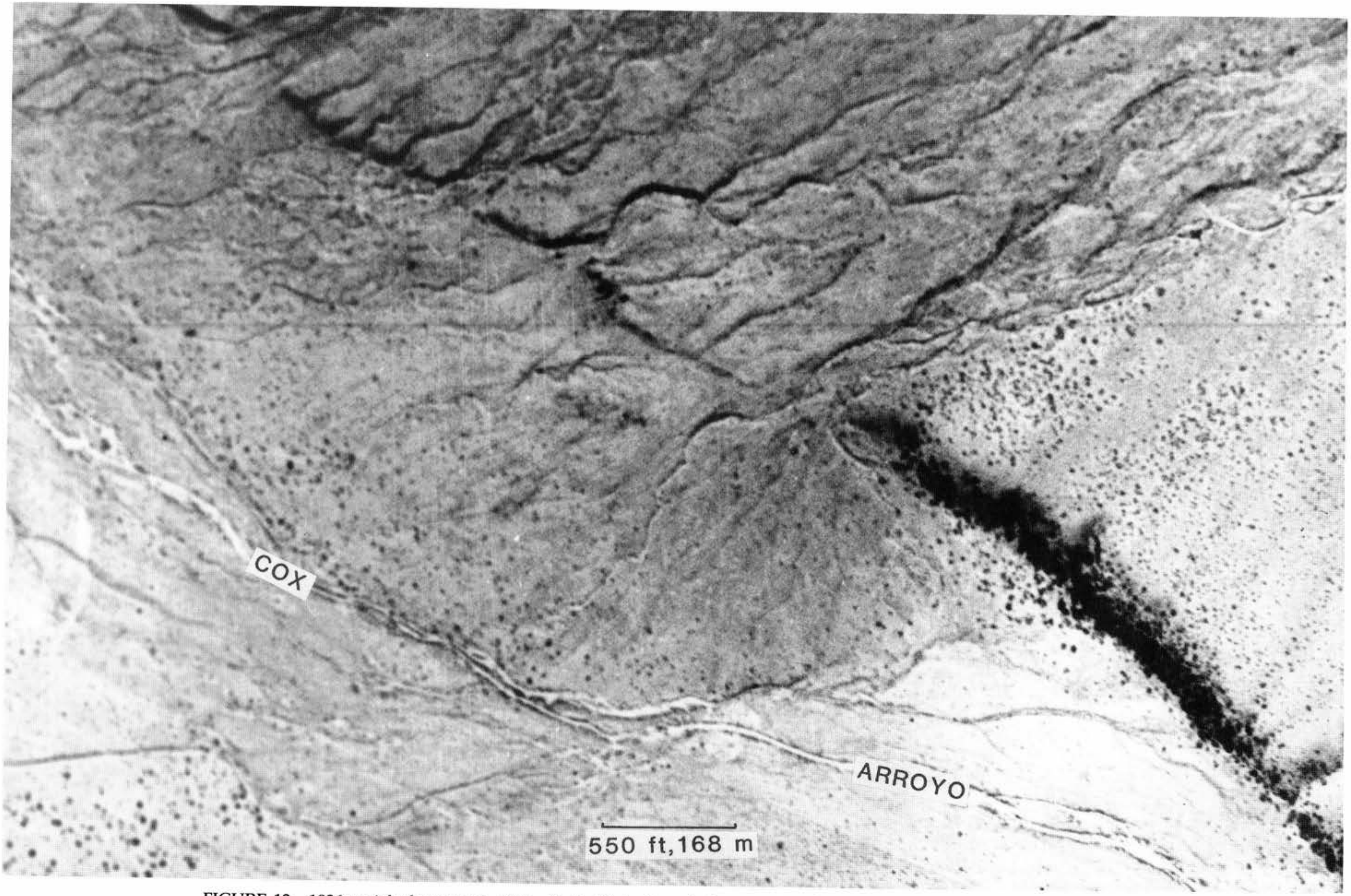


FIGURE 13—1936 aerial photograph of the fault. Note the relative sparcity of shrubs, reflected by the density of dark spots, as compared to the 1983 photograph (see text discussion). Note clarity of former channels of Cox Arroyo at K, L, and M (see Fig. 6).

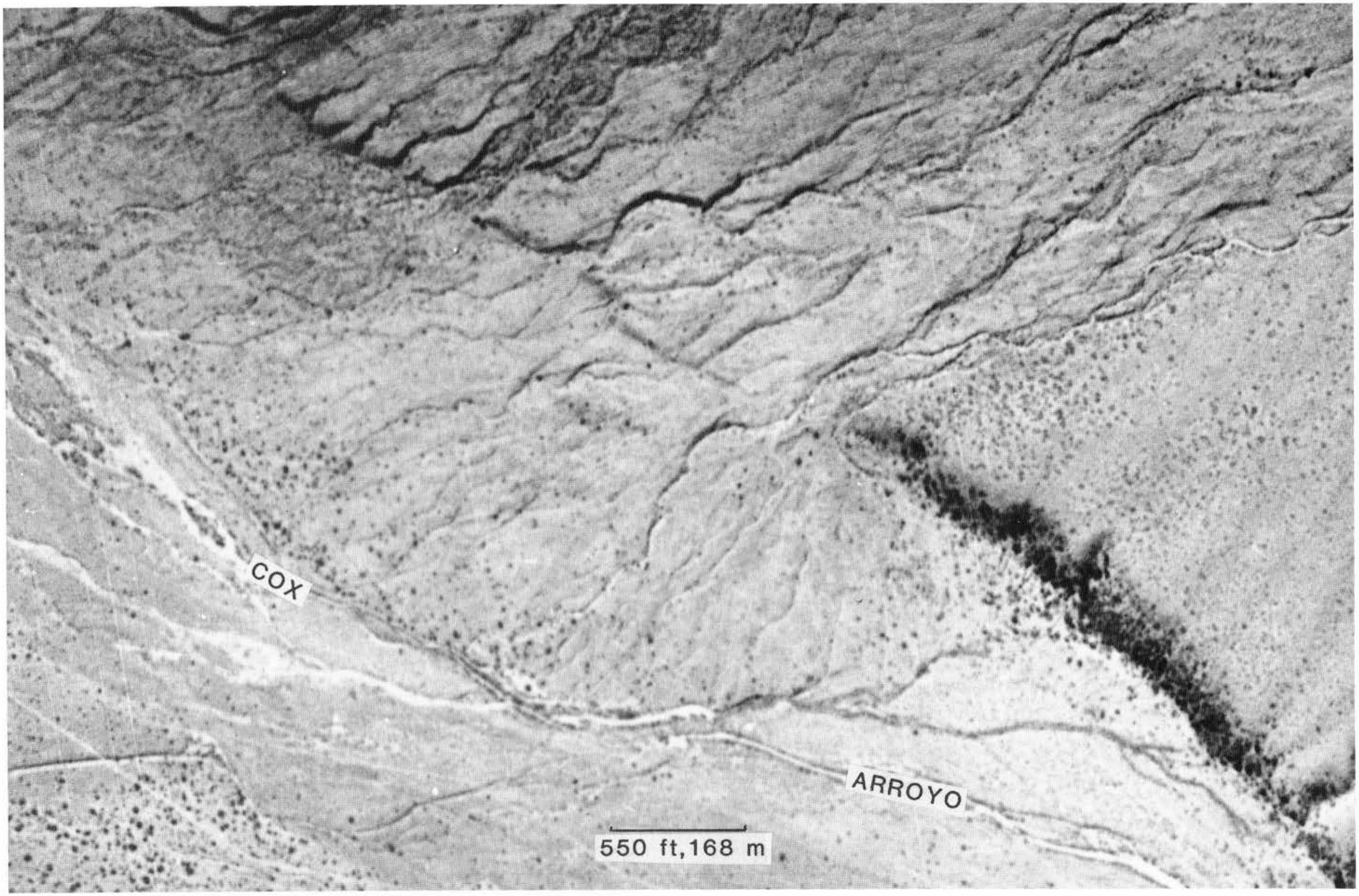


FIGURE 14—1942 aerial photograph of the fault. The photograph reveals effects of the record (at that time, Table 2) rainfall of 1941 by a number of widened channels visible at lower left and center. Former channels K, L, and M (see Fig. 6) are evident.

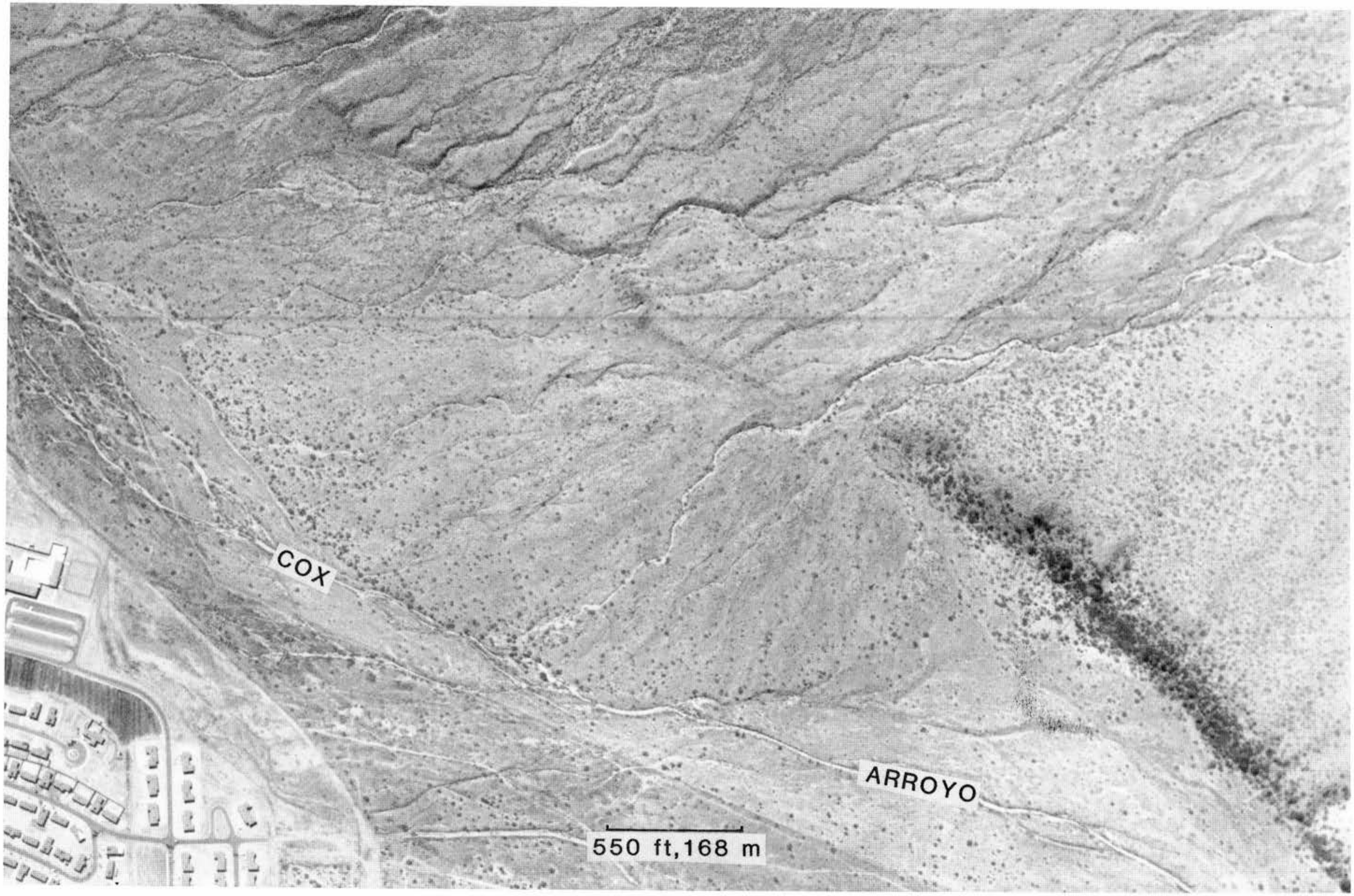


FIGURE 15—The 1963 aerial photograph shows part of the WSMR Headquarters at lower left. A slight increase in dark spots reflects shrub increase and growth since 1936. Former positions of Cox Arroyo K, L, and M are still clear.

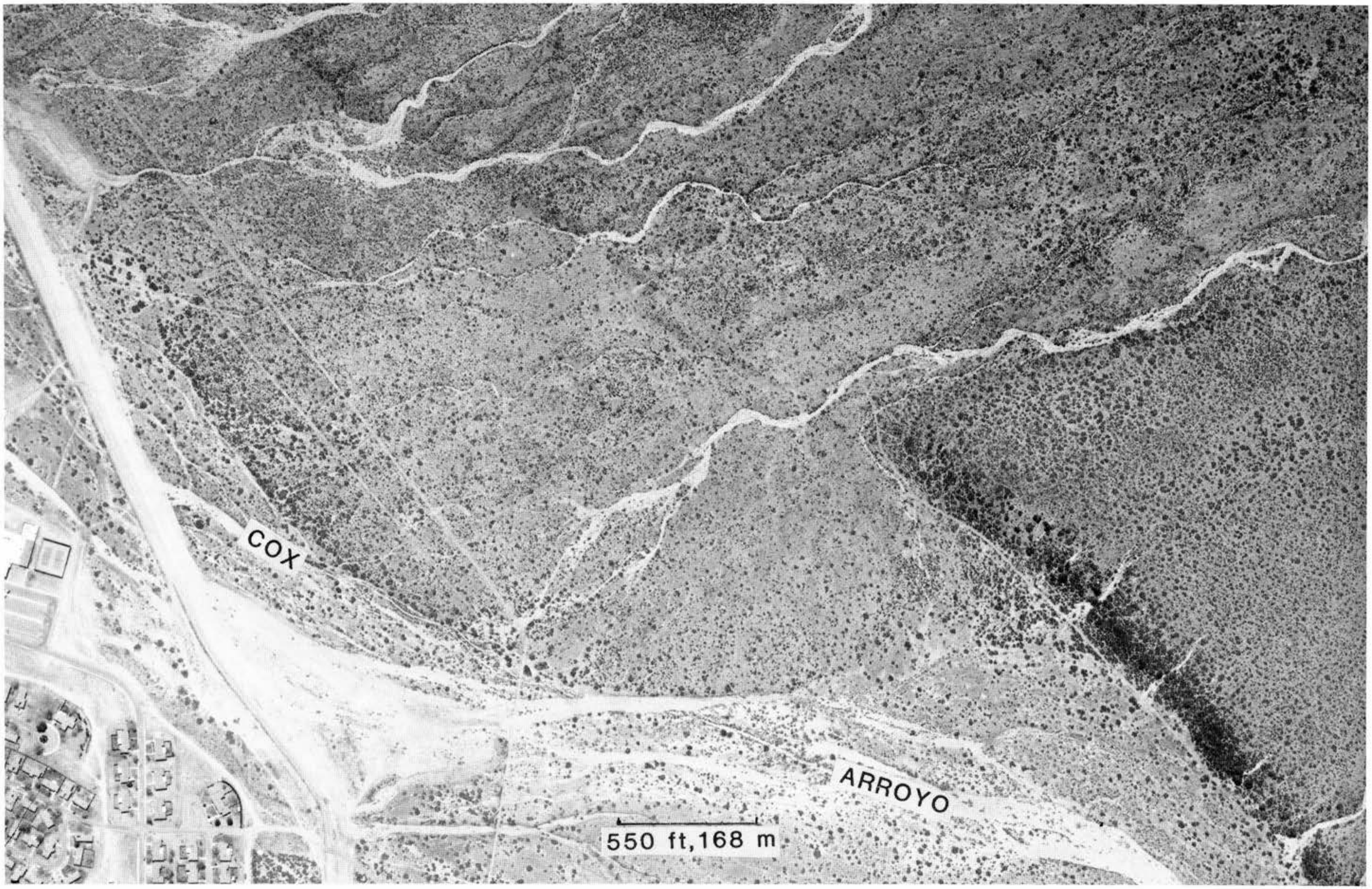


FIGURE 16—The 1983 aerial photograph of the fault shows a number of changes, many of which are due to the 1978 flood. Cox Arroyo was greatly enlarged, as are streams that cross the fault. Former Cox Arroyo positions K, L, and M are less clear, partly due to the considerable growth of shrubs (compare with 1936 aerial photograph). Newly cut stream channels down the Holocene–Pleistocene scarp are evident at lower right.

FIGURE 17—Landscape at site 15, at the south bank of North Arroyo, photographed in March, 1979. The south bank was examined on July 29, 1978, when the bank was beveled and mantled with large rock fragments; no exposures of the soils and sediments were available. The arroyo channel was greatly widened in the August, 1978 flood, resulting in long exposures of the soils and sediments.

soils and Pachic Haplustolls (Santo Tomas and its variant) occur in skeletal colluvium along the late Holocene scarp (Figs. 6, 23). Ustic Torriorthents (Yana variant), formed in primarily fine earth, also occur along the scarp in a narrow belt just below the Haplustolls. The Ustic Torriorthents (Rockspring soils) occur mostly at lower elevations. Camborthids (Vado variant) occur on some of the occasional narrow ridges of early Organ III sediments. Streamwash occurs in arroyo channels.

Boundaries to units A and C are discussed in those units. Figure 23 shows the boundary to unit D along the top of the late Holocene scarp. A similar boundary occurs between units B and E along the top of the scarp. The boundary to unit F is marked by the steeper slopes of the Holocene—Pleistocene scarp. Upslope of the scarp zone, the soils of unit B are inset against the higher soils of units D, E, and G.

Vegetation consists mainly of mesquite, catdaw, prickly pear, Lippia, snakeweed, Mormon tea, buckwheat, buckthorn, black grama, sideoats grama, lovegrass and burro brush.

Torriorthentic and Pachic Haplustolls at sites 1, 6, 8a—c, and 13-16

Soils at sites 1 and 6, and 8a—c have been discussed (Gile, 1987). Table 7 gives data for these soils. Site 13 is an exposure in the west bank of a small gully. The soil is very gravelly throughout and has a thick, dark A horizon underlain by C horizon material. Organic carbon content is easily sufficient for a mollic epipedon (Table 8).

The study trench at site 14 (Fig. 24, Table 8) was dug into the north bank of a small arroyo. The arroyo is the south edge of a broad interfluve that is nearly level transversely. The surface is generally free of rock fragments except for a few fine pebbles. This soil is weakly developed and no evidence of B horizon reddening is apparent. Materials to a depth of about 1 ft (30 cm) have few rock fragments and are water-laid; the abundant rock fragments below this depth are debris-flow materials. Upper horizons contain enough organic carbon for a mollic epipedon (Table 8).

Site 15 (Fig. 17, Table 8) illustrates Haplustolls on the south bank of North Arroyo, and is in a ridge of early Organ III age. The thick, dark A horizon is typical. The site also illustrates development of a very thin, discontinuous B horizon. The B horizon, which is slightly redder and lighter colored than the overlying A horizon, thins eastward and is not present at the tape.

The Haplustoll at site 16 (Figs. 7, 8; Table 9) is on a low, narrow terrace above the south fork of South Arroyo. The numerous large rock fragments show that the bulk of the material was deposited as part of a debris flow. This soil has a very thick, dark A horizon. Color of the A2 horizon is 7.5YR 4/2, dry, 7.5YR 2.5/3, moist; adjacent horizons have similar color.

Ustic Torriorthents at sites 7, 8, 17, and 18

As illustrated by some of the Camborthids (e.g., site 9), some soils formed in Organ H sediments have epipedons that are dark enough but have too little organic carbon for mollic. This is also the case for some of the Ustic Torrior-

FIGURE 18—Soil map of the study area. A = Roswell sand; B = Baylor complex; C = Holliday-Soledad complex; D = Holliday very cobbly sandy loam; E = Holliday complex; F = Argiustoll-Haplargid complex; G = Earp very cobbly sandy loam; H = Coxranch complex.

thents. The Torriorthents just below the late Holocene scarp at sites 7 and 8 have been discussed (Gile, 1987); data are in Table 10. Sites 17 and 18 illustrate Torriorthents in different geomorphic settings.

The Ustic Torriorthent at site 17 is in a new exposure made in the 1978 flood (compare 1963 and 1983 aerial photographs). As with a number of other soils in the area, this soil is easily dark enough for a mollic epipedon but does not have quite enough organic carbon (Table 8).

Site 18 (Fig. 25, Table 8) illustrates a Torriorthent formed in alluvium derived from a small stream that rises a short distance above the scarp (Fig. 6). Gravel content is about 10% by volume throughout; nearly all of it is fine. Sparcity of gravel and its small size is attributed to the limited watershed above the scarp. A gully has cut the deposit (Fig. 25), and the study trench was dug in its north bank. The thin C horizon at the surface is weakly stratified in places. The underlying A horizon is distinctly darker, but would have too little organic carbon for a mollic epipedon. No B horizon is evident. Materials in the C horizon have 5YR hue because they were derived from Bt horizons in the source watershed. The scarcity of roots is attributed partly to the sparcity of large fragments, which would concentrate moisture for greater vegetative growth, and partly to the droughty position of this soil (a small topographic high with a gully in the center; see Fig. 25).

TABLE 6. Characteristics of late Organ III soils at sites 11 and 12. Most abbreviations for soils follow Soil Survey Staff (1951) usage. *Structure:* lm, cpl = weak medium and coarse platy; lmpl = weak medium platy; 2mpl = moderate medium platy; lf, msbk = weak fine and medium subangular blocky; lcsbk = weak coarse subangular blocky; 2msbk = moderate medium subangular blocky; 2mpr = moderate medium prismatic; m = massive; sg = single grain. *Dry consistence:* l = loose; s = soft; sh = slightly hard, vh = very hard, eh = extremely hard. *Textural class:* vg = very gravelly; g = gravelly; vb = very bouldery; vst = very stony; vc = very cobbly; s = sand; ls = loamy sand; sl = sandy loam; scl = sandy clay loam; c = clay. Abbreviations for geomorphic surfaces and associated sediments are: H = Historical; O = Organ undifferentiated; O–I = Organ I; O–III = Organ III undifferentiated; O–III, e = Organ III, early; O–III, l = Organ III, late; IR = Isaacks' Ranch; J–II = Jornada II. J–I(S) refers to beveled Jornada I sediments of the Holocene–Pleistocene scarp, not to the Jornada I geomorphic surface. Intermediate hue designations indicate the closest hue (e.g., 9YR indicates that the hue is between 7.5YR and 10YR, but closer to 10YR than 7.5YR). Horizon designations follow Guthrie and Witty (1982) except for the K horizon nomenclature (Gile *et al.*, 1965). →

Horizon	Depth, cm	Hue	Value/chroma Dry	Value/chroma Moist	Textural class	Structure	Dry consistence	pH
Ustic Torripsamment at site 11								
A1	0–3	7.5YR	5/2.5	3/2	s	sg, m	s, l	7.0
A2	3–14	7.5YR	4.5/3	3/3	s	m	sh	7.0
A3	14–18	7.5YR	5/3	3/3	s	m, sg	s, l	7.0
A1b	18–24	7.5YR	4.5/2	3/2	s	m, sg	s, l	7.2
A2b	24–42	7.5YR	4.5/2	3/2	s	m, sg	s, l	7.2
C1b	42–66	10YR	6/2	4.5/2	s	sg	l	7.0
C2b	66–90	10YR	6/2	4.5/2	s	sg	sl	7.0
C3b	90–102	10YR	6/2	4.5/2	s	sg	l	7.0
Ustic Torrifluvent at site 12								
A1	0–6	9YR	4.5/2	3/2	s	m	s	7.0
A2	6–15	9YR	4.5/2	3/2	s	m	s	7.0
A3	15–32	9YR	4.5/2	3/2	s	m	s	7.0
A1b	32–39	10YR	4/1.5	2.5/1.5	fsl	m	sh	7.2
A2b	39–48	10YR	4/1.5	2.5/1.5	sl	m	sh	7.2
A3b	48–68	10YR	4/1.5	2.5/1.5	s	m	s	7.2
A4b	68–85	10YR	4/1.5	2.5/1.5	s	m	s	7.0
A5b	85–97	10YR	5/2	3/2	s	m	s	7.0
Cb	97–115	10YR	5.5/2	4/2	s	m, sg	s, l	7.2

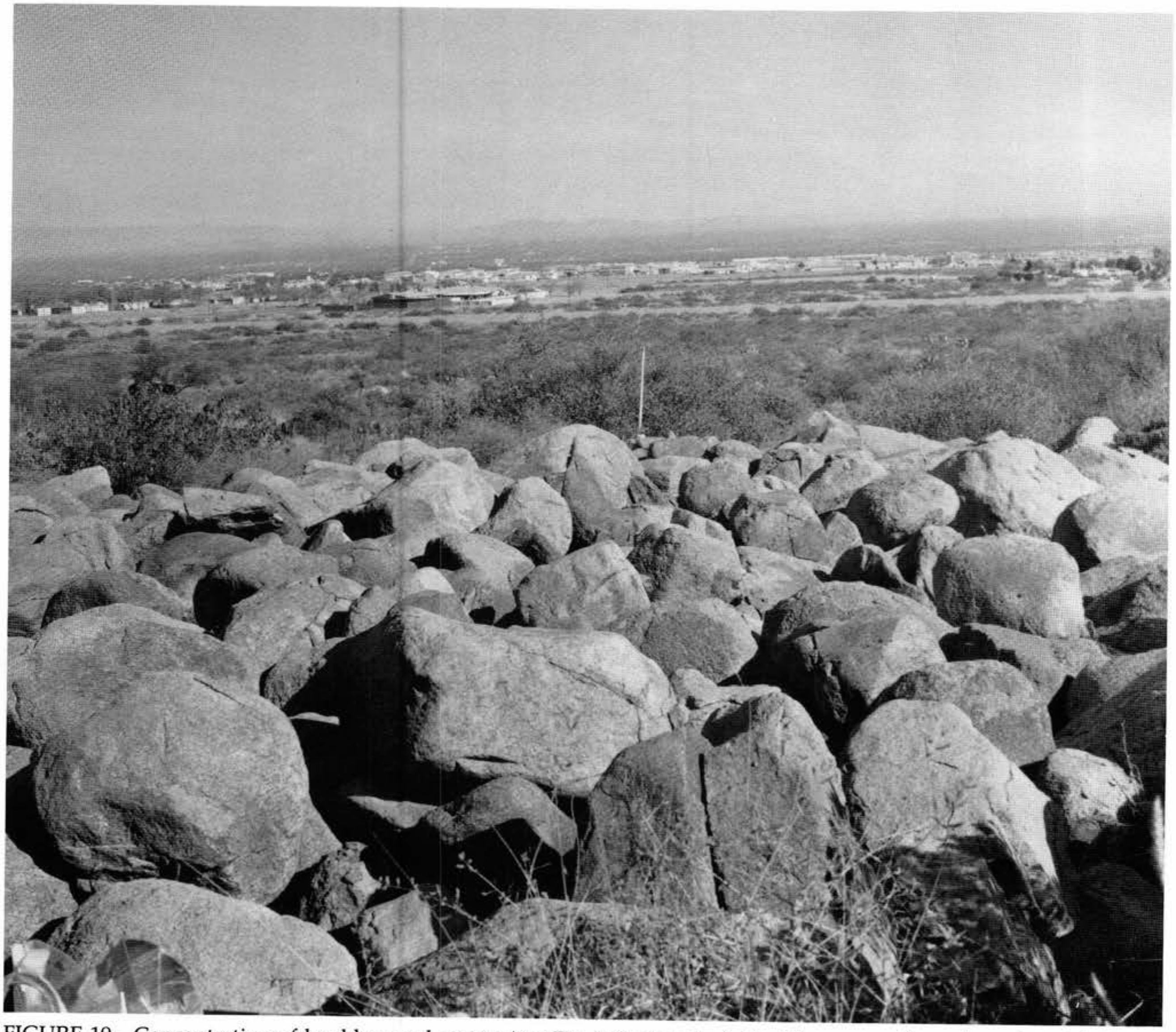


FIGURE 19—Concentration of boulders and stones (see Fig. 6 for location). Boulders range from about 3 to 6 ft (0.9 to 1.8 m) in diameter. The layer is so thick that little or no vegetation can grow. The WSMR Headquarters are in the middle ground.

TABLE 7—Characteristics of Organ III soils at sites 1, 6, and 8a–c (Gile, 1987). Abbreviations are explained in Table 6 caption (p. 32).

Horizon	Depth, cm	Hue	Value/chroma Dry	Value/chroma Moist	Structure	Dry consistence	Textural class	Sand 2.0–0.05 mm	Silt 0.05–0.002 mm	Clay <0.002 mm	Organic carbon
Torriorthentic Haplustoll at site 1–Organ III, early								percent			
A1	0–7	7.5YR	4.5/2	3/2	lm, cpl	s, l	vcls	77	16	7	1.28
A2	7–18	7.5YR	3.5/2	2/2	lf, msbk	s	vcsl	77	15	8	1.17
A3	18–30	7.5YR	3.5/2	2/2	m	s	vcls	80	14	6	0.73
	30–42	7.5YR	3.5/2	2/2	m	s	vcls	82	11	7	0.73
A4	42–55	7.5YR	3.5/2	2.5/2	m	s	vcls	82	14	5	0.55
A5	55–68	7.5YR	4/2	3/2	m	s	vcls	88	8	5	0.45
CA1	68–85	9YR	5/2	3.5/2	m, sg	s, l	vcs	91	7	3	0.30
CA2	85–113	9YR	5.5/2	4/2	m, sg	s, l	vcs	95	5	1	0.12
C	113–119	10YR	6/2	4/2	sg	l	vcs	93	5	2	0.06
Torriorthentic Haplustoll at site 6–Organ III, early											
A1	0–5	7.5YR	4.5/2	2.5/2	lmpl, sg	s, l	sl	75	17	8	0.69
A2	5–22	7.5YR	4/2	2.5/2	m	s, l	ls	78	14	8	0.61
2A3	22–48	7.5YR	4/2	2.5/2	m	s	vcls	78	14	8	0.49
2A4	48–72	7.5YR	4.5/2	3/2	m	s	vcls	83	10	7	0.35
2CA	72–107	10YR	5.5/2	3.5/2	sg	l	vcs	90	6	5	0.23
2C	107–140	10YR	6/2	4/2	sg	l	vcs	91	5	4	0.06
Torriorthentic Haplustoll at site 8a—Organ III, early											
A1	0–5	7.5YR	4.5/2	3/2	lcpl, m	s	vcsl				
A2	5–15	7.5YR	4/2	2/2	lf, msbk	sh, s	vcsl				
A3	15–31	7.5YR	4/2	2/2	lf, msbk	sh, s	vcsl				
A4	31–49	6.5YR	4.5/2.5	3/2.5	m	s	vcsl				
AC	49–74	7YR	5/3	3.5/3	m, sg	s, l	vcs				
CA1	74–96	7.5YR	5/3	3.5/3	m, sg	s, l	vcs				
CA2	96–114	7.5YR	5/3	3.5/3	sg	l	vcs				
Pachic Haplustoll at site 8b—Organ III, early											
A1	0–5	7.5YR	4.5/2.5	3/2	sg, m	s, l	vcls				
A2	5–17	7.5YR	4/2	2/2	lmsbk	s	vcsl				
A3	17–39	7.5YR	4/2	2/2	lmsbk	s, sh	vcsl				
A4	39–63	7.5YR	4/2	2/2	m	s, sh	vcsl				
A5	63–92	6YR	4/2.5	3/2	m	s, sh	vcls				
AC	92–130	7.5YR	4.5/3	3/3	m	s	vcsl				
CA	130–140	7.5YR	5/3	3.5/3	m, sg	s, l	vcs				
Pachic Haplustoll at site 8c—Organ III, late											
A1	0–4	7.5YR	4/2.5	2.5/2.5	m, sg	s, l	sl				0.62
A2	4–18	7.5YR	4/2.5	2.5/2.5	lmsbk	sh	sl				0.69
A3	18–34	7.5YR	4/3	2.5/3	lmsbk	sh	sl				0.73
2A4	34–55	7.5YR	4/3	2.5/3	lmsbk	sh	vgsl				0.67
2CA1	55–79	7.5YR	4.5/3	3/3	m, sg	s, l	vgs				
2CA2	79–96	7.5YR	5/3	3.5/3	m, sg	s, l	vgs				
2CA3	96–119	6.5YR	5/3	3.5/3	m	s	vgls				
3C	119–128	6.5YR	5/3	3.5/3	m	s	vgls				

Ustollic Camborthids at sites 9, 19, and 20

Soils at sites 9, 19 and 20 (Tables 9, 10) have very thick Bt horizons that grade to sand C horizons. All three soils have a deceptively smooth surface; they have formed in an upper layer of water-laid, mostly fine earth materials, and an underlying layer of debris-flow materials with abundant rock fragments. The Camborthid at site 9 (Figs. 9, 10; Table 10) is on a slight ridge of early Organ III alluvium. The clay increase from A to B is too slight for an argillic horizon (Table 10).

Soils at sites 19 and 20 (Table 9) are morphologically similar to the soil at site 9 and are also considered to be Camborthids. Site 19 occurs in an area of late Organ III sediments below the late Holocene scarp. Site 20 occurs in a slight ridge of early Organ III sediments.

Soils of the Organ II surface (1,100-2,100 yrs B.P.)

Soils of Organ II age have accumulations of silicate clay that usually qualify as argillic horizons. Sites 2-5 and 2124 (Fig. 5B) illustrate Organ II soils. Soils at sites 2-5 have been discussed (Gile, 1987); soils at sites 21-24 will be discussed in this report (Figs. 26-28). In contrast to the Organ III soils, the soils of Organ II have been downfaulted along the scarp (Gile, 1987).

Soils of ridges below the late Holocene scarp: Holliday—Soledad complex (C, Fig. 18)

Landscape, soil occurrence, unit boundaries, vegetation

Soils of map unit C occur on three remnants of the Organ II surface on the large fan below the late Holocene scarp (Fig. 18). Slopes range from 4% on the lowest parts of the remnants to 6% on the highest parts. In many places

TABLE 8—Characteristics of Organ III soils at sites 14, 15, 17, and 18. Organic carbon values for the 0–12 and 12-26 cm zones at site 13 are 0.88% and 1.00% respectively. Organic carbon values for the 0–14 and 14-26 cm zones at site 17 are 0.59% and 0.45% respectively. Abbreviations are explained in Table 6 caption (p. 32).

Horizon	Depth, cm	Hue	Value/chroma Dry	Value/chroma Moist	Tex-tural class	Struc-ture	Dry consis-tence	pH	Organic C
Torriorthentic Haplustoll at site 14—Organ III, late									
A1	0–6	7.5YR	4.5/2	3/2	sl	lmsbk	sh	7.0	0.85
A2	6–31	7.5YR	4.5/2	2.5/2	sl	lmsbk	sh	7.0	0.55
2A3	31–54	7.5YR	4.5/2	2.5/2	vcsl	m	s	7.0	0.45
2A4	54–76	7.5YR	4.5/2	3/2	vcls	m	s	7.0	
2CA	76–103	9YR	5.5/3	4/3	vcs	m, sg	s, l	7.0	
2C	103–118	9YR	6/3	4/3	vcs	sg	s, l	7.0	
Torriorthentic Haplustoll at site 15—Organ III, early									
A1	0–5	8YR	4.5/2	3/2	vcsl	m	sh	6.8	
A2	5–22	7.5YR	4/2	2.5/2	vcsl	m	s, sh	7.0	
A3	22–41	7.5YR	4/2	2.5/2	vcsl	m	s	7.2	
AC	41–68	7.5YR	5/3	3.5/3	vcs	m	s	6.8	
C	68–95	10YR	5.5/2	4/2	vcs	m, sg	s, l	6.6	
Ustic Torriorthent at site 17—Organ III, late									
A1	0–7	7.5YR	4/2	2.5/2	ls	lmpl, m	s, sh		
A2	7–20	7.5YR	4/2	2.5/2	ls	lmsbk	s, sh	7.2	
2A3	20–46	7.5YR	4/2	2.5/2	vcls	m, gr	s, sh	7.2	
2A4	46–60	7.5YR	4/2	2.5/2	vcls	m	s	7.2	
2A5	60–75	7.5YR	4/3	2/3	vsts	m	s	7.2	
2AC	75–95	7.5YR	4.5/3	3/3	vsts	m	s	7.2	
2CA	95–118	7.5YR	5/3	3/3	vsts	m, sg	s, l	7.2	
2C	118–125	7.5YR	5/3	3.5/3	vcs	m, sg	s, l	7.2	
Ustic Torriorthent at site 18—Organ III, late									
C	0–11	6YR	4.5/2	3/3	ls	m	s	6.8	
A11b	11–17	6YR	4/2	3.5/2	sl	m	sh	7.0	
A2b	17–32	6YR	4.5/2.5	3/2.5	ls	m	sh	7.0	
A3b	32–50	6YR	4/3	2.5/3	sl	m	sh	7.2	
A4b	50–79	5YR	4/3	3/3	sl	m	sh	7.2	
C1b	79–113	5YR	4.5/3	3/3	sl	m	sh	7.2	
C2b	113–162	5YR	5/3	3.5/3	ls	m	s	7.2	

TABLE 9—General horizonation and texture of Organ III soils at sites 16, 19, and 20. Abbreviations are explained in Table 6 (p. 32).

Horizon	Depth, cm	Textural class
Torriorthentic Haplustoll at site 16—Organ III, late		
A1	0–5	sl
A2	5–25	sl
2A1	25–52	vstsl
2A2	52–80	vstsl
2A3	80–104	vstls
2A4	104–135	vstls
2C	135–148	vsts
Ustollic Camborthid at site 19—Organ III, late		
A	0–4	sl
Blt	4–10	sl
Bt2	10–33	sl
Bt3	33–56	sl
2Bt1	56–87	vcsl
2Bt2	87–109	vcsl
2BCt1	109–146	vcls
2BCt2	146–184	vcs
2C	184–203	vcs
Ustollic Camborthid at site 20—Organ III, early		
A	0–4	sl
Bt1	4–11	sl
Bt2	11–36	sl
2Bt1	36–69	vcsl
2Bt2	69–94	vcsl
2BCt1	94–117	vcls
2BCt2	117–161	vcs

these remnants lack the large surficial concentrations of stones and boulders that are common on the middle anc upper slopes of unit B.

The Typic Haplargid at site 21 (Fig. 26) contains substantially less organic carbon than Organ H soils above the scarp (Table 11). Higher percentages of organic carbon for the Organ II soils above the scarp may be associated with the larger rock fragments at the surface and denser vegetation there. Of the Organ II soils above the scarp, the Pachic Argiustoll at site 5 has substantially more organic carbon than the Ustollic Haplargids at sites 2-4 (Table 12). The Pachic Argiustoll also has by far the thickest cover of large rock fragments (see Fig. 10 in Gile, 1987). However, soils of unit C have enough organic carbon for the Ustollic subgroups as indicated by organic carbon data for site 23 (Table 11). Thus the area is considered to be a complex of the Typic and Ustollic Haplargids Soledad and Holliday. Minor areas of the Haplustolls, Baylor soils, occur in the younger topographic lows. Camborthids occur where the Bt horizon does not qualify as an argillic horizon (see site 24). Stream-wash occurs in arroyo channels.

Unit C borders the boundary of the study area on the east and north. Unit C borders units A and B in other areas; most soils of these units are lower than the ridges of unit C. Vegetation is mainly fluffgrass, three-awn, black grama, bush mutely, prickly pear, snakeweed, Mormon tea, cat-claw, and mesquite.

Typic Haplargids at sites 21 and 22

Site 21 (Fig. 26, Table 11) is on a broad Organ II ridge. This is the down-dropped Organ II remnant used for slope

TABLE 10—Characteristics of Organ III soils at sites 7b, 8d, and 9 (Gile, 1987). Abbreviations are explained in Table 6 caption (p. 32).

Horizon	Depth, cm	Hue	Value/chroma Dry	Value/chroma Moist	Structure	Dry consistence	Textural class	Sand 2.0–0.05 mm	Silt 0.05–0.002 mm	Clay <0.002 mm	Organic carbon
Ustic Torriorthent at site 7b—Organ III, late								percent			
C	0–3	7.5YR	4.5/2	3/2	lmpl, sg	l, s	ls				0.58
A1b	3–15	7.5YR	4/2	2.5/2	m	sh, s	sl				0.42
A2b	15–34	7.5YR	4/2	2.5/2	m	sh, s	ls				0.41
	34–53	7.5YR	4/2	2.5/2	m	sh, s	ls				0.33
A3b	53–67	7.5YR	4/2	2.5/2	m	s	ls				
A4b	67–87	7.5YR	4.5/2	3/2	m	s	gls				
2A5b	87–114	7.5YR	4.5/3	3/3	m	s	vcs				
2CA1b	114–141	7.5YR	5/3	3.5/3	m, sg	s, l	vcs				
2CA2b	141–175	7.5YR	5/3	3.5/3	m, sg	s, l	vcs				
Ustic Torriorthent at site 8d—Organ III, late											
C	0–4	7.5YR	4.5/3	3/3	lcpl, m, sg	s, l	ls				
A1b	4–19	7.5YR	4.5/2	3/2	m	sh	ls				
A2b	19–48	7.5YR	4.5/3	3/3	m	s, sh	ls				
A3b	48–68	7.5YR	4.5/3	3/3	m	s, sh	sl				
2A4b	68–82	7.5YR	4.5/3	3/3	lmsbk	s	gsl				
3C1b	82–112	7.5YR	4.5/3	3/3	lmsbk	s, sh	sl				
3C2b	112–141	6YR	5/3	3.5/3	m	s	sl				
4C3b	141–166	6YR	5/3.5	3.5/3.5	m	s	gsl				
5C4b	166–189	9YR	5.5/4	4/4	m	h	ls				
Ustollic Camborthid at site 9—Organ III, early											
A	0–4	7.5YR	4.5/3	3/3	lmpl, sg	s, l	sl	75	17	8	0.55
Bt1	4–24	7.5YR	4/3	2.5/3	lmsbk	s	sl	74	18	8	0.36
Bt2	24–41	7.5YR	4.5/3	3/3	lmsbk	sh, s	sl	73	16	10	0.32
2Bt3	41–74	7.5YR	4.5/3	3/3	lmsbk	sh, s	vcsl	76	17	8	0.29
2Bt4	74–112	7.5YR	4.5/3	3/3	m	s	vcls	81	11	8	0.25
2BCt1	112–148	7.5YR	5/3	3.5/3	m	s	vcls	84	11	6	0.14
2BCt2	148–183	8YR	5.5/3	4/3	m, sg	s, l	vcs	88	7	5	0.09
2C	183–202	8YR	6/3	4.5/3	sg	l	vcs	89	7	4	0.10

TABLE 11—Characteristics of Organ II soils at sites 21, 23, and 24. Abbreviations explained in Table 6 caption (p. 32).

Horizon	Depth, cm	Hue	Value/chroma Dry	Value/chroma Moist	Structure	Dry consistence	Textural class	pH	Sand 2.0–0.05 mm	Silt 0.05–0.002 mm	Clay <0.002 mm	Organic carbon
Typic Haplargid at site 21									percent			
A1	0–5	7.5YR	4.5/3	3/3	lf, mpl	sh	vcsl	6.8	75	16	9	0.35
A2	5–19	7.5YR	4.5/3	3/3	lmsbk	sh	vcsl	6.8	76	15	9	0.25
BAt	19–43	6YR	4.5/3	3/3	lmsbk	sh	vcsl	7.0	74	14	12	0.43
Bt1	43–64	5YR	4.5/3.5	3/3.5	lmsbk	s, l	vcsl	7.2	76	10	14	
Bt2	64–85	6YR	5/3.5	3.5/3.5	m	s, l	vcls	7.2	80	10	10	
BCt1	85–125	7.5YR	5/4	3.5/4	m, sg	l	vcls	7.2				
BCt2	125–152	7.5YR	5/4	3.5/4	sg	l	vcs	7.2				
C	152–174	9YR	5.5/3	4/3	sg	l	vcs	7.2				
Ustollic Haplargid at site 23												
A1	0–4	10YR	4.5/2	3/2			vcls	6.8	76	18	6	0.87
A2	4–12	9YR	4.5/2	2.5/2			vcsl	7.2	76	16	8	0.49
Bt1	12–32	7.5YR	3.5/2.5	2.5/3			vcsl	7.4	74	18	8	0.49
Bt2	32–53	7.5YR	4/2.5	3/3			vcsl	7.4	76	16	8	0.35
Bt3	53–76	7.5YR	5/3	3.5/3			vcsl	7.4	80	10	10	
Bt4	76–103											
BC1	103–122											
BC2	122–152											
BC&C	152–182											
Typic Camborthid at site 24												
A	0–5	7.5YR	5/2.5	3/2	lf, mpl	s	vcsl	6.8	73	15	12	
BAt	5–11	7.5YR	4.5/2.5	3/2	lmsbk	s, sh	vcls	7.0	75	15	10	
Bt1	11–21	7.5YR	5/3	3/3	lmsbk	s, sh	vcsl	7.0	73	17	10	
Bt2	21–40	6YR	5/3	3.5/3	m	s	vcsl	7.0	72	18	10	
BCt1	40–61	5YR	5/3.5	3.5/3	m	s	vcsl	7.0				
BCt2	61–96	6YR	5/3	3.5/3	m	s	vcls	7.0				
BCt3	96–126	7.5YR	5/3	3.5/3	m, sg	s, l	vcs	7.0				
CB	126–145	7.5YR	5.5/3	4/3	sg	l	vcs	7.0				

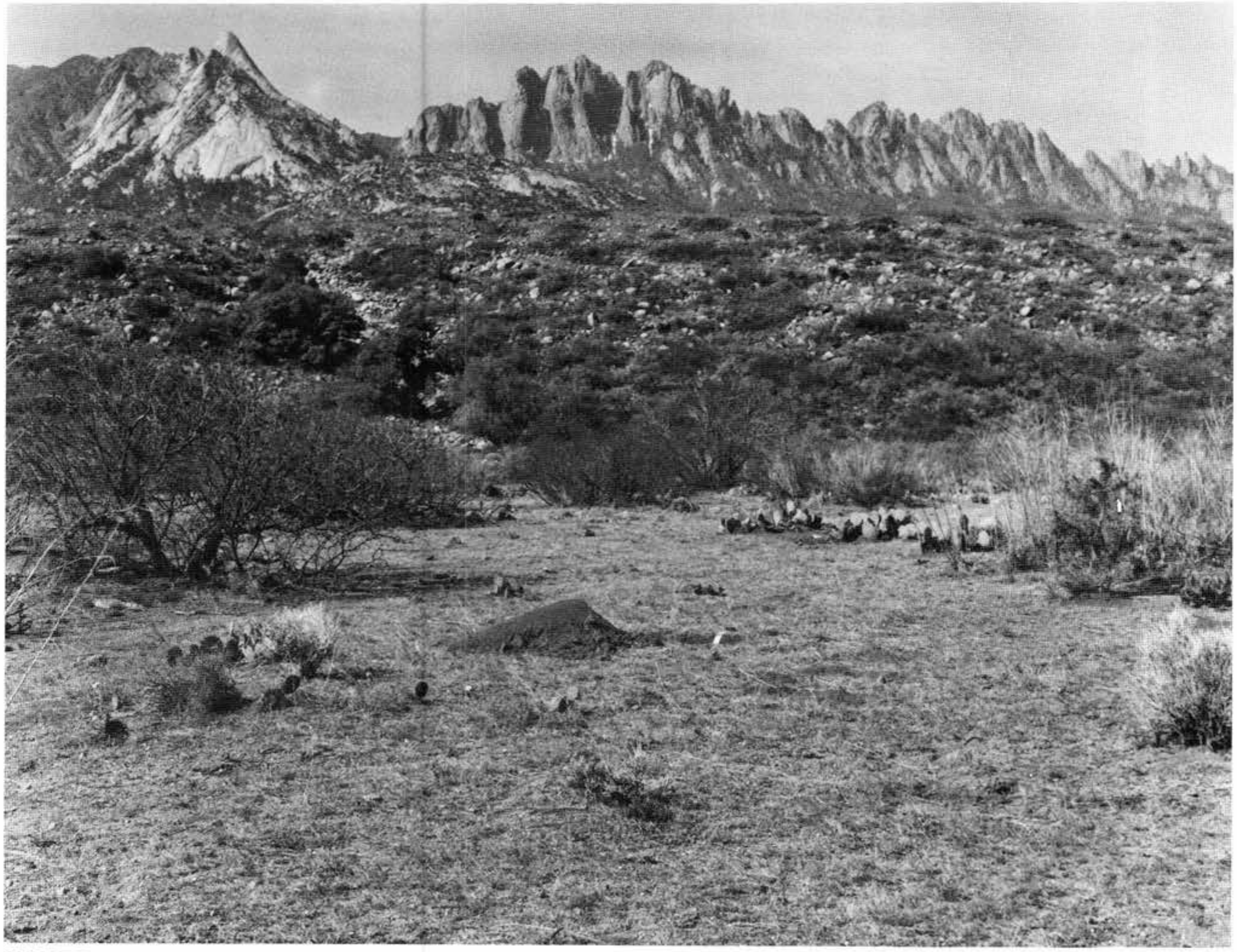


FIGURE 20—Late Organ III terrace of Cox Arroyo, and soil pit in the Ustic Torripsamment, Roswell (see Table 6) at site 11. Vegetation is sparse in these sandy sediments. The Holocene–Pleistocene scarp is in the middle ground and the Organ Mountains are on the skyline.

FIGURE 21—Landscape at site 12, looking to the southeast. This relict channel (at M, Fig. 6) was abandoned by Cox Arroyo before 1936 (see Fig. 13). This channel and its bank were apparently little affected by the 1978 flood. Photographed in April, 1979.

FIGURE 22—The Ustic Torrifluvent, Minneosa variant (see Table 6) in late Organ III sediments. Arrow locates stone for long-term assessment of erosion of the relict arroyo bank. The stone is about 1 ft (0.3 m) in diameter. In March, 1988, its north edge was about 1 ft (0.3 m) from the point at which the beveled slope into the arroyo began. The Holocene-Pleistocene scarp is in the middle ground and the Organ Mountains are on the skyline.

extrapolation and estimation of amount of displacement in the late Holocene fault (Gile, 1987). The surface is nearly level transversely, lacks drainageways, and appears very stable; thus maximum infiltration of precipitation for downward movement of clay and carbonate in the soil solution would be expected.

The soil at site 21 has an A horizon, a Bt horizon, and lacks a carbonate horizon (Table 11). The reddest part of the Bt horizon (the Bt1, Table 11) is continuous on the central and east end of the trench but is discontinuous on the west end. This may be due to the influence of organic carbon, in masking the redder colors where it is more abundant.

Partially weathered rock fragments are an additional feature of Organ II soils (Gile, 1987, p. 38). In the study trench (Fig. 26), three monzonite cobbles just east of the sampled pedon are so soft that they could not survive transport; individual grains and clumps of grains are easily broken out with the finger. A number of weathered cobbles and pebbles also occur on the east end of the pit.

There are a few roots in the C horizon, indicating occasional penetration of moisture to considerable depths. As in other pedons of Organ II age, the C horizon is distinctively loose and sandy, and upward gradation from the C into the B horizon is marked by increases in reddening, percentage of silt and clay, and grade of dry consistence (Table 11). The latter reflects the increasing tendency for the fine earth to hold together as the percentage of silt and clay increases.

Site 22 (Fig. 5B) is another study trench on the Organ II remnant. The soil at site 22 is very similar to the one at site 21.

Ustollic Haplargid at site 23

Sites 23 and 24 occur on a small Organ II remnant that has been strongly affected by erosion, both by Cox Arroyo and by streams of Organ **III.** The Ustollic Haplargid, Holliday, at site 23 (Fig. 27, Table 11) is located along the southwest bank of Cox Arroyo. Comparison of the 1963 and 1983 aerial photographs and ground observation in March, 1979,

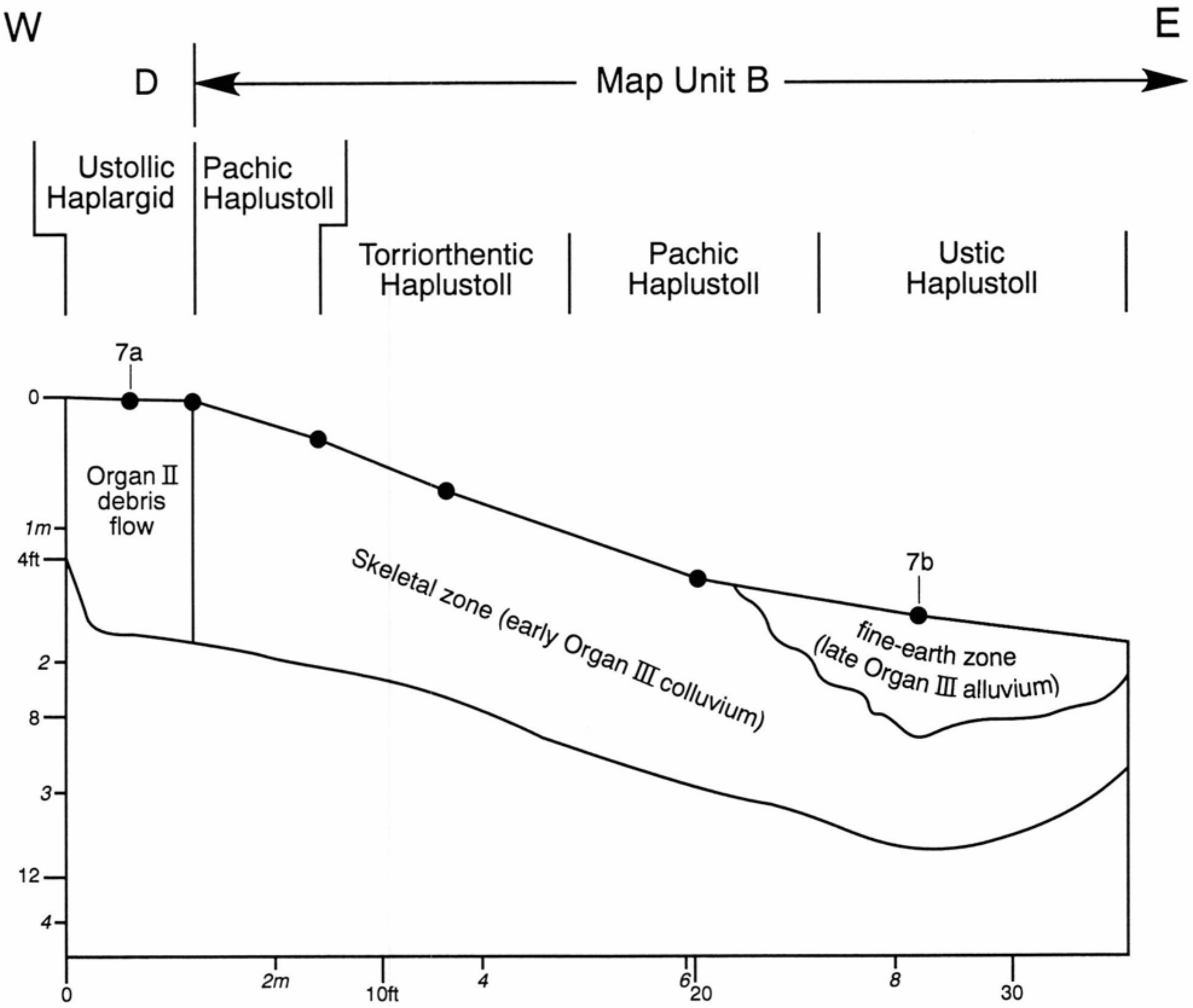


FIGURE 23—Diagram of the study trench at site 7, showing soil occurrence in map unit B along the scarp at site 7, the boundary to map unit D (see Fig. 18), the stratigraphy of Organ II and III sediments, the skeletal and fine-earth zones, and location of the sampled pedons. The lower line represents the bottom of the trench. Modified from Fig. 15 in Gile, 1987.

show that the present cut is about 20 ft (6 m) west of the exposure that existed in 1963. Thus the new exposure along the bank must have been made by the 1978 flood.

Laboratory analyses (Table 11) show that there is enough clay increase from the A horizon to the Bt horizon to qualify as an argillic horizon, and enough organic carbon for the Ustollic Haplargids. Very few of the weathered rock fragments discussed at site 21 are present here. A possible reason for their sparcity here and at site 24 upslope is that these deposits may be from a source area that lacked the partially weathered rock fragments that contributed to the Organ II deposits in other areas. The remnant itself is considered to be Organ II instead of Organ III because this remnant stands well above Organ III to the west, and because Bt horizons here and at site 24 are more strongly developed than in Organ III soils.

Typic Camborthid at site 24

The Bt horizon of the Typic Camborthid at site 24 is distinctly redder than adjacent horizons (Table 11). The higher percentage of clay in the A horizon than in the Bt horizon (Table 11) is not typical of Camborthids in the area. A possible reason may be associated with an overwash effect as sociated with Organ III deposits that occur a short distance upslope (see site 14, Fig. 6).

Soils of ridges above the late Holocene scarp: Holliday very cobbly sandy loam (D, Fig. 18)

Landscape, soil occurrence, unit boundaries, vegetation

Soils of map unit D occur on the upthrown side of the fault. Slopes range from 6% to 7%. Rock fragments ranging in size from pebbles to boulders are common on the surface.

Ustollic Haplargids dominate the ridges. Typic Argiustolls (Earp soils) and Pachic Argiustolls (Earp variant) occur at stablest sites, such as those well protected from erosion by concentrations of rock fragments. Map unit D is bordered by units B and E. The boundary to unit B has been described. The boundary to unit E is marked by the transition from Organ II ridges to the varied terrain of unit E, much of which consists of three general levels, with Organ I being the highest, and Organ II and III being successively lower. In other areas two or more of these three sediments occur at about the same elevation (e.g., see site 25). Vegetation consists primarily of catclaw, black grama, snakeweed, prickly pear, buckwheat, sideoats grama, Mormon tea, and mesquite.

TABLE 12—Characteristics of Organ II soils at sites 2–5 and 7a. Abbreviations explained in Table 6 caption (p. 32).

			Value/chroma					Particle-size distribution, mm									
								Sand fractions						Sand	Silt		
Horizon	Depth, cm	Hue	Dry	Moist	Structure	Dry consistence	Textural class	2–1	1–0.5	0.5–0.25	0.25–0.2	0.2–0.1	0.1–0.05	2.0–0.05	0.05–0.002	Clay <0.002	Organic C
								percent									
Ustollic Haplargid at site 2																	
A	0–5	7.5YR	4.5/3	3/3	lmpl	s, l	sl	8	14	11	9	13	20	76	16	8	0.73
Bt1	5–21	6YR	4/3	2.5/3	lmsbk	sh	sl	14	16	10	8	11	17	76	14	10	0.54
2Bt2	21–37	5YR	4.5/3	3/3	lmsbk	sh	vcsl	11	16	10	8	12	16	74	16	11	0.48
2Bt3	37–54	5YR	4.5/3	3/3	lmsbk	sh	vcsl	12	15	10	8	12	18	76	13	12	0.41
2Bt4	54–84	5YR	4.5/3	3/3	m	sh	vcsl	11	16	11	8	12	17	75	14	11	0.39
2BCt1	84–130	6YR	5/3	3.5/3	m	s	vcsl	12	18	13	9	12	15	78	12	10	0.26
2BCt2	130–179	7.5YR	5/3	3.5/3	m, sg	s, l	vcsl	14	20	13	9	11	12	80	12	8	0.17
2C	179–210	7.5YR	5/3	3.5/3	sg	l	vcs	28	29	14	8	7	4	90	5	5	0.07
Ustollic Haplargid at site 3																	
A	0–5	7.5YR	4/2	2.5/2	sg, lmpl	s, l	ls	12	19	12	8	11	15	78	14	8	0.53
Bt1	5–26	5YR	4.5/3	3/3	lmsbk	sh	sl	10	15	11	9	13	16	74	16	10	0.48
Bt2	26–40	5YR	4.5/3	3/3	lmsbk	sh	sl	12	17	11	9	12	14	75	14	11	0.50
2Bt3	40–70	6YR	4.5/3	3/3	lmsbk	sh	vcsl	11	17	11	9	12	14	75	15	10	0.46
2Bt4	70–112	6YR	4.5/3	3/3	m	sh	vcls	13	20	13	9	12	12	80	10	10	0.28
2CBt1	112–137	6YR	5/3	3.5/3	m	s	vcls	23	26	14	8	9	7	86	8	6	0.14
2CBt2	137–162	7.5YR	5/3	3.5/3	m, sg	s, l	vcs	25	25	13	10	9	7	89	5	6	0.13
2C	162–192	7.5YR	5/3	3.5/3	sg	l	vcs	25	29	14	8	7	5	88	6	6	0.12
Ustollic Haplargid at site 4																	
A	0–4	7.5YR	4/2	2.5/2	lfpl	s, l	sl	15	19	11	8	10	15	78	12	10	0.52
Bt1	4–26	6YR	4/3	2.5/3	lmsbk	sh	sl	14	17	10	7	10	15	72	18	10	0.46
2Bt2	26–51	5YR	4/3	2.5/3	lmsbk	sh	vcsl	13	16	10	7	10	13	69	17	14	0.42
2Bt3	51–76	5YR	4.5/3.5	3/3.5	m	sh	vcsl	16	16	10	7	10	10	68	20	12	0.39
2Bt4	76–104	6YR	5/3.5	3.5/3.5	m	sh	vcsl	20	18	10	7	10	11	75	15	10	0.25
2BCt1	104–140	7.5YR	5/3	3.5/3	m	s	vcsl	14	19	11	9	11	10	74	17	8	0.19
2BCt2	140–178	7.5YR	5/3	3.5/3	m	s	vcls	20	22	12	8	9	9	80	13	7	0.14
2C	178–198	7.5YR	5/3	3.5/3	sg	l	vcs	30	34	12	7	5	3	91	5	4	0.07
Pachic Argiustoll at site 5																	
A	0–5	7.5YR	4.5/2.5	3/2.5	lfpl	s, l	vbsl	15	18	9	6	9	12	69	22	9	1.12
Bt1	5–19	7.5YR	4/2	2.5/2	lmsbk	sh	vbsl	19	16	9	6	9	13	71	18	11	0.92
Bt2	19–47	7.5YR	4.5/2	3/2	lmsbk	sh, h	vcsl	14	17	9	6	9	13	67	22	11	0.86
Bt3	47–79	7.5YR	4.5/2.5	3/2.5	lmsbk	sh, h	vcsl	14	19	9	6	8	11	67	22	11	0.73
BCt1	79–105	7.5YR	4.5/3	3/3	m	sh	vcsl	14	16	10	6	9	13	69	19	12	0.67
BCt2	105–160	7.5YR	5/3	3.5/3	m	sh	vcsl	16	20	11	8	9	9	72	19	9	0.26
CBt	160–202	9YR	5/3	3.5/3	m, sg	s, l	vcsl	16	17	11	9	11	10	74	18	8	0.14
C	202–215	9YR	5.5/3	4/3	sg	l	vcsl	24	28	13	7	7	6	85	9	6	0.14
Ustollic Haplargid at site 7a																	
C	0–4	7.5YR	5/3	3.5/3	lcpl, m, sg	s, l	gs							88	9	3	
Ab	4–9	7.5YR	4.5/3	3/3	2mpl, m	sh	gls							77	16	6	
2BAt1b	9–21	7.5YR	4/3	2.5/3	lmsbk	sh, s	vcsl							75	14	11	
2BAt2b	21–45	6YR	4/3	2.5/3	lmsbk	sh, s	vcsl							71	16	12	
2Btb	45–72	5YR	4/3	3/3	lmsbk	s	vcsl							71	12	17	
2BCt1b	72–97	5YR	4/4	3/4	m	s	vcs										
2BCt2b	97–120	6YR	4.5/3.5	3/3.5	m	s	vcs										
2CBt1b	120–141	6YR	5/3	3.5/3	m, sg	s, l	vcs										
2CBt2b	141–175	6YR	5/3	3.5/3	m, sg	s, l	vcs										

Ustollic Haplargids and a Pachic Argiustoll at sites 2-5 and 7a

Four Ustollic Haplargids and one Pachic Argiustoll were sampled at sites 2-5 and 7a (Fig. 6). These soils have been discussed (Gile, 1987); data are in Table 12.

Pedogenic accumulation of clay, silt, very fine sand, and fine sand in debris flows

As previously discussed, sediments in the study area are dominantly debris-flow materials, with smaller amounts of water-laid materials. Discontinuous bedding, a lack of well defined strata, and an assortment of debris of all sizes are typical of debris flows (Beaty, 1963). These features are characteristic of sediments considered to be debris flows in the study area, and are useful in soil studies because much of the soil parent materials must have been quite uniform. Thus the soils may be assessed with respect to the debris-flow materials, to the water-laid materials that commonly follow them, and to subsequent effects of pedogenesis after abandonment of the deposits by streams.

Debris flows occupy topographic highs in many places and no water-laid material is present (see Fig. 27, for example). But topographic lows in debris-flows are also common, and these lows eventually tend to fill or partly fill with water-laid fine earth, so that no rock fragments or only their upper parts are visible at the surface. Thus, a surface that once had a high proportion of rock fragments is changed to one that is dominated by fine earth (Fig. 10). Some filling of lows by fine earth is thought to have happened with

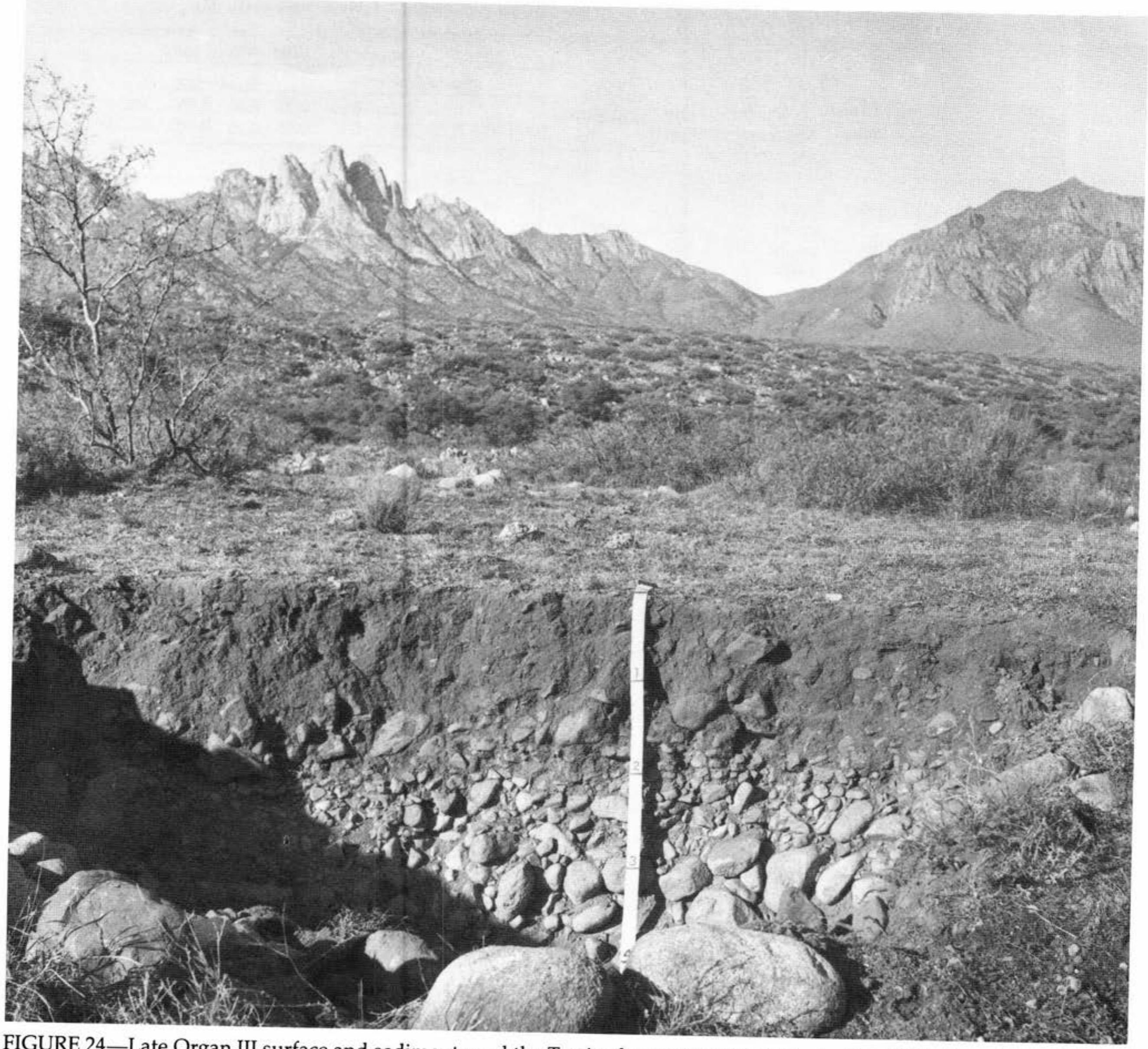


FIGURE 24—Late Organ III surface and sediments and the Torriorthentic Haplustoll Baylor (see Table 8) at site 14, looking northwest. The Holocene-Pleistocene scarp is in the middle ground; the Organ Mountains are on the skyline. Scale is in feet.

decline in competence of streams as they gradually abandoned an area. Other lows were probably filled by local wash as the area stabilized and pedogenesis began.

A previous report (Gile, 1987) presented evidence for movement of dust-derived clay, silt, very fine sand and fine sand into soils of Organ I and III age. In the soil of Organ III age, distinctly higher percentages of these four components were found above the C horizon than in it; and dust-fall analyses at the Desert Project were found to contain substantial percentages of the same components. This is strong evidence that they have moved from dustfall on the soil surface downward into the soil; refer to page 36 in Gile (1987) for a more detailed discussion of this movement. Carbonate also occurs in the dustfall and moves into the soil, but in these pervious materials, the wetting front moves so deeply that no horizon of accumulation forms in soils of Organ II and III age.

This section presents additional data on the sand fractions, including soils of Organ II age. The effects of sand, silt, and clay from both dustfall and water-laid materials on debris flows are considered, as well as the effects of splitting the fine sand into two parts (from 0.25 to 0.2 mm and from 0.2 to 0.1 mm). Splitting the fine sand more precisely documents the size limit for significant downward movement of both dust-derived and other sand in the soil. Tables 12 and 13 give particle size data for soils of Organ I, II and III age.

The Haplustoll at site 1 has formed in debris-flow materials that occupy a topographic high, and no water-laid materials are present. Numerous rock fragments, commonly of cobble size or larger, occur both on the soil surface and throughout the soil. This should maximize dust infiltration because the surficial rock fragments constitute an efficient dust trap that would tend to reduce the blowing-away of dust after it had fallen. Also, the numerous rock fragments deeper in the soil would concentrate the fine earth that is analyzed in the laboratory.

Substantially more clay, silt, very fine sand and fine sand occur above the C horizon than in it, suggesting an extraneous source of these materials. The percentages of

FIGURE 25—Late Organ III surface and upper horizons of the Ustic Torriorthent Yana Variant (see Table 8) at site 18. This soil has formed in late Organ III sediments derived from a small stream that crosses the late Holocene scarp just upslope.

clay, silt and very fine sand show a very gradual decrease with depth, also supporting their downward movement in the soil. But the percentages of fine sand do not gradually decrease with depth, indicating greater soil resistance to downward movement of sand that is this large.

The Haplustoll at site 6 has about 9 inches (22 cm) of surficial water laid materials over debris-flow materials (Table 13). The Haplustoll has higher percentages of clay, silt, and very fine sand in horizons above the C than in it, but the fine sand shows little difference. The slight difference that does exist (the slightly higher percentage of fine sand in horizons above the C than in it) occurs in the smaller of the two splits in the fine sand (from 0.2 to 0.1 mm, Table 13). This supports the evidence at site 1 that there is resistance to downward movement of fine sand (whether its origin is water-laid material or dustfall) in the soil, and suggests that the critical size that determines downward movement is about 0.2 mm: there appears to be virtually no downward movement of sand grains larger than 0.2 mm in these soils.

The Organ II soils at sites 2-4 contain surficial deposits of water-laid materials ranging from 8 to 16 inches (21 to 40 cm) thick. The water-laid materials are underlain by debris-flow materials with abundant large rock fragments that are dominantly of cobble size, with some stones. Distinct accumulations of clay, silt, and very fine sand are evident above the C horizon (Table 12); some of this accumulation was undoubtedly derived from the water-laid materials at the surface. Although a slight increase in fine sand above the C horizon is evident in the three soils, the increase occurs only in the 0.2 to 0.1 mm fraction. A decrease in sand percentage with depth does not occur in the 0.25 to 0.2 mm fraction, which is like the medium, coarse and very coarse sands in this respect. This confirms the evidence at site 6 that downward movement of sand in those soils is not a significant factor in sands that are larger than 0.2 mm in diameter.

The soil at site 5 does not contain a surficial zone of water-laid materials; instead, the soil surface is thickly covered with large boulders (see Fig. 10 in Gile, 1987). Despite

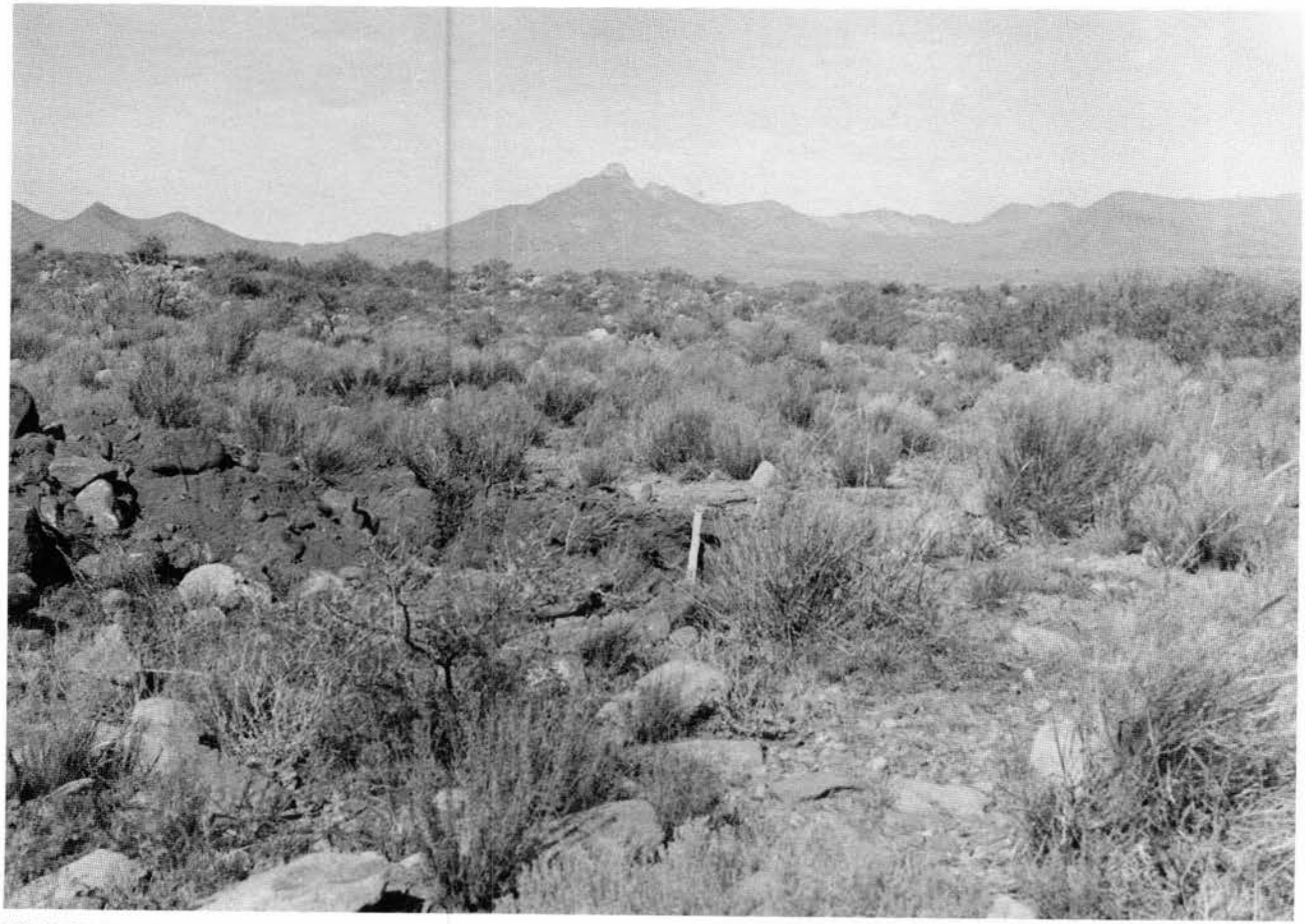


FIGURE 26—Organ II surface and upper horizons of the Typic Haplargid, Soledad (see Table 11) at site 21, looking north. The San Andres Mountains are on the skyline.

TABLE 13—Particle size distribution of soils at sites 1, 6, and 10a. The 0.25–0.1 mm fraction was split into two parts at site 6 but not at sites 1 and 10a (see discussion in text). See Table 15 for additional data at site 10.

		Particle-size distribution, mm, percent								
		Sand							Silt	
Horizon	Depth, cm	2–1	1–0.5	0.5–0.25	0.25–0.1	0.25–0.2	0.2 0.1	0.1–0.05	0.05–0.002	Clay <0.002
Torriorthentic Haplustoll at site 1										
A1	0–7	7	15	19	21			14	16	7
A2	7–18	9	19	19	19			12	15	8
A3	18–30	9	21	20	19			11	14	6
	30–42	11	21	20	19			10	11	7
A4	42–55	10	22	20	19			9	14	5
A5	55–68	12	23	23	21			9	8	5
CA1	68–85	13	28	26	19			5	7	3
CA2	85–113	12	30	30	19			4	5	1
C	113–119	30	35	19	8			1	5	2
Torriorthentic Haplustoll at site 6										
A1	0–5	10	17	13		9	11	15	17	8
A2	5–22	14	21	13		8	9	12	14	8
2A3	22–48	11	19	13		9	12	14	14	8
2A4	48–72	13	22	15		10	12	11	10	7
2CA	72–107	20	25	16		10	11	8	6	5
2C	107–140	22	29	17		9	9	6	5	4
Ustollic Haplargid at site 10a (upper horizons only)										
A1	0–4	8	18	18	22			14	13	7
A2	4–15	12	19	16	19			12	16	9
BAt1	15–36	8	16	17	21			15	16	14
BAt2	36–55	10	17	17	20			12	14	16
Bt	55–81	15	22	17	14			8	13	16
Bt	55–81	25	21	13	9			6	14	18

FIGURE 27—Landscape of the Ustollic Haplargid, Holliday (see Table 11), at site 23, looking west. This fresh exposure of Organ II sediments along Cox Arroyo was made in the August, 1978 storm. The Organ Mountains are on the skyline. Scale is in feet. Photographed May, 1979.

this, the soil at site 5 is similar to the other Organ II soils with respect to the percentages of clay, silt, very fine sand and fine sand above the C horizon. This appears to reflect the strong influence of dustfall on the fine-earth component of these soils.

Aridic Argiustoll at the Beehner site

Another Organ II soil, an Aridic Argiustoll, was sampled by Beehner (1989). Table 14 gives some of the characteristics of this soil; laboratory data may be found in Beehner (1989). This site is a large bulldozer trench that illustrates a very thick section of Organ II alluvium. The soil has a mollic epipedon, a thick Bt horizon, and a C horizon of 10YR hue. Presence of 10YR hues suggests that the redder (7.5 YR) horizons designated C at the base of pedons 2-4 and 7 may in fact be Ct horizons as previously discussed (Gile, 1987, p. 18). These redder colors are caused by very thin coatings of oriented illuvial clay on sand grains. Such coatings are typical of horizons of clay accumulation in the Desert Project and in many other arid and semiarid regions (Gile et al, 1981, p. 71, 72). The clay coatings reflect occasional penetration of clay-carrying soil water into the C horizon. No carbonate horizon was found in this soil (Table 14), and this is consistent with its being of Organ II age.

In discussing the top of the fault scarp and the down-dropped Organ II remnant, and my use of them in estimating the amount of displacement, Beehner (1990, p. 5) states that both the top of the fault scarp and the down-dropped remnant ". . . may be a result of erosion. During

TABLE 14—Characteristics of the Organ II soil at the Beehner site. Size of rock fragments not included in the designation of textural class. Abbreviations are explained in Table 6 caption (p. 32).

Horizon	Depth, cm	Hue	Value/chroma		Textural class	Structure	Dry consistence
			Dry	Moist			
A1	0–6	7.5YR	3.5/2	2/2	ls		s, sh
A2	6–14	7.5YR	3.5/2.5	2/2	sl	lmsbk	sh
A3	14–28	7.5YR	3.5/3	2/3	sl	lmsbk	sh
Bt1	28–46	7.5YR	3.5/3	2/3	sl	lmsbk	sh
Bt2	46–63	6YR	5/3.5	3.5/3.5	sl	lcsbk	sh
Bt3	63–87	6YR	5/3	3.5/3	sl	lcsbk	sh
BCt1	87–115	7.5YR	6/3	4/3	ls	mg	s
BCt2	115–155	7.5YR	6/3	5/3	s	m	s
BCt3	155–187	7.5YR	6/3	4/3	s	m	s
C1	187–218	10YR	6/3	4/3	s	m	s
C2	218–260	10YR	6/2.5	4/2.5	s	m	s, sh
C3	260–296	10YR	6/2.5	4/2.5	s	sg	l

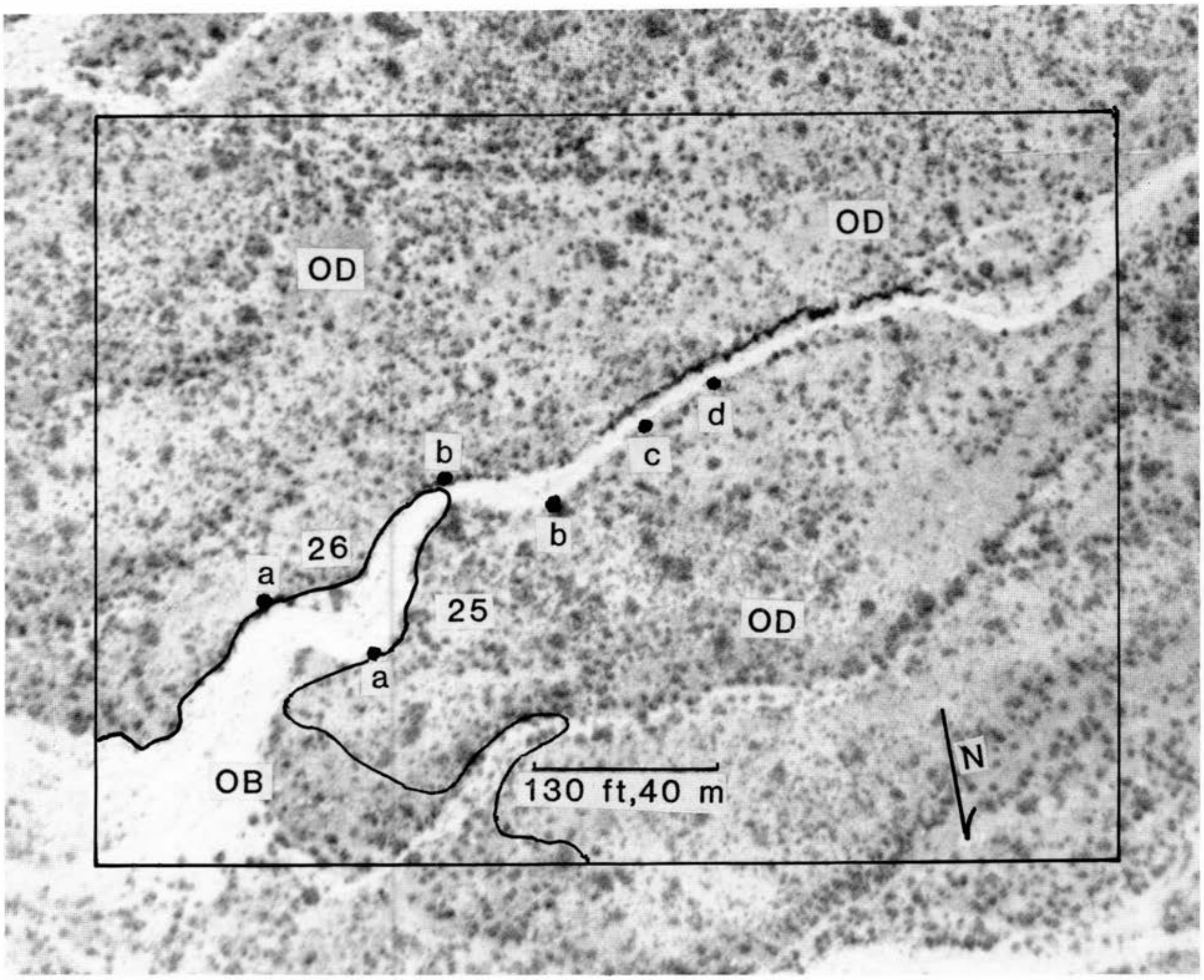


FIGURE 28—Enlargement of part of Fig. 5A, locating sites 25 and 26, in the southern part of the study area. The symbols OB and OD designate geomorphic surfaces (see Fig. 5A).

periods of high rainfall, intermittent streams flow parallel to the fault scarp eroding and depositing materials at the base of the scarp". For reasons discussed elsewhere (Gile, 1991) it is concluded that the sites selected for estimation of downdropping are stable constructional surfaces and not erosional surfaces as proposed by Beehner (1990, p. 5).

Soils of the Organ I, II, and III surfaces (100-7,000 yrs B.P.) above the late Holocene scarp: Holliday complex (E, Fig. 18)

Soils of Organ I age have been found only on the upthrown side of the fault and presumably were buried and/or eroded on the downthrown side. The Organ I soils differ from Organ II soils in having slightly redder, harder and more clayey Bt horizons, and in having deep (below 3.3 ft, 1 m depth) stage I carbonate horizons. These differences were not considered to be sufficient to warrant separation at the series level. Thus the loamy-skeletal, Ustollic Haplargids of Organ I and II ages were both placed in the same series, Holliday.

Landscape, soil occurrence, unit boundaries, vegetation

In most places the soils occur on Organ I ridges and on Organ II and III terraces that are inset against the ridges. With increasing distance westward from the scarp, some of the Organ I sediments have been buried or eroded away, and Organ II, III or Historical sediments are at the surface.

Ustollic Haplargids (Holliday soils) dominate the Organ I ridges. Typic Argiustolls (Earp soils) and Pachic Argiustolls (Earp variant) occur on stablest Organ I and II surfaces where a mollic epipedon has been preserved. Torriorthentic and Pachic Haplustolls (Baylor and Santo Tomas soils) occur in Organ III deposits. Ustic Torriorthents (Rockspring soils) occur in a few small areas of Historical deposits that are thick enough (thicker than 50 cm) to be considered in the classification system. Streamwash occurs in arroyo channels.

Map unit E borders map units B and D; boundaries to these units have been described. Vegetation consists mainly of catclaw, black grama, sideoats grama, prickly pear, mesquite, buckwheat, Lippia, lovegrass, Mormon tea, Apache plume, and bush muhly.

Site 10 (Table 15) illustrates the northern part of the Organ I surface and has been discussed (Gile, 1987). The Organ I ridge at site 10 extends westward for a substantial distance and stands well above adjacent surfaces and their soils.

In contrast to the site 10 ridge, parts of the Organ I ridges at sites 25 and 26 have been strongly affected by post-Organ I sedimentation, and have been buried in many

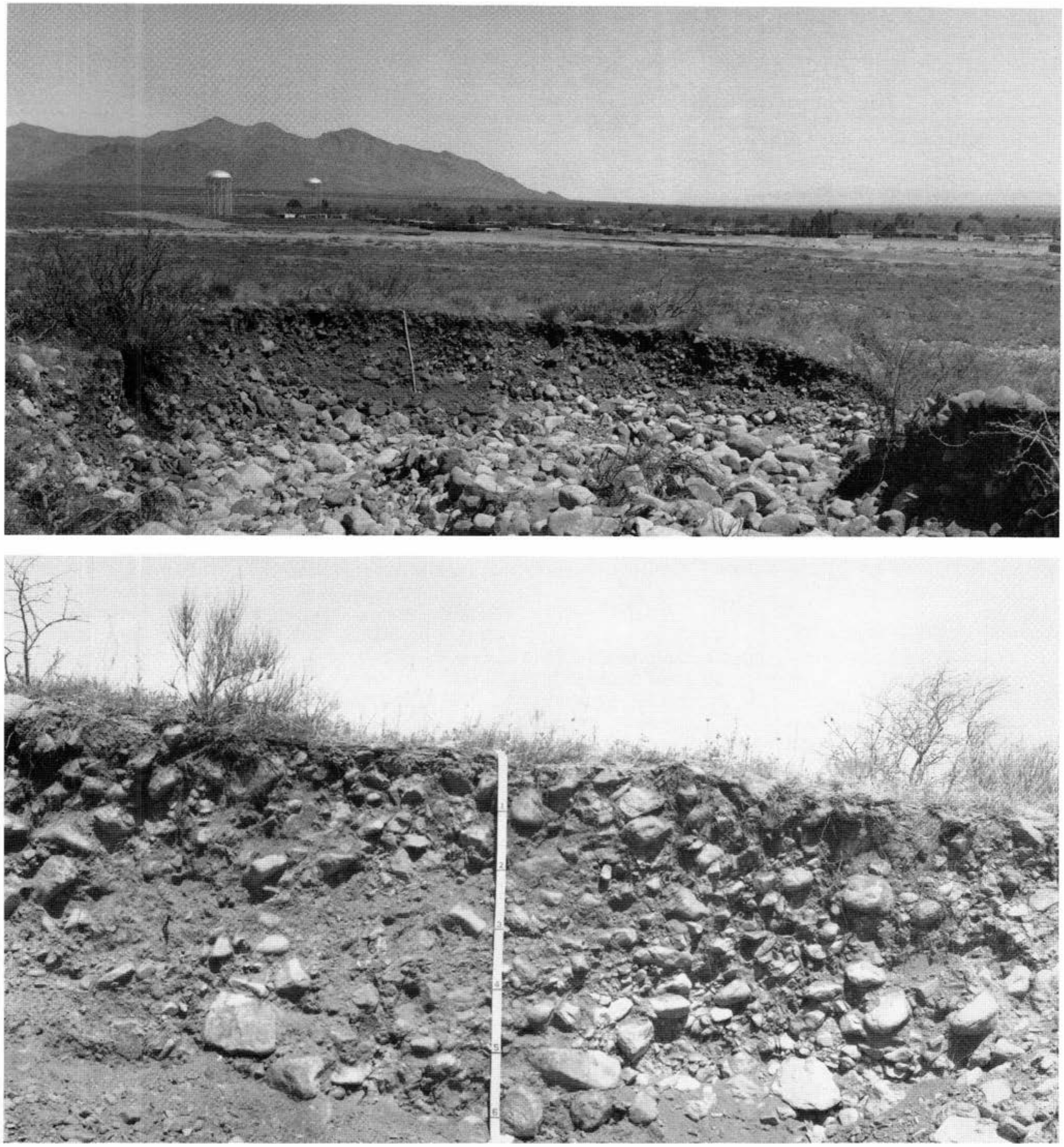


FIGURE 29—A) Landscape at site 25a. The late Holocene scarp and the east end of the Organ I ridge are at the extreme right of the cut with the tape. The WSMR Headquarters are in the middle ground; the San Andres Mountains are on the skyline at left. B) The Ustollic Haplargid, Holliday (see Table 16), in Organ I sediments. Scale is in feet. Photographed April, 1979.

places. Organ **I** soils are well preserved at and near the scarp where arroyos are deeply entrenched below the Organ I ridges. But a short distance upslope, some Organ **I** soils have been buried by both Historical and late Organ **III** sediments, as shown by exposures on both sides of the arroyo.

Figure 28 is an enlargement locating remarkably fresh and long exposures that were caused by the 1978 flood, and along which sites 25 and 26 are located. Ground photographs of the exposures were taken in March, 1979; arroyo banks were still vertical and had changed little since their formation by the storm. As noted in the photography section, this would be an excellent area to study the degree of backwearing of the gully walls with time.

Most notes on the deposits and soils were taken in 1979, and this must be kept in mind in considering statements about age of Historical deposits and their relation to plant growth.

Haplargids, Torriorthents, and Haplustolls at site 25

The storm-widened arroyo exposed the Ustollic Haplargid, Holliday, both in land-surface and buried position.

TABLE 15—Characteristics of Organ I soils at site 10 (Gile, 1987). The Bt horizon of pedon 10a was sampled in two parts according to hardness. Abbreviations are explained in Table 6 caption (p. 32).

Horizon	Depth, cm	Hue	Value/chroma Dry	Value/chroma Moist	Structure	Dry consistence	Textural class	Sand 2.0–0.05 mm	Silt 0.05–0.002 mm	Clay <0.002 mm	Organic carbon
Ustollic Haplargid at site 10a—Organ I									percent		
A1	0–4	7.5YR	5/3	3.5/3	lmpl, m	s	vcls	80	13	7	
A2	4–15	7.5YR	5/3	3/3	lm, csbk	sh	vcsl	75	16	9	
BAt1	15–36	5YR	4/3	3/3	lmsbk	sh	vcsl	70	16	14	
BAt2	36–55	5YR	4.5/3	3/3	lf, msbk	sh	vcsl	70	14	16	
Bt1	55–81	5YR	4.5/4	3/4	m	sh	vcsl	71	13	16	
Bt2	55–81	5YR	4/4	3/4	m	h	vcsl	68	14	18	
Ustollic Haplargid at site 10b—Organ I											
A1	0–7	7.5YR	4.5/3	2.5/3	lcpl	s	vcls				0.33
A2	7–19	6YR	4/3	2.5/3	lmsbk	sh	vcsl				0.47
BAt1	19–37	5YR	4/3	2.5/3	lf, msbk	sh	vcsl				0.50
BAt2	37–52	5YR	4/3.5	3/3.5	lf, msbk	s, sh	vcsl				
Bt1	52–70	5YR	4/3.5	3/3.5	lf, msbk	s, sh	vcsl				
Bt2	70–89	5YR	4.5/3	3.5/3	lmsbk	s, sh	vcsl				
BCt1	89–120	7.5YR	5/3	4/3	m	s, sh	vcsl				
BCt2	120–151	7.5YR	5/3	4/3	m	s, sh	vcls				
BCtk1	151–176	7.5YR	5/3	4/3	m	s	vcls				
BCtk2	176–208	7.5YR	5/3.5	4/3.5	m	s	vcs				

Sites 25a—d illustrate the soils and stratigraphy on the north side of the arroyo: sites 26a,b illustrate the eastern part of the south side of the arroyo. Soil characteristics at sites 25a—d are given in Table 16.

Ustollic Haplargid at site 25a

Figure 29 shows the Ustollic Haplargid at site 25a. The west end of the exposure is slightly redder and has slightly more clay than the central part. A former drainageway may be responsible for this increased reddening and clay (see site 10 in Gile, 1987). The soil is noncalcareous above the stage I carbonate horizon, which has discontinuous carbonate coatings on pebbles.

The thin C horizon at the surface (Table 16) is distinctly stratified and is present over most of the cut. This material has buried some of the older grass clumps, but some of the plants are rooted in the deposit and it must predate the 1978 flood. The surficial C horizon is not present a short distance north of the cut, where small drainageways have encroached; thus, it may have been eroded during that storm. Presence of occasional pebbles in the deposit indicate that the deposit is alluvial and not eolian.

The Btb horizon is quite continuous across the cut, and is slightly less red than the underlying BCt horizon, as is common in Organ I soils in this area. A few monzonite fragments may be broken apart with the hands, and are stained internally (on crystal faces) with reddish clay.

The BCt horizon is redder and has less clay than above, but westward along the cut it grades into less red material that has lower chroma. The reason for this gradation may be associated with differences in fine earth of the parent materials. Thus the illuvial clay, which is distinct in sediments with very little fine earth, may be masked by increasing amounts of clay and/or silt in the parent materials. The BCtkb horizon has zones with visible carbonate separated by redder tongues of illuvial clay that descend from above. These zones reflect partial carbonate engulfment of a formerly continuous BCtb horizon.

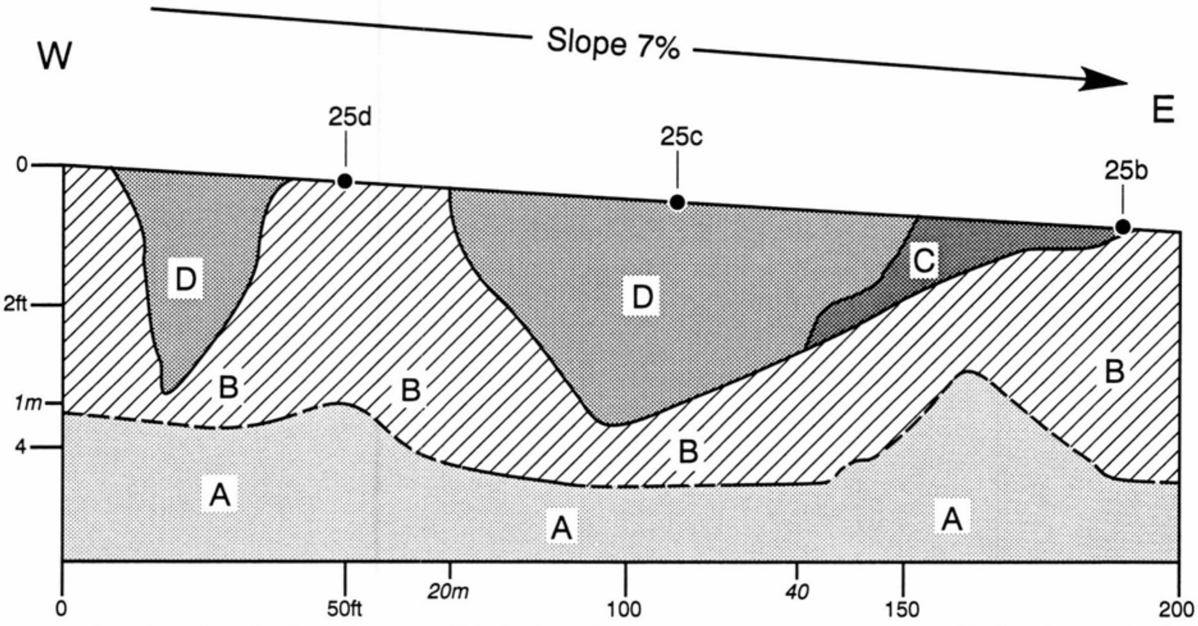


FIGURE 30—Stratigraphy of sediments at sites 25b-d, along the north bank of the arroyo at site 25. A = Organ I sediments; B = late Organ III sediments (oldest); C = late Organ III sediments (next oldest); D = late Organ III sediments (youngest). Historical sediments not shown. Dashes between A and B indicate areas of uncertainty.

TABLE 16—Characteristics of Organ I and III soils at site 25. Abbreviations are explained in Table 6 caption (p. 32).

Sediment	Horizon	Depth, cm	Hue	Value/chroma Dry	Value/chroma Moist	Texture	Structure	Dry consistence	pH
Ustollic Haplargid at site 25a									
H	C	0–4	8YR	4.5/2	3/2	fsl			
O-I	A1b	4–10	7.5YR	4.5/2	3/2	vcsl	m	s	7.4
	A2b	10–29	7.5YR	4.5/2	3/2	vcsl	m	sh	7.0
	BAtb	29–51	6YR	4/3	3/3	vcsl	m	sh	7.2
	Btb	51–91	6YR	5/4	3.5/4	vcsl	m	sh	7.4
	BCtlb	91–127	5YR	5/4	3.5/4	vcls	m	sh	7.2
	BCt2b	127–155	5YR	5/4	3.5/4	vcs	m	s	7.2
	BCtkb	155–183	7.5YR	5/3	4/3	vcs	m	s	7.6
Pachic Haplustoll at site 25b									
H	C	0–5	7.5YR	4/2	2.5/2	vcsl	m	s	7.6
O-III, l	Ab	5–13	7.5YR	4/2	2.5/2	vcsl	m	s	6.8
O-III, l	A1b2	13–21	7.5YR	4/2	2.5/2	vcsl	m	s	6.8
	A2b2	21–38	7.5YR	4/2	2.5/2	vcsl	m	sh	6.2
	A3b2	38–64	7.5YR	4/3	2.5/3	vcsl	m	s	6.2
	A4b2	64–80	7.5YR	4.5/3	3/3	vcsl	m	s	6.4
	Cb2	80–99	9YR	5/3	3.5/3	vcs	m, sg	s, l	6.4
O-I	Bt1b3	99–126	5YR	5/4	4/4	vcsl	m	sh, s	6.4
	Bt2b3	126–146	5YR	5/4	4/4	vcsl	m	s	6.6
	BCtb3	146–181	5YR	5/4	4/4	vcls	m	s	7.0
Ustic Torriorthent at site 25c									
H	C	0–6	9YR	4.5/2	2.5/2	fsl	m	s	7.4
O-III, l	A1b	6–17	9YR	4.5/3	3/3	vcs	m	s	7.0
	A2b	17–27	9YR	5/2.5	3/2.5	vclfs	m	s	6.8
	A3b	27–40	9YR	5/2	3/2	vcs	m	s	6.8
	A4b	40–49	7.5YR	4.5/2	3/2	vcs	m	s	6.8
	Cb	49–86	7.5YR	5/2	3.5/2	vcls	m	s	7.2
O-III, l	2A1b2	86–106	7.5YR	4.5/2	3/2	ls	m	sh	7.2
	2A2b2	106–119	7.5YR	5/2	3/2	s	m	s, sh	7.2
O-I	3Bt1b3	119–145	6YR	5/3.5	4/3.5	vcls	m	sh	7.4
	3Bt2b3	145–171	6YR	5/3.5	4/3.5	vcs	m	sh	7.4
	3BCtb3	171–199	6YR	5/3	4/3	vcs	m	s, sh	
Pachic Haplustoll at site 25d									
O-III, l	A1	0–5	7.5YR	4.5/2	3/2	vcsl	m	s, sh	6.8
	A2	5–28	7.5YR	4/2	2.5/2	vcsl	m	sh	7.0
	A3	28–47	7.5YR	4/2	2.5/2	vcsl	m	sh	6.8
	A4	47–67	7.5YR	4/2	2.5/2	vcsl	m	s, sh	6.4
	A5	67–96	7.5YR	4/2.5	2.5/2.5	vcsl	m	s	6.2
O-I	Bt1b	96–131	5YR	5/4	4/4		m	s	6.2
			7.5YR	5/3	3.5/3	vcsl	m	h, sh	6.4
	Bt2b	131–154	5YR	5/4	4/3	vcls	m	sh	6.8
	BCt1b	144–198	5YR	5/4	4/3	vcs	m	sh	6.8
	BCt2b	198–221	7.5YR	5/3	4/3	vcs	m	s	7.6

Pachic Haplustoll at site 25b

Sites 25b—d (Fig. 28) illustrate post-Organ I sedimentation that has buried Organ I sediments and soils along parts of the Organ I ridge. Figure 30 shows stratigraphy at the three sites. A Pachic Haplustoll occurs at site 25b (Table 16). Although the thin C horizon at the surface is beneath the prickly pear leaves, it has buried part of the aboveground portion of the plant. This young C horizon is not to be confused with a still younger deposit (possibly from the 1978 flood) that has buried part of the prickly pear just north of the exposure. The thin C horizon is quite dark because of organic carbon in the sediments, which must have been derived from upper horizons of soils upslope. The C horizon is underlain by an Ab horizon, which is underlain in turn by a soil of Organ III age. The Cb2 horizon rests on the buried Organ I soil, which must have been eroded before burial because the reddish brown Bt horizon is the uppermost horizon.

About 30 ft (9 m) west of pedon 25b, the analogue of the Ab horizon at pedon 25b is buried by a deposit with a thin A horizon (Fig. 30). Westward the Ab analogue is truncated, the overlying deposit thickens and grades to the upper deposit at site 25c. Judging from the weak A horizon development in each deposit, both are likely of latest Organ III age because late Organ III soils in this position commonly have thick, dark A horizons.

Ustic Torriorthent at site 25c

Figures 31 and 32 show the Ustic Torriorthent at site 25c (Fig. 30; Table 16). The thin C horizon at the surface is stratified and very similar to the thin C horizon at site 25b. The skeletal deposit beneath the C horizon has an Al horizon (Table 16), but it is weakly developed, would have too little organic carbon for a mollic epipedon, and the soil is classified as an Ustic Torriorthent. The deposit has an abrupt lower boundary (Fig. 32) to a buried A horizon with very few rock fragments. The buried A horizon is thought to date from earlier in late Organ III time, and overlies an Organ I Bt horizon.

Interiors of some of the cobbles in the Organ I Bt horizon are stained with reddish day, a feature seen elsewhere along the exposure in Organ I soils. This is another feature that distinguishes Organ II and Organ I soils because interiors of Organ II rock fragments are not stained with day. The Bt horizon contains less day and is not as red as other Organ I soils; this soil may have been strongly eroded before it was buried.

FIGURE 31—Landscape at site 25c, looking to the east. The WSMR Headquarters are in the middle ground; the Tularosa Basin is in the background. Photographed April, 1979.

The latest Organ III deposit thins westward and is abruptly inset against the A horizon of the late Organ III soil, which traces to the thick A horizon of pedon 25d (Fig. 30).

Pachic Haplustoll at site 25d

In the Pachic Haplustoll at site 25d (Fig. 30; Table 16) a skeletal, late Organ **III** deposit buries an Organ I soil although a younger deposit is not apparent on cursory view. That it is in fact younger is shown by the occasional presence of a thin C horizon at the base of the Organ III deposit.

Carbonate in the BCtkb horizon is most prominent as coatings on the bottoms of cobbles and stones that have no visible carbonate on the upper sides. There are alternating zones of reddish low-carbonate materials and less red materials with visible carbonate.

West of site 25d, latest Organ III again descends into late Organ III as a prominent gully fill (Fig. 30).

Haplargid and Argiustoll at site 26

Sites 26a,b illustrate soils on the east end of the south side of the arroyo, and show the contact between Organ and Isaacks' Ranch sediments. Table 17 gives characteristics of soils at sites 26a and 26b.

Ustollic Haplargid at site 26a

Figure 33 shows the Ustollic Haplargid at site 26a (Table 17), which is the easternmost exposure of Organ I soils on the south side of the arroyo. The exposure is similar to site 25a on the north side of the arroyo but is deeper, and shows the horizon of carbonate accumulation occurring continuously across the exposure.

Pebbles in the BCt horizon are stained 5YR 5/5, thus have higher chroma than fine earth between the pebbles (Table 17). Roughly vertical extensions of the reddish stainings descend into the BCtk horizon and are separated by zones in which thin carbonate coatings occur on pebbles.

Remarkably, the whole B horizon is soft. This may be associated with the unusually high percentage of rock fragments—nearly all of the clay must have had to infiltrate from dustfall. The only slightly hard consistence is in the Ck horizon (Table 17).

The exposure also illustrates weathering of rock fragments by pedogenesis. Only a very few greenish andesite fragments have started to fracture, and these only slightly; interiors of some fragments in the Bt horizon are thinly and discontinuously stained with illuvial clay. A few softened andesite fragments also occur in the BCtk horizon. These have discontinuous carbonate coatings as well as clay coatings. But the softened andesite is more apparent in the Bt horizon. This would be expected because it is wetted more frequently.

Aridic Argiustoll at site 26b

Figure 34 shows the Aridic Argiustoll at site 26b (Table 17). The thick A horizon in Organ sediments would have enough organic carbon for a mollic epipedon.

TABLE 17—Characteristics of Organ and Isaacks' Ranch soils at site 26. Abbreviations are explained in Table 6 caption (p. 32).

Horizon	Depth, cm	Hue	Value/chroma Dry	Value/chroma Moist	Textural class	Structure	Dry consistence	pH
Ustollic Haplargid at site 26a—Organ I								
A1	0–3	7.5YR	4.5/3	3/3	vgsl	m	s	6.6
A2	3–16	7.5YR	4/3	2.5/3	vgsl	m	s	6.6
BAt	16–39	5YR	4/3	2.5/3	vgsl	m	s	7.0
Bt1	39–56	5YR	4/3	3/3	vgsl	m	s	7.0
Bt2	56–80	5YR	4.5/4	3/4	vgsl	m	s	7.4
BCt	80–107	5YR	5/4	3.5/4	vgs	m	s	7.4
BCtk1	107–140	5YR	5/4	3.5/4	vgs	m	s	7.4
BCtk2	140–172	7.5YR	5/3	4/3	vgs	m	s	7.6
Ck	172–220	7.5YR	5/3	4/3	vgs	m	s, sh	
Aridic Argiustoll at site 26b—Organ over Isaacks' Ranch								
A1	0–4	7.5YR	4.5/3	3/3	vcsl	m	sh	6.4
A2	4–26	7.5YR	4/2	2.5/2	vcsl	m	sh	6.4
BAt	26–41	7.5YR	4/3	3/3	vcsl	m	sh	6.4
Bt1b	41–63	5YR	4/4	3/4	vcsl	m	sh	6.6
Bt2b	63–86	5YR	4/4	3.5/4	vcsl	m	sh, h	6.8
Bt3b	86–132	5YR	4.5/4	4/4	vcsl	m	h	7.0
BCtb	132–160	6YR	5.5/4	4.5/4	vcsl	m	sh, h	7.2

FIGURE 32—The Ustic Torriorthent, Rockspring (see Table 16), at site 25c. This site illustrates sediments of four ages—Historical, two of late Organ III, and Organ I. Scale is in feet. Photographed April, 1979.

The Bt horizons of Isaacks' Ranch soils differ from the Bt horizons of Organ I soils in being slightly redder in part and in having a higher percentage of fine earth between the rock fragments, harder consistence when dry, and a higher percentage of clay. Nowhere in the exposure is texture of the Btb horizon finer than heavy sandy loam. Commonly, texture is only a medium sandy loam, despite its relative stickness, because of high content of the coarser sand fractions. The BCtb horizon has scattered zones with thin coatings of illuvial clay, 4YR 4/6, dry, on grains and along pores.

The andesite has weathered further in Isaacks' Ranch sediments than in Organ I sediments; nearly all of it has been softened to a greater degree, with some spalling parallel to faces of the rock fragments. Several monzonite fragments in the Bt horizon are easily taken apart with the fingers, and are distinctly clay-coated on crystal faces.

Positional significance of the Organ I and III deposits

West of site 26b are analogues of the extensive exposures of Organ III sediments discussed at site 25, on the north side of the arroyo. Trends of the exposures on the north side match those on the south side. Clearly, the two depositional systems were once connected, were emplaced before the present arroyo was cut, and must have been deposited during an early stage of arroyo development. Because the arroyo shows on the 1936 aerial photographs, all of the Organ III deposits must date from before 1936.

At site 25 on the north side of the arroyo, the late Organ III deposits occur in a narrow east-west band that is inset against the Organ I ridge just north. In places, the Organ I and III deposits are about at the same elevation. Such patterns of deposition should be kept in mind in assessing soil variations because they could help to explain differences encountered in much older soils that now occupy major

FIGURE 33—Landscape of the Ustollic Haplargid, Holliday (at the tape; see Table 17) at site 26a. The late Holocene scarp and the east end of the Organ I ridge are at the left end of the cut. The WSMR Headquarters are in the middle ground; the Tularosa Basin is in the background. Photographed April, 1979.

topographic highs. Thus accordant ridge crests that would appear to be about the same age could differ in age by thousands of years.

Multiple ages of the Organ III sediments at site 25 and west of site 26 must have been caused by their position just downslope of an arroyo mouth (Fig. 28). This contrasts with deposits that are emplaced a considerable distance from arroyo mouths, and that are subsequently isolated and stabilized so that pedogenesis can begin. Such occurrence of multiple deposits helps to explain the multiplicity of sediments and soils in certain areas where the present topography would not suggest it. Thus, relict distributary systems no longer evident could be responsible for multiple deposits that laterally could grade into markedly fewer or a single deposit. Also, because deposits below arroyo mouths would be emplaced as a result of normal storms during a given climate, these deposits clearly would not reflect and would not require the major climatic shifts that are considered to be responsible for major episodes of erosion and deposition in arid regions (Antevs, 1955; Haynes, 1975; Gile et al, 1981).

Soils of the Jornada II and younger surfaces (100-150,000 yrs B.P.) along the Holocene—Pleistocene scarp: Argiustoll—Haplargid complex (F, Fig. 18)

Landscape, soil occurrence, soil boundaries, vegetation

Soils of map unit F occur along the Holocene—Pleistocene scarp (Figs. 18, 35). The scarp cuts the Jornada I fan and therefore must postdate formation of the fan. Soils and soil-geomorphic relations along the scarp, to be discussed at sites 27-32, indicate the presence of deposits and soils dating from both the Holocene and the Pleistocene. However, the prominent soils on large parts of the scarp indicate that, as a general landscape feature, the scarp must date from the Pleistocene.

Elevational surveys were made up the scarp using a dumpy level, rod, and a 100—ft steel tape. The intent was

FIGURE 34—The Aridic Argiustoll, Earp (see Table 17) at site 26b. Organ deposits are underlain by Isaacks' Ranch sediments and soil. The Organ Mountains are in the background. Scale is in feet.

not to make a morphometric analysis; this has already been done by Machette (1987a). Instead, the objectives were to determine the approximate height of the scarp between major drainageways, to determine the minimum displacement of the Jornada I surface, and to distinguish major slope changes along the scarp in order to relate them to soil occurrence along the fault.

Map unit F has the most complex soil pattern encountered in the study area. Although the unit is small it contains numerous soils (Table 18). No series are known to fit the soils of the steep scarp. Soils of the drainageways are illustrated by the storm-caused exposures and are classified at the level of family particle-size class. No exposures were available between drainageways; because of the numerous large rock fragments and the difficulty of digging between them, these soils are classified at the great group or subgroup level only.

Boundaries to map units A and B were discussed in these units. Gradation to units G and H is marked by gradually decreasing slopes of the upper part of the scarp; the boundaries to these units are drawn approximately where the slope accords with that of the Jornada I alluvial fan above the scarp (about 7%). Some soils in the western part of unit B are included in unit F for discussion because their geomorphic and pedogenic history are so closely associated with the scarp.

Vegetation includes mesquite, snakeweed, four-wing saltbush, black grama, sideoats grama, blue grama, Mormon tea, beardgrass, prickly pear, catclaw, desert thorn, squirrel tail, Lippia, mulberry, hackberry, and oak (Table 3). Vegetation tends to be densest along the lower slope of the scarp, where hackberry trees up to 15 ft (4.5 m) tall are common, along with a few oak.

Soils of map unit F are considered under two general

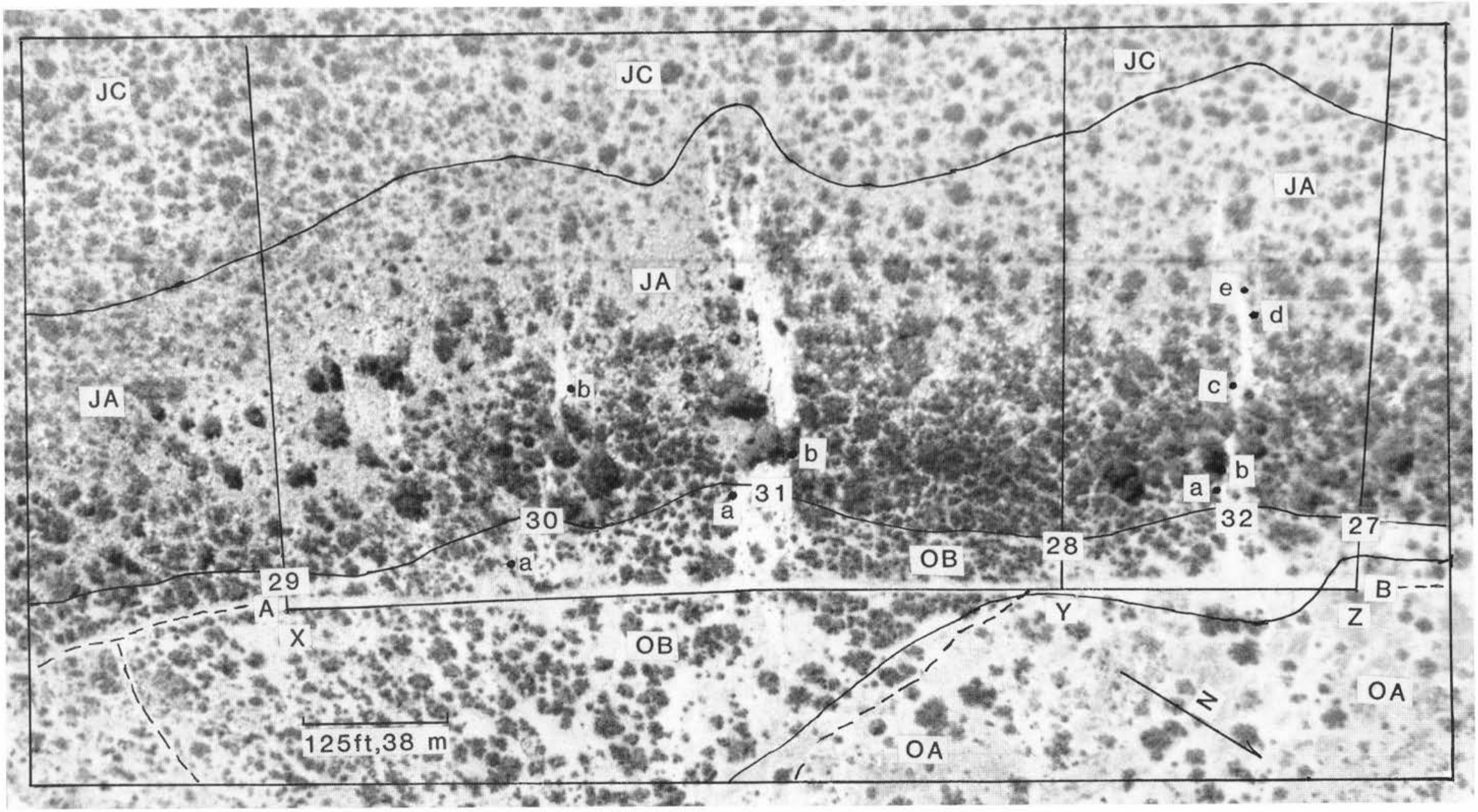


FIGURE 35—Enlargement locating sites 27–32, along and below the Holocene–Pleistocene scarp. The symbols OA, OB, JA, and JC designate geomorphic surfaces (see Fig. 5A). Line AB is the baseline for transects X, Y, and Z up the scarp (see Fig. 36). Scale shown is along line AB; transect scale is 1 in = 100 ft (30 m).

TABLE 18—Soils of map unit F. Soils between the drainageways were examined only in shallow pits between the numerous rock fragments. Soil characteristics below the upper part of the Bt horizon are not known, and soils other than the indicated subgroups may also be present. Soils in map unit F that occur at sites 27–32 are classified below the subgroup level (see Table 5). In places, thin post-Jornada II deposits occur between drainageways.

Landscape position	Geomorphic surface	Soil age	Subgroup (if more than one, subgroups are listed in estimated order of abundance)
		Between drainageways	
Upper slope of scarp	Jornada II colluvium over beveled Jornada I sediments	Late Pleistocene	Ustollic Haplargids Aridic Argiustolls
Middle slope of scarp	same as above	same as above	Ustollic Haplargids Aridic Argiustolls
Lower slope of scarp	same as above	same as above	Ustollic Calciorthids Aridic Calciustolls Petrocalcic Calciustolls Ustollic Paleorthids Petrocalcic Paleustolls Aridic Argiustolls
		In drainageways	
Upper slope of scarp	Jornada II and younger colluvium over beveled Jornada I sediments	Late Pleistocene or younger	Aridic Argiustolls
Middle slope of scarp	Jornada II and/or younger colluvium over beveled Jornada I sediments	same as above	Ustollic Haplargids Aridic Argiustolls
Lower slope of scarp	same as above	same as above	Ustollic Calciorthids Aridic Argiustolls

landscape positions: soils of drainageways that descend the scarp, and soils between the drainageways.

Soils between drainageways

Major soils between drainageways are illustrated by transects X, Y, and Z, which extend westward from line AB up the high scarp (Figs. 35, 36). Sites 27-29 are at the lower ends of the transects, illustrate soils along and just below the scarp base, and extend across the Holocene fault. Line AB (Fig. 36), on the eastern edge of the road at the base of the scarp, is the eastern baseline of the three transects. Figure 36 shows elevations along line AB and the position of the eastern ends of the transects along this line.

The distinctive skeletal and fine-earth zones (see glossary) found along and just below the base of the late Holocene scarp at sites 7 and 8 were also found associated with the Holocene—Pleistocene scarp at sites 27-29. Several factors indicate that these zones are the same age at both scarps, with the skeletal zone being a colluvium of early Organ III age and the fine-earth zone being an alluvium of late Organ III age: (1) the skeletal colluvium crosses and overlies the fault plane and, as at the late Holocene scarp, must have accumulated immediately after the faulting took place; (2) the skeletal colluvium and the younger fine-earth alluvium show the same stratigraphic relation to each other at both scarps; (3) soil development in the fine-earth and skeletal zones is similar at both scarps, with two exceptions. First, soils of these zones associated with the Holocene—Pleistocene scarp have stage I carbonate horizons but those associated with the late Holocene scarp do not. This is ex-

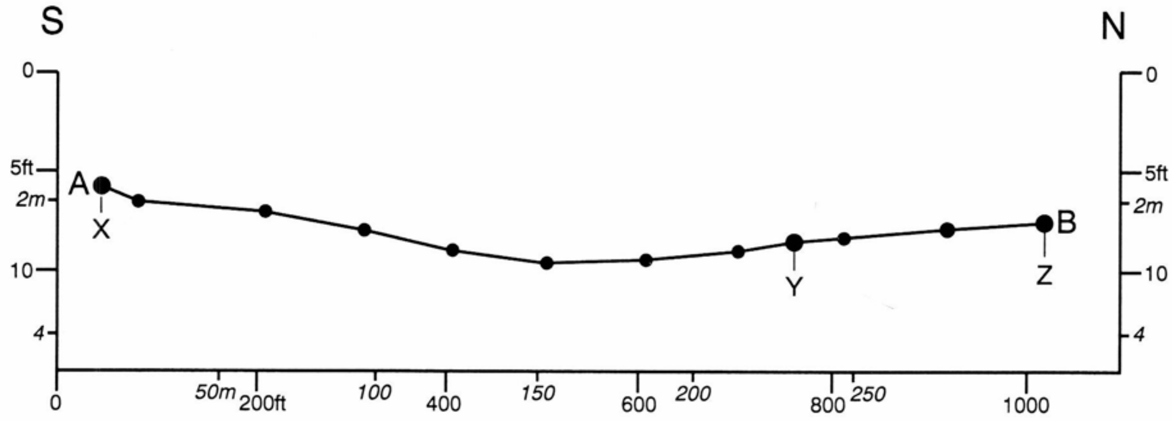


FIGURE 36—Elevations along line AB (see Fig. 35). Letters X, Y, and Z locate the east ends of transects up the scarp (see Fig. 35).

plained by the calcareous parent materials, discussed later, along and just above the base of the Holocene-Pleistocene scarp. Stage I carbonate horizons are to be expected in calcareous parent materials of Organ III age, and were found in charcoal-dated Organ III soils at the Gardner Spring radiocarbon site (Gile and Hawley, 1968). Second, weak argillic horizons were found in some Organ III soils associated with the Holocene-Pleistocene scarp but not the late Holocene scarp. This is explained by greater runoff from the high scarp and by much more clay in the contributing watershed (soils of the Holocene-Pleistocene scarp). This extra moisture and clay has speeded development of the argillic horizon in some areas below the scarp.

Haplustolls and Torrifluvent at site 27

Site 27 (Figs. 11, 35; Table 19) is the northern of sites 27-29, and illustrates soils and sediments along the fault where Cox Arroyo has impinged against it. Figure 37 shows the location of site 27 in transect Z, a survey line that ascends the scarp.

The landscape at site 27 contains two contrasting features—the steeply sloping scarp base and the gently sloping area below it—that also differ in particle size, vegetation, soil morphology and soil age (Fig. 38). The scarp base has numerous large rock fragments on the surface and dense vegetation such as catclaw, four-wing saltbush, mulberry, buckthorn, three awn, desert thorn, Lippia, squirrel tail, and snakeweed. The area below the scarp base has almost no rock fragments and vegetation is much less dense, consisting mainly of mesquite and snakeweed. Differences in soil morphology and age are discussed in following sections.

Upslope of the fault—Pedon 27a (Figs. 37, 38; Table 19) illustrates sediments and soil upslope of the fault, near the west end of the trench. All of the sediments were derived from the scarp upslope, but at different times. A thin, stratified deposit of Historical age is at the surface and thickens downslope (Fig. 38). Skeletal colluvium of Organ III age underlies the Historical deposit and is termed the *skeletal zone* (see glossary; Figs. 37, 38). The skeletal zone rests abruptly on the K horizon of a soil designated Jornada II because it is very similar to the extensive Jomada II soils of the Desert Project. The skeletal zone represents a major discontinuity, and is highly significant because it crosses and rests on the fault; it must have been deposited very soon after displacement as previously discussed (Gile, 1987, p. 22-24).

The skeletal colluvium has a stage I carbonate horizon; rock fragments in the 2Akb horizon have thin discontinuous carbonate coatings. A fragment of indurated K-fabric (Gile et al., 1965) with thin laminae was found in the 2A3kb horizon. This reflects the presence of indurated carbonate upslope in the scarp, and shows that the 2A horizon had calcareous parent materials. This contrasts with sites 7 and 8, where the colluvium is noncalcareous throughout. A thin cobbly horizon with zones of weak K-fabric was found above the Jornada II K horizon at one place in the trench (Fig. 27). There is no evident sedimentary boundary between the cobbly sediments with the zones of K-fabric and the cobbly Organ III sediments above (Fig. 27). The zones of weak K-fabric may represent local mixing of the upper part of the Jornada II carbonate horizon with basal Organ III sediments.

The K horizon beneath the Organ III skeletal zone is not indurated and is typical of Jornada II soils in sediments dominated by fine earth. The Jornada II fine-earth zone in this soil contains few rock fragments and thus contrasts with the stony and bouldery Jornada I fan sediments exposed in the scarp above. The proportion of the fine earth and the position of this soil just below the scarp base are very similar for the late Holocene fine-earth zone below the base of the scarp, and for the late Holocene scarp to the south (e.g., sites 7 and 8). These factors strongly indicate that this Jornada II fine-earth zone is also the result of a displacement, but one dating from the late Pleistocene instead of the late Holocene. Location of the fault plane is not known but could be analogous to the fault plane discussed later at site 31.

The K3b2 horizon contains a few reddish volumes of Bt material. This suggests that much or all of the K horizon was formerly a Bt horizon before its engulfment by carbonate (Gile and Grossman, 1979). Soils with K horizons are common along the lower slopes of the Jornada II scarp, and in places a Bt horizon is present above the K horizon.

The 7-33 cm zone (Table 19) is dark enough, thick enough, and is thought to have ample organic carbon for a mollic epipedon. The buried K horizon is a calcic horizon and should be considered in classification because of its shallow depth even though it is buried deeper than 50 cm (Soil Survey Staff, 1975). No subgroup presently exists in Soil Taxonomy (Soil Survey Staff, 1975) for this kind of soil. However, provision is made in Soil Taxonomy for the recognition of buried soils using the Thapto nomenclature (Soil Survey Staff, 1975, p. 82). Using that provision, the soil at site 27a is tentatively classified as a Thapto-Calciorthidic Haplustoll.

At the fault—The soil at site 27b (Figs. 37-40; Table 19) illustrates sediments and soils that overlie the fault plane. Most strata in the Historical deposit differ slightly from each other in color, texture, and/or consistence. The presence of large shrubs, such as catclaw and four-wing saltbush that rooted in the deposit, indicates the deposit accumulated before the 1978 flood. But trunks of mesquite trees are partly buried by the deposit, which is attributed to upslope erosion associated with the introduction of large numbers of cattle in the late 1800s (see history section) and subsequent heavy grazing.

Beneath the Historical deposit there is evidence that most of the fine-earth zone must have been deposited by Cox Arroyo instead of being derived from the scarp to the west. Many strata are roughly horizontal instead of sloping up to the scarp. Also, strata of clean sand and fine gravel in the lower part of the deposit are very similar to deposits in and adjacent to the present channel of Cox Arroyo. The upper part of the fine-earth zone is inset against the scarp-derived colluvium of the skeletal zone, and the dark A horizon formed in arroyo alluvium grades directly into the dark A horizon formed in the skeletal zone.

The length of time that Cox Arroyo was present at site 27 is unknown. However, the arroyo must have been very close to the scarp, as shown by the arroyo alluvium; thus sedimentation from the scarp should have started to force the arroyo eastward fairly soon after faulting took place.

Because the Historical deposit is less than 50 cm thick, soil classification is based on the buried soil. The dark buried A horizon formed in the arroyo alluvium has a stage I carbonate horizon and enough organic carbon for a mollic epipedon and the Pachic Haplustolls (Table 19).

The K horizon of the Jornada II soil slopes strongly to the east (Fig. 37) and just east of the fault has been downfaulted below the bottom of the trench. As can be seen in Figs. 39 and 40, the trench provides a cross section of the fault plane. Because the faulted materials are dominantly fine-earth materials in which prominent pedogenic horizons have formed, the fault plane can be recognized and precisely located by the displacement of soil horizons and by their disturbed parts. The fault plane is marked by steeply dipping platy units that do not occur in the bordering Jornada H soils. The nearly vertical platy zone is about 10 inches (25 cm) wide; the plates consist of reddish brown Bt material and light-colored K-fabric. Just west of the fault is

TABLE 19—Characteristics of Organ and Jornada II soils at sites 27–29. Abbreviations explained in Table 6 caption (p. 32).

Sediment	Horizon	Depth, cm	Hue	Value/chroma		Structure	Dry consistence	Textural class	pH	Organic C
				Dry	Moist					
Thapto-Calciorthidic Haplustoll at site 27a										
H	C	0–7	7.5YR	4.5/3	3/3	m	s	sl	8.2	
O-III, e	2A1kb	7–19	7.5YR	4.5/2	3/2		sh	vcsl	8.2	
	2A2kb	19–33	7.5YR	4.5/2	3/2	m	s	vcsl	8.4	
	2A3kb	33–60	7.5YR	5/2	3.5/2	m	s	vcsl	8.6	
J-II	3K2b2	60–76	7.5YR	7.5/3	6/3	lmsbk	sh	sl	8.4	
	3K3b2	76–97	7.5YR	7.5/3	6/3	lmsbk	h, vh	sl	8.4	
Pachic Haplustoll (Santo Tomas, coarse-loamy variant) at site 27b										
H	C1	0–3	7.5YR	4.5/3	3/3		s, l	ls	8.0	
	C2	3–12	7.5YR	5/2	3/2	m	sh	sl	8.2	
	C3	12–18	7.5YR	4/2	2.5/2	m	s	sl	8.4	
	C4	18–24	7.5YR	4/2	2.5/2	m	s, sh	sl	8.4	
	C5	24–30	7.5YR	4.5/2.5	3/2.5	m	s, sh	ls	8.4	
	C6	30–35	7.5YR	4.5/2.5	3/2.5	m	s, sh	ls	8.4	
	C7	35–39	7.5YR	4.5/3	3/3	m	s, sh	sl	8.4	
O-III, l	A1kb	39–51	7.5YR	4/2	2/2	m	s	sl	8.4	1.92
	A2kb	51–60	7.5YR	4/2	2/2	m	s	sl	8.4	1.69
	A3kb	60–77	7.5YR	4.5/2	2.5/2	m	s	sl	8.4	1.49
	A4kb	77–101	7.5YR	5/2	3/2	m	s	sl	8.4	
	A5kb	101–126	7.5YR	5/2	3.5/2	m	s	sl	8.4	
O-III, e	2Cb	126–170								
J-II	3Btkb2	170–209								
Thapto-Haplargidic Haplustoll at site 28a										
H	C	0–11	7.5YR	4/3	2.5/3	m	sh	sl	7.4	
O-III, l	Ab	11–22	7.5YR	4/2	2/2	m	sh	sl	7.4	
	A2kb	22–40	7.5YR	4/2	2.5/2	m	sh	sl	8.2	
O-III, e	2A3kb	40–64	7.5YR	4.5/2	3/2	m	sh	vcsl	8.2	
	2A4kb	64–82	7.5YR	4.5/2.5	3/2.5	m	sh	vcsl	8.2	
J-II	3B1tkb2	82–111	5YR	5/4	3.5/4	lm, csbk	vh	scl	8.2	
	3B2tkb2	111–137	5YR	5.5/4	4/4	lmsbk	vh	scl	8.4	
	3B3tkb2	137–162	5YR	5.5/4	4/4	lmsbk	vh	scl	8.4	
Ustollic Camborthid at site 28b										
H	C	0–3	7.5YR	4.5/2	3/2	m, sg	s, l	ls	7.2	
O-III, l	A1b	3–15	7.5YR	4/2	2/2	m	sh	sl	7.4	0.52
	A2b	15–30	7.5YR	4/2	2.5/2	m	sh	sl	7.6	0.62
	A3b	30–50	7.5YR	4.5/2	3/2	m	sh	sl	8.4	
	A4kb	50–69	7.5YR	4.5/2	3/2	m	sh	sl	8.4	
	A5kb	69–98	7.5YR	4.5/2.5	3/2.5	m	sh	sl	8.4	
O-III, e	2A6kb	98–124	7.5YR	5/3	3.5/3	m	sh	vcsl	8.4	
	2A7kb	124–146	7.5YR	5/3	3.5/3	m	sh	vcsl	8.4	
J-II	3Btkb2	146–161	5YR	5/4	3.5/4	lcsbk	vh	scl	8.2	
Pachic Argiustoll (Earp, Pachic variant) at site 29a										
H	C	0–8	6YR	5/2.5	3.5/2.5		s, l	gls	6.8	
O-III, l	Ab	8–19	6YR	4/2	2.5/2	lcsbk	sh	gsl	7.0	
	Bt1b	19–33	5YR	4/2.5	2.5/2	lmsbk	sh	gsl	7.0	
	Bt2b	33–48	6YR	4.5/2	3/2	lmsbk	sh	gsl	7.2	
O-III, e	2BAtb2	48–65	6YR	4.5/2	3/2	lmsbk	sh, h	vcsl	7.2	
	2Bt1b2	65–83	5YR	4.5/3.5	3/3	lmsbk	sh, h	vcsl	7.2	
	(bouldery zone, not sampled)									
O	2Bt2b2	104–139	5YR	5/3	3.5/3	lmsbk	sh, h	vcsl	7.4	
	2BCtk1b2	139–168	7.5YR	5/3	3.5/3	lmsbk	sh	vcsl	8.0	
	2BCtk2b2	168–190	7.5YR	5.5/3	4/3	m	sh	vcsl	8.6	
Ustollic Haplargid (Summerford) at site 29b										
O-III, l	A1	0–5	7.5YR	4.5/2	3/2		s, l	gls	6.8	
	A2	5–10	7.5YR	4.5/2	3/2	lmsbk	s, sh	gsl	7.4	
	BAt	10–27	6YR	4.5/2.5	3/2	lc, msbk	sh	gsl	7.4	
	Bt1	27–44	6YR	4.5/3	3/3	lmsbk	sh	gsl	7.4	
	Bt2	44–70	6YR	4.5/3	3/3	lmsbk	sh	gsl	7.4	
	Bt3	70–102	6YR	5/3	3.5/3	lmsbk	sh	gsl	7.6	
O-III, e	BCt	102–123	7.5YR	5/3	3.5/3	lmsbk	s, sh	gsl	7.6	
O	BCk1	123–141	7.5YR	5/3	3.5/3	lmsbk	s, sh	gsl	8.2	
	BCk2	141–171	7.5YR	5.5/3	4/3	m	s	gsl	8.8	

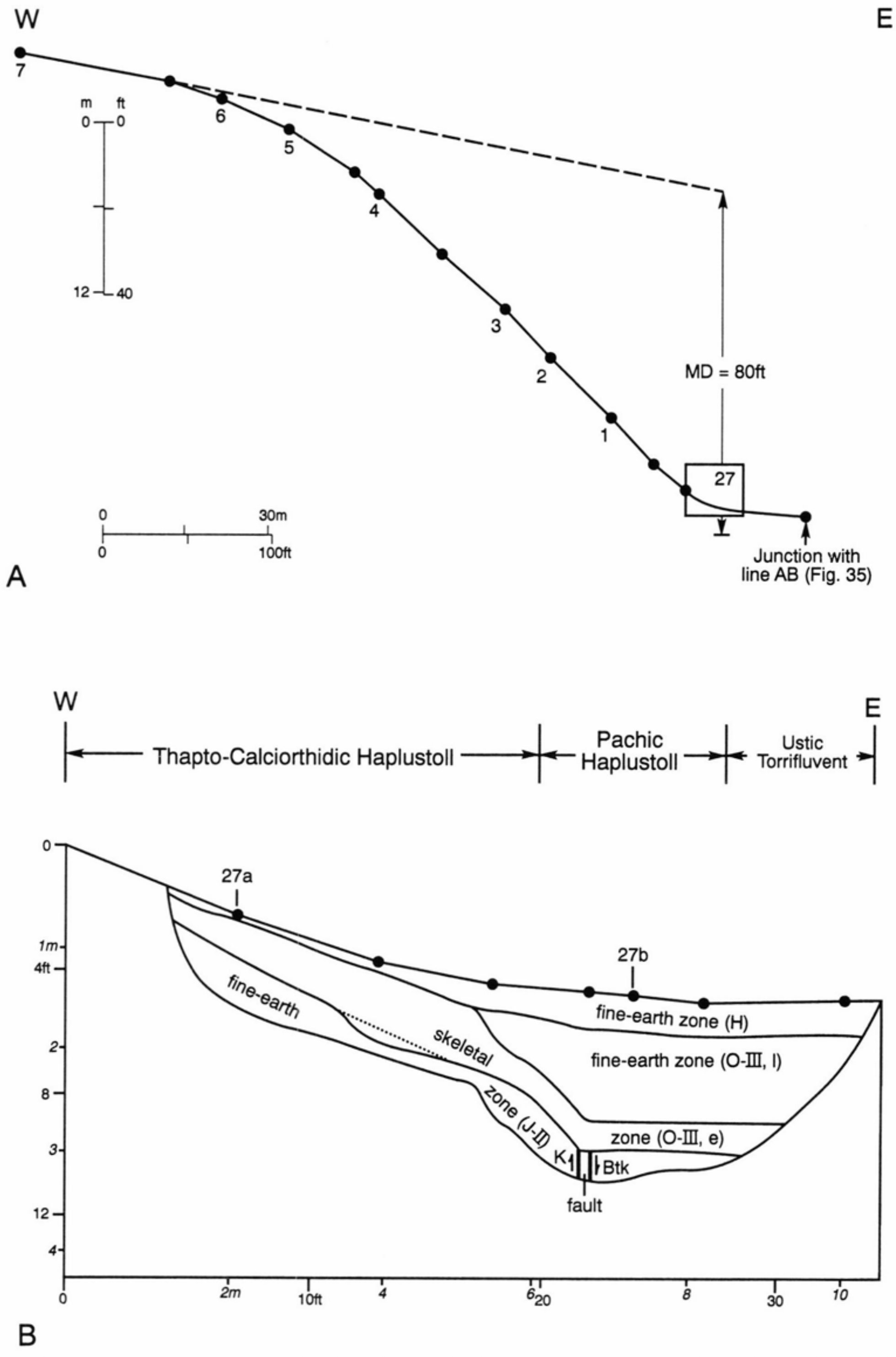


FIGURE 37—A) Diagram showing transect Z (Fig. 35), its relation to the study trench at site 27 (at right), and minimum displacement (80 ft, 24 m) of the Jornada I surface. Nos. 1–7 locate notes on the upper horizons of soils (see text). B) Diagram of the study trench at site 27, showing the fault plane, pedons 27a and 27b, elevations, subgroups, and the skeletal and fine-earth zones. In the lower part of the skeletal zone, material beneath the dotted line contains zones of weak K-fabric (see text discussion).

the Jornada II K horizon with no overlying Bt horizon. Just east of the fault is a Btk horizon in which reddish brown Bt material is dominant, with smaller volumes of carbonate nodules and cylindroids. The trench was not deep enough or long enough to determine the amount of displacement of the Jornada II K horizon. However, presence of the Jornada II Btk horizon east of the fault plane suggests that displacement at the fault plane probably could not have been greater than about 3 ft (0.9 m).

Downslope of the fault plane—East of the fault, the Pachic Haplustoll changes abruptly to an Ustic Torrifluvent in the eastern part of the trench (Fig. 37). The Torrifluvent has less clay than the Haplustoll, is lighter-colored, and appears to have formed in a younger, coarser-textured deposit of Cox Arroyo. This interpretation is supported by coincidence of termination of individual strata of the eastern deposit with the contact between the Haplustoll and the Torrifluvent. The Torrifluvent is in the sandy family, but

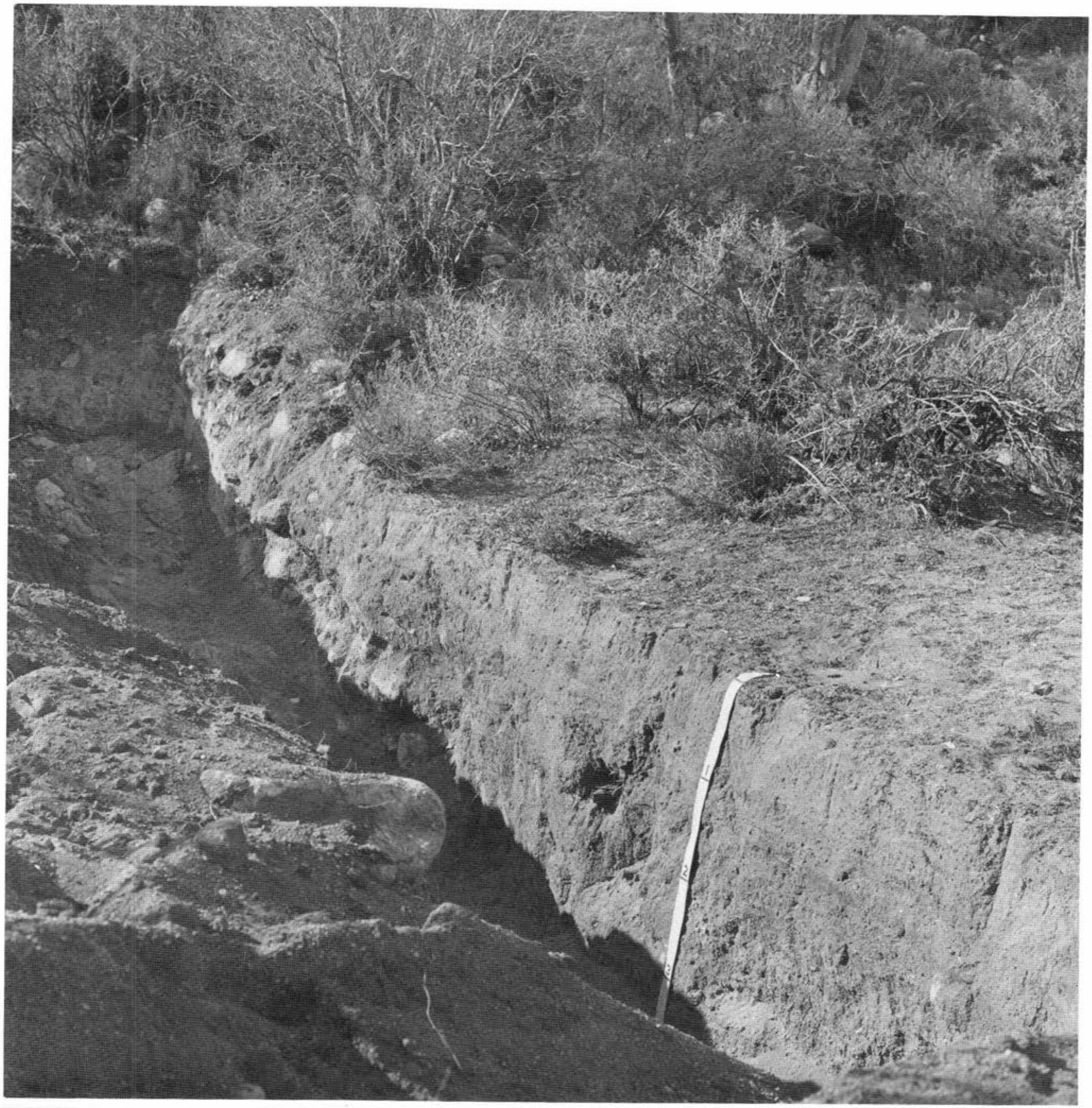


FIGURE 38—Base of the Holocene-Pleistocene scarp at site 27, and the buried late Organ III surface below the scarp base. The scarp base, exposed at upper left in the study trench, contains more rock fragments and vegetation than does the fine-earth zone downslope. The tape is at the Pachic Haplustoll pedon 27b (see Table 19). The late Organ III surface and soil occur beneath 15 inches (39 cm) of Historical sediments. Scale is in feet.

sandy loam strata occur below 25 cm depth, and would contain enough organic carbon, as compared to intervening coarser-textured strata, that organic carbon would decrease irregularly with depth and the soil would thus qualify as a Fluvent.

Soils above site 27

Following are notes on vegetation, surficial rock fragments and soils between rock fragments up the scarp west of site 27. Comments are located by number on Fig. 37 (upper).

Number 1—This is a densely vegetated area typical of the lower part of the scarp. Hackberry trees up to about 15 ft (4.5 m) high are common, as well as mesquite, snakeweed, bush mutely, four-wing saltbush, sideoats grama, catclaw, buckthorn, and three-awn. The soil surface has a nearly continuous cover of stones, mostly $1^1/2$-2 ft (0.5-0.6 m) in diameter; there are also boulders up to 4 ft (1.2 m) diameter. The A horizon is dominantly 7.5YR 3/2, moist, and is a very stony sandy loam. Organic carbon is easily high enough for a mollic epipedon. This lower slope has ideal conditions for development of a mollic epipedon—dense vegetation for high organic carbon; a thick cover of stones for relative stability and protection against erosion; and contribution of moisture from slopes above. The Bt horizon is 5YR 4/3, moist, a very stony sandy

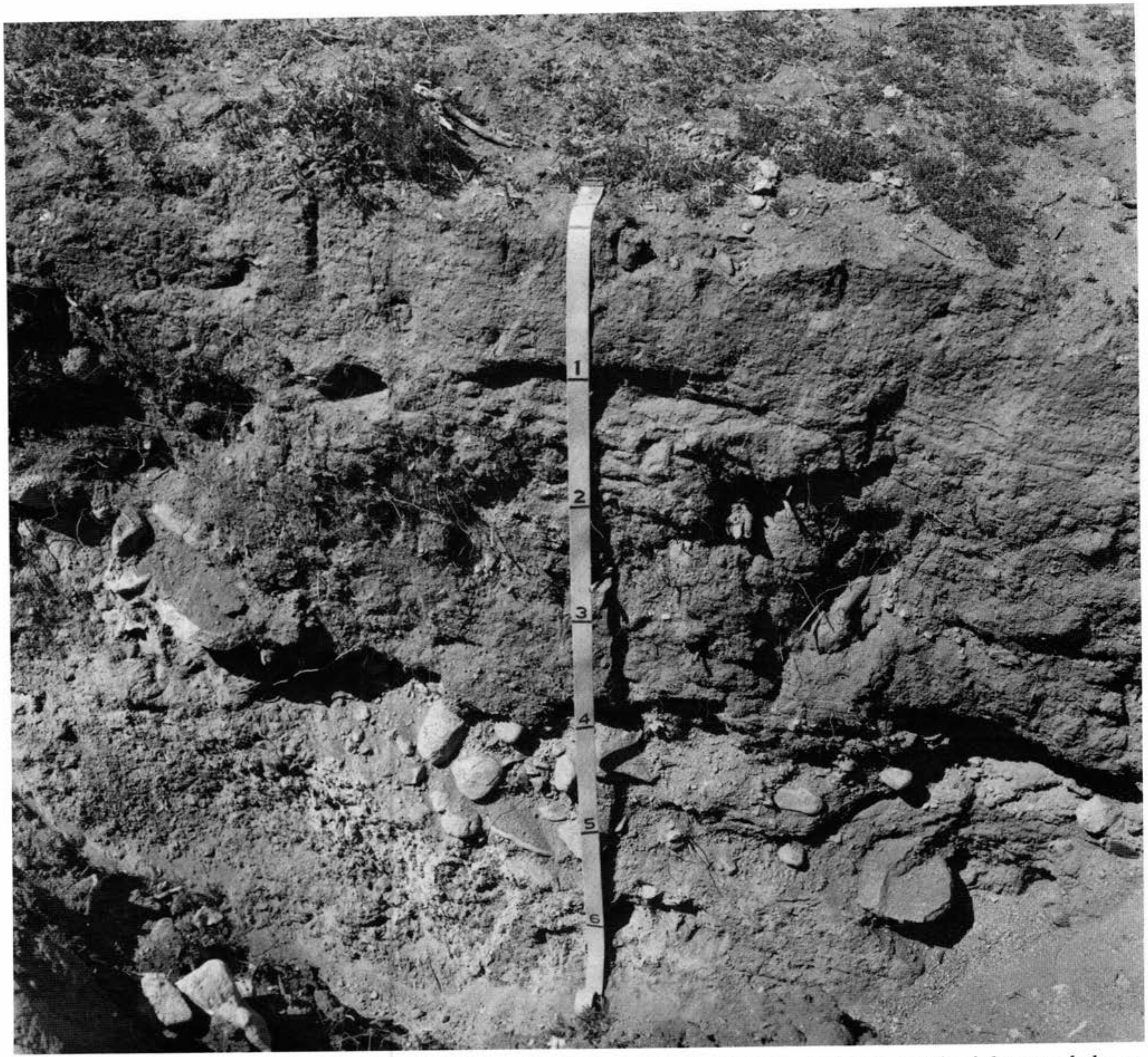


FIGURE 39—The study trench at site 27 after deepening to locate the fault plane, which is at left of the tape below a depth of about 5½ ft (see Fig. 40). Nail at left of bottom of tape parallels slope of platy units that mark the fault plane. Historical, late Organ III, early Organ III and Jornada II sediments are at the tape (see Table 19). Scale is in feet.

clay loam that starts at 11 inch (28 cm) depth. This part of the slope appears to be dominated by Argiustolls. A short, slight gully a few meters north shows an argillic horizon over a stage III carbonate horizon.

Number 2—This area is thickly mantled with stones and boulders. Vegetation is dense between them and is mostly four-wing saltbush, mesquite, snakeweed, and desert thorn. This area is just above the "tree zone" on the lower part of the scarp. The Bt horizon is 5YR 4/4, moist, a very stony sandy clay, and is too shallow for a mollic epipedon. Ustollic Haplargids appear to be dominant on this portion of the scarp.

Number 3—This area is also thickly mantled with large rock fragments. Snakeweed is more common here and there are fewer of the larger shrubs, though mesquite is common. A shallow pit in a typical area shows the Bt horizon only 4 inches (10 cm) from the surface. The Bt horizon is 4YR 4/5, moist; chromas are too high for a mollic epipedon. Texture is a very stony heavy sandy clay loam, and the soil is an Ustollic Haplargid.

Number 4—The moffic epipedon is discontinuous here; low chromas extend deep enough for a mollic epipedon in some places but not in others, and both Argiustolls and Ustollic Haplargids are present.

Number 5— This area is typical of a transitional zone between the steep slope above and gentler slopes below. The area is thickly mantled with rock fragments but more of them are of cobble size. The Bt horizon is 5YR 5/4, moist, and begins at 6 inch (15 cm) depth; it is a very cobbly sandy clay. The A horizon is 7.5YR 3/2, moist. The 710 inch (18-25 cm) zone has chroma too high for a mollic epipedon, and the soil is an Ustollic Haplargid.

Number 6— Here the slope is gentler, but still steeper than the slope of the fan. Blue grams and black grama

FIGURE 40—A closer view of the fault plane (outlined at left, with nail in lower center) in Jornada II sediments. The downdropped Jornada II Btk horizon occurs between the tape and the fault plane. In contrast to the skeletal Organ III colluvium at top, the underlying Jornada II sediments are dominated by fine earth. Scale is in feet.

are common; mesquite, snakeweed and prickly pear are also present. Occasional barren areas between the larger rock fragments are usually dominated by fine gravel. The larger rock fragments are mostly cobble size, with some stones and only a few boulders. The A horizon is 7.5YR 3/2, moist, a very stony sandy loam. The high-chroma Bt horizon starts 8 inches (20 cm) below the surface and is 4YR 3/4, moist. Ustollic Haplargids dominate this area.

Number 7—This is on the east edge of the Jomada I fan. Vegetation is mainly blue grama, black grama, beardgrass, mesquite, snakeweed, prickly pear, and a few Mormon tea. There are quite a few small areas that are barren and dominated by fine gravel between the larger rock fragments. The surface appears quite stable, with no evident drains. The Bt horizon, a very cobbly sandy clay loam, is redder and has higher chroma than observed in the shallow pits below; color is 2.5YR 3/6, moist. The top of the Bt horizon is at 11 inch (28 cm) depth, so this pedon barely makes the Mollisols.

Minimum displacement

The survey lines up the scarp (Fig. 35) show its height and relate it to the soils and deposits exposed in the trenches at sites 27-29. The westernmost two readings at each transect were made on the Jornada I fan to determine its slope where unaffected by the scarp. Between drainageways the scarp, despite its considerable height, appears to have had remarkably little effect on the original slope of the fan. This is probably due to the numerous large rock fragments and the thick, tightly packed Bt horizon. Both would tend to protect the Jomada I soil from erosion.

A line extrapolated from the two readings on the fan slope is taken as representing the approximate slope of the fan surface before faulting. As shown in Fig. 37, from this extrapolation the Jornada I surface at transect Z must have downfaulted at least 80 ft (24 m), the vertical distance between the end of the extrapolated line to the deepest material exposed in the study trench at site 27. As pointed out by Machette (1987b), as much as half of the offset on the fault may be masked by deposits that accumulate at the toe of a fault scarp. Thus 80 ft (24 m) is a minimum figure for the amount of displacement along the fault at site 27; the actual amount of displacement would be much greater.

Haplustoll and Camborthid at site 28

Site 28 (Figs. 35, 41-43) is the central of the three sites between major drainageways in the scarp. No evidence of alluvium from Cox Arroyo was found at this site, and all sediments were apparently derived from the scarp. Site 28 is just downslope of the scarp base, and a fine-earth zone overlies the skeletal zone for the full length of the trench. Table 19 gives characteristics of two pedons at the site.

The western, steeper end of the study trench is next to the scarp base, is more heavily vegetated than the area downslope, and is dominated by snakeweed, buckthorn, prickly pear, bush muhly, mesquite, and four-wing saltbush. Downslope, vegetation consists mostly of snakeweed, mesquite and fluffgrass, with many barren areas.

Upslope of the fault—Pedon 28a illustrates sediments and soils upslope of the fault, near the west end of the

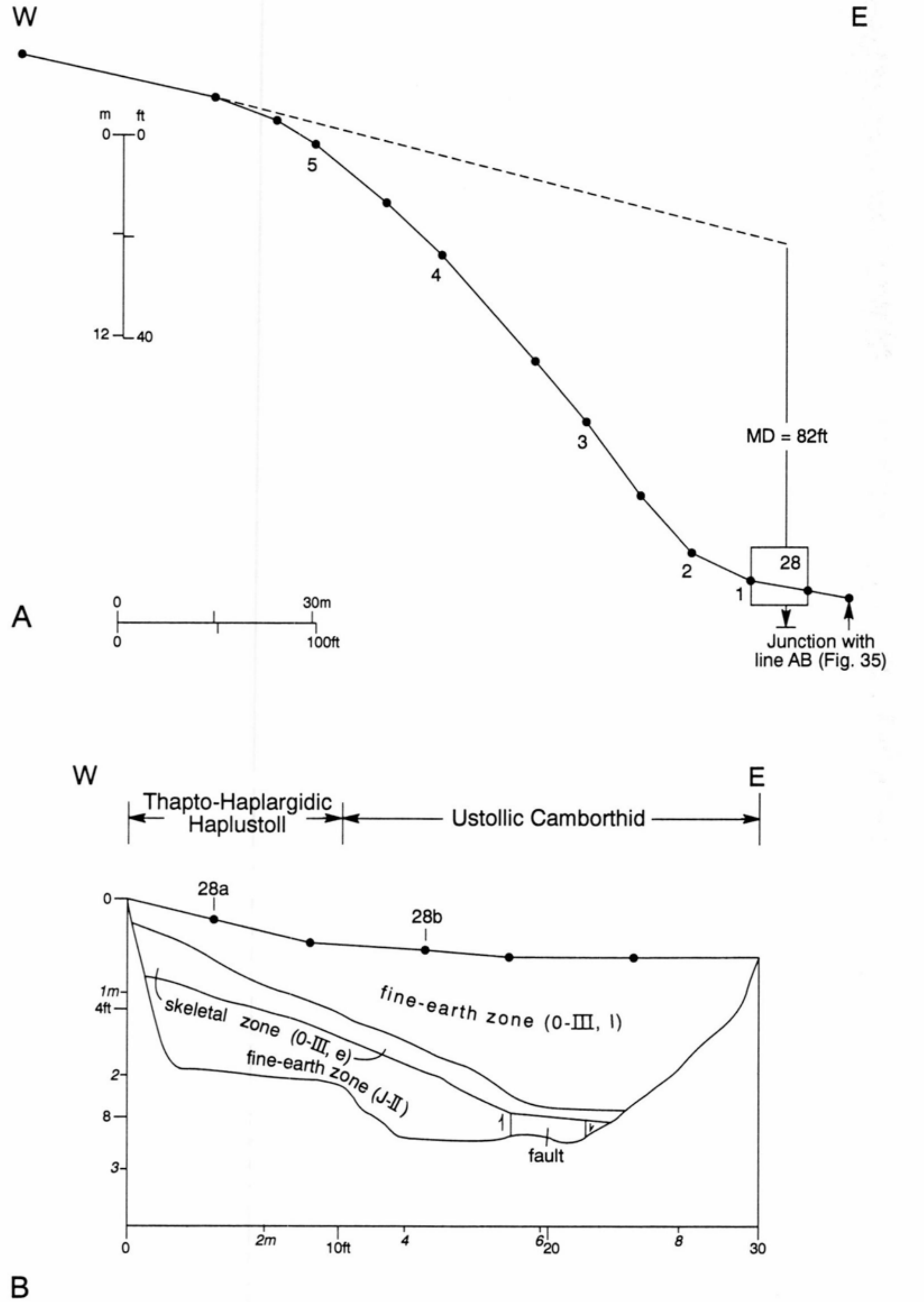


FIGURE 41—A) Diagram showing transect Y (Fig. 35), its relation to the study trench at site 28 at right, and minimum displacement (82 ft, 24.6 m) of the Jornada I surface. Nos. 1–5 locate notes on upper horizons of soils (see text). B) Diagram of the study trench at site 28, showing the fault plane, pedons 28a and 28b, elevations, subgroups, and the skeletal and fine-earth zones.

trench. The Historical deposit (not shown in Fig. 41) is thin and discontinuous. The deposit has been preserved in and adjacent to shrubs, but did not accumulate (or has been eroded) in the vicinity of small drainageways that descend the scarp. The thin C horizon and the underlying Alb horizon (Table 19) are noncalcareous; a noncalcareous zone of about the same thickness extends for the full length of the trench, and is underlain by a stage I carbonate horizon. A small fragment of indurated carbonate was found both in the C and in the underlying Alb horizon. The fragments must have been derived from a petrocalcic horizon (or a remnant of one) upslope as discussed later. Because the prominent Jornada II soil is at shallow depth, pedon 28a is classified as a Thapto-Haplargidic Haplustoll (Fig. 41).

The Organ III deposit overlies the Jornada II fine-earth zone, which contains scattered pebbles and cobbles, and in which a thick Bt horizon has formed (Fig. 41, Table 19). The discontinuity is interpreted as being the same age as the Organ III—Jornada II contact at site 27.

At the fault—Pedon 28b illustrates an Ustollic Camborthid; not quite enough organic carbon is present for a mollic epipedon (Table 19). More carbonate is visible in this part of the trench, and at the fault plane (Fig. 41) the whole Jornada II fine-earth zone is occupied by the K horizon (upslope the trench was not deep enough to expose the typical stage III carbonate horizon of the Jornada II soils). The west plane of the fault is marked by an abrupt, nearly vertical boundary of the K horizon. The fault occupies a zone about 3 ft (0.9 m) wide that is filled with loose, shattered-appearing, reddish brown fragments of Bt material.

The characteristic Jornada II Bt horizon occurs just east of the fault at a depth of from 74 to 81 inches (187 to 207 cm). The trench was not deep enough to determine the amount of displacement of the K horizon. However, presence of the Jornada II Bt horizon east of the fault indicates that the amount of displacement at the fault plane was not great, probably not more than about 3 ft (0.9 m). If the displacement had been much more than that, the Jornada

FIGURE 42—The Holocene–Pleistocene scarp and the late Organ III surface below it at site 28. Prominent differences in vegetation and slope are associated with the skeletal and fine-earth zones.

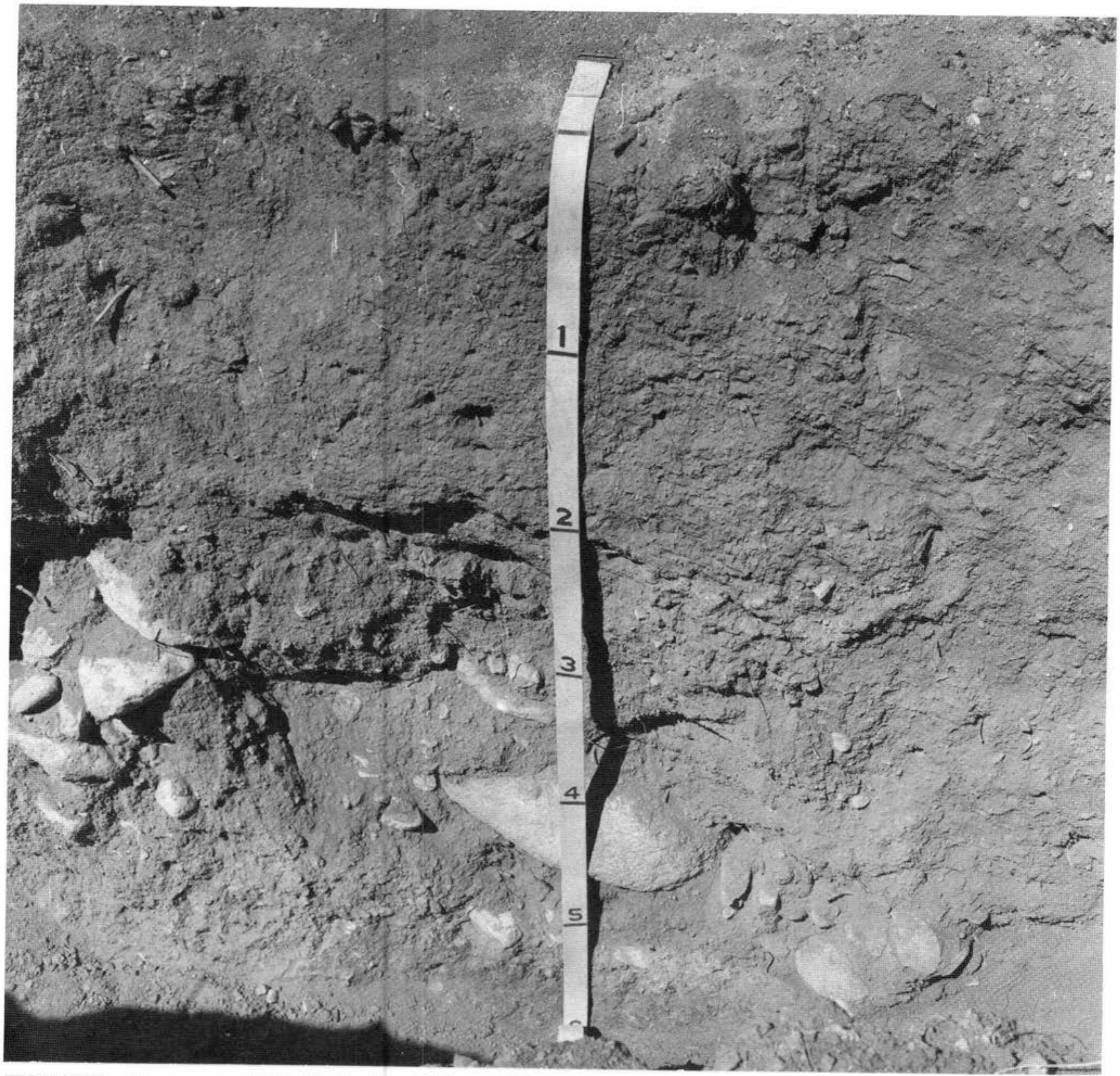


FIGURE 43—The unnamed Ustollic Camborthid (see Table 19) at site 28b. The strongly sloping skeletal zone (early Organ III) rests on the Jornada II fine-earth zone. The fault cannot be seen; at extreme right, the skeletal zone is dipping into and across it. The trench was later deepened and the fault zone was clearly visible (see text discussion).

II Bt horizon would have been displaced more and would be more deeply buried.

The survey line up the scarp (Fig. 41) shows a minimum displacement of 82 ft (24.6 m). This is similar to the minimum displacement at transect Z (80 ft., 24 m).

Soils above site 28

Vegetation and rock fragments are similar to those above site 27. Comments are located by number in Fig. 41, upper.

Number 1—An exposure in a small drainageway showed an argillic horizon and a stage III carbonate horizon. This soil is similar to the Argiustolls seen just above site 27.

Number 2—The upper 3 inches (8 cm) are noncalcareous and 7.5YR 4/3 moist. Below this depth the epipedon is not dark enough for mollic because of carbonate influence, and this soil is an Ustollic Calciorthid. Plates of a formerly continuous petrocalcic horizon are at and close to the surface near and beneath a large oak tree just north of the survey line. Calciorthids and Paleorthids are present in this area, along with a few Paleargids where an argillic horizon is preserved above the petrocalcic horizon.

Number 3—The A horizon is 7.5YR 3/2 moist, and overlies a Bt horizon at a depth of 6 inches (15 cm). The Bt horizon is 7.5YR 4/2 moist, and the pedon is a loamy-skeletal Ustollic Haplargid.

Number 4—The Bt horizon is too light-colored for a mollic epipedon; this is a loamy-skeletal Ustollic Haplargid.

Number 5—A high-chroma Bt horizon is at 6 inch (15 cm) depth, too shallow for a mollic epipedon, and this soil is an Ustollic Haplargid. Soils up the rest of the scarp are about the same, and Ustollic Haplargids clearly dominate the upper slopes of the scarp. Long-term erosion has gradually eroded upper horizons, so the high-chroma Bt horizons are at shallow depth, precluding a mollic epipedon and the Mollisols.

Argiustoll and Haplargid at site 29

Site 29 (Figs. 35, 44-46A; Table 19) is the southern of the three sites between major drainageways in the scarp. Site 29 illustrates soils and sediments of the Holocene–Pleistocene scarp where it has been affected by the Organ III fan to the south (Fig. 5A). Deposition of the latter sediments has resulted in a slope to the north as well as east, instead of the gentle southward slope controlled by Cox Arroyo at sites 27 and 28. The steeper slopes have also resulted in greater erosion of the post-faulting, scarp-derived sediments below the scarp base.

The area in the vicinity of the study trench has common rounded drainageways that lead directly to slight lows in the scarp upslope. The trench was dug in a small ridge, parallel to adjacent drainageways, so that the best-preserved soil could be examined.

Vegetation in the less dissected, western end of the trench (where surficial rock fragments are common; west of 8.4 m, Fig. 44) consists of mesquite, snakeweed, bush muhly, four-wing saltbush, and sideoats grama. East of 8.4 m (Fig. 44) vegetation is much less dense and consists of scattered mesquite and snakeweed; barren areas are common between the shrubs.

Vicinity of the fault—west—Pedon 29a (Figs. 44-46A; Table 19) is a Pachic Argiustoll that illustrates soils in the western part of the study trench, and argillic horizon formation in soils of late Organ **III** age. In contrast to sites 27 and 28, no sediments and soils of Pleistocene age are evident in the exposures. The surficial C horizon of Historical age is discontinuous and present only along the scarp base. Drainageways occur below the scarp base, so that any Historical deposit would have been eroded.

The study trench was deepened just before it was filled, and additional notes were taken on the exposures. Figure 45 shows pedon 29a before the trench was deepened. In deepening the trench, the boulder shown at the right side of Fig. 46A was removed. A 5YR Bt horizon beneath the boulder may be buried, although the exposure was not adequate to be certain. The Bt horizon disappeared at the right (east) margin of the boulder shown at the right in Fig. 46A. Because of the possibility of post-faulting erosion of the Bt horizon, and possible disturbance due to displacement of the numerous large rock fragments, it is uncertain whether disappearance of the Bt horizon marks the fault or whether it is farther downslope.

Vicinity of the fault—east—Eastward the Organ III skeletal zone deepens and the overlying fine earth zone correspondingly thickens. Pedon 29b illustrates the soil in the eastern part of the trench; this is the Ustollic Haplargid, Summerford. Laboratory analyses (Table 20) show that this soil has a distinct clay bulge and an argillic horizon; its formation in Organ HI sediments is attributed to increased moisture and clay from the high scarp upslope. The increased moisture, as compared to sites 27 and 28, is attributed to the relative sparcity of vegetation on the high scarp above site 29, as compared to the scarp above sites 27 and 28. Also attesting to increased moisture is the greater depth of leaching: the trench as a whole reveals a very thick noncalcareous zone. For example, the deepest part of the trench is about 0.6 m west of pedon 29b (Fig. 44). There the noncalcareous zone extends to 132 cm depth. A similarly thick zone, underlain by a stage I carbonate horizon, extends east and west of this point. This very thick noncalcareous zone shows that the wetting front extends to this depth frequently enough to keep the zone above it carbonate-free. It also supports the idea of increased moisture and clay from the high scarp being involved in the increased clay movement and speeded argillic horizon formation in these soils.

Site 29 differs from sites 27 and 28 in having multiple fine-earth and skeletal zones (Fig. 44). Slope of the lower zones suggests that they may reflect sedimentation from the North Arroyo fan to the south (Fig. 5A).

Soils above site 29

An area just northwest of the west end of the trench appears to have received sediments from upslope very recently, possibly during the 1978 flood. Many cobbles and pebbles have moved downslope; the soil at the west end of the trench shows a concentration of them on **the** surface, but few in the fine-earth zone beneath (Fig. 46A). Very recent erosion and deposition are also suggested by slight, recent-appearing rills, and by stones and boulders that are still in place (because they are larger and set deeper in the soil) with a reddish boundary on the lower sides of exposed surfaces, marking the former presence of a soil horizon now eroded away. Clearly, a considerable amount of fine earth, pebbles and cobbles have recently been moved by erosion. Comments below are located by number in Figure 44, upper.

Number 1—In contrast to the area below, which has common cobbles and a slight, undulating appearance suggesting deposition, this area has larger rock fragments and appears to have been eroded. Color of the Bt horizon is 5YR 3.5/4, moist, at 25 cm **depth.** Chromas of the epipedon are too high for a Mollisol, but laterally some less eroded sites would qualify. This is a complex of Argiustolls and Ustollic Haplargids. Numerous roots and vegetation indicate that organic carbon would be high.

Number 2—A boulder has moved about 10 ft (3 m) downslope, and the upslope side of the cavity provides a good exposure. This soil is an Aridic Argiustoll with a thick, dark A horizon, 7.5YR 2/2, moist, dominantly a very cobbly sandy loam that is about 45 cm thick. The Bt horizon has 5YR hue.

Number 3—This is the eroded, upper part of the scarp, just below the slope of the stable fan. Vegetation is similar to other transects up the scarp in this position. A high-chroma Bt horizon is at 25 cm depth; this pedon is nearly a Mollisol in this stable area selected for digging. But adjacent areas are eroded more and the high-chroma Bt horizons are shallower. Ustollic Haplargids are clearly dominant in this area.

TABLE 20—Particle size distribution for pedon 29b. Abbreviations explained in Table 6 caption (p. 32).

Horizon	Depth, cm	Sand 2.0–0.05 mm	Silt 0.05–0.002 mm	Clay <0.002 mm	Textural class
A1	0–5	78	14	8	ls
A2	5–10	76	14	10	sl
BAt	10–27	72	17	11	sl
Bt1	27–44	72	14	14	sl
Bt2	44–70	70	18	12	sl
Bt3	70–102	76	14	10	sl
BCt	102–123	72	16	12	sl

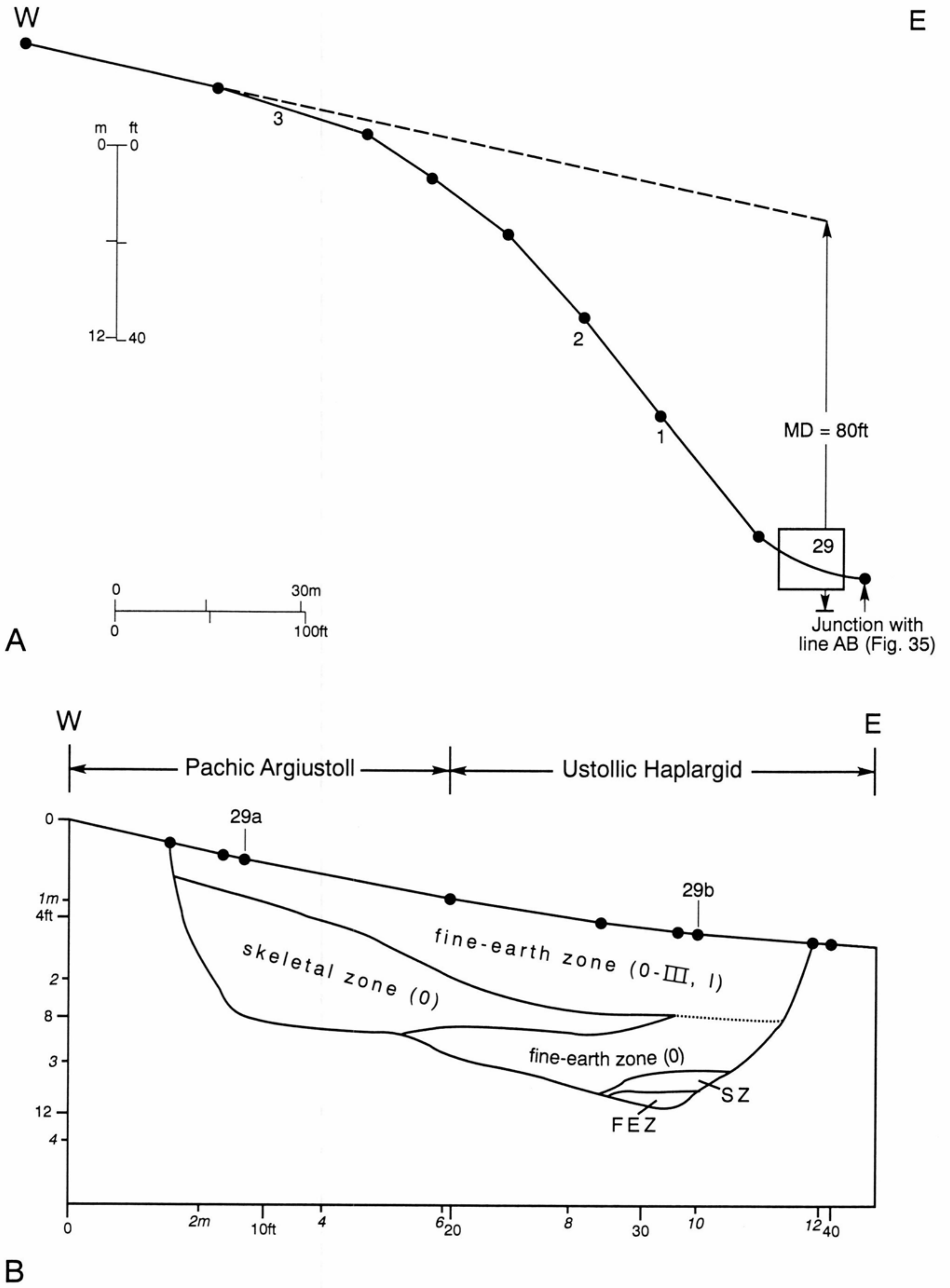


FIGURE 44—A) Diagram showing transect X (Fig. 35), its relation to the study trench at site 29 at right, and minimum displacement (80 ft, 24 m) of the Jornada I surface. Nos. 1–3 locate notes on the upper horizons of soils (see text). B) Diagram of the study trench at site 29, showing location of pedons 29a and 29b, elevations, subgroups, and the skeletal and fine-earth zones.

FIGURE 45—Landscape view of the study trench at site 29, looking to the northeast. Boulders in the foreground of the trench are early Organ III, mark the top of the skeletal zone (Fig. 44), and are overlain by late Organ III sediments of the fine-earth zone. The tape is at pedon 29b, the Ustollic Haplargid, Summerford (see Table 19). The San Andres Mountains are at left.

Soils of drainageways

Three drainageways descend the scarp between sites 27 and 29 (Fig. 40). The larger drainageways in the scarp consist of two general parts—well-defined channels that carry the streams, and adjacent areas that grade laterally into these channels (Fig. 46B). Many parts of these channels were cut by the 1978 flood and are plainly visible in the 1983 aerial photographs (Figs. 18, 35). Banks of the channels provide excellent exposures of soils adjacent to the channels. These soils were studied, photographed and sampled in the spring of 1979, when the exposures made in the 1978 flood were still quite fresh. Sites 30-32 occur along these three channels.

Haplustoll and Haplargid at site 30

Site 30 (Fig. 35, Table 21) is the southern of the three sites illustrating soils of the broad drainageways that are cut in the scarp. Site 30 has two parts, 30a and 30b.

Typic Haplustoll at Site 30a—The soil at site 30a (Fig. 47) is a Typic Haplustoll that is located in the north-facing bank of the channel below the scarp base. Slope is 5% to the east.

The fine-earth zone in which this soil has formed appears to be similar to the upper fine-earth zone at site 29. However, particle size analyses do not show a clay increase in the Bt horizon (Table 21). The Bt horizon is a Iambic horizon and the soil is a Typic Haplustoll (Soil Survey Staff,

FIGURE 46A—The Pachic Argiustoll, Earp Variant (see Table 19) at site 29a. The boulders at right and the smaller rock fragments at left mark the top of the early Organ III sediments and the skeletal zone (Fig. 44). The rock fragments are overlain by late Organ III sediments of the fine-earth zone. Scale is in feet.

1975, 1990a); the epipedon contains enough organic carbon for mollic (Table 21).

The soil at site 30a is noncalcareous throughout, reflecting the considerable depth of wetting, perhaps augmented here by channels in the drainageway. Two buried B horizons are in the pedon (Table 21).

Site 30a was photographed in 1979, and distinct changes have taken place since then. A key locator boulder, about 25 inches (0.6 m) in diameter, appeared to be at least 3 ft (0.9 m) south of the bank when photographed in 1979 (Fig. 47). When viewed on March 13, 1989, the bank had eroded enough that the boulder was on the edge of the bank. Nearby shrubs were also much larger.

Observations between sites 30a and 30b—On the south side of the channel upslope is an exposure of a stage III K horizon that is similar to the one at sites 27 and 28. Farther upslope, the stage III horizon grades out and does not occur in the vicinity of site 30b.

Several large oak, mesquite and hackberry trees are in the channel. The oak trees range up to 20 inches (50 cm) diameter. In May, 1979, the trees were seen to be scarred and some were bent by piles of stones and boulders deposited by the 1978 flood. In places near the trees are exposures of a Bt horizon below a surficial zone with abundant rock fragments.

Ustollic Haplargid at Site 30b—Site 30b (Figs. 35, 48, 49; Table 21) occurs on the north side of a long, wide channel that was cut by the 1978 flood. Slope is about 50%. The incised channel grades out upslope (Fig. 48).

Site 30b is in the zone of strong leaching and lateral movement of clay and carbonate shown in Fig. 46B. The soil has formed in thin, stony colluvium that overlies beveled, stony and bouldery Jornada I alluvium. The A and E horizons have formed in the colluvium; the Bt horizon has formed in the beveled Jornada I alluvium. Rate of movement of the colluvium is not known, but it is clearly not fast

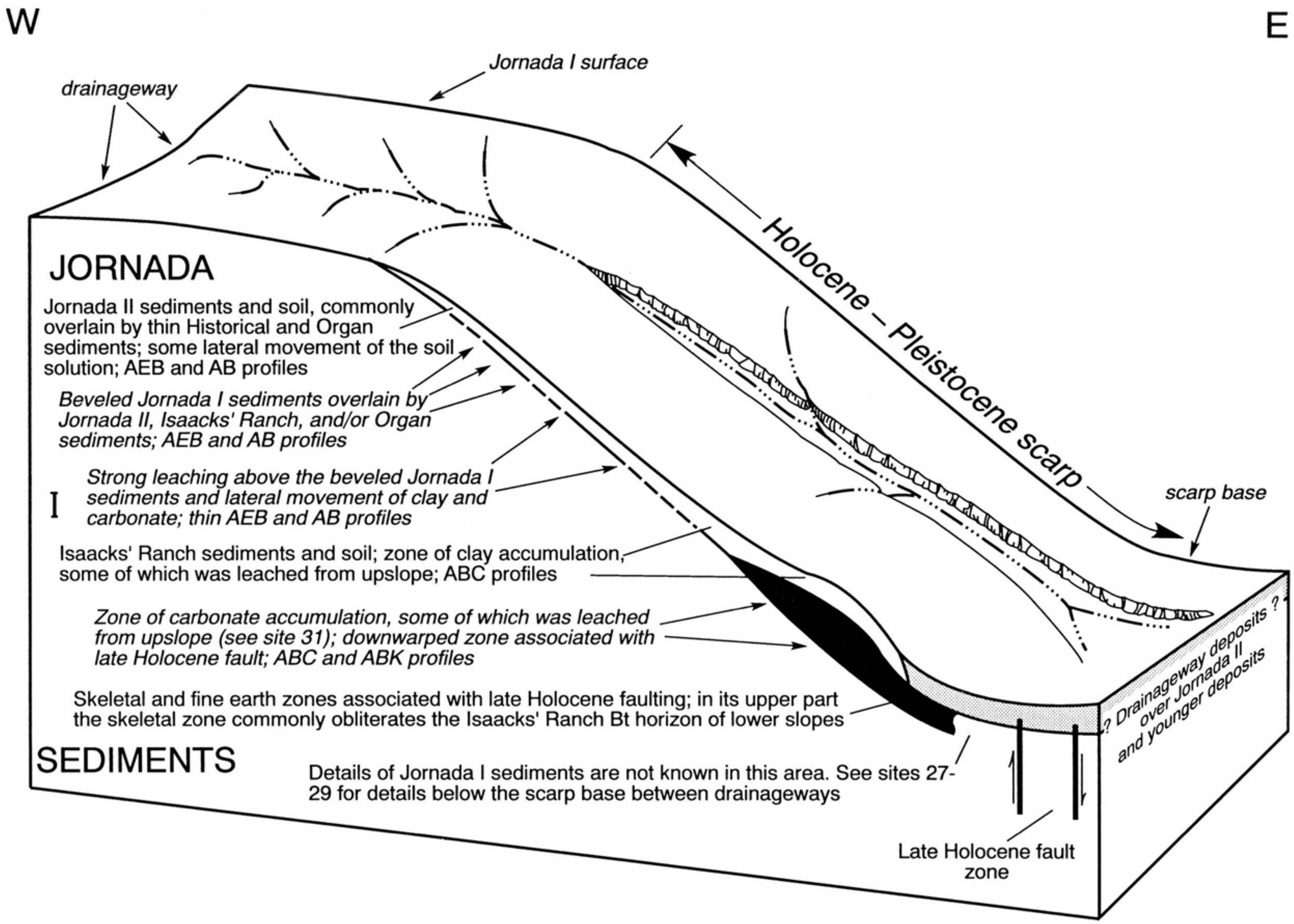


FIGURE 46B—Generalized diagram of a drainageway in the Holocene–Pleistocene scarp. The dominant sediments and horizonation, the late Holocene fault zone, and major zones of leaching and accumulation are indicated. A pre-Holocene fault zone, not shown, is located in the downwarped area (see site 31b).

TABLE 21—Characteristics of Organ soils at site 30. Clay percentages for the 0–5, 5–21, and 21–44 cm horizons of pedon 30a are 7.6%, 6.4% and 7.6% respectively. Abbreviations are explained in Table 6 caption (p. 32).

Horizon	Depth, cm	Hue	Value/chroma Dry	Value/chroma Moist	Textural class	Structure	Dry consistence	pH	Organic C
Typic Haplustoll at site 30a—Organ III over buried B horizons of unknown age									
A1	0–5	7.5YR	4.5/2	2.5/2	sl	m	s, sh	6.8	0.56
Bt1	5–21	7.5YR	4/2	2/2	sl	lcsbk	sh	7.4	0.69
Bt2	21–44	7.5YR	4.5/2	2.5/2	sl	lcsbk	sh	7.4	0.58
Bt3	44–59	7.5YR	4/3	2.5/3	sl	lcsbk	sh	7.4	
BCt	59–82	7.5YR	4.5/3	3/3	sl	lmsbk	sh	7.4	
BAb	82–104	7.5YR	4.5/3	3/3	sl	lmsbk	sh	7.6	
Btb	104–119	7YR	5/3.5	3.5/3.5	sl	lmsbk	sh	7.6	
Btkb	119–146	6YR	5/3	3.5/3	sl	lmsbk	sh		
Bkb2	146–150	5YR	5/3	3.5/3	sl	lmsbk	sh		
Ustollic Haplargid at site 30b—Organ (?)									
A	0–12	7.5YR	4/2	2.5/2	vstsl	lmsbk	sh	6.6	
E1	12–26	7.5YR	4.5/2	3.5/2	vstsl	lfsbk	sh	6.6	
E2	26–41	9YR	6/3	4.5/3	vstsl	lfsbk	sh	6.2	
2Bt	41–43	7.5YR 7.5YR	5/3 4/2	4/3 3/2	vstsl	lcsbk	vh	6.2	

FIGURE 47—The unnamed Typic Haplustoll (see Table 21) in Organ III sediments at site 30a, looking east. Key locator boulder is at right of tape. Scale is in feet. Photographed June, 1979.

FIGURE 48—View of the drainageway up the scarp at site 30b, looking west. Beveled Jornada I sediments are exposed in the channel at center. Sediments and soils of the drainageway slope towards and occur on both sides of the channel. Pedon 30b is at the tape at right. Photographed June, 1979.

enough to prevent the development of distinct A and E horizons.

The E horizon contains less clay and is lighter-colored than the A horizon. Such E horizons are common in soils with beveled Jornada I alluvium at shallow depth in the broad drainageways in the scarp. These E horizons differ partly in origin from the typical thin E horizons of desert soils in that their development on steep slopes of the scarp clearly reflects a substantial component of lateral movement of water in the soil. Several factors tend to promote leaching and the development of E horizons in these soils. The slopes are steep and the colluvium is relatively coarse-textured and permeable. Materials of very low permeability—stony, tightly packed Jornada I alluvium—are at shallow depth. These characteristics would tend to slow movement of soil water into Jornada I alluvium; thus during moist times a substantial amount of water would be available for lateral movement. Due to the strong leaching regime the soil has pH values that are well below 7 (Table 21) and thus there is no flocculating effect of carbonate to retard clay movement. When site 30b was examined in March, 1989, the pedon sampled in 1979 had largely eroded away, and E horizons were discontinuous at the existing exposure.

Jornada I sediments at the base of the pedon and in the adjacent channel constitute Bt material, with dark illuvial clay occurring in intricate pattern with yellowish material. The illuvial clay is readily observed because it is dark and penetrates not only the fine earth but cracks in rock fragments that are lighter in color. The Bt material in the channel is interpreted as pedogenic clay that accumulated from overlying horizons that were eroded away in the 1978 flood.

FIGURE 49—The unnamed Ustollic Haplargid at site 30b (see Table 21), looking north. Note continuous cover of stones and boulders. Steep slopes, cover of rock fragments, and the very hard Jornada I sediments at shallow depth promote lateral leaching and development of E horizons, which occur discontinuously in the fine earth between the rock fragments and the Jornada I sediments. Photographed June, 1979.

It should be stressed that site 30b and other locations along the scarp (e.g., sites 31 and 32) have excellent potential for studying rates of colluviation. Photographs taken in 1979 constitute good chronological benchmarks, and rock fragments ranging in size from cobbles to boulders are positive locators in the steep scarp landscape. Because the scarp is on WSMR, it would be a permanent site for long-term study.

Observations upslope—Upslope of site 30b, rock fragments in the Jornada I sediments change from largely rotted boulders to smaller, less weathered rock fragments. A prominent reddish Bt horizon is exposed in the upper part of the channel. Slope along the Jornada **I** fan is 7%. Slope of the first 4 m of scarp is 30%; slope of the next 7 m of scarp is 55%. There is a cobbly transition zone, of intermediate slope, between the 7% and 30% slopes.

The upper part of the scarp has no distinct channels, but there are occasional slight lows that reflect more apparent drains upslope, where large boulders are common. These boulders control the location of the drainageways, which go around them.

Camborthid and Argiustoll at site 31

Site 31 (Fig. 35, Table 22) is the central of the three sites illustrating soils of the broad drainageways. Soils at two sites, 31a and 31b, were sampled at site 31.

Ustollic Camborthid at site 31a—Figures 35 and 50 locate the Ustollic Camborthid at site 31a. The soil is exposed

TABLE 22—Characteristics of Organ and Isaacks' Ranch soils at site 31. The soil at site 31a is calcareous throughout. Abbreviations are explained in Table 6 caption (p. 32).

Horizon	Depth, cm	Hue	Value/chroma		Textural class	Structure	Dry consistence	pH
			Dry	Moist				
Ustollic Camborthid at site 31a—Organ III over Bbk of unknown age								
A1	0–11	8YR	5/2	3/2	sl	m	s	
A2	11–23	8YR	5/2	3/2	sl	m	s	
A3	23–37	9YR	5/2	3/2	sl	m	s	
Ck1	37–58	9YR	5.5/2	3.5/2	sl	m	s	
Ck2	58–76	9YR	5.5/2	3.2/2	sl	m	s	
Ck3	76–84	9YR	5.5/2	3.5/2	sl	m	s	
Bbk	84–99	9YR	5.5/2	3.5/2	sl	lmsbk	sh	
Aridic Argiustoll at site 31b—Organ over Isaacks' Ranch over beveled Jornada I								
A1	0–4	9YR	5/1.5	3/1.5	vcsl	lmsbk	sh	7.4
A2	4–19	9YR	5/1.5	3/1.5	csl	lmsbk	sh, h	7.4
Bt1b	19–35	6YR	5/3	4/3	cscl	2mpr-lmsbk	vh	7.4
2Bt2b	35–48	6YR	5/3	4/3	scl	2mpr-lmsbk	vh	7.4
2BCt1b	48–61	6YR	5.5/4	4.5/4	sl	lmsbk	sh	7.6
2BCt2b	61–69	7.5YR	6/3	4.5/3	sl	lfsbk	sh	7.6
2BCtkb	69–76	7.5YR	6/3	4.5/3	sl	lfsbk	sh	
3Ck1b	76–95	10YR	8/3	6.5/3	sl	m	s, sh	
3Ck2b	95–125	10YR	9/3	7/3	ls	m	sh, h	
		5YR	6/4	5/4				
		5YR	3.5/3	3/3				

in the north-facing bank of the large channel below the scarp base. A pile of large rock fragments in the main stream just north has forced part of the stream to the south where the sediments contain little or no skeletal material; this is the fine-earth zone, in which the soils at site 31a have formed.

Stage I carbonate filaments occur in the Ck horizon. Presence of the Ck horizon here (and not at site 30a in the same landscape position) is attributed to the presence of more carbonate in these parent materials. The soil contains about 5 to 10% pebbles throughout, as is typical of the fine earth zones.

Aridic Argiustoll at site 31b—The soil at site 31b (Figs. 35, 51-53) is exposed in the north bank of the main channel that was cut by the 1978 flood, just above the base of the steep scarp. When photographed in June, 1979, the exposure was still well preserved. Vegetation is dense compared to areas higher on the scarp, and includes trees and large shrubs (Fig. 51). Slope is 42% to the east.

The exposures at site 31b illustrate the effects of two different displacements on sediment disposition and morphology. The exposures also illustrate the transition from a strong leaching regime on the middle slope of the scarp to a regime of clay and carbonate accumulation on the lower slope of the scarp. Occurrence of E horizons is also associated with slope position; they are generally absent on lower slopes.

The Argiustoll at site 31b (Table 22) has a sandy clay loam Bt horizon with 6YR hue and is a common soil in the drainageways on the lower part of the scarp. Three different materials are in the studied pedon: an upper part that is cobbly, stony and bouldery (Organ sediments); a central part that is sandy clay loam with few rock fragments (Isaacks' Ranch sediments); and a lower part with sandy loam and sandy textures, in places with common rock fragments (Jornada I sediments).

The Jornada I sediments contain evidence of faulting that predates the overlying materials. The Ck horizon contains carbonate and whitish, noncalcareous salts in light colored strata that alternate with reddish brown strata (Fig. 53). The reddish brown strata are commonly wholly or partly noncalcareous. On the west margin of the fault plane, slope of the strata abruptly increases to nearly vertical (slope about 155% to the east). This zone of nearly vertical plates is about 7.5 ft (2.2 m) wide from east to west. The Jornada II fine-earth zone at sites 27 and 28 may have been deposited as a result of this displacement.

Slope abruptly increases at the tape (Fig. 51), and this is interpreted as downwarping associated with the latest displacement. At the extreme right of Figure 51, early Organ III sediments truncate both Isaacks' Ranch sediments and Organ sediments that are pre-Organ III. The early Organ III sediments are thought to be analogues of the fault-caused early Organ **III** sediments at sites 27 and 28. Thus the site illustrates the contact of fault-caused colluvium and colluvium emplaced due to change in climate or other cause as discussed in the following section.

Origin of the Isaacks' Ranch sediments

The Bt horizon at site 31b has formed in a distinctive deposit that overlies beveled Jornada I alluvium, and that was found only in drainageways on the lower slope of the scarp. The clay maximum is a sandy clay loam that commonly has few rock fragments, though skeletal materials do occur in places. The deposit is thought to be of Isaacks' Ranch age because hue of the Bt horizon (commonly 5YR, or between 5YR and 7.5YR) is about the same as hue of Isaacks' Ranch Bt horizons with these textures in the Desert Project (Table 22). Origin of the deposit is of interest because of its abundant clay and sparcity of rock fragments. Origin by stream deposition seems unlikely because of the steep slopes; nearby channels with the same slope were swept clean by water action (see Fig. 48). A mechanism for origin is required by which large amounts of fine earth could be emplaced on a steep slope. Overland flow (glossary) was noted at the Desert Project for gentler slopes of the fan-piedmont (Gile et al., 1981, pp. 174-175), but may also be involved in the much steeper slopes of the scarp. Fine earth in the Isaacks' Ranch deposit may have accumulated by overland flow as described by Horton (1945, pp. 316, 317). As slope decreases below the steepest part of the scarp, the ability of overland flow to carry materials away may decrease because the flow is fully charged with material in suspension, in which case sedimentation instead of erosion will occur (Horton, 1945, pp. 317). The slope shown in Fig. 51 would have been gentler east of the tape prior to down-warping.

Strong lateral leaching from steeper soils upslope (e.g., from areas like site 30b previously discussed) may also have been involved in emplacement of some of the clay in Isaacks' Ranch sediments. Clay could move downslope in soil water along the contact to the beveled Jornada I sediments and then accumulate on top of the stripped Jornada I surface downslope, as at site 31b and vicinity. The process would be similar to the lateral movement of clay downslope along clay bands in soils of sandhills, which caused thicker clay bands on sides of dunes than on dune crests (Gile, 1985, p. 205). Here, however, such laterally deposited clay could be thicker because of the much steeper slopes and the dense Jornada I sediments that are only slowly pervious. Clay deposited in this manner would now be largely diluted with coarser sediments because of pedogenic mixing and the formation of soil horizons.

Preservation of the Isaacks' Ranch sediments on lower slopes of the scarp must have been helped by dense vegetation, which includes trees and large shrubs, and the common rock fragments at the surface. Both factors would tend to stabilize the lower slope of the scarp, minimize erosion (except that caused by faulting) and favor infiltra-

FIGURE 50—Sediments of the late Organ III surface and an unnamed Ustollic Camborthid (see Table 22) are at the tape at site 31a, looking southeast. Scale is in feet.

tion of dustfall, which would also contribute additional fine earth.

To summarize, the proposed sequence of events for deposition of Isaacks' Ranch sediments is as follows. First an episode of faulting took place, in which Jornada I sediments at site 31b were displaced (Figs. 51-53). The faulting must have accelerated erosion, which would strip away any post-Jornada I soils and sediments and expose Jornada I sediments at the surface. Then the Isaacks' Ranch sediments were emplaced by overland flow and/or leaching from the soils upslope. This was followed by deposition of a thin layer of skeletal Organ colluvium, after which the the once-gentler slope was considerably increased by downwarping associated with the late Holocene fault downslope (see sites 27 and 28).

The time of colluvial deposition is difficult to estimate if the colluvium is very thin and only A and/or E horizons are present above the Bt horizon in beveled Jornada I sediments. But in many places the colluvium is thick enough that both E and Bt horizons have formed in it, and in these cases erosion and deposition of the colluvium may reflect major changes in climate as is the case for alluvia of much gentler slope at the Desert Project (Gile et al., 1981). The distinct horizons indicate that some colluvia have either stopped moving downslope or are moving so slowly that soil morphology is virtually undisturbed. Thus soils of Organ, Isaacks' Ranch, and Jornada II age have been identified in the colluvia because they are very similar to soils of these ages and textures in the Desert Project.

Source of carbonate

Exposures along the north bank above site 31b shed light on the source of carbonate that is typical in Jornada I sediments along and just above the scarp base. Accumu-

FIGURE 51—Landscape view of site 31b, in the north bank of the scarp arroyo. This site illustrates the thickly vegetated zone, including oak and hackberry trees, that is typical of lower slopes of the scarp. Pedon 31b, at the tape, illustrates an unnamed, fine-loamy Aridic Argiustoll (Table 22). Sediments below a depth of about 2 ft (0.6m) are beveled Jornada I sediments; overlying colluvium is thought to be of Isaacks' Ranch and Organ age (see text discussion). Scale is in feet. Photographed June, 1979.

lation of pedogenic carbonate must have been controlled in large part by long-continued lateral leaching down the scarp. This is indicated by evidence of strong leaching in soils upslope, and by characteristics of carbonate accumulation, to be discussed, that are associated with the 3Ck1b and 3Ck2b horizons in pedon 31b and their adjacent analogues.

Carbonate filaments occur in upper parts of the 3Ckl horizon of pedon 31b, just below the silicate clay maximum in the Bt horizon. This is in characteristic position for carbonate accumulation by vertical or near vertical leaching in young soils—below the silicate clay. But carbonate deeper in the 3Ckl horizon occurs along sedimentary strata and could have accumulated by leaching from upslope. Carbonate gradually decreases in the 3Ckl horizon upslope. At a point about 16 ft (4.8 m) west of pedon 31b, the last visible carbonate may be traced upward as filaments into the overlying Bt horizon. This carbonate was clearly leached from overlying horizons and not by lateral leaching from up-slope. Thus carbonate of both origins—lateral and vertical leaching—are present in this exposure.

Carbonate in the 3Ck2b horizon of pedon 31b may be traced upslope to where it first gradually thins, occurring mainly on tops of rock fragments. At 12 ft (3.6 m) west of pedon 31b, carbonate in both the 3Cklb and 3Ck2b horizons becomes much more diffuse. This suggests that carbonate in both horizons has similar origin, and that some of this

FIGURE 52—Closer view of Aridic Argiustoll at site 31b. The tape (Fig. 51) was moved before cleaning the fault plane (see Fig. 53); former location of the tape is indicated by the vertical line. Geologic hammer at left, and nail below and left of the inked line also give scale.

carbonate may have been emplaced as a result of lateral leaching. At 16 ft (4.8 m) west of pedon 31b the carbonate finally disappears altogether, grading into a noncalcareous heavy sandy clay loam that overlies stony Jornada I sediments. The spot where the transition between calcareous and noncalcareous material takes place is directly beneath the point at which the last filamentary carbonate grades directly upward into the Bt horizon of the Isaacks' Ranch soil.

Downslope of pedon 31b, carbonate in the 3Ckb horizon gradually becomes more abundant until (near the east end of the exposure, Fig. 51) the horizon qualifies as a K horizon. Relation of this K horizon to the K horizon below the scarp base (e.g., at sites 27 and 28) is not known. The two K horizons occur in different geomorphic settings, the former being emplaced largely as a result of downslope movement of carbonate from higher on the scarp. The latter (the Jornada II K horizon) has formed in a fault-caused Jornada II deposit instead of Jornada I sediments (see site 27), although it too may have been influenced by long-term leaching from upslope.

At the Desert Project, the Isaacks' Ranch soils commonly have stage II carbonate horizons that are a significant chronological-morphological marker. But here on steep slopes of the scarp, the strong effect of lateral leaching on carbonate accumulation preludes the chronological use of carbonate because the percentage of carbonate associated with Isaacks' Ranch soils ranges widely.

General occurrence of the zone of carbonate accumulation beneath the Isaacks' Ranch sediments may not be coincidental. Accumulation of carbonate beneath silicate clay is the usual situation in young soils in which the wetting front moves vertically or nearly so. Similar position of the two accumulations could also be caused by lateral leaching,

FIGURE 53—Closer view of the fault plane. Nail parallels near-vertical platy units in the fault plane.

with most of the carbonates leached from upslope moving in solution into the Jomada I sediments and the clay deposited from suspension above them, thus enriching the clay content of the zone in which the Isaacks' Ranch Bt horizon has formed.

Argiustolls, Haplargid, and Calciorthids at site 32

Site 32 (Fig. 35, Table 23) is the northern of the three sites illustrating soils of drainageways in the scarp. Sites 32a-e illustrate soils of the drainageway.

Ustollic Calciorthid at site 32a, and its contact to site 32b—At site 32a (Figs. 35, 54-56), skeletal sediments of early Organ III age bury a K horizon in Jornada I sediments. The early Organ III sediments are considered to be analogous to the early Organ III sediments at nearby sites 27 and 28 (Fig. 35), and to have been deposited as a result of the latest displacement. At the contact to site 32b upslope, the early Organ III sediments abruptly cut the Isaacks' Ranch sediments at a large boulder, which has protected them from erosion (Fig. 56). The prominent, but nonindurated K horizon is typical on lower slopes of the drainageways (see also site 31).

Aridic Argiustoll at site 32b—Figures 35 and 55 locate the Argiustoll at site 32b. Deposits of two ages are presentIsaacks' Ranch and Jornada I (Table 23). The Isaacks' Ranch soil has the same 5YR-7.5YR Bt horizon seen in numerous places on the lower slope of the drainageway. Here the Isaacks' Ranch soil contains more rock fragments than at site 31b, and a K horizon is present in Jornada I sediments. Most of the Btl horizon is 5YR 4/3, dry, but scattered parts are 5YR 5/4, dry, illustrating sporadic development of 4 chroma.

Ustollic Haplargids at site 32c—Figure 35 locates an Ustollic Haplargid at site 32c, in the south bank of the channel. Slope is 40% to the east .

This soil illustrates one of the thickest and most prominent E horizons observed along the scarp. Large boulders are common; they would tend to stabilize the slope and favor the formation of E horizons. Texture contrasts with that of the Bt horizon beneath, which is formed in beveled Jornada I alluvium (Table 23). The pH values decrease with depth, to 6.6 in Jornada I alluvium, reflecting the leaching environment; compare with pedon 32b downslope where pH values are 7.2 or above throughout.

TABLE 23—Characteristics of Organ, Isaacks' Ranch, and Jornada II soils at site 32. Abbreviations are explained in Table 6 caption (p. 32).

Sediment	Horizon	Depth, cm	Hue	Value/chroma		Texture	Structure	Dry consistence	pH
				Dry	Moist				
Ustollic Calciorthid at site 32a									
O-III, I	A1	0–10	7.5YR	4/2	2/2	vstfsl	m	sh	7.4
	A2	10–20	7.5YR	5/2	3.5/2	vstfsl	m	sh	7.6
	2Bk	20–29	9YR	6.5/2	4/2	fsl	m	sh	—
J-I (S)	2K21b	29–38	10YR	8/2	6.5/3	sl	m	sh	—
	2K22b	38–48	10YR	7.5/2	6/3	s	m	sh, h	—
Aridic Argiustoll at site 32b									
IR	A1	0–5	7.5YR	4/1.5	2/2	vstsl	m	sh	7.2
	A2	5–16	7.5YR	4/2	2/2	vstscl	m	sh	7.2
	A3	16–32	7.5YR	4.5/2	3/2	vstscl	m	sh	7.2
	Bt1	32–53	5YR	4/3	3/3	vstscl	1csbk	h	7.2
	Bt2	53–72	5YR	5.5/3	4/3	vstscl	1csbk	h	7.2
	Btk	72–83	5YR	6/3	4.5/3	vcscl	1csbk	sh	7.6
J-I (S)	2K21b	83–112	9YR	8/2.5	6/3	sl	m	sh, vh	—
	2K22b	112–135	10YR	8/2	6.5/3	ls	m	h, vh	—
Ustollic Haplargid at site 32c									
O (?)	A	0–8	7.5YR	4.5/2	2.5/2	sl	m	sh	7.0
	E1	8–16	7.5YR	5/2	3/2	sl	m	sh	7.0
	E2	16–31	7.5YR	5/2	3.5/2	ls	m	sh	6.8
	E3	31–45	7.5YR	5/2	3.5/2	sl	m	sh	6.8
J-I (S)	2Bt	45–54	7.5YR	3/4	3/4	c	m	vh	6.6
Aridic Argiustoll at site 32d									
H	C	0–7	6YR	5/3	3.5/3	vsts	m	sh	6.6
O	Ab	7–18	7.5YR	4/2	2.5/2	vstfsl	m	s	6.8
J-II	2Ab2	18–33	7.5YR	4.5/2	3/2	fsl	m	sh	6.6
	2Eb2	33–42	6YR	5.5/2	4/2	sl	m	sh	6.6
	2Bt1b2	42–54	2.5YR	4/4	4/4	c	2msbk	vh	6.8
	2Bt2b2	54–69	5YR	4/4	4/4	scl	1msbk	vh	6.4
	2Bt3b2	69–90	5YR	4/4 3/4	4/4 3/4	scl	1msbk	vh	6.4
J-I (S)	3Btb2	90–95	2.5YR 5YR 7.5YR 10YR	4/4 4/3 4/2 7/1	3.5/4 3/3 3/2 6/1	csl	1msbk	vh	6.4
Aridic Argiustoll at site 32e									
O	A1	0–9	7.5YR	4/2	2.5/2	vstsl	m	s	6.6
	A2	9–19	7.5YR	4/2	2.5/2	vstsl	m	sh	6.8
	Bt	19–30	7.5YR	4/2	2.5/2	vstscl	m	sh	6.8
J-II	2BAtb	30–40	5YR	3.5/3	2.5/3	scl	m	sh	6.8
	2EB/BAtb	40–52	5YR	5/3	4/3	scl	m	sh	6.8
	2Bt1b	52–66	2.5YR	4/6	3.5/6	scl	2msbk	vh	6.8
	2Bt2b	66–75	5YR	4/6	4/6	scl	2msbk	vh	6.8
J-I (S)	3Btb	75–90	2.5YR	4/6	4/6	vstscl	1msbk	vh	6.8

Aridic Argiustolls at site 32d—Site 32d (Figs. 35, 57, 58) shows an Aridic Argiustoll exposed in the north bank of the channel. Slope is 35% to the east.

The soil surface has a close-packed mantle of stones, cobbles and boulders (Fig. 58). The thin, surficial C horizon (Table 23) is discontinuous and occurs between large rock fragments; it is reddish and coarser-textured compared to the underlying dark Ab horizon. The layer is obviously young but has been in place long enough for plants to have rooted in it, and must predate the 1978 flood.

Sediments overlying the beveled Jomada I alluvium are interpreted as Jomada II colluvium and dustfall, not weathered Jornada I alluvium, because the materials commonly contain substantially fewer rock fragments, occur in a zone that roughly parallels the land surface, and have an abrupt boundary to the underlying Jornada I sediments.

The soil in Jornada II sediments has an E horizon and a clay Bt horizon (Table 23). Development of the clay Bt horizon would be favored by the strong leaching regime of the drainageway; by the more moist position of the drainageway; by the very hard, beveled Jornada I sediments at fairly shallow depth; and by the protective mantle of rock fragments. The latter should also serve as an efficient trap for dust falling or washing down between the rock fragments, and subsequent incorporation into the soil. The 2.5YR hue is typical in soils of Jornada II age. This soil has markedly fewer coarse fragments than overlying and underlying materials, and some of the fragments are so weathered that the component crystals no longer hold together.

The Jomada II sediments may have accumulated much as the overlying sediments apparently did—by thin increments of colluvium and dustfall between surficial rock fragments at various times. However, much of the area in the vicinity of site 32d must have been relatively stable for a long period of time, as required for development of the prominent Jomada II soil.

FIGURE 54—General view of the scarp arroyo at site 32, looking west. Sites 32a and 32b are at left in the south bank of the arroyo. The large rock fragments in the foreground were deposited in the 1978 flood. Photographed June, 1979.

A gigantic desert pavement

Most definitions of the term "desert pavement" will need to be modified to accommodate the ideas of McFadden et al. (1987). For example, the definition of desert pavement in the Glossary of Geology (Bates and Jackson, 1987) is as follows:

> *Desert pavement*—A natural residual concentration of wind-polished, closely packed pebbles, boulders, and other rock fragments, mantling a desert surface (such as an area of reg) where wind action and sheetwash have removed all smaller particles, and usually protecting the underlying fine-grained material from further deflation.

McFadden et al. (1987, p. 507) recognize that some desert pavements consist of a lag gravel caused by eolian or fluvial removal of fines, and indeed such pavements are common in dissected landscapes. But they also demonstrate that the desert pavements of many soils can form as a result of eolian deposition of fines and their subsequent movement into materials beneath the pavement. Continued incorporation of eolian fines into materials beneath the pavement keeps it at the soil surface.

The virtually continuous mantle of large rock fragments shown in Figs. 49 and 58 may be viewed as a desert pavement (see Glossary) of gigantic proportions. McFadden et al. (1987) described formation of a pavement by colluviation of basaltic clasts from a topographic high; the pavement is maintained at the surface by downward movement of dustfall to a position beneath the surface fragments. A similar process may be envisioned for maintaining the surficial position of the pavement shown in Figs. 49 and 58 except that in these soils, some of the fines beneath the pavement are reworked sediments originally derived from beveled Jornada I sediments upslope. Presence of the desert pavement, Historical sediments, and Organ sediments above the Jornada II soil at site 32d is clear evidence of sediment movement across the Jornada II soil. This agrees with the work of Kojan (1967), who found surficial materials to move downslope faster than the materials beneath.

Long-continued movement of a surficial mantle of large rock fragments down the steep scarp may be visualized as having a "planing" effect on the underlying fine earth in some positions on the scarp. Thus at steepest slopes (such

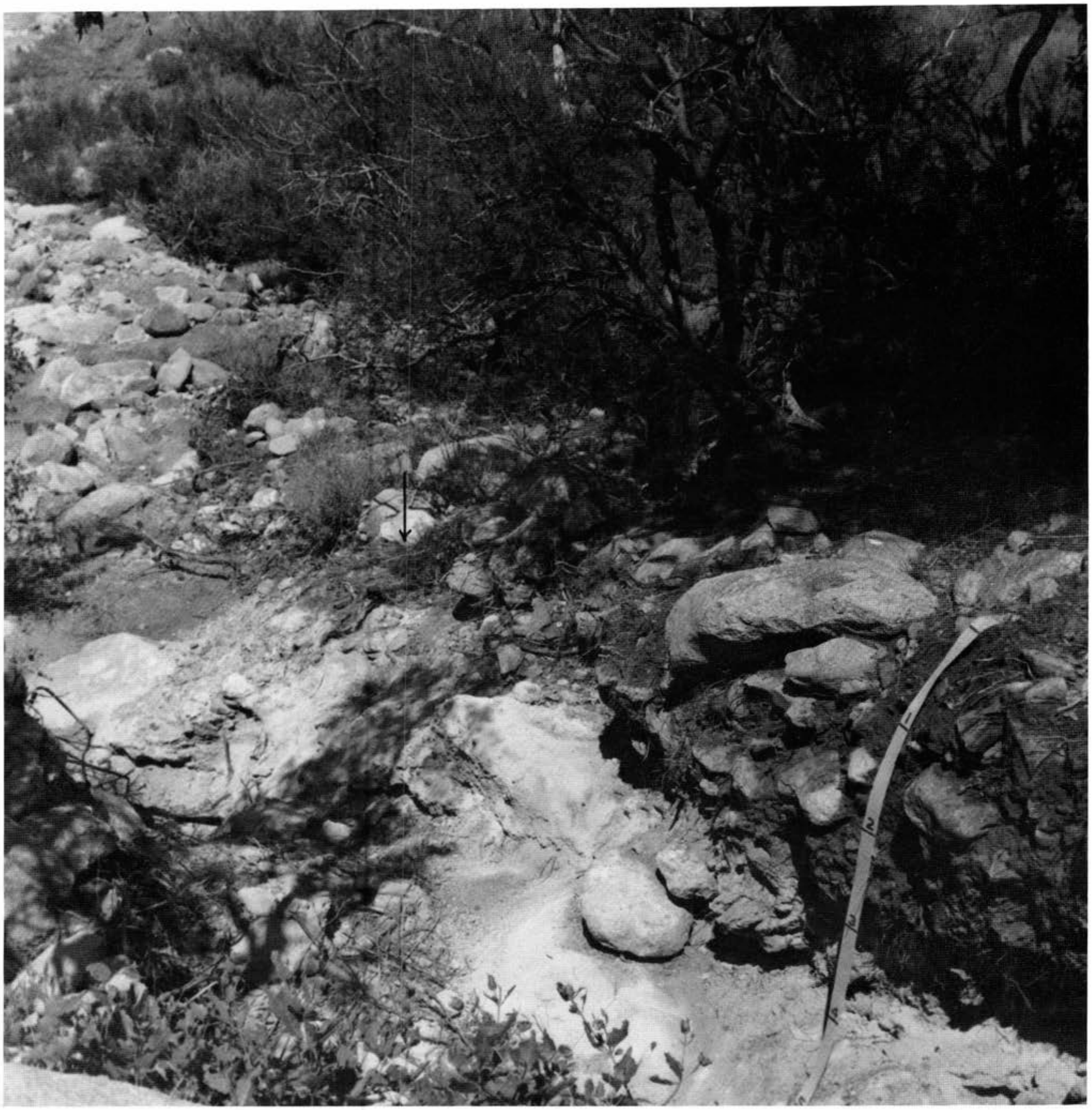


FIGURE 55—Arrow at left locates Calciorthid, pedon 32a, (see Table 23). Argiustoll, pedon 32b, (in Isaacks' Ranch over Jornada I sediments) is at the tape. Both pedons have a K horizon, as is typical near the scarp base. Scale is in feet. Photographed June, 1979.

as at site 30b) and at breaks in slope, the zone of abundant fine earth below the pavement and above the beveled Jornada I sediments may be very thin.

Aridic Argiustolls at site 32e—Figure 35 locates the Aridic Argiustoll at site 32e, exposed in the north bank of the channel. Slope is 35% to the east.

As at site 32d, a mantle of closely packed stones and cobbles covers the surface. Generally, the Jornada II soil contains few rock fragments and is very similar to the Aridic Argiustoll discussed at site 32d. Both soils have Bt horizons with 2.5YR hue in part, with the reddest and most clayey subhorizons of the Bt being in its upper part (the 2Btlb horizon in pedon 32e is a heavy sandy clay loam). The 2Eb/BAt2b horizon may still be functioning to some extent as an E horizon but its 5YR hue and 3 chroma suggest some clay accumulation.

The 3Btb2 horizon is in beveled Jornada I alluvium and has numerous andesite and monzonite rock fragments. Due to peripheral weathering of the rock fragments, the boundary between the original fine earth and rock fragments cannot be precisely located in many instances.

Exposures on both sides of the channel indicate that this Argiustoll is an extensive soil in drainageways in this position on the slope.

FIGURE 56—The tape marks the boundary between the soil with an argillic horizon (protected from erosion by the boulder at right) and the soil without an argillic horizon at left. This illustrates how large rock fragments can protect soils from erosion in some areas along the steep scarp. The Organ III colluvium at left of tape is thought to be a fault-caused drainageway analogue of the Organ III skeletal zone that overlies the fault at sites 27 and 28. The area shown is between pedons 32a and 32b (see Fig. 55). Scale is in feet. Photographed June, 1979.

Soils of the Jornada II surface (25,000-150,000 yrs B.P.): Earp very cobbly sandy loam (G, Fig. 18)

Landscape, soil occurrence, unit boundaries, vegetation

Soils of this unit occur in one area, the Jornada II terrace remnant that is inset against and lower than the Jornada I fan (Fig. 5A). Only one backhoe pit was available to examine these soils and thus variations at depth are not known. Morphology and analyses (Table 24) indicate that most soils have enough organic carbon for a mollic epipedon, but some soils have high-chroma Bt horizons at depths too shallow for a mollic epipedon. The area is dominated by Aridic Argiustolls (Earp soils), with smaller areas of Ustollic Haplargids (Caralampi soils).

Map unit G borders three map units—unit B to the south, unit F to the east and unit H to the north. Soils of unit B occur on Organ III terraces inset against the higher Jornada II. Soils of unit F occur on the scarp that cuts the Jornada II surface, a continuation of the scarp that cuts the Jornada I fan. Soils of unit H occur on the Jornada I fan, which is higher than the Jornada II terrace. On the eastern edge of unit G, the boundary to unit H is marked by a long gentle slope up to the level of the Jornada I fan; the boundary was placed at the south edge of this slope. To the west,

FIGURE 57—View up the drainageway channel at site 32d, looking west. Beveled, stony and bouldery Jornada I sediments are exposed in the channel. Drainageway sediments and soils occur on both sides of the channel. Pedon 32d (Table 23) is at the tape at right. Photographed May, 1979.

the boundary between units G and H gradually becomes less distinct.

Vegetation consists mainly of mesquite, snakeweed, prickly pear, beardgrass, catclaw, black grama and sideoats grama.

Aridic Argiustoll (Earp) at site 33

Figure 59 shows the Aridic Argiustoll at site 33, in the north bank of an arroyo where an exposure was made by backhoe. Many of the surficial rock fragments are stained reddish brown in part, and have spalled surfaces that are less red. Such spalling must also give rise to some of the numerous pebbles between large rock fragments.

The soil is very gravelly and cobbly throughout; the rock fragments are difficult to remove both because of their number and because of the clay tightly packed between the rock fragments. Reddish brown Bt material is prominent in the Bt horizon. Zones in the BCtkl horizon are less red, have less clay and are easier to remove than the Bt horizon.

The soil is noncalcareous to 110 cm depth. Most parts of the Btk and BCtkl horizons (which contain the carbonate maximum) are calcareous; filamentary carbonate is common, as well as carbonate coatings on pebbles and cobbles. Carbonate decreases in the BCtk2 horizon, and noncalcareous zones are more common than calcareous zones. The bottom of the trench was still in B horizon material at a depth of 83 inches (210 cm, Table 24). Clearly these soils are very thick. This would be expected in view of the skeletal materials (which would tend to expedite deep penetration of wetting fronts) and late Pleistocene age of these soils (which shows that they must have formed during at least one major pluvial).

An important difference between this Jornada II soil and Organ I soils concerns the character of the rock fragments. There are many more weathered fragments in the Jornada II soil and their interiors are more clayey, with clay often coating faces of the component crystals of the fragments.

FIGURE 58—Landscape of the unnamed Aridic Argiustoll (see Table 23) at site 32d, looking north. Jornada II sediments underlie thin Historical and Organ sediments, and extend to beveled Jornada I sediments at the bottom of the exposure. Note the nearly continuous mantle of stones and boulders. Scale is in feet.

Soils of the Jornada I surface (250,000-400,000 yrs B.P.): Coxranch complex (H, Fig. 18)

Landscape, soil occurrence, unit boundaries, vegetation

Soils of this unit occur in one area, the jornada I fan, where two backhoe trenches were dug at sites 34 and 35 (Figs. 5B, 18; Table 24). The backhoe could not penetrate below the sampled depths (Table 24), as discussed in the following section. For this reason the character of deeper horizons is not known. The dominant soil is an Ustollic Haplargid that is like Caralampi in upper horizons. Soil characteristics and organic carbon analyses (Table 24) indicate that pedons 34 and 35 would have enough organic carbon for a mollic epipedon but do not quite meet chroma and thickness requirements. Some soils in unit H do meet these requirements, and are unnamed Aridic Argiustolls (Table 5). These Argiustolls and the Coxranch soils occur in complex pattern, with the Argiustolls occurring at stablest sites where the mollic epipedon is still preserved, and the Haplargids where it is not present.

Map unit H borders two map units, unit F to the east and unit G to the south. These boundaries have been discussed in those units. Vegetation consists mainly of mesquite, snakeweed, prickly pear, three-awn, black grama, blue grama, beardgrass, sideoats grama, and Mormon tea.

Ustollic Haplargid at site 34

Figure 12 shows the Ustollic Haplargid at site 34 (Table 24). Slope is 7% to the east.

TABLE 24—Characteristics of Jornada I and II soils at sites 33–35. Abbreviations are explained in Table 6 caption (p. 32).

Horizon	Depth, cm	Hue	Value/chroma Dry	Value/chroma Moist	Structure	Dry consistence	Textural class	pH	Sand 2.0–0.05 mm	Silt 0.05–0.002 mm	Clay <0.002 mm	Organic C
Aridic Argiustoll at site 33—Jornada II												
A	0–10	6YR	3.5/2	2/2			vcsl	6.4	71	16	13	0.70
BAt	10–35	7.5YR	3/3	2/3	1msbk	sh	vcscl	6.6	62	17	21	0.74
B1t	35–56	2.5YR	4/4	3/6	m	h, vh	vcscl	6.8	67	10	23	
Bt2	56–77	2.5YR	4/6	3/6	m	vh	vcscl	7.2	67	8	25	
Bt3	77–110	4YR	4/4	3.5/4	m	vh	vcscl	7.2	64	11	25	
Btk	110–141	2.5YR	4.5/6	4/6	m	vh	vcscl	8.2	72	7	21	
BCtk1	141–172	2.5YR	4.5/6	4/6	m	vh	vstsl	8.2				
BCtk2	172–210	2.5YR	4.5/6	4/6	m	vh	vstls	8.2				
Ustollic Haplargid at site 34–Jornada I												
A1	0–4	6YR	4.5/3.5	3/3.5	1cpl	s, l	vcsl	6.4				
A2	4–11	6YR	3.5/3	2/3	1msbk	sh	vcsl	6.2				
BAt	11–22	5YR	4.5/3.5	2.5/3.5		sh	vcscl	6.8				
Bt1	22–41	2.5YR	4/4	3/4	m	vh	vcscl	7.0				
Bt2	41–61	2.5YR	4/4	3/4	m	vh	vcscl	7.6				
Bt3	61–88	2.5YR	4/4	3/4	m	vh	vcscl	8.2				
Btk	88–107	2.5YR	5/4	4/4.5	m	vh	vstscl	8.2				
Ustollic Haplargid at site 35—Jornada I												
A1	0–6	7.5YR	4.5/3	3/3	lcpl	s, l	vgsl	6.6	77	13	10	0.70
A2	6–12	7YR	4.5/3	2.5/3	lmsbk	sh	vcsl	6.8	77	12	11	0.66
BAt	12–25	5YR	4/3	2.5/3		h	vcsl	6.8	71	12	17	0.70
Bt1	25–42	4YR	4/4	3/4	m	h, vh	vcscl	7.0	65	10	25	0.50
Bt2	42–61	2.5YR	4/4	3/4	m	vh	vcscl	7.2	62	10	28	
Bt3	61–93	2.5YR	4/4	3/4	m	vh	vcscl	7.2	61	11	28	
Bt4	93–119	2.5YR	5/4	4/4	m	vh	vcscl	7.4	62	9	28	

Evidence of spalling of rock fragments found on the surface at site 33 was also found at site 34, and such spalling must be responsible for some of the smaller rock fragments on the surface. The soil is noncalcareous to 88 cm depth; the Btk horizon has scattered carbonate filaments and some parts are noncalcareous. Although some rock fragments in the Bt horizon are quite weathered and have clay coatings on component crystals, others have fresh-appearing interiors.

The backhoe could not dig below a depth of 42 inches (107 cm). This illustrates the difficulty of digging in Jornada I soils that are stony and bouldery, because enough fine earth has accumulated between rock fragments to tightly bind them. Rock fragments of the same size were readily removed by backhoe in soils of Organ age.

Ustollic Haplargid at site 35

The Ustollic Haplargid at site 35 (Fig. 60) is similar to soil at site 34 (Table 24). The data show the size of the silicate clay maximum to be distinctly larger than in the Jornada II soil at site 33. No visible carbonate is present on the north side of the trench, where the soil is noncalcareous throughout. Stage I filamentary carbonate like that at site 34 occurs just above the trench bottom on the south side.

Summary and discussion

The studied fault is one of the youngest if not the youngest in New Mexico, and it cuts across fans ranging in age from late Holocene to late middle Pleistocene at the study site. Displacement ranges from a maximum of about 15 ft (4.5 m) in late Holocene sediments to substantially more than a minimum of about 82 ft (24.6 m) in Pleistocene sediments. This indicates repetitive, long-term faulting in the same place. The site is also of interest because the WSMR Headquarters are only about 1 mi (1.6 km) downslope from the studied part of the fault; other parts of the same fault are much closer (see cover).

Several factors suggest the desirability of additional work at this classic site. The fault zone is very close to WSMR, suggesting prudence and a motive for monitoring. The area should be permanently preserved and protected because it is in WSMR. Additional work is needed on the chronology of faulting, as discussed in a later section. Studies of rock varnish (e.g., Dom et al., 1987; Harrington and Whitney, 1987; Dethier et al., 1988) may yield valuable climatic and chronological information. The study area is an excellent one to photographically document the long-term effects of erosion of sediments and soils exposed in arroyo banks because numerous photographs were taken of them soon after the flood of August, 1978 (mostly from March through June, 1979). At the time of photography the arroyo banks were still quite fresh, and vertical or nearly vertical. Other potential uses of the photographs include chronological studies of colluviation down the steep Holocene-Pleistocene scarp, and changes in vegetation over time. These photographs and color slides will be permanently available for study at the NMSU Archives. The area selected for study could well be extended to the southeast, including an area first studied by Reiche (1938).

Soils and soil-geomorphic relations

All geomorphic surfaces found in the Desert Project except for the Dona Ana surface (Table 1) have been identified in this study area. Degree of soil development increases with increasing age of surface and soil. Dustfall has contributed carbonate, clay, silt, very fine sand and fine sand to the soils during their development.

FIGURE 59—The Aridic Argiustoll, Earp (see Table 24) in Jornada II sediments at site 33. Scale is in feet.

Soils of terraces and fans

The soils have formed in dominantly debris-flow materials, with minor amounts of water-laid materials. The significance of silicate clay, carbonate, organic carbon, texture, color, structure and consistence for Organ I, II and III soils were presented in detail (Gile, 1987, pp. 35-38) and are not further considered here except in summary statements. Data for soils of Organ III, Organ II, Organ **I,** Jornada II and Jornada **I** show that the accumulation of silicate clay increases with increasing soil age (Tables 7, 12, 15, and 24). The accumulations reflect eluviation of clay from the soil surface and from upper horizons, and clay accumulation in deeper horizons as the wetting front slows its downward movement. No data are available for Isaacks' Ranch soils, but field observations indicate that their clay percentages would fit into this developmental scheme, being higher than Organ **I** and lower than Jornada **II.**

The data also indicate that silt and very fine sand are moving downward and accumulating in the soil, along with lesser amounts of fine sand. When the fine sand is split into two sizes (from 0.25 to 0.2 mm and from 0.2 to 0.1 mm) the slight increase in fine sand is seen to be in the 0.2 to 0.1 mm fraction (Table 12). This indicates very little or no downward movement of sand larger than about 0.2 mm in these soils.

Except for Organ **III** soils below the Holocene—Pleistocene scarp, discussed later, soils of Organ III and II age have no carbonate horizons. This is attributed to deep penetration of the wetting front in these pervious materials, and relatively high precipitation compared to more arid areas downslope. Weak stage **I** carbonate horizons (Gile et al., 1966) occur in Organ I soils, in which enough clay has accumulated to slow the wetting front so that carbonate can accumulate. Soils of the Jornada II terrace (Fig. 5A) have a more prominent stage **I** carbonate horizon. Stage of carbonate accumulation for the Jornada I soils is not known; a stage I horizon was found in the study trenches, but lower horizons could not be excavated by backhoe because the large rock fragments were so tightly bound by fine earth between them. The most prominent carbonate horizons were found on lower slopes of the Holocene—Pleistocene scarp as discussed in the following section.

FIGURE 60—Upper horizons of the Ustollic Haplargid Coxranch (see Table 24), in Jornada I sediments at site 35. Scale is in feet.

Soils of the fault scarps

Fault scarps of two ages were studied, one of late Holocene age (sites 7 and 8, Fig. 6; Gile, 1987) and the other ranging in age from late Holocene to late middle Pleistocene (sites 27-32, Fig. 35). Soils of the late Holocene scarp have formed in skeletal colluvium. Soils of the Holocene—Pleistocene scarp have formed partly in skeletal and nonskeletal colluvium and partly in beveled Jornada I sediments that underlie the colluvium. Soils of the two scarps differ greatly. Soils of the late Holocene scarp, estimated to be about 1,000 yrs old, have only thick, dark A horizons above C horizons. In contrast, soils have wide morphological variety at the Holocene—Pleistocene scarp, where soils of Organ, Isaacks' Ranch, and Jornada II age have been identified. Clay content increases with increasing age of soil, but part of the difference is due to differences in clay content of the parent materials (Tables 21-23).

Soils of upper and middle slopes in drainageways of the Holocene—Pleistocene scarp have been strongly leached and E horizons are common. Carbonates have been leached from this zone and occur only on lower slopes of the scarp, where the soils of drainageways have stage III (calcic) horizons. Some soils of the oldest part of the scarp (between drainageways) have stage IV (petrocalcic) horizons. Most soils of the scarp have argillic horizons; in the upper and middle slopes of the drainageways, illuvial clay has **accumulated** in the beveled Jornada I sediments.

Colluviation

As used in this report, colluviation includes soil creep, overland flow, and rainwash (see glossary). Not included in colluviation are clay accumulations that may have been laterally leached from E horizons of soils of the middle slopes to lower slopes of the scarp (see sites 31 and 32).

Colluviation is known to be extensive in the Desert Project area (e.g., see pp. 125-130 in Gile et al., 1981). But the **rate** at which colluvial processes operate in this area is not known, and more work is clearly needed on this aspect. Photographs taken in 1979 show key marker stones and boulders that could be checked at appropriate intervals to determine if movement has taken place. Despite differences between this study area and that of Kojan (1967; he worked in the climates of northern California, with soil materials much more susceptible to soil creep) his emphasis on the significance of soil creep and the need for more work on it also applies to this area. Kojan (1967) aptly quotes Terzhagi as follows on the need for research on soil creep: "On account of the extraordinary variety of creep phenomena and this implication, creep research is a very promising field for the cooperation between the geologist and the engineer. So far, this field has hardly been touched."

That the post-Jornada I sediments along the Holocene—Pleistocene scarp are colluvium and not alluvium is indicated by the slope, which is too steep for the accumulation of alluvium along channels. Because of the steep slope, all of the three studied channels at sites 30-32 were swept clean of sediment by channel water during the 1978 flood. Thus the distinct bodies of post Jornada I sediment found in many parts of the drainageways in the scarp are attributed to colluviation. Upper slopes of the scarp have been affected mostly by erosion, with little accumulation of sediment.

Colluviation along the late Holocene scarp (sites 7 and 8) is relatively simple and involves essentially a single post-faulting deposit of skeletal colluvium. Colluviation at the Holocene—Pleistocene scarp is much more complex, and in the drainageways involves colluvia of Historical, Organ, Isaacks' Ranch, and Jornada II age. Between drainageways are still older colluvia that may occupy the oldest part of the Jornada II age range; little is known about these because of lack of exposures and difficulty of digging between the numerous large rock fragments.

Some of the colluvia in the drainageways may reflect the same sort of climatic control on erosion and sedimentation as at the Desert Project (Gile et al., 1981). This is the current interpretation for many of the deposits because it fits the stratigraphy, and soils identified as Organ, Isaacks' Ranch, and Jornada II are similar to soils of these ages and textures in the Desert Project. But (as at the late Holocene scarp) the early Organ III skeletal colluvium at and near the base of the .Holocene—Pleistocene scarp records sedimentation initiated as an erosional response to downdropped materials below the late Holocene fault. This is illustrated on lower slopes of the scarp at sites 31 and 32. Although extension of fault-caused colluvium above lower slopes of the scarp cannot be ruled out, the abrupt boundaries of fault-caused Organ III colluvium to older sediments upslope (e.g., at sites 31b and the contact between sites 32a and 32b) suggest that the fault-caused colluvium associated with the latest displacement does not extend upslope much above the lower slopes of the scarp.

Thus several general causes and kinds of colluviation may be envisioned at the Holocene—Pleistocene scarp. One kind is apparently caused by major changes in climate and another is clearly caused by faulting. An erosional contact between the two is shown at site 31b and at the contact between sites 32a and 32b. Drainageways of the scarp illustrate a gigantic desert pavement that in some areas may now be gradually moving downslope across the top of colluvium dominated by fine earth. This would agree with the work of Kojan (1967), who found surficial material to move downslope faster than deeper materials. However, prominent soil horizons beneath the pavement indicate that some of the deeper colluvia have either stopped moving or are moving so slowly that soil morphology is virtually undisturbed.

Because the Jornada I sediments beveled by the Holocene—Pleistocene scarp are compact and commonly contain numerous large rock fragments, the sediments have a high resistance to colluviation as the slope gradually stabilizes after episodes of faulting. In many places between drainageways the landscape has been stable and has undergone virtually no colluviation for a very long period of time. This is shown by petrocalcic horizons at shallow depth in various places on lower slopes of the scarp. These petrocalcic horizons also show that, in contrast to the displacement of late Holocene sediments, which formed a new scarp, the late Holocene displacement had only a very minor effect on the stablest parts of the Holocene-Pleistocene scarp (between drainageways).

Post-faulting sediments along the scarp base

An earlier study (Gile, 1987) found two major zones that differ considerably in particle size along the studied late Holocene scarp (at sites 7 and 8, Fig. 6). One, consisting of colluvium dominated by skeletal materials such as cobbles and stones, was termed the skeletal zone. The other, an alluvium dominated by fine earth, was termed the fine-earth zone. The skeletal zone is of particular significance because it is emplaced almost immediately after faulting as an erosional response to the downdropped materials below the fault. The fine-earth zone was deposited later by small streams and overland flow that descend the scarp, and commonly buries the skeletal zone in part. Soils formed in one or both of these two zones are major chronological markers that are useful in estimating the approximate time of displacement (Gile, 1986, 1987).

Skeletal and fine-earth zones marking the late Holocene displacement were also found at the Holocene-Pleistocene scarp (at sites 27-29, Fig. 35), but in a different position. The skeletal zone, instead of occupying the whole scarp as the late Holocene scarp, occurs just below the base of the Holocene—Pleistocene scarp, and is largely buried by the fine-earth zone. This indicates that the late Holocene faulting previously reported (Gile, 1986, 1987) could be much more extensive than suggested by the downfaulted late Holocene sediments alone. Several factors indicate that the skeletal and fine-earth zones are the same age at both scarps, with the skeletal zone being colluvium of early Organ III age and the fire-earth zone being alluvium of late Organ III age: (1) the skeletal colluvium crosses and overlies the fault plane and (as at the late Holocene scarp) must have accumulated immediately after the faulting took place; (2) the skeletal colluvium and the younger fine-earth alluvium show the same stratigraphic relation to each other at both scarps; (3) soil development in the fine-earth and skeletal zones is similar at both scarps, with two exceptions. First, soils of these zones associated with the Holocene—Pleistocene scarp have stage I carbonate horizons but those associated with the late Holocene scarp do not. This is explained by the calcareous parent materials (calcic and petrocalcic horizons) along and just above the base of the Holocene—Pleistocene scarp. Stage I carbonate horizons are to be expected in calcareous parent materials of Organ III age, and were found in charcoal-dated Organ III soils at the Gardner Spring radiocarbon site (Gile and Hawley, 1968). Second, weak argillic horizons were found in some Organ III soils associated with the Holocene-Pleistocene scarp but not the late Holocene scarp. This is explained by greater runoff from the high scarp and by much more clay in the contributing watershed (soils of the Holocene—Pleistocene scarp and the Jornada I surface). This extra moisture and clay have speeded development of the argillic horizon in some areas below the scarp. The skeletal zone is thinner and the fine-earth zone is thicker at the Holocene—Pleistocene scarp than at the late Holocene scarp, reflecting the materials more resistant to erosion at the Holocene—Pleistocene scarp.

Displacement in the fault plane in the soil of late Pleistocene age is estimated to be about 3 ft (0.9 m). But if the downwarping observed nearby (see site 31b) is associated with this displacement, then the total for the late Holocene displacement (estimated to be about 1,000 yrs ago, Gile, 1987) would be considerably greater.

The late Holocene displacement and the buried late Pleistocene fine-earth zone at sites 27 and 28, further discussed in the next section, indicate that multiple displacements have taken place along the Holocene-Pleistocene scarp. The proportion of fine earth and its position at the scarp base are very similar to the late Holocene fine-earth zones at both the late Holocene and the Holocene-Pleistocene scarps. These factors and soil morphology indicate that the buried fine-earth zone is also the result of a displacement, but one that dates from the late Pleistocene instead of late Holocene. Machette (1978b) notes that as much as half of the total offset of a fault may be masked by deposits that accumulate along the base of the scarp. For the foregoing reasons, total displacement along the Holocene-Pleistocene scarp would be more than the minimum figure of 80 to 82 ft (24 to 24.6 m) indicated by the present scarp.

Recurrence intervals

The late Holocene fault could not be located at site 29 because the trench was not deep enough to get through the thick zone of post-faulting sediments. But the fault plane was precisely located at sites 27 and 28 because the down-faulted soil of late Pleistocene age is prominent, occurs at relatively shallow depth, and has formed in materials with few rock fragments. This contrasts with site 7 and 8 at the late Holocene scarp, where the fault plane could not be located because of numerous large rock fragments and weakly developed soils.

Machette (1987a) suggests recurrence intervals ranging from 4,000 to 5,000 yrs for surface ruptures on individual faults along the Organ Mountains fault. Evidence at sites 27 and 28 suggests that some recurrence intervals at some localities may be longer than this. The prominent Bt and carbonate horizons at sites 27 and 28 have formed in a fine-earth zone of late-Pleistocene age. Although this soil needs further study as previously discussed, its prominent horizons could indicate a time longer than 5,000 yrs for the maximum interval of time of stability and soil formation between faulting episodes at some locations along the fault. The carbonate horizon has potential for dating (Gile et al., 1981; Machette, 1985), but trenches of this study were not deep or wide enough to study the soil and determine the total amount of carbonate. Further work on this is suggested. Deeper and wider trenches, requiring support of trench walls, would be required. Such trenches were used by Machette in his studies of the La Jencia fault (Machette, 1988, p. 10). A chronological interpretation is complicated by landscape position at the base of the scarp. Due to strong lateral leaching of the scarp, the rate of carbonate accumulation would appear to be more rapid at the base of the scarp than in the much gentler slopes on which research on carbonate totals and ages has been done. Although carbonate morphology indicates a late Pleistocene age for the soil, carbonate values by laboratory analysis could be higher than for soils of the same age that are not below scarps.

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Glossary

Most of these definitions were derived from Guthrie and Witty (1982); from the unpublished manuscript of the revised *Soil Survey manual,* in preparation by the National Cooperative Soil Survey; from *Soil Taxonomy* (Soil Survey Staff, 1975); from *Webster's Dictionary* (Third Unabridged); and from the *Glossary of Geology* (Bates and Jackson, 1987). Definitions of diagnostic horizons-the cambic and argillic horizons and the mollic and ochric epipedons-have been greatly abbreviated. See *Soil Taxonomy* (Soil Survey Staff, 1975) for complete definitions. Italicized words in the definitions below are also defined as specific terms.

A horizon-See *soil horizons.*

Aggradation-The raising of a surface by sediment deposition.

Alluvial fan-A body of stream deposits whose surface approximates a segment of a cone that radiates downslope from the point where the stream leaves a valley in a mountainous, or less prominent upland, area. Also termed simply "fan."

Alluvium-Materials (such as clay, silt, sand, and pebbles) deposited by running water.

Altithermal-A warm, dry period from about 7,500 to 4,000 yrs ago according to Antevs (1955).

Argillic horizon-See *soil horizons.*

Arroyo-The channel of an ephemeral stream, commonly with vertical banks of unconsolidated material several feet or more high.

B horizon-See *soil horizons.*

Basin-A broad topographic low, commonly many miles across that occurs between mountain ranges. A closed basin is one that is internally drained. The two major landscape components of an intermontane basin are the *basin floor* and *piedmont slope.*

Basin-and-range topography-Topography characterized by mountain ranges and intervening basins and usually caused by faulting or warping.

Basin floor-The level or nearly level surface that occupies the central part of a basin.

C horizon-See *soil horizons.*

Calcareous--Containing sufficient free $CaCO_3$ and/or $MgCO_3$ to effervesce visibly when treated with cold 0.1 M HCl. Materials containing insufficient free $CaCO_3$ and/or $MgCO_3$ to effervesce visibly are termed *noncalcareous.*

Cambic horizon-See *soil horizons.*

Carbonate horizon-See *stage of carbonate accumulation.*

Chroma-See Munsell color system.

Coalescent alluvial-fan piedmont-A broad body of *alluvium* formed by downslope coalescence of individual *alluvial fans.* Also termed simply *fan piedmont.*

Colluvium-Deposits on or at the foot of a slope that were moved there primarily by gravity and unconcentrated runoff, including rainwash, overland flow, and soil creep. **Color-See** *Munsell color system.*

Constructional surface-Owing its origin, form, position, or general character to building-up processes such as the accumulation of sediment in development of an *alluvial fan.*

Control section—Names of *particle-size* classes are not applied to indurated *soil horizons* or layers, but to specified horizons or to materials between given depth limits defined in terms of either 1) the distance below the surface of the mineral soil or 2) the upper boundary of a specified horizon. The vertical section so defined is called the *control section.* The control section is defined as follows for the soils considered in this report: for the Entisols, Camborthids, Calciorthids, Aridic Calciustolls, and Haplustolls it extends from 25 to 100 cm in depth; for the Haplargids, Argiustolls, and Petrocalcic Paleustolls, it is the whole argillic horizon if it is less than 50 cm thick or the upper 50 cm of the argillic horizon if it is 50 cm or more thick; for the Paleorthids and the Petrocalcic Calciustolls the control section extends from the soil surface to the top of the petrocalcic horizon.

Debris flow—A moving mass of *rock fragments* and *fine earth.* According to Bull (1972, p. 69), "Debris flows have a high density and viscosity compared to stream flows. Because of these traits, debris-flow deposits are poorly sorted, have lobate tongues extending from sheetlike deposits, have well defined margins, and are capable of transporting boulders weighing many **tons."**

Degradation—The lowering of a surface or stream channel by erosion.

Desert pavement—A concentration of pebbles and/or larger rock fragments on the soil surface in arid and semiarid regions. Some pavements consist of a lag gravel caused by eolian or fluvial removal of fines, as in dissected terrains. Other pavements form as result of colluviation of rock fragments and the subsequent movement of eolian and/or colluvial fines between and below the fragments. Continued movement of fines from the surface to beneath the pavement keeps it at the surface (McFadden et al., 1987).

Eluviation—The removal of soil material in suspension or in solution from the upper part of a soil or from the surface.

Fan—See *alluvial fan.*

Fan piedmont—see *coalescent alluvial-fan piedmont.*

Fault—A fracture in the earth's crust accompanied by displacement of one side of the fracture with respect to the other in a direction parallel to the fracture.

Fault scarp—A steep slope or cliff formed by movement along a *fault* and representing the exposed surface **of the fault before modification by erosion and/or weathering. For brevity, in this publication the term** *scarp* **refers to steep, linear concentrations of** *rock fragments* along the trend of the fault zone.

Fine earth—Particles <2 mm in diameter.

Geomorphic surface—A part of the land surface that may be defined in space and time (Ruhe, 1967). As used here, the term is commonly shortened to *surface* **for brevity. At stable sites, a given geomorphic surface has a characteristic assemblage of** *soil horizons.*

Hiatus—an episode of nondeposition.

Historical—A.D. 1850 to present.

Holocene—The later of two epochs in the *Quaternary Period;* the earlier is the *Pleistocene.* **The Holocene extends from the present to about 10,000** yrs **B.P.**

Horizons—See *soil horizons.*

Hue—See *Munsell color system.*

Illuviation—A process by which material moved in water from upper horizons of a soil, or from the soil surface, accumulates in lower horizons by deposition either from solution (e.g., carbonate) or from suspension (e.g., silicate clay).

Interpluvial—See *pluvials.*

K horizon—See *soil horizons.*

Linear scarp—See *fault scarp.*

Mixed mineralogy class—Soils that have <40% of any one mineral other than quartz or **feldspar.**

Mollic epipedon—See *soil* **and** *diagnostic horizons.*

Munsell color system—A system of color notation that identifies color in terms of three attributes—hue, *value, chroma—which* are arranged in scales of equal visual steps. The hue notation of a color indicates its relation to 10 major hues, of which the dominant one for soils of the study area is YR (yellow-red). The value notation indicates the degree of lightness or darkness of a color in relation to a neutral gray scale that ranges from black to white. The chroma notation indicates the degree of departure of a given hue from a neutral gray of the same value; chroma of each color increases with increase in its vividness. Designations for hue, value, and chroma are recorded as hue, value/chroma. Thus, color of soil materials that have hue of 5YR, value of 5 and chroma of 4 is indicated as 5YR 5/4.

Noncalcareous—See *calcareous.*

Ochric epipedon—See *soil horizons.*

Overland flow—Runoff in the form of a continuous film moving over relatively smooth soil or rock surfaces and not concentrated into channels larger than **rills.**

Parent materials—Materials, such as *alluvium* or bedrock, in which soil formation started. Materials from dry dust and from dust in precipitation that have been added to soils during their development are not considered parent materials because they were added to soils at various times after soil development **started.**

Particle size—The grain-size distribution of the whole soil, including *rock fragments* if they are present; *texture* refers to the *fine-earth* (<2 mm) fraction.

Particle-size class—Groupings of *particle size* used to distinguish soils at the family level. See table 25 for definitions.

Pedogenesis—Of or relating to the formation or development of soils, including obliteration of the original organization of the parent material (e.g., mixing of sedimentary strata) and the development of such genetic soil features as clay accumulation, structure, carbonate filaments, and *soil horizons.*

Pedogenetically unmodified materials—Materials so deep, so recently deposited, or so newly exhumed that they show essentially no evidence of disturbance by biotic or other factors of soil formation.

Pedon—A small volume of soil that, as a minimum, includes all genetic horizons of the soil at the land surface, but may also include one or more buried soils as determined by the lower limit of the studied horizons. The pedon has a surface area of 1 to 10 m^2, depending on variability in the *soil horizons.* In the usual situation, where the horizons are continuous and of nearly uniform thickness and composition, the pedon has a horizontal area of about 1m^2.

Piedmont slope—A general term for slopes between the intermontane basin floor and the mountain upland. Pied-

TABLE 25—Particle-size classes for soils considered in this report. Modified from *Soil Taxonomy* (Soil Survey Staff, 1975).

Class	Definition
Sandy-skeletal	Rock fragments 2 mm in diameter or larger make up 35% or more by volume; enough fine earth to fill interstices >1 mm; the fraction <2 mm is sandy as defined for the sandy particle-size class.
Loamy-skeletal	Rock fragments make up 35% or more by volume; enough fine earth to fill interstices >1 mm; the fraction <2 mm is loamy as defined for the loamy particle-size class.
Sandy	The texture of the fine earth is a sand or a loamy sand that is coarser than very fine sand or loamy very fine sand respectively; rock fragments are <35% by volume.
Loamy	The texture of the fine earth is loamy very fine sand, very fine sand, or finer, but the amount of clay is <35 percent; rock fragments are <35 percent by volume. *Coarse-loamy.* By weight, 15 percent or more of the particles are fine sand (diameter 0.25–0.1 mm) or coarser, including fragments up to 7.5 cm in diameter; <18 percent clay in the fine-earth fraction. *Fine-loamy.* By weight, 15 percent or more of the particles are fine sand (diameter 0.25–0.1 mm) or coarser, including fragments up to 7.5 cm in diameter; 18 through 34 percent clay in the fine-earth fraction (<30 percent in Vertisols).
Clayey	The fine earth contains 35 percent or more clay by weight, and rock fragments are <35 percent by volume. *Fine.* A clayey particle-size class that has 35 through 59 percent clay in the fine-earth fraction (30 through 59 percent in Vertisols). *Very-fine.* A clayey particle-size class that has 60 percent or more clay in the fine-earth fraction.

mont slopes consist of individual fans and interfan valleys along the mountain fronts, the *fan piedmont* downslope, and pediments.

Pleistocene—The earlier of two epochs in the Quaternary Period; the later is the *Holocene.* The Pleistocene extends from about 10,000 to 2,000,000 yrs B.P.

Pluvials—Intervals when there was considerably more effective moisture than now. The last major pluvial was in late Pleistocene time, about 17,000 to 23,000 yrs ago according to Martin and Mehringer (1965). Intervals between the pluvials are termed *interpluvials.*

Quaternary—The youngest period of geologic time, consisting of the *Holocene* and *Pleistocene* epochs. The Quaternary extends from the present to about 2,000,000 yrs B.P.

Rainwash—The washing-away of loose surface material by rainwater before it has concentrated into definite streams; sheet erosion.

Rock fragments—Particles 2 mm or larger in diameter. Rock fragments in the study area include gravel (diameter 27.6 mm), cobbles (diameter 7.6-25 cm), stones (diameter 25-60 cm), and boulders (diameter >60 cm).

Scarp—See *fault scarp.*

Scarp base—The lower margin of the steep, linear concentration of rock fragments that marks the *fault scarp.*

Skeletal—A term used informally in this volume to designate materials of any texture and thickness that contain 35% or more, by volume, of *rock fragments.*

Soil—Soil may be defined as the natural medium on the Earth's surface suitable for the growth of land plants. Under this definition, soil occupies all of the land surface except for areas of hard rock, ice, or salt where land plants cannot grow. Soil may also be defined as surficial material that has been affected by one or more of the soil-forming factors of climate, topography, *parent materials,* biota, and time. With age, and depending on influences of the other soil-forming factors, distinct horizons may form (see *soil horizon).*

Soil creep—The gradual, steady downhill movement of soil and loose rock material on a slope that may be very gentle but is usually steep.

Soil horizon—A layer of material below the earth's surface and approximately parallel to it, that differs from adjacent layers in various physical, biotic, and/or chemical properties as a result of *pedogenesis.* A soil horizon is considered to have formed in a deposit when there is evidence of alteration by the soil-forming factors noted above. This includes the physical disruption of sedimentary strata as well as the accumulation and removal of substances. The degree of alteration ranges from very slight in young soils to prominent in older ones.

Soil horizons—Nomenclature for soil horizons is of two general types. In one, master horizons and subhorizons are indicated by symbols (such as A and B) that are used to describe soils in the field. The other consists of diagnostic horizons (such as *mollic epipedon* and *argillic horizon)* that are definitive for various taxa in soil classification. Only the horizons used in this study are described here.

Symbols for soil horizons and layers

Capital letters designate master horizons and layers; lower case letters are used as suffixes to indicate certain characteristics of the master horizons and layers; and arabic numbers are used both as suffixes to indicate subdivision with master horizons and layers and as prefixes to indicate discontinuities.

Master horizons and layers—The *A horizon is* a surface horizon characterized by accumulation of organic matter and is not dominated by properties characteristic of B horizons. The *B horizon* is characterized by obliteration of rock structure such as sedimentary strata and by accumulation of silicate day. In the K horizon, fine-grained carbonate occurring as an essentially continuous medium ocupies 90% or more of the horizon. The C horizon or layer has been little affected or unaffected by pedogenic processes.

Transitional horizons—These horizons occur between master horizons and have characteristics of both the overlying and underlying horizon. Symbols for both master horizons are used to denote transitional horizons, with the dominant one given first. Thus a BA horizon has characteristics of both an overlying A horizon and an underlying B horizon, but is more like the B than the A. Transitional horizons in sampled pedons of this study are BA, BC, CB, CA, and AC.

Subordinate distinctions of master and transitional horizons—These distinctions are indicated by appending lower case letters as suffixes to designations for master horizons, layers, and transitional horizons; *k* = pedogenic accumulation of carbonates, dominantly calcium carbonate; *t* = accumulation of silicate clay, some of which is of *illuvial origin.*

Diagnostic horizons

Six diagnostic horizons are important in the classification of soils in this area. Two of these—the *mollic epipedon* and the *ochric epipedon—are* surface horizons. The other two (the *cambic* and *argillic horizons)* are subsurface horizons.

The mollic epipedon has at least 0.6% organic carbon. Color values are darker than 3.5 when moist and 5.5 when dry, and chromas are less than 3.5 when moist. Thickness requirements vary depending on other horizons present; however, in the soils considered here, the mollic epipedon must be at least 25 cm thick. *Ochric epipedons are* too light in color, too thin, and/or have too little organic carbon for mollic epipedons.

The **cambic horizon** is an altered horizon with texture of very fine sand or finer and with its base at least 25 cm below the surface. Most or all of the rock structure (such as sedimentary strata) has been obliterated. In Camborthids of this area, the most common type of cambic horizon has evidence of *illuvial* clay but not enough clay increase for an argillic horizon.

The **argillic horizon** contains *illuvial silicate* clay. The argillic horizon is at least 7.5 cm thick if it is loamy or clayey and at least 15 cm thick if it is sandy. If the *eluvial* horizon has not been truncated, the increase in clay required for the argillic horizon depends on soil texture (Soil Survey Staff, 1975). In addition to the clay increase, various kinds of evidences for day iluviation are required in different situations. In this desert area the pertinent evidence is at least 1% of oriented clay as viewed in thin section. Most argillic horizons in this area easily meet the requirement because the Bt horizons are characterized by a fabric in which the sand grains are prominently coated with oriented clay.

The **calcic horizon** is a horizon of secondary carbonate enrichment, at least 15 cm thick and having a calcium carbonate equivalent content of 15% or more unless the particle size class is sandy, sandy-skeletal, coarse-loamy, or loamy-skeletal with less than 18% clay. In these cases the 15 percent requirement for $CaCO_3$ equivalent is waived and the calcic horizon must have at least 5% (by volume) more soft, powdery secondary $CaCO_3$ than an underlying horizon; it must also be at least 15 cm thick and have an upper boundary within 1 m of the surface of the soil.

The **petrocalcic horizon** is cemented by carbonates. Dry fragments do not slake in water. It is cemented or indurated and cannot be penetrated by spade or auger when dry. It is massive or platy, very hard or extremely hard when dry, and very firm or extremely firm when moist. Hydraulic conductivity is moderately slow to very slow. Accessory silica may be present but is not enough for a duripan. Laminar horizons are commonly present in the uppermost part of the horizon but are not required.

Soil temperature class—See *thermic soil temperature class.*

Stable surface or soil—An area that shows little or no evidence of erosion in the form of rills, drainageways, or missing *soil horizons.*

Stage of carbonate accumulation—Two morphogenetic sequences of carbonate accumulation associated with increasing soil age and amount of pedogenic carbonate have been ordered in stages, summarized as follows (see Gile et al., 1966, for more detail). In materials with abundant rock fragments the sequence is (I) carbonate forms thin, partial or complete coatings on fragments; (II) carbonate coatings on fragments are thicker, and some interstices between them are filled with carbonate; (III) carbonate fills all or nearly all of the interstices between rock fragments and occupies 90% or more of the horizon, forming a K horizon; and, (IV) carbonate forms a laminar horizon on top of an indurated horizon that is plugged with pedogenic carbonate. The sequence in materials with few or no rock fragments differs in that stage I consists of carbonate filaments or faint coatings, stage II consists of few to common carbonate nodules, and stage III consists of many nodules and internodular fillings.

Surface—See *constructional surface, geomorphic surface,* or *stable surface.*

Terrace—A step-like surface, often long and narrow, which is bounded by a steeper ascending slope on one side and a steeper descending slope on the opposite side.

Texture—The grain-size distribution of the fine earth, as determined by the percentages of sand, silt, and clay; also see particle size.

Thermic soil temperature class—The mean annual soil temperature at 30 cm depth is from 15 to 22°C (59 to 72°F).

Value—See *Munsell color system.*

Water-laid—Materials deposited in or by water.

Selected conversion factors*

TO CONVERT	MULTIPLY BY	TO OBTAIN
Length		
inches, in	2.540	centimeters, cm
feet, ft	3.048×10^{-1}	meters, m
yards, yds	9.144×10^{-1}	m
statute miles, mi	1.609	kilometers, km
fathoms	1.829	m
angstroms, Å	1.0×10^{-8}	cm
Å	1.0×10^{-4}	micrometers, μm
Area		
in^2	6.452	cm^2
ft^2	9.29×10^{-2}	m^2
yds^2	8.361×10^{-1}	m^2
mi^2	2.590	km^2
acres	4.047×10^{3}	m^2
acres	4.047×10^{-1}	hectares, ha
Volume (wet and dry)		
in^3	1.639×10^{1}	cm^3
ft^3	2.832×10^{-2}	m^3
yds^3	7.646×10^{-1}	m^3
fluid ounces	2.957×10^{-2}	liters, l *or* L
quarts	9.463×10^{-1}	l
U.S. gallons, gal	3.785	l
U.S. gal	3.785×10^{-3}	m^3
acre-ft	1.234×10^{3}	m^3
barrels (oil), bbl	1.589×10^{-1}	m^3
Weight, mass		
ounces avoirdupois, avdp	2.8349×10^{1}	grams, gr
troy ounces, oz	3.1103×10^{1}	gr
pounds, lb	4.536×10^{-1}	kilograms, kg
long tons	1.016	metric tons, mt
short tons	9.078×10^{-1}	mt
oz mt^{-1}	3.43×10^{1}	parts per million, ppm
Velocity		
ft sec^{-1} (= ft/sec)	3.048×10^{-1}	m sec^{-1} (= m/sec)
mi hr^{-1}	1.6093	km hr^{-1}
mi hr^{-1}	4.470×10^{-1}	m sec^{-1}

TO CONVERT	MULTIPLY BY	TO OBTAIN
Pressure, stress		
lb in^{-2} (= lb/in^2), psi	7.03×10^{-2}	kg cm^{-2} (= kg/cm^2)
lb in^{-2}	6.804×10^{-2}	atmospheres, atm
lb in^{-2}	6.895×10^{3}	newtons (N)/m^2, N m^{-2}
atm	1.0333	kg cm^{-2}
atm	7.6×10^{2}	mm of Hg (at 0° C)
inches of Hg (at 0° C)	3.453×10^{-2}	kg cm^{-2}
bars, b	1.020	kg cm^{-2}
b	1.0×10^{6}	dynes cm^{-2}
b	9.869×10^{-1}	atm
b	1.0×10^{-1}	megapascals, MPa
Density		
lb in^{-3} (= lb/in^3)	2.768×10^{1}	gr cm^{-3} (= gr/cm^3)
Viscosity		
poises	1.0	gr cm^{-1} sec^{-1} *or* dynes cm^{-2}
Discharge		
U.S. gal min^{-1}, gpm	6.308×10^{-2}	l sec^{-1}
gpm	6.308×10^{-5}	m^3 sec^{-1}
ft^3 sec^{-1}	2.832×10^{-2}	m^3 sec^{-1}
Hydraulic conductivity		
U.S. gal day^{-1} ft^{-2}	4.720×10^{-7}	m sec^{-1}
Permeability		
darcies	9.870×10^{-13}	m^2
Transmissivity		
U.S. gal day^{-1} ft^{-1}	1.438×10^{-7}	m^2 sec^{-1}
U.S. gal min^{-1} ft^{-1}	2.072×10^{-1}	l sec^{-1} m^{-1}
Magnetic field intensity		
gausses	1.0×10^{5}	gammas
Energy, heat		
British thermal units, BTU	2.52×10^{-1}	calories, cal
BTU	1.0758×10^{2}	kilogram-meters, kgm
BTU lb^{-1}	5.56×10^{-1}	cal kg^{-1}
Temperature		
°C + 273	1.0	°K (Kelvin)
°C + 17.78	1.8	°F (Fahrenheit)
°F − 32	5/9	°C (Celsius)

***Divide by* the factor number to reverse conversions.
Exponents: for example 4.047×10^{3} (see acres) = 4,047; 9.29×10^{-2} (see ft^2) = 0.0929.

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