Late Holocene displacement along the Organ Mountains fault in southern New Mexico

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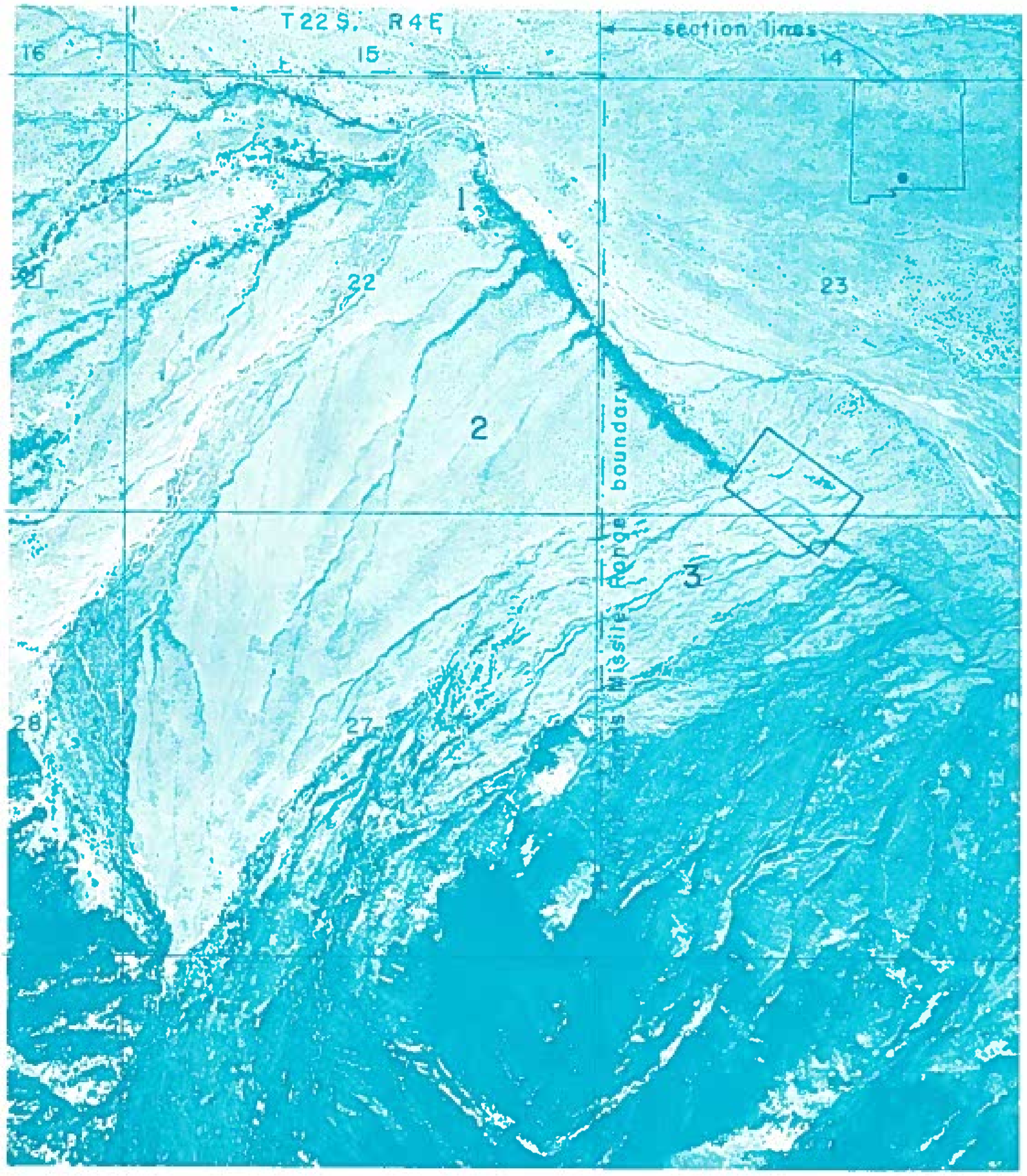

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COVER-1942 aerial photograph showing features in the vicinity of the study area. 1 = Cox Ranch house; 2 = large alluvial fan, dominantly Jornada I (late middle Pleistocene age); 3 = ridges and terraces, dominantly Organ (middle and late Holocene age). The rectangle at right center locates the area of detailed study (see Fig. 4); it is about 1,390 x 855 ft. The Cox segment of the Organ Mountains fault is the prominent linear feature that extends southeast from just below Cox Ranch house.

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Abstract

An extensive fault system occurs along the east side of the Organ and San Andres Mountains in southern New Mexico. Alluvial fans of several ages have been displaced by the fault, indicating long-term faulting at different times in the same place. In many arid regions there is widespread evidence of erosion caused by past changes in climate, particularly by long, severe droughts after cooler periods with more effective moisture. Thus, episodes of climatically controlled erosion and deposition provide both discrete deposits and, where the deposits can be dated, a chronology that is independent of faulting and the sedimentation associated with it. Charcoal in the lower parts of such deposits has been dated by ^{14}C methods at the Desert Soil—Geomorphology Project west and north of the Organ Mountains. These dates give chronological control on important episodes of sedimentation in the middle and late Holocene for the area. Soil morphology can be used to distinguish deposits of different ages if the morphological range has been determined for soils that have formed in the deposits. Both the faulting event and the deposits caused by faulting can then be placed in this chronological framework. Soil features having chronological significance in the study area are accumulations of organic carbon, silicate clay, and carbonate, as well as soil color, consistence, and structure. Soil morphology, coordinated with the geomorphic and stratigraphic arrangement of the deposits, was used to extrapolate the chronology from the dated sites to the fault area. The evidence indicates that a major displacement took place about 1,000 yrs B.P. Maximum displacement is estimated to have been about 15 ft.

Introduction

Evidence for a late Holocene displacement along the Organ Mountains fault is reported in this paper. The fault, which may be one of the youngest in New Mexico, must have been accompanied by severe and extensive earthquake activity. Although New Mexico contains abundant evidence of faulting, most of it apparently has not taken place in geologically recent time. This aspect needs further study because of the greatly increased significance of potential for earth movement and its effects on urban development and storage of hazardous wastes. Because many faults show evidence of repetitive, long-term faulting in the same place, studies are also needed on the chronology and prediction of faulting and the earthquakes that accompany it. A summary of this study has been published (Gile, 1986).

The fault was first studied by Reiche (1938), who indicated that the faulting was recent but did not suggest actual times that might be involved. The chronological problem was called to my attention by Bill Seager during his work on geology of the Organ Mountains (Seager, 1981). The chronology of movement is of particular interest because the White Sands Missile Range (WSMR) Headquarters are only about 1 mi downslope. The fault also occurs extensively north and south of the area studied by Reiche, and, as a whole, has been named the Organ Mountains fault by Seager (1981). The studied segment of the fault is designated the Cox segment, after the historic Cox Ranch house on the upthrown side (see cover).

The study area, which is in the basin-and-range topography of southern New Mexico (Figs. 1 and 2), is tectonically active. Seager (1980) shows numerous Quaternary faults in the northern Hueco and southern Tularosa Basins. Elevation of the area considered here is about 4,500 ft. 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 contain abundant rock fragments that range in size from pebbles to boulders. In many places the materials appear to have been emplaced primarily as debris flows (Beaty, 1963; Bull, 1972). Exceptions are scarp colluvium and thin, discontinuous water-laid deposits.

Precipitation data are available for two nearby locations, the Cox Ranch house (see cover), elevation 4,520 ft, and the WSMR Headquarters weather station, elevation 4,238 ft. For the years 1950-1976, precipitation averaged 10.8 inches at the WSMR station (Novlan, 1977) and 12.4 inches at the Cox Ranch house (Rob Cox, pers. comm. 1978). More precipitation would be expected at the Cox Ranch house because it is closer to the mountains. Mean annual temperature at the WSMR station is 64°F for the years 1950-1976 (Novlan, 1977).

A severe rainstorm and flash flood occurred in the vicinity of the fault on August 19, 1978. Ten inches of rain were recorded at the Cox Ranch house during a four-hour period that evening (Rob Cox, pers. comm. 1978).

Acknowledgments

I am indebted to Bill Seager for informing me about the chronological problem of latest displacement along the Organ Mountains fault. The study was greatly aided by the interest and assistance of Rob Cox, who graciously expedited access to the fault and provided precipitation data. Initial investigations began in 1978, but due to the pressure of other work it was impossible for me to return to the fault until the fall of 1983. I thank LeRoy Daugherty and Carol Taschek for arranging the initial excavations and John Hawley for making arrangements for me to resume investigations in 1983. John Hyndman, White Sands Missile Range, provided valuable assistance in arranging security clearance and in obtaining aerial photographs of the fault. I thank the New Mexico Bureau of Mines and Mineral Resources for financial support of the study and Director Frank Kottlowski for his interest and support. I am grateful to John Hawley and Bill Seager for reviewing the manuscript and to Deborah Shaw for helpful editorial comments. Finally, many thanks go to my wife, Dora, for typing the manuscript.

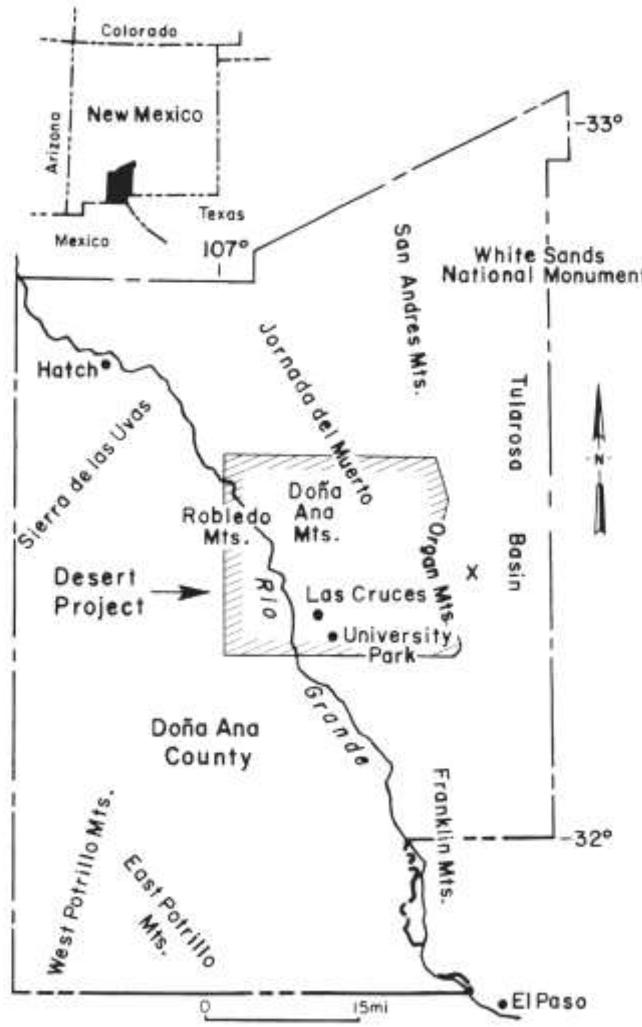


FIGURE 1—Location of the Desert Soil-Geomorphology Project and the studied part of the Organ Mountains fault (marked by x).

The chronological approach—a model from the Desert Project

The chronological question of the latest displacement is approached by comparing soils and soil-geomorphic relations at the Cox segment with those at the nearby Desert Soil-Geomorphology Project, a study of soil and landscape evolution astride the Rio Grande valley (Fig. 1). This project, covering a 400-mi^2 area west and north of the Organ Mountain divide, was conducted from 1957-1972 by Soil Survey Investigations, USDA-SCS (Hawley, 1975b; Gile et al., 1981). Piedmont-slope geomorphic surfaces similar to those of the Desert Project (Ruhe, 1967; Hawley, 1975a) also are present on the east side of the mountains. Table 1 summarizes ages of soils and geomorphic surfaces of the upper piedmont slope in the Desert Project. The sediments associated with a geomorphic surface—that is, the sediments in which the soils have formed—are designated by the geomorphic surface name (e.g., Organ sediments; Hawley and Kottlowski, 1969). In this report, attention is centered on an area illustrating the latest displacement, as shown by soils and sediments of the Organ surface.

The boundary between the Holocene and the Pleistocene is generally considered to be about 10,000 yrs B.P. (Fairbridge, 1968; Hopkins, 1975). The Holocene of the region has been divided into three intervals: late Holocene, present-2,500 yrs B.P; middle Holocene, 2,500-7,500 yrs B.P.; and early Holocene, 7,50010,000 yrs B.P. (Gile et al., 1981).

Buried charcoal in the lower part (but not the base) of Organ alluvium has been dated at about 6,400 yrs B.P. (Gile, 1975). Thus the beginning of Organ erosion and deposition is thought to coincide approximately with onset of the warm, dry Altithermal interval about 7,500 yrs B.P. (Antevs, 1955). The Altithermal lasted from about 7,500 to 4,000 yrs B.P. according to Antevs (1955). Van Devender et al. (1984) studied plant remains in packrat middens in the Sacramento Mountains, on the east side of the Tularosa Basin. From about 8,000 to 4,000 yrs B.P. there were very warm summers with strong monsoons and relatively dry, cold winters. At about 4,000 yrs B.P seasonal precipitation shifted back slightly towards the winter, and

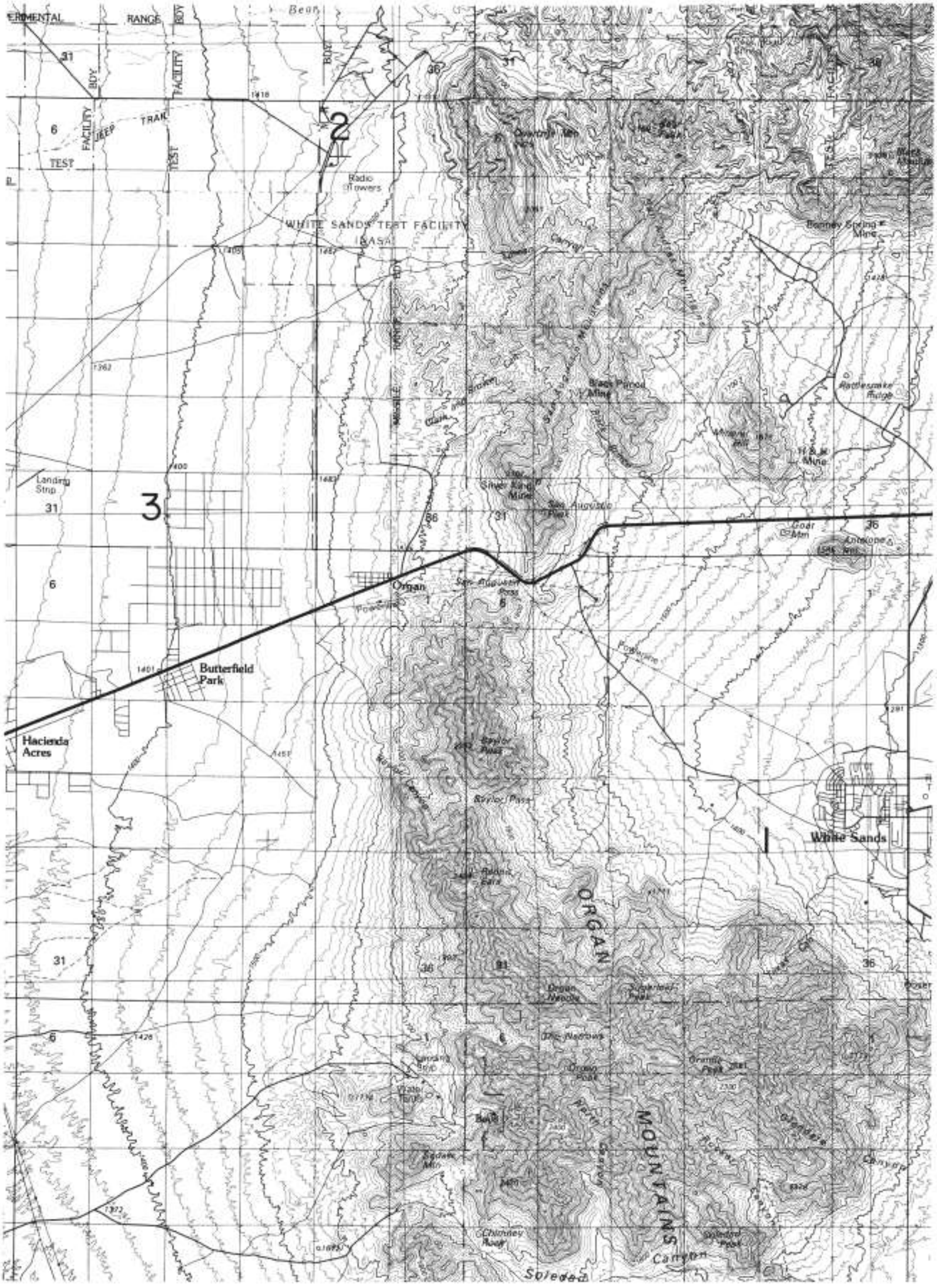


FIGURE 2—Location of the studied part of the Organ Mountains fault (1), the Gardner Spring radiocarbon site (2), and the Isaacks' radiocarbon site (3). Contour intervals are in meters.

Van Devender et al. (1984) consider the climate during the last 4,000 yrs to have been more stressful on the biota than during the Altithermal.

Others believe that the Altithermal extended from 7,500 to 5,000 yrs B.P. (e.g., Irwin-Williams and Haynes, 1970. Benedict (1979) found evidence of a "two-drought" Altithermal with two short, severe droughts, one from 7,000 to 6,000 yrs B.P. and the other from 6,000 to 5,500 yrs B.P. Holliday (1982) also found evidence of two phases of the Altithermal, from 6,500 to 6,000 yrs B.P. and from 5,500 to 4,500 yrs B.P.

As will be discussed later, the critical time involving latest displacement at the Cox segment was not during the Altithermal but after it ended. Evidence at the Gardner Spring radiocarbon site (to be discussed) indicates at least two deposits caused by drought in post-Altithermal time.

The remarkable ubiquity of Organ deposits in areas accessible to Holocene sedimentation is additional evidence for climatic change as the main cause of Organ alluviation. Organ sediments occur downslope of all mountain ranges in the area, even the small ones. Past changes to warmer and drier climates should have decreased vegetative cover, which would tend to cause soil erosion. Haynes (1968) presented evidence indicating widespread synchroneity of climatic variations and associated erosion and deposition throughout the Southwest.

Episodes of climatically controlled erosion and sedimentation thus provide both discrete deposits and, where the deposits can be dated, a chronology that is independent of sedimentation caused by faulting. Morphology of soils that have formed in the deposits may be used to distinguish soils in sediments of different ages if the morphological range of the various soils has been determined (Gile, 1977). In making the morphological comparisons, allowance must be made for differences in such factors as parent materials and climate because differences in these factors can have major effects on soil morphology (Gile, 1975, 1977).

^{14}C ages of buried charcoal found in the Desert Project provide good chronological control on sediments and soils of middle and late Holocene age. The Gardner Spring radiocarbon site (Fig. 3) has been particularly useful. Although the soils there formed in high-carbonate parent materials and thus differ from the materials at the Cox segment, eight charcoal lenses in different stratigraphic positions give chronological control for important episodes of sedimentation on the piedmont slope in the Desert Project region.

TABLE 1—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 Cox segment. Years B.P. = years before 1950, following the custom for reporting radiocarbon ages.

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	2,200–7,000
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)

High-carbonate parent materials—the Gardner Spring radiocarbon site

Organ alluvium and its soils were studied in detail at the Gardner Spring radiocarbon site (Fig. 2; Gile and Hawley, 1968; Gile, 1975). Alluviums of three ages, designated Organ I, II, and III, were dated by ^{14}C ages of buried charcoal (Fig. 3). The alluviums were traced along numerous exposures provided by Gardner Spring Arroyo and its tributaries. Organ I alluvium is at least 2,200 yrs old, but the bulk of it is less than 6,400 yrs old (Fig. 3). The younger dates in Organ I alluvium (4,570 and 4,640 yrs B.P.) are from charcoal well below the top of Organ I alluvium. This suggests that at least in this area, the Altithermal may have lasted until 4,000 yrs B.P. as proposed by Antevs (1955).

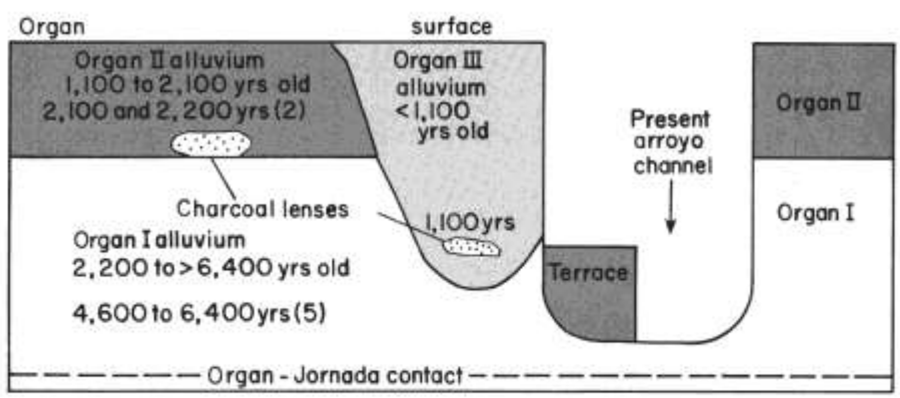


FIGURE 3—Diagram showing charcoal lenses dated by ^{14}C and the chronostratigraphic relationships at the Gardner Spring radiocarbon site. Numbers in parentheses indicate the number of dated charcoal lenses. Location of charcoal in Organ I alluvium ranges from central to near its base.

Gardner Spring Arroyo heads in Quartzite Mountain (Fig. 2); Organ I and II alluviums are exposed extensively not only along Gardner Spring Arroyo but also in tributary arroyos that head only in the Bear Canyon fan, which is lower and more arid than Quartzite Mountain. The relationships suggest that: 1) erosion and deposition of Organ I and II alluviums were initiated by regional climatic changes to times of lower effective moisture; 2) Organ I alluviation commenced about at the beginning of the Altithermal; 3) Organ I sediments, which typically contain little or no gravel, represent gradual erosion of fine earth from upper horizons of soils upslope; and 4) the alluviation was followed by a hiatus during which weak soils formed in the alluvium.

Between 2,100 and 1,100 yrs B.P. another change to a time of lower effective moisture resulted in the erosion of more gravelly, erosion-resistant materials deeper in the soils upslope. The resulting sediment is Organ II alluvium.

Organ III alluvium filled a gully 60 ft wide and 7 ft deep, and must be less than 1,100 yrs old (Fig. 3). Old arroyos filled with sediments record droughts; the arroyos were cut by severe floods during the dry periods and filled during periods of transition to more moist climates (Bryan, 1925; Antevs, 1955; Haynes, 1968).

The alluvial chronology at Gardner Spring closely agrees with Haynes' (1968) alluvial chronology for the Southwest. Thus Organ I alluvium corresponds to Haynes' Deposition C2; Organ II to Deposition D; and Organ III to Deposition E. Low terraces along Gardner Spring Arroyo (Fig. 3) are thought to be less than 100 yrs old (Gile and Hawley, 1968).

All soils at Gardner Spring are calcareous throughout because of high-carbonate parent materials. Although soils of Organ alluvium have morphological features associated with high-carbonate parent materials (see Gile and Hawley, 1968; Gile, 1975, for details), they lack noncalcareous, reddish Bt horizons found in many soils of Organ age that have formed in low-carbonate parent materials such as those at the Cox segment. Such soils occur at the Isaacks' radiocarbon site and elsewhere as discussed in the following section.

Low-carbonate parent materials—the Isaacks' radiocarbon site

Soils at the Isaacks' radiocarbon site (Fig. 2; Gile, 1975) have formed in monzonite sediments derived from the San Agustin Mountains. Lithology of the parent materials is similar to lithology at the Cox segment, although large rock fragments are much more abundant at the fault. Elevation at the Isaacks' radiocarbon site is 4,600 ft, which is slightly higher than the Cox segment. Despite this, A horizons at the Isaacks' radiocarbon site contain less organic carbon than at the Cox segment, Bt horizons are thinner, and horizons of carbonate accumulation are at shallow depths (most of the studied soils at the Cox segment lack carbonate horizons). These morphological differences are attributed to lower precipitation at the Isaacks' radiocarbon site.

Two buried charcoal lenses were dated at Isaacks' radiocarbon site. The first buried charcoal was exposed in the south bank of a gully and was dated at 4,035 yrs B.P. by "C methods. Because the soil along the edge of the gully was truncated, a sampling site was selected on a stable surface 230 ft to the west. Much more charcoal, dated at 4,200 yrs B.P., was found. Because the charcoal was in C horizon material beneath pedogenic horizons, the latter horizons must be less than 4,200 yrs old. The pedogenic horizons are a reddish, noncalcareous Bt horizon with hue of about 6YR and an underlying stage I carbonate horizon (Gile et al., 1966). A thin, buried soil beneath the charcoal must have formed before 4,200 yrs B.P. The buried soil has a Bt horizon of 5YR hue, in contrast to 6YR hue of the Bt horizon above the charcoal. However, occasional 5YR hues have also been found in nearby arroyo-bank exposures of the Bt horizon above the charcoal. The buried soil is believed to have developed in Organ I alluvium.

The alluvium above the charcoal could be nearly 4,200 yrs old if the alluvium was deposited soon after the fire that made the charcoal. But another possibility should be considered. Because the alluvium is less than 4,200 yrs old it could fall within the age range of Organ II alluvium, which is between 1,100 and 2,100 yrs old. This range in age would also apply to much of the younger part of the extensive Fillmore alluvium along the valley border, suggesting regional significance for this general time of erosion and deposition. Charcoal beneath this younger Fillmore alluvium has been dated at 3,960, 3,750, 2,850, and 2,620 yrs B.P. Archaeological evidence indicates that large areas of Fillmore alluvium were stabilized by 1,000 yrs ago; thus the minimum age of much of the Fillmore alluvium is similar to that of Organ II alluvium. For the above reasons it is believed that alluvium above the charcoal lenses at the Isaacks' radiocarbon site is analogous to late Fillmore alluvium and the Organ II alluvium at Gardner Spring. The same climatic change could have triggered erosion and subsequent deposition of all three alluviums.

Soils and sediments of the Fillmore surface also provide evidence for the time required for the development of reddish Bt horizons. Most soils of the Fillmore surface occur in less stable landscape positions because of erosion associated with downcutting of the Rio Grande valley, and they are more arid than most soils of the Organ surface. Nevertheless, soils that have formed in low-carbonate parent materials at stablest sites have distinct, though thin, reddish Bt horizons.

Soils and sediments in the age range of Organ III, although not identified at Isaacks' radiocarbon site, have been observed at various places. Soils with thick, dark A horizons, but without reddish Bt horizons, occur in youngest landscape positions (low, young terraces) adjacent to arroyos along the mountain fronts. These soils have formed in the youngest Organ sediments and would fall within the age range of Organ III (about 100 to 1,100 yrs B.P.).

Chronology at the fault—scarp terminology and disposition

The cover shows Organ sediments in a situation common in the Desert Project: inset against older, higher sediments of the Jornada surface. The linear scarp (see glossary) is prominent on the aerial photograph and displaces the Jornada and most Organ sediments. The cover also shows a prominent alluvial fan that has formed east of the scarp. The fan is the northern of the two shown by Reiche (1938). The arroyo that built the fan has the largest watershed of any arroyo in the study area. For convenience it is designated North Arroyo, and another large arroyo, in the southern part of the study area, is designated South Arroyo (Figs. 4 and 5).

In some areas debris flows can occur as a result of heavy storms under the present climate (Beaty, 1963). Most Organ alluvium is beyond reach of debris flows because most of it stands well above channels available to such flows. But highly interesting eyewitness accounts and Beaty's reconstruction of events facilitate an understanding of debris flows and associated phenomena (Beaty, 1963, pp. 520, 521, 524, and 530):

> . . . after a heavy thunderstorm in the mountains . . . loud rumbling and roaring noises were heard emanating from the lower canyons . . . About 30 minutes later, masses of debris were noticed advancing downslope . . . the leading edge of the debris appeared to be a low wall of boulders and thick mud without visible water. . . The flows were accompanied by noises likened to "the sound of a thousand freight cars bumping together simultaneously." . . . After the debris flows had come to rest, high-water flow continued . . . for 24 to 48 hours . .
>
> The high discharge which *followed* debris deposition dissected the fresh material. . . The excavated material was transported beyond the debris flow and deposited as tongues of silt and sand.. .
>
> As high water recedes, the streams quickly become clear, and it is during such periods of falling water that deposition of the water-sorted fines occurs.

Thus debris flows can account for the presence of large boulders found a considerable distance from the mountains (see site 5). The high water flow after the debris flow stopped explains (as water-laid materials) the presence of surficial sediments that consist almost wholly of fine earth above debris-flow sediments dominated by large rock fragments.

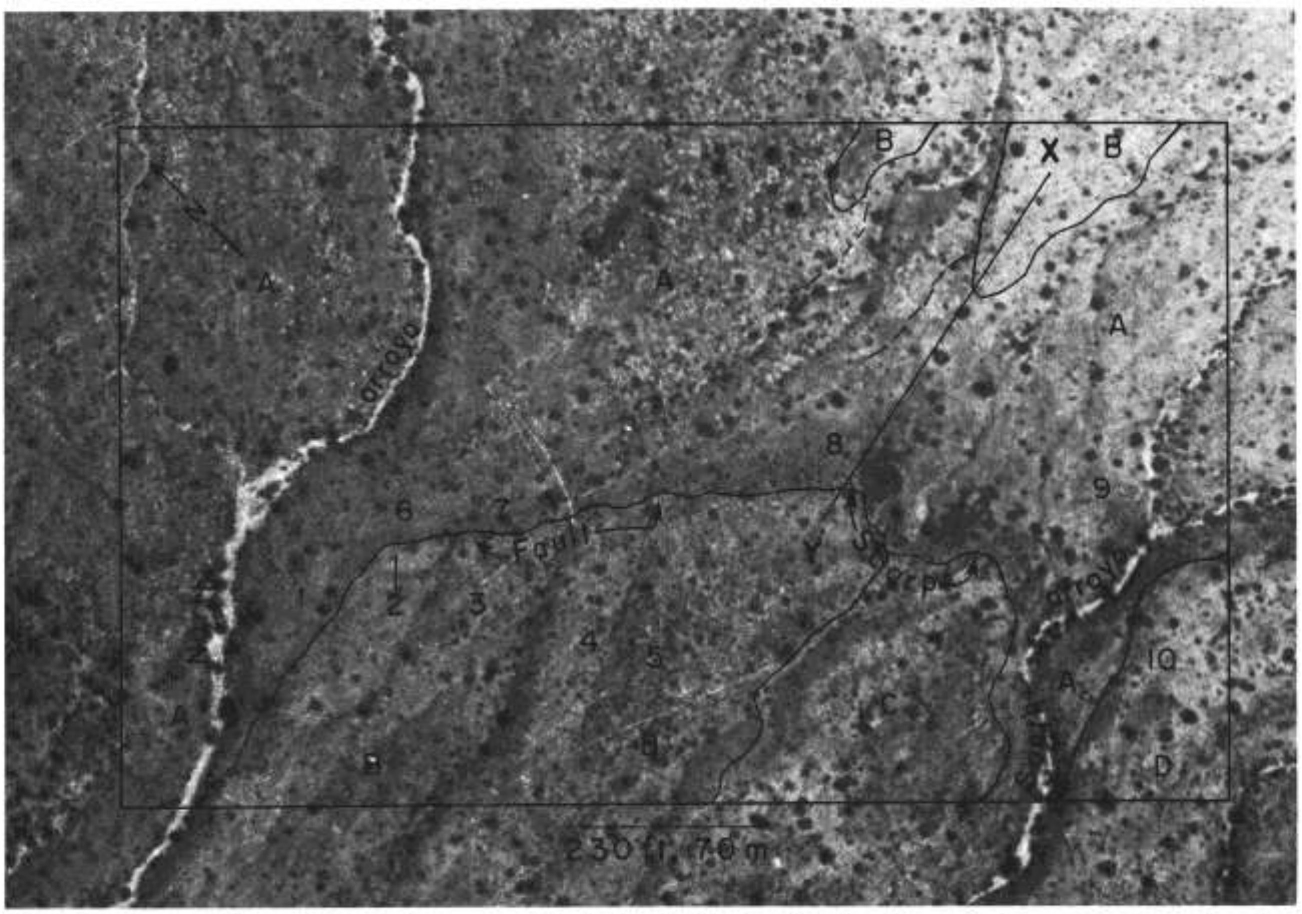


FIGURE 4—Geomorphic map of the study area on aerial photograph taken in 1963. **A** = dominantly Organ III surface, with minor amount of arroyo channel surface. **B** = dominantly Organ II surface, with minor amount of arroyo channel surface. **C** = dominantly a complex of Organ I and II surfaces, with minor amount of arroyo channel surface. **D** = Organ I surface. Numbers 1–10 locate the study sites. Line **XY** locates survey line from downdropped Organ II remnant up across the east (main) scarp. Dashed lines locate part of an abandoned, channel of North Arroyo. Location of site 2 indicated by a leader line so that the extension of the west fault can be clearly seen; the leader crosses it. The top of the east (main) scarp is shown for most of its distance by the boundary between units A and B, downslope from sites 2–5.

According to Beaty (1963) discontinuous bedding, a lack of well-defined strata, and an assortment of debris of all sizes are typical of debris flows. These features are characteristic of sediments considered to be debris flows in the study area, and are of interest in studies of soils because much of the material must have been quite uniform. Thus the soils may be assessed with respect to the debris-flow materials, the effect of the water-laid materials that in many places follow them, and the subsequent effects of pedogenesis after abandonment of the deposits by streams.

Figure 4 is a geomorphic map of an area illustrating the latest displacement; the sites of detailed study are indicated on it. The three Organ alluviums at Gardner Spring have also been identified in this area (Fig. 5). Figure 5 is a cross section from North Arroyo to Organ I alluvium just south of South Arroyo. The survey line angles northward at site 5 to show the slope across the Organ II ridges perpendicular to slope of ridge crests. The Organ II ridge crests are virtually level transversely and show no evidence of inset relations that could indicate younger sediments. In contrast, Organ III alluvium at site 1 is lower than the Organ II ridges. This and soil morphology, much weaker in Organ III alluvium than in Organ II ridges (see sites 2-5, Fig. 4), indicate that sediments of a younger terrace have been emplaced against Organ II alluvium.

A different sort of geomorphic and stratigraphic arrangement exists between Organ I and II alluviums (Fig. 5). Instead of younger sediments being lower than and inset against older sediments (as discussed for Organ III and II), Fig. 5 shows Organ II sediments occurring as topographic highs in comparison to adjacent Organ I sediments. The soils of Organ I are more strongly developed, and soil morphology is an important diagnostic tool for determining age of soils and sediments. The relations indicate that Organ II alluvium has buried Organ I alluvium. However, this has not been demonstrated because the backhoe could not ascend the scarp (see site 8, Fig. 18). A similar situation—in which soils have been buried by younger sediments that constitute a topographic high—has also been observed in the Desert Project (see Gile, 1977, pp. 116-120, for an illustration).

Cross sections across the fault zone (Fig. 6) show prominent increases in slope along the main scarp, which is distinct on the aerial photograph (Fig. 4). Another increase in slope is also apparent to the west (Fig. 6). This slope increase shows on the aerial photograph east of sites 3-5 and west of site 2 (Fig. 4). Because this second increase in slope is linear, parallels the main scarp, and cuts across the slope of the alluvium nearly at right angles, the slope increase must be due to faulting and must represent a fault scarp. The east and west scarps are thought to be the same age, with the west scarp representing a drag effect from the main displacement.

Along the west scarp, scarp height decreases from south to north (Fig. 6). At site 2, slope of the land surface smoothly crosses the line that shows on the airphoto (Fig. 4). Apparently, displacement along the west fault was very slight at site 2. Soils on both sides of the west fault are very similar and will be discussed later. The relationships suggest that the amount of displacement increases from north to south.

As can be seen by extrapolation along the fault zone adjacent to this study area (see cover), the west scarp actually fits better with the general trend of the scarp than does the east scarp, which projects outward and eastward from that trend. The eastward projection coincides with the location of major arroyos and a prominent concentration of Organ II alluvium. These factors may have affected scarp location. The down-dropped soil of Organ II occurs on Organ II ridges below the west scarp, but has not been observed below the east scarp, apparently because of strong erosion by arroyos.

Wallace (1977, p. 1267) summarized useful terms for designating the various parts of a fault scarp:

> The *upper* and *lower original surfaces* are the segments of the original surface that have been separated by faulting. The *toe* or *base* of the scarp and the *crest* of the scarp are, respectively, the lower and upper extremes of the fault scarp; *free face is*

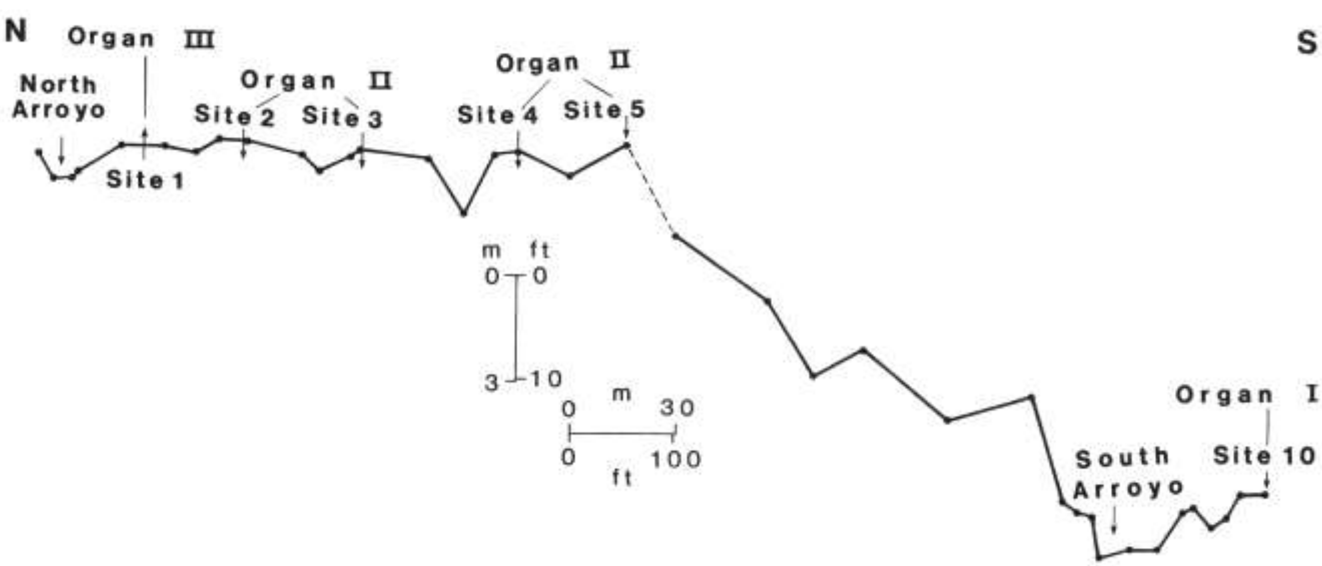


FIGURE 5—Cross section from North Arroyo to Organ I alluvium just south of South Arroyo. North of site 5, the survey line angles northward to cross the Organ II ridges at right angles to their longitudinal slope.

the exposed surface resulting from faulting or succeeding gravity spalling; *debris slope* is the talus slope accumulated below the free face; and *wash slope* is any part of the scarp controlled by fluvial erosion or deposition.

Figure 7 is a cross section of the scarp at site 7 (Fig. 4), showing pertinent terms for parts of the scarp that are still preserved. The term "upper surface" is used instead of "original upper surface" because fine earth has accumulated since displacement (see site 7). Slope of the free face is generally between 45° and overhanging (Wallace, 1977). From Fig. 7 it is evident that no free face is present in the scarp at site 7, and one may never have formed in these skeletal, mostly coarse-textured materials. In these materials the upper part of the fault plane (or initial scarp) must have been immediately obliterated by slumping. The crest of the scarp is not rounded at site 7, but this may be due to the protective disposition of rock fragments because rounding is apparent at other locations thong the scarp.

The debris slope, formed mainly by gravity accumulation, is not present. Instead, even the steepest part of the slope falls within the range of 8-25° slope designated as wash-controlled (Wallace, 1977, fig. 3E). The steeper slopes are similar to the common colluvial slopes that develop on sides of ridges in arid regions.

The scarp colluvium is thought to have graded to sediments of North Arroyo, a channel of which must have swung along the scarp base immediately after displacement (see discussion at site 7, p. 23).

The wash-controlled slope of this study contains two distinctive components that differ considerably in particle size (Fig. 7): the skeletal zone, dominated by cobbles and stones; and the fine-earth zone, dominated by fine earth (see glossary). Both the skeletal and fine-earth zones are essentially continuous features along the scarp.

In discussing wash slopes, Wallace (1977, p. 1271) stated: "Below the debris slope on young scarps a wedge of alluvium commonly develops that overlaps the debris slope and the original fan slope . . . These deposits range in slope from. . . commonly 3° to 7°, to as much as 10° or 15°." This description is very similar to the distinctive materials designated fine-earth zone (Fig. 7), which overlaps the skeletal colluvium upslope. But downslope, instead of overlapping the original fan slope as shown in Wallace (1977, fig. 2), the fine-earth zone rests on youthful sediments that were apparently derived from North Arroyo.

Neither the base of the scarp nor the original lower surface is evident; both are thought to have been eroded away by torrents from North Arroyo immediately after displacement.

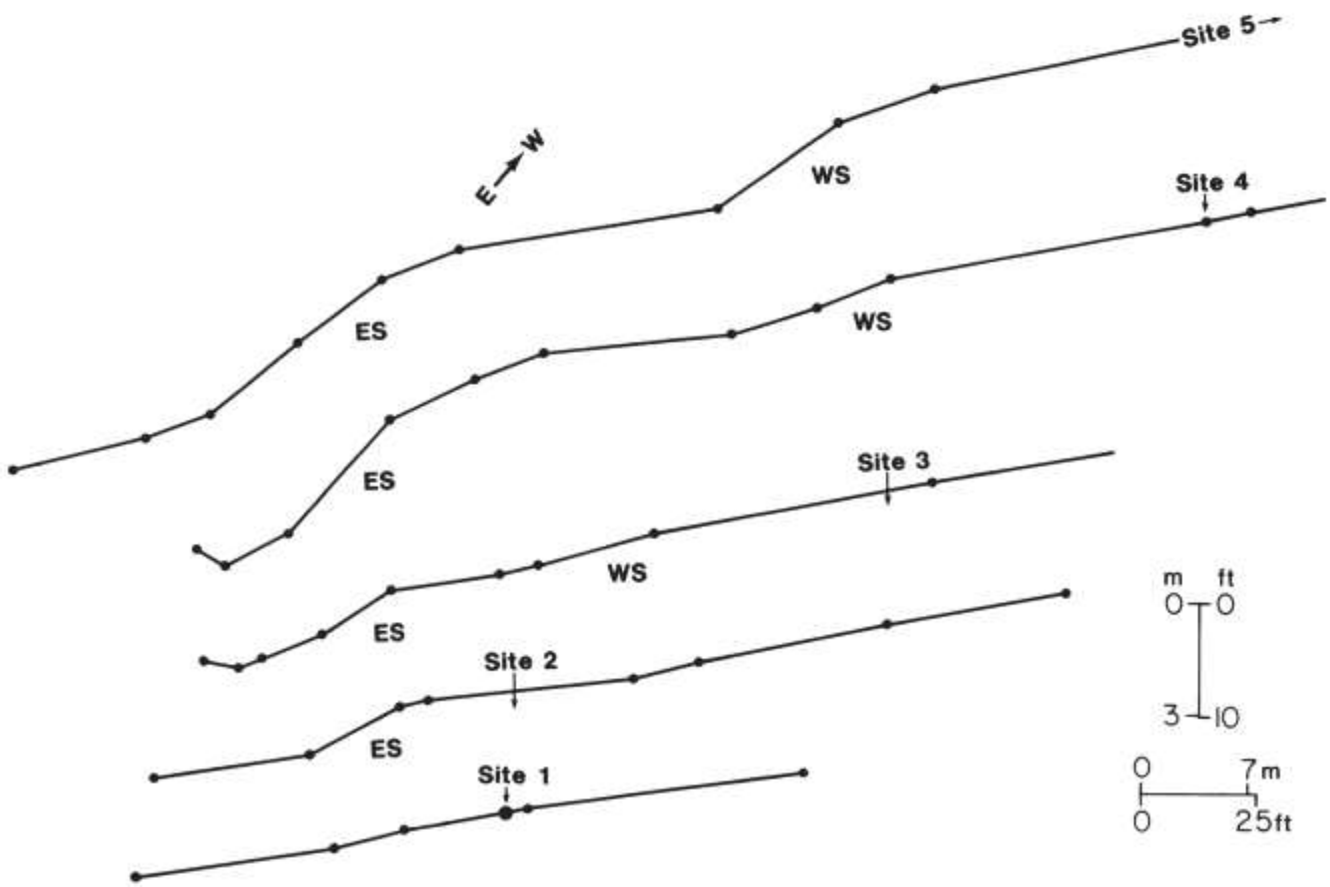


FIGURE 6—Elevations up the scarps and along the interfluves on which sites 1–5 are located. The survey lines up the scarps were drawn at right angles to the scarp trends. Because the scarps are at an angle to longitudinal slopes of the Organ II ridges, lines above the scarps angle westward to accord with these slopes. The Organ III terrace (on which site 1 is located) has no evidence of a scarp and the survey line is straight. Scales refer to survey lines and not to distance between them. Sites 1–5 are on or near the survey lines, as indicated. **ES** = east (main) scarp; **WS** = west scarp.

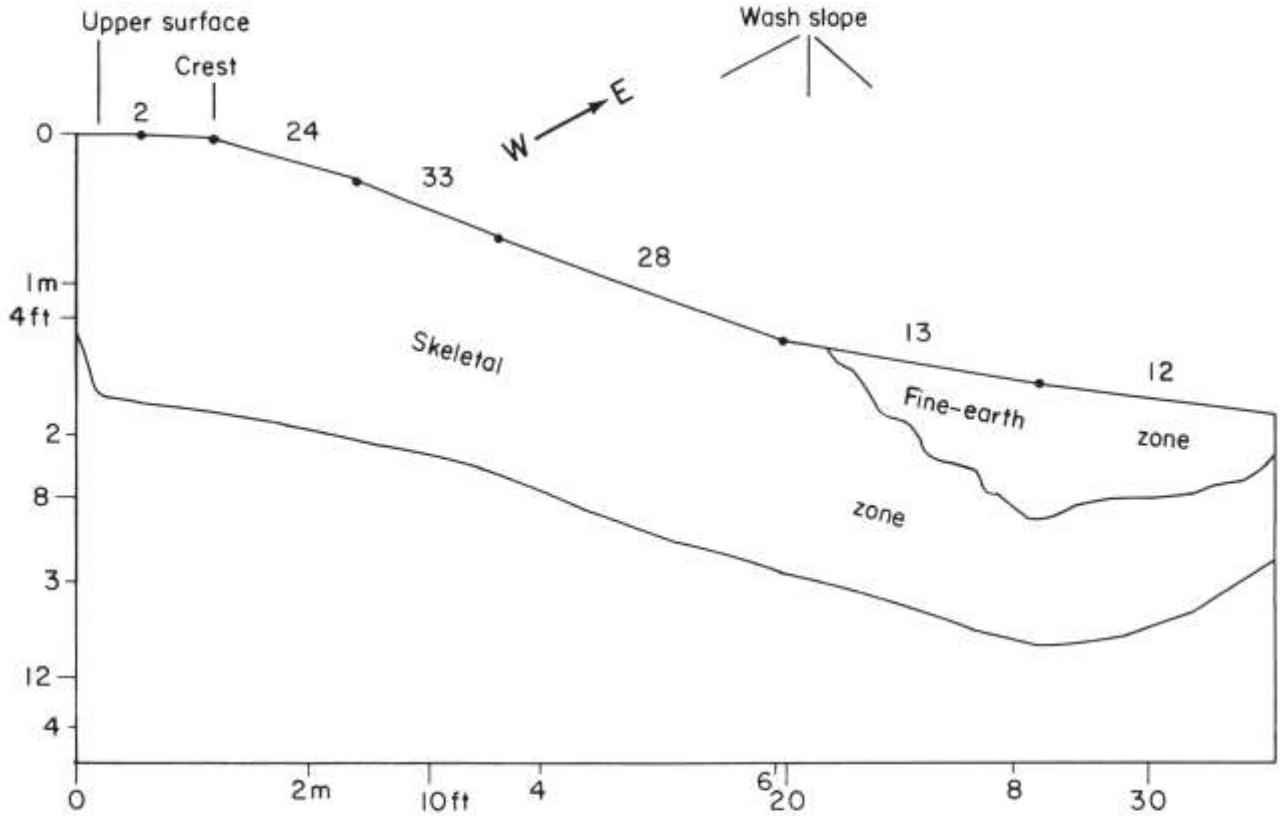


FIGURE 7—Diagram of the study trench at site 7, showing the scarp and the skeletal and fine-earth zones. Dots are surveyed points along the north side of the trench. Numbers along the surface are slopes in percent. The 2% slope of the upper surface is less than the typical slope of about 6% along crests of the Organ II ridges, and this is attributed to differences in local microrelief and to accumulation of fine earth since displacement. The wash slope occupies the entire area below the crest. The term scarp, as used in this report (see glossary), occupies the steeper parts of the wash slope (24%, 33%, and 28% slopes).

Soil classification and conventions

Classification of soils discussed in this paper is given in Table 2. The orders Entisols, Aridisols, and Mollisols are all present in this small area. The study area occurs in a broad transition zone between Mollisols and Aridisols, in which occurrence of one or the other at a particular spot depends on such factors as particle size and landscape instability (with its associated soil erosion). East of the study area, the climate becomes drier and all soils are either Aridisols or Entisols. Because of differences in soil age, runoff, and particle size the Entisols also occur in complex patterns from one spot to another.

Tables of data that will be presented in following sections illustrate soil features having chronological significance in the study area. These features are accumulations of organic carbon, silicate clay, and carbonate, as well as soil color, consistence, and structure. The data illustrate accumulations of organic carbon and clay. 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 (B. L. Allen, pers. comm 1983).

Soil color is an important chronological property. The chronological changes cannot be shown precisely with the U.S. Munsell soil color charts because the critical chips for three chroma are not given for the 7.5YR hue. These chips are given in a Japanese color book (Oyama and Takehara, 1967).

In most horizons, colors given in the tables occur uniformly throughout the horizons. But for C horizons and for some horizons transitional to C, soil colors are not uniform, and colors given in the tables are those of the finer fractions (mainly the clay, silt, and very fine sand). The other colors, not given in the tables, are the primary or near-primary color of the rocks, and they dominate colors of the horizons concerned because of the much greater volume occupied by rock fragments. In the C horizons of some Haplustolls, most colors are primary; the rock fragments and coarser sand grains are dominantly 10YR 8/1, 10YR 8/2, 10YR 7/2, 2.5GY 5/1, and 10Y 5/1. In other soils, colors of rock fragments in the studied C horizons are near-primary; the rock fragments have

TABLE 2—Classification and diagnostic horizons and features of soils discussed in this report. See *Soil Taxonomy* (Soil Survey Staff, 1975) for detailed definitions of the listed orders, suborders, great groups, and subgroups. The listed family designation is for particle-size class; all soils are in the thermic soil temperature class and the mixed mineralogy class (see glossary for definitions of these terms and for explanations of diagnostic soil horizons and features). Yana, Vado, Earp, and Santo Tomas are established series. Holliday and Baylor are informal series names. Yana Variant, as used in this report, includes both sandy and coarse-loamy families.

Order	Suborder	Great group	Subgroup	Family	Series or variant and illustrative pedon
Entisols	Orthents	Torriorthents	Ustic	Sandy, coarse-loamy	Yana Variant (7b, 8d)
Aridisols, cambic, or argillic horizon	Argids, argillic horizon	Haplargids	Ustollic	Loamy-skeletal	Holliday (2, 3, 4, 7a, 10a, 10b)
	Orthids	Camborthids, cambic horizon	Ustollic	Loamy-skeletal	Vado Variant (9)
Mollisols, mollic epipedon	Ustolls	Argiustolls, argillic horizon	Pachic	Loamy-skeletal	Earp Variant (5)
		Haplustolls	Torriorthentic	Sandy-skeletal	Baylor (1, 6, 8a)
			Pachic	Loamy-skeletal	Santo Tomas (8b)
				Sandy-skeletal	Santo Tomas Variant (8c)

been very slightly stained with clay, so that they are slightly redder and darker than the primary colors, and they also may have higher chroma.

The individual study sites are designated by numbers 1-10 (Fig. 4). In addition, sites 7 and 8 consist of more than one part, designated by a lower case letter (e.g., 7a, 7b). A specific pedon under discussion is designated according to site (e.g., pedon 7a).

Slopes are given in percent (rather than degrees) because this convention is followed in soils work. Horizon designations are summarized in the glossary. The terms single grain and massive designate materials considered to be structureless (Soil Survey Staff, 1951), but are included in structure for convenience in this report.

Soils of Organ II and III age above the main scarp

Sites 1 and 3-5 (Fig. 4) illustrate the soils and relative ages of Organ II and III sediments upslope of and independent of the scarp. Site 2 (Fig. 8) occurs between the east (main) and west scarps. Soil characteristics for sites 1-5 are given in Table 3. All soils contain more silt and clay in upper horizons than in the C horizon, which contains very little of these materials (Table 3). This accumulation and youth of the soils indicate that much of the silt and clay in the A and B horizons was derived from dustfall, as proposed for soils formed in very gravelly materials in the Desert Project (Gile et al., 1981, pp. 74, 200). Surficial water-laid materials may have been a source of some of the silt and clay in underlying debris flows (see sites 2-4 and 6).

Organ III terrace—site 1

Site 1 is in Organ III alluvium (Fig. 4), between North Arroyo and the Organ II ridges just south. Organ III sediments are inset against Organ II sediments and are therefore younger. On the ground at site 1, two ages of Organ III terraces are evident: the terrace next to the Organ II ridges, designated Organ III, early, in which site 1 occurs; and a slightly lower terrace just to the north, bordering North Arroyo, designated Organ III, late. Torriorthentic Haplustolls with thick, dark A horizons but no B horizons, have formed in sediments of both terraces. Table 3 gives soil characteristics at site 1 (see site 6 for a photograph of a similar soil). Numerous rock fragments occur throughout, and no water-laid deposit is evident.

The Torriorthentic Haplustoll at site 1 illustrates a prominent accumulation of organic carbon in sandy soils that lack B horizons. Table 3 shows the concentration of organic carbon in upper horizons, its gradual decrease with depth, and the associated lightening in color with depth. The considerable thickness of the organic carbon accumulation is attributed to coarse texture (Table 3), the pervious nature of these soils, and the numerous large rock fragments. The rock fragments would confine the soil solution to relatively small volumes and thus increase the depth of wetting. The soil has no carbonate horizon and is noncalcareous throughout, reflecting deep penetration of the wetting front in these pervious soils.

The C horizon at site 1 contains very little clay or silt, and particle-size analyses indicate that both have accumulated in the thick A horizon (Table 3). The horizon of maximum clay (Table 3) does not have the higher clay percentages, thickness, redder hues, and higher chromas that are typical of Bt horizons in the older soils. No water-laid deposit occurs at site 1, and the bulk of silt and clay in upper horizons is attributed to dustfall.

Magnitude of the silt accumulation in upper horizons suggests that additions of the finer sand fractions may also have been derived from dustfall. Table 4 presents particle-size distribution data, including sand size, for the Haplustoll at site 1 and for three dust traps with similar topography, elevations, and parent materials in the Desert Project. At site 1, distinctly higher percentages of fine and very fine sand occur in horizons above the C horizon than in it, indicating accumulations in the soil since the parent materials were deposited. Dust in the traps contain from 10 to 35% of fine sand and from 7 to 35% of very fine sand; thus, the dustfall is a source of fine and very fine sand. In the dust, only 1 to 6% of sand was found in the 2-0.25 mm range (Table 4). This generally agrees with the sand data at site 1, which do not suggest dustfall accumulation in the 2-0.5 mm fraction and only slight accumulation in the 0.5-0.25 mm fraction. Dustfall from all three traps contains abundant silt and clay, with more silt than clay, and this agrees with the proportion of silt and clay in the upper horizons at site 1.

TABLE 3—Soil characteristics at sites 1–5. The A3 horizon of pedon 1 was split for sampling. Most abbreviations follow Soil Survey Staff (1951) usage. *Structure:* **1m, cpl** = weak medium and coarse platy; **1mpl** = weak medium platy; **2mpl** = moderate medium platy; **1f, msbk** = weak fine and medium subangular blocky; **m** = massive; **sg** = single grain. *Dry consistence:* **l** = loose; **s** = soft; **sh** = slightly hard. *Textural class:* **vg** = very gravelly; **g** = gravelly; **vb** = very bouldery; **vc** = very cobbly; **s** = sand; **ls** = loamy sand; **sl** = sandy loam. Sand, silt, clay, and organic carbon at site 1 determined by the Soil and Water Testing Laboratory, New Mexico State University; at sites 2–5 by Carol Taschek.

Horizon	Depth cm	Hue	Value/chroma Dry	Moist	Structure	Dry consistence	Textural class	Sand 2.0–0.05 mm	Silt 0.05–0.002 mm	Clay <0.002 mm	Organic carbon
								percent			
Torriorthentic Haplustoll at site 1—Organ III, early											
A1	0–7	7.5YR	4.5/2	3/2	1m, cpl	s, l	vcls	77	16	7	1.28
A2	7–18	7.5YR	3.5/2	2/2	1f, 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
Ustollic Haplargid at site 2—Organ II											
A	0–5	7.5YR	4.5/3	3/3	1mpl	s, l	sl	76	16	8	0.73
Bt1	5–21	6YR	4/3	2.5/3	1msbk	sh	sl	76	14	10	0.54
2Bt2	21–37	5YR	4.5/3	3/3	1msbk	sh	vcsl	74	16	11	0.48
2Bt3	37–54	5YR	4.5/3	3/3	1msbk	sh	vcsl	76	13	12	0.41
2Bt4	54–84	5YR	4.5/3	3/3	m	sh	vcsl	75	14	11	0.39
2BCt1	84–130	6YR	5/3	3.5/3	m	s	vcsl	78	12	10	0.26
2BCt2	130–179	7.5YR	5/3	3.5/3	m, sg	s, l	vcsl	80	12	8	0.17
2C	179–210	7.5YR	5/3	3.5/3	sg	l	vcs	90	5	5	0.07
Ustollic Haplargid at site 3—Organ II											
A	0–5	7.5YR	4/2	2.5/2	sg, 1mpl	s, l	ls	78	14	8	0.53
Bt1	5–26	5YR	4.5/3	3/3	1msbk	sh	sl	74	16	10	0.48
Bt2	26–40	5YR	4.5/3	3/3	1msbk	sh	sl	75	14	11	0.50
2Bt3	40–70	6YR	4.5/3	3/3	1msbk	sh	vcsl	75	15	10	0.46
2Bt4	70–112	6YR	4.5/3	3/3	m	sh	vcls	80	10	10	0.28
2CBt1	112–137	6YR	5/3	3.5/3	m	s	vcls	86	8	6	0.14
2CBt2	137–162	7.5YR	5/3	3.5/3	m, sg	s, l	vcs	89	5	6	0.13
2C	162–192	7.5YR	5/3	3.5/3	sg	l	vcs	88	6	6	0.12
Ustollic Haplargid at site 4—Organ II											
A	0–4	7.5YR	4/2	2.5/2	1fpl	s, l	sl	78	12	10	0.52
Bt1	4–26	6YR	4/3	2.5/3	1msbk	sh	sl	72	18	10	0.46
2Bt2	26–51	5YR	4/3	2.5/3	1msbk	sh	vcsl	69	17	14	0.42
2Bt3	51–76	5YR	4.5/3.5	3/3.5	m	sh	vcsl	68	20	12	0.39
2Bt4	76–104	6YR	5/3.5	3.5/3.5	m	sh	vcsl	75	15	10	0.25
2BCt1	104–140	7.5YR	5/3	3.5/3	m	s	vcsl	74	17	8	0.19
2BCt2	140–178	7.5YR	5/3	3.5/3	m	s	vcls	80	13	7	0.14
2C	178–198	7.5YR	5/3	3.5/3	sg	l	vcs	91	5	4	0.07
Pachic Argiustoll at site 5—Organ II											
A	0–5	7.5YR	4.5/2.5	3/2.5	1fpl	s, l	vbsl	69	22	9	1.12
Bt1	5–19	7.5YR	4/2	2.5/2	1msbk	sh	vbsl	71	18	11	0.92
Bt2	19–47	7.5YR	4.5/2	3/2	1msbk	sh, h	vcsl	67	22	11	0.86
Bt3	47–79	7.5YR	4.5/2.5	3/2.5	1msbk	sh, h	vcsl	67	22	11	0.73
BCt1	79–105	7.5YR	4.5/3	3/3	m	sh	vcsl	69	19	12	0.67
BCt2	105–160	7.5YR	5/3	3.5/3	m	sh	vcsl	72	19	9	0.26
CBt	160–202	9YR	5/3	3.5/3	m, sg	s, l	vcsl	74	18	8	0.14
C	202–215	9YR	5.5/3	4/3	sg	l	vcls	85	9	6	0.14

TABLE 4—Particle-size distribution at site 1 and of dustfall for traps 2, 5, and 5a at the Desert Project. The A3 horizon of pedon 1 was split for sampling. Trap 2 is on a coalescent fan piedmont on the west side of the Organ Mountains at an elevation of 5,000 ft. Slope is 4%, and the sediments were derived primarily from rhyolite, monzonite, and andesite. Traps 5 and 5a are on a coalescent fan piedmont on the east side of the Doña Ana Mountains at an elevation of 4,350 ft. Slope is 2% and the sediments were derived primarily from monzonite, rhyolite, and andesite. Particle-size distribution for site 1 determined by the Soil and Water Testing Laboratory, New Mexico State University. Data for dust traps from Gile and Grossman (1979, p. 82).

		Particle-size distribution, mm, percent						
		Sand					Silt	Clay
Horizon	Depth cm	2–1	1–0.5	0.5–0.25	0.25–0.1	0.1–0.05	0.05–0.002	< 0.002
		Dust trap 2, 90 cm height						
		———	1	———	10	7	45	37
		Dust trap 5, 90 cm height						
		———	2	———	20	22	34	22
		Dust trap 5a, 30 cm height						
		———	6	———	35	29	17	13
		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

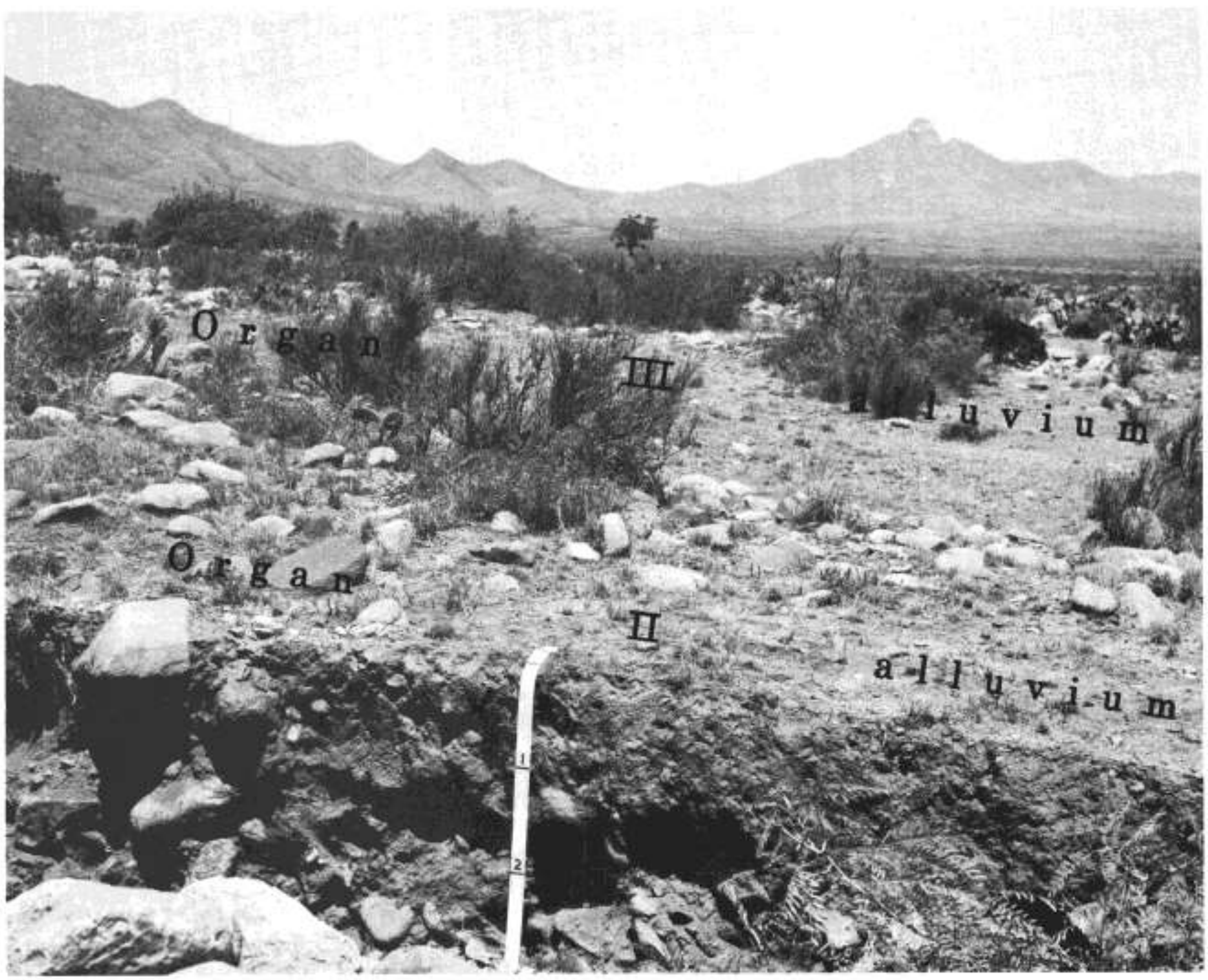


FIGURE 8—Landscape at site 2, looking to the north. Organ II sediments are exposed in the trench and extend into the cobble-mantled area in the foreground. Organ III sediments underlie the area largely free of rock fragments beyond Organ II sediments and extend to North Arroyo, beyond the shrubs in the middle ground. Note the smooth surface of materials dominated by fine earth, but the considerable increase in rock fragments below. San Agustin Peak is on the skyline at right center. Scale is in feet.

Organ II ridges—sites 2-5

Sites 2-5 (Figs. 4-6 and 8-10; Table 3) occur on four slight ridges of Organ II alluvium. Most of the sediments are debris-flow deposits; thin, surficial water-laid deposits also occur at sites 2-4. Fig. 9 illustrates the filling, by water-laid fine earth, of low areas in the cobbly microrelief of the debris flow at site 2. The water-laid materials may have been the source of some of the silt and clay between rock fragments of the underlying debris flow (see also site 6). However, the abundant silt and clay and the lack of a water-laid deposit at site 5 suggests that dustfall may have been the major source of silt and clay. The numerous surficial boulders at site 5 (Fig. 10) would constitute a highly efficient dust trap.

Soils at all four sites have a thick horizon of clay accumulation that qualifies as an argillic horizon (Soil Survey Staff, 1975), and thus contrast with the soil at site 1. Soils at sites 2-5 are noncalcareous throughout. The thick horizons of clay accumulation and lack of carbonate horizons indicate that the wetting front descends to considerable depths in these soils.

The soils at sites 2-5 are Ustollic Haplargids except for the one at site 5 (Fig. 10), which has a mollic epipedon and is a Pachic Argiustoll (Table 3). Numerous boulders occur on the surface at site 5 (Fig. 10); they have protected the soil from erosion, thus preserving the mollic epipedon. In contrast, soils at sites 2-4 lack such protection, and organic carbon is too low for a mollic epipedon.

Soils at sites 2-5 also illustrate weathering of rock fragments. Some of the component crystals, or groups of crystals, of individual rock fragments (commonly pebbles or cobbles) are so loose that they would have separated in transport before being deposited. Thus, the weathering must have occurred after the materials were deposited and must have been caused by soil moisture because the soils are regularly moistened to substantial depths. Both monzonite and andesite

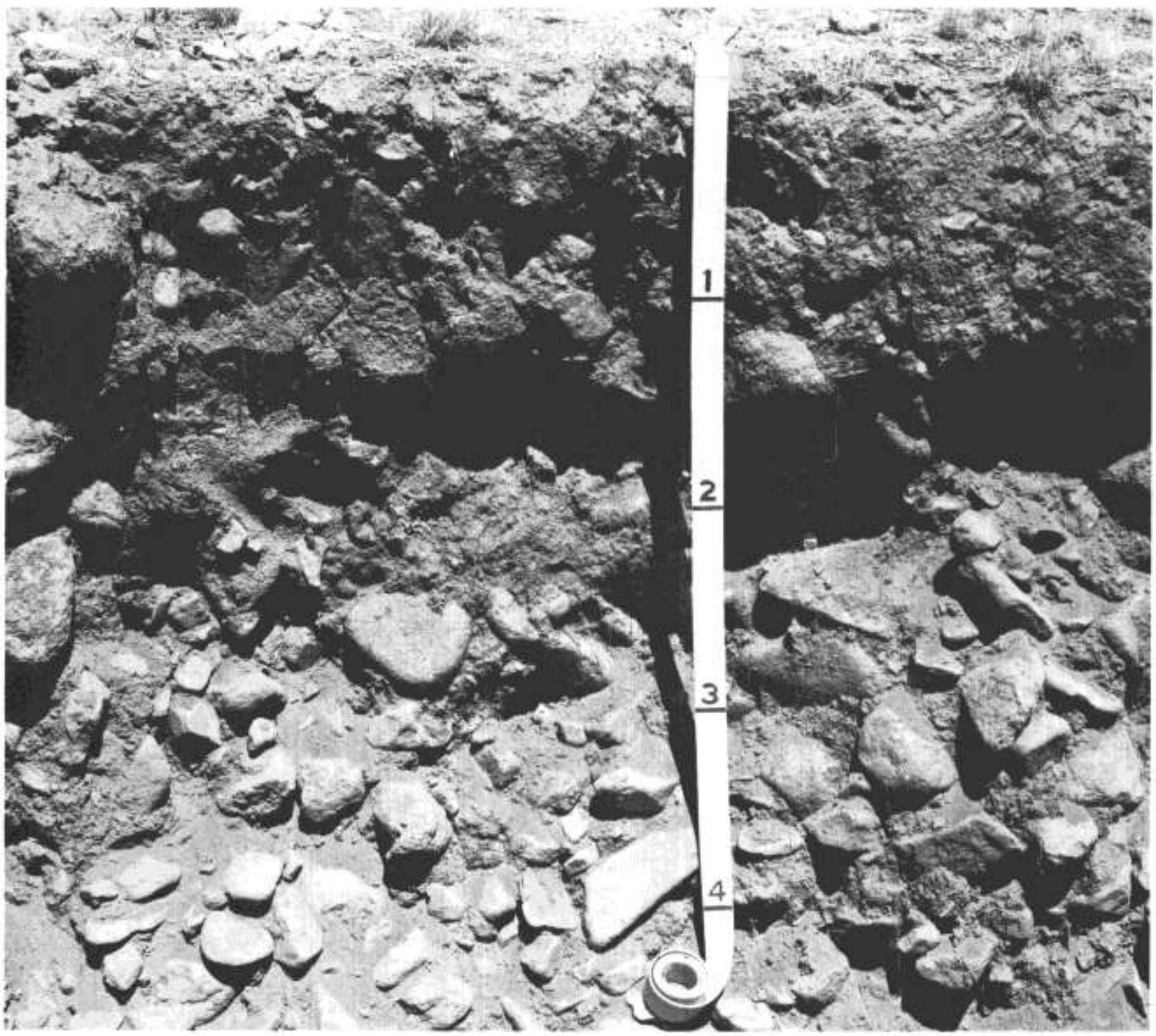


FIGURE 9—Profile of the Ustollic Haplargid, Holliday (see Table 2), at site 2. Scale is in feet.

fragments have been affected. Rock fragments weathered in this way are in the minority, however; most are so hard that they are broken with a hammer only with difficulty. This indicates that a few of the fragments were weathered before they were picked up by the transporting stream. The weathering appears to be physical rather than chemical because interiors of the rocks appear fresh and there is little or no visible clay. Presence of these weathered rock fragments in soils of Organ I and II age, but not Organ III, indicates that such weathering can occur in a minimum time ranging from about 1,100 to 2,100 yrs (Table 1).

The C horizons of pedons 2-4 are slightly redder, darker, and less gray than the C horizon of pedon 1 (7.5YR 5/3, dry, vs 10YR 6/2). These color differences may reflect very slight accumulations of illuvial clay in the C horizons of pedons 2-4, in which case such illuviation could be indicated by adding "t" to the symbol C. This would require further study, however, and in this report the horizons are designated simply as C.

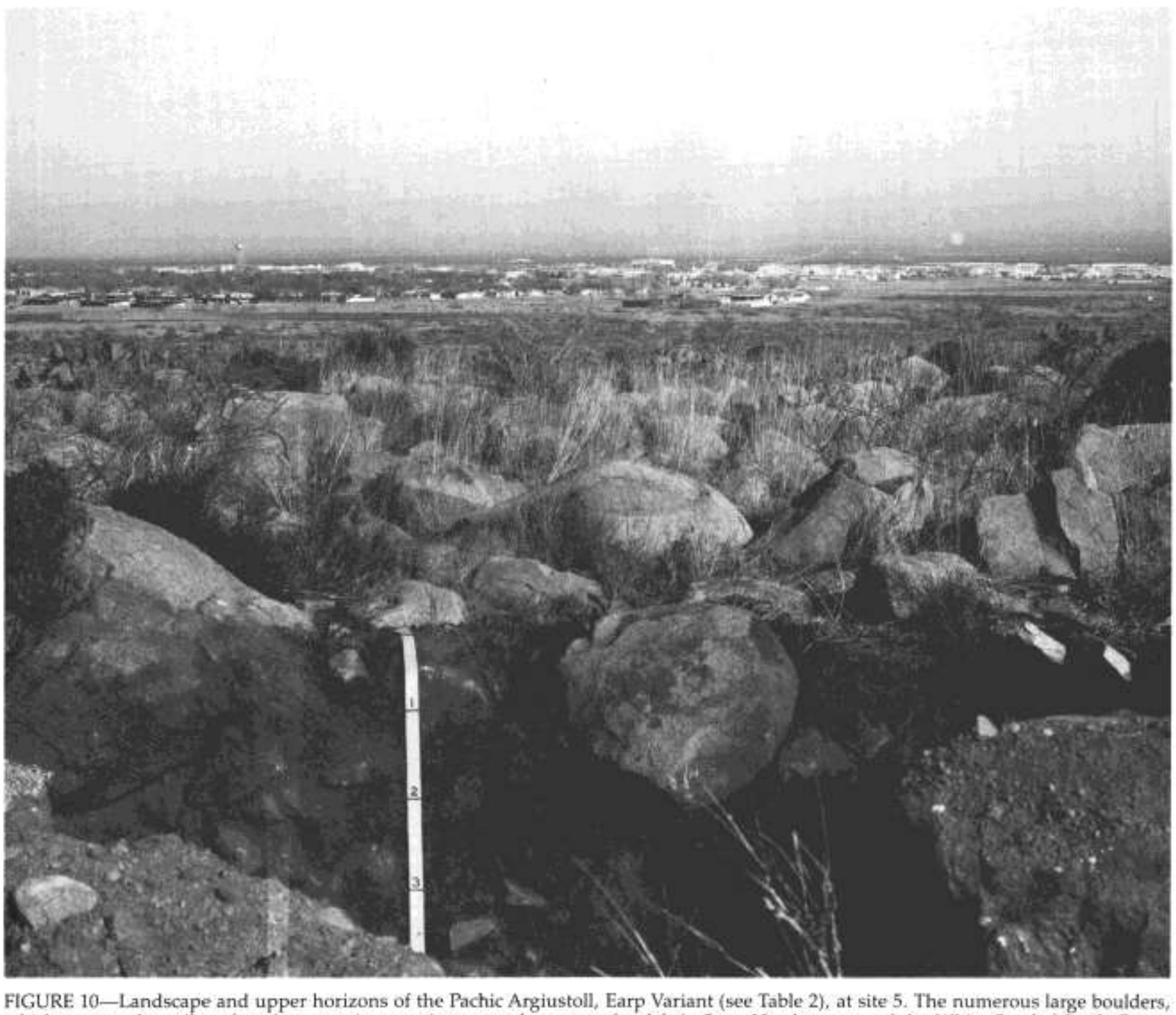


FIGURE 10—Landscape and upper horizons of the Pachic Argiustoll, Earp Variant (see Table 2), at site 5. The numerous large boulders, which protect the soil surface from erosion, are interpreted as part of a debris flow. Headquarters of the White Sands Missile Range are in the background. Scale is in feet.

Soils of Organ II and III age along and below the main scarp

South of North Arroyo, the land surface below the main scarp slopes prominently to the south. Some of the slope is thought to have been caused by greater displacement to the south as discussed earlier, but some may also be due to more post-faulting sedimentation in the north because of the large size of North Arroyo and because abundant sediments must have been deposited by it after the latest displacement. Soils of Organ II age occur above the scarp; soils of Organ III age occur along the scarp and also below it in a large fan (cover; Fig. 4).

Organ III fan—site 6

Figure 4 shows a large area of Organ III alluvium adjacent to North Arroyo below the fault. Organ III, late, occurs as occasional low surfaces adjacent to North Arroyo. Site 6 (Figs. 4, 11-13; Table 5) occurs in Organ III, early, which occupies topographic highs in the Organ III landscape. The sediments at site 6 must postdate the fault because they can be traced upstream where they cross the fault zone but are not displaced by it.

The soil at site 6 is a Torriorthentic Haplustoll. It is similar to the Haplustoll at site 1, except that the A horizon of the latter soil is slightly darker and contains more organic carbon. Pedon 1 also contains a much greater volume of rock fragments in upper horizons (Tables 3 and 4). By convention, laboratory analyses are reported on a fine-earth (<2 mm) basis. Pedons with many rock fragments have higher percentages of organic carbon than nearby pedons with few rock

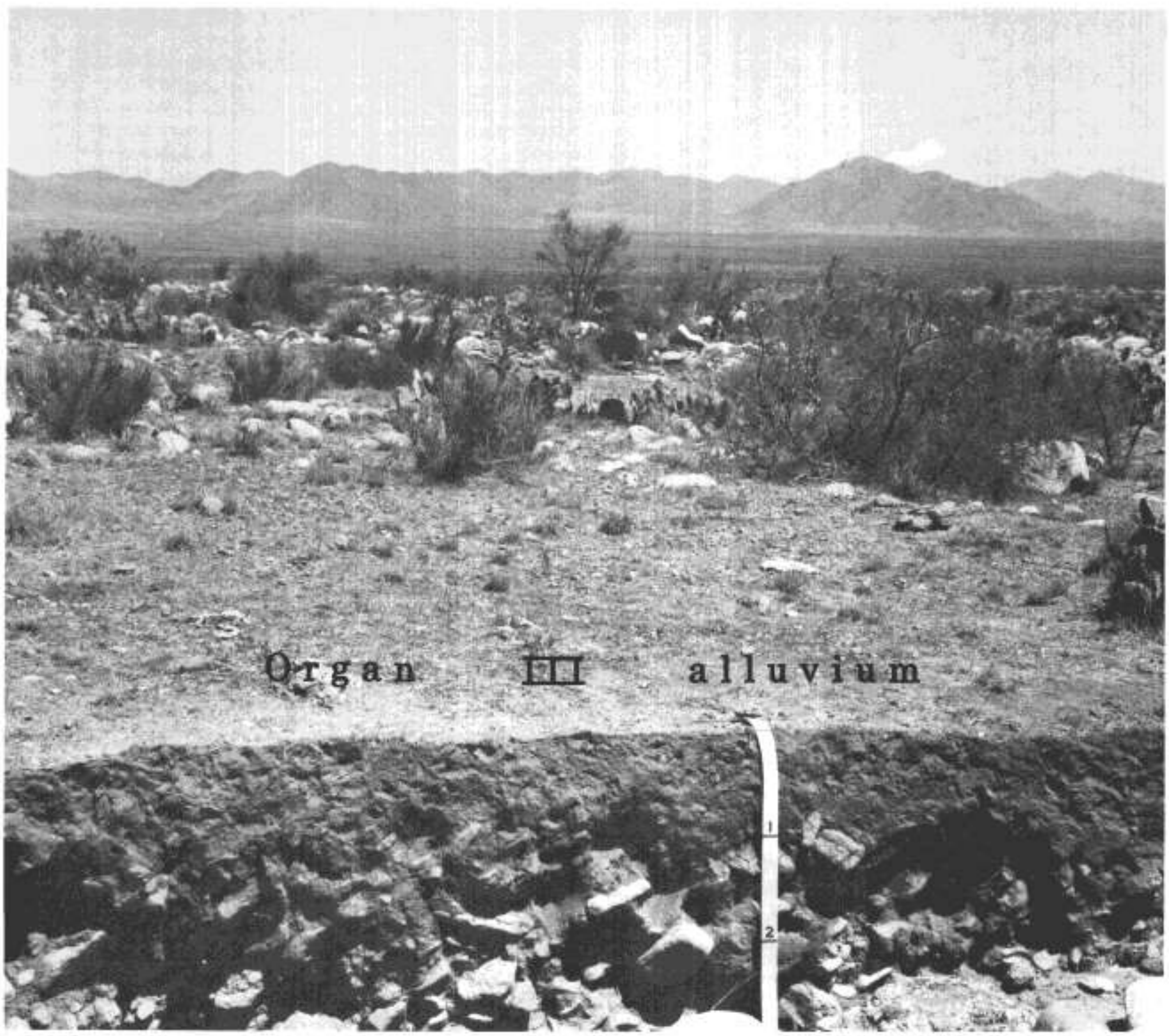
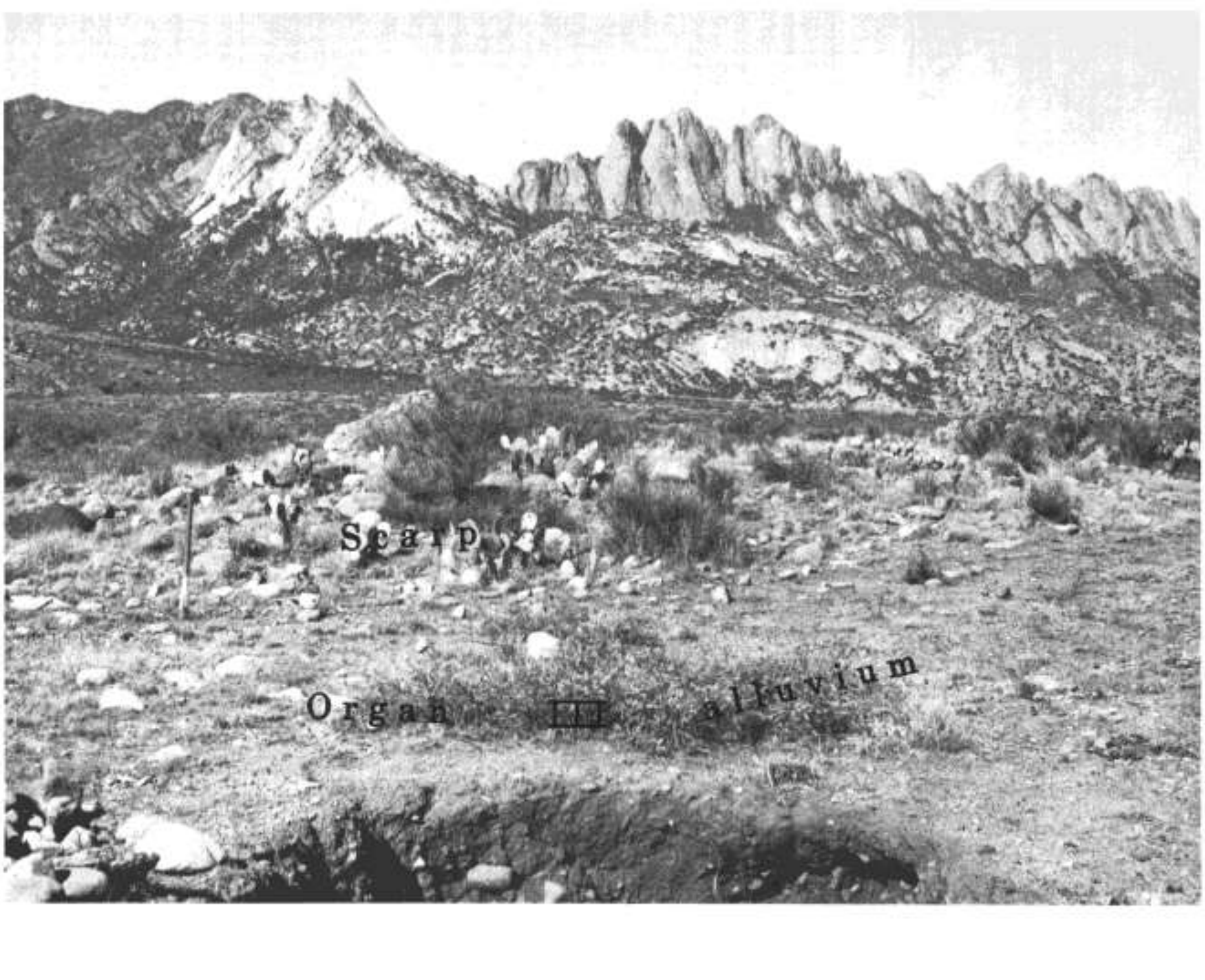


FIGURE 11—Landscape and profile of the Torriorthentic Haplustoll, Baylor (see Table 2), at site 6, looking to the north. Organ III alluvium is exposed in the trench and extends to North Arroyo in the middle ground. In about the upper foot the sediments contain very few rock fragments and are considered to be water-laid. Sediments below that depth contain abundant rock fragments and are interpreted as a debris flow. The San Andres Mountains are in the background. Scale is in feet.

TABLE 5—Soil characteristics at sites 6 and 7. The A2b horizon of pedon 7b was split for sampling. Sand, silt, clay, and organic carbon for site 6 determined by Carol Taschek; for site 7, by the Soil and Water Testing Laboratory, New Mexico State University. Abbreviations are explained in Table 3 caption (p. 15).

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 6—Organ III, early								percent			
A1	0–5	7.5YR	4.5/2	2.5/2	1mpl, 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
Ustollic Haplargid at site 7a—Organ II											
C	0–4	7.5YR	5/3	3.5/3	1cpl, 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	1msbk	sh, s	vcsl	75	14	11	
2BAt2b	21–45	6YR	4/3	2.5/3	1msbk	sh, s	vcsl	71	16	12	
2Btb	45–72	5YR	4/3	3/3	1msbk	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				
Ustic Torriorthent at site 7b—Organ III, late											
C	0–3	7.5YR	4.5/2	3/2	1mpl, sg	l, s	ls				
A1b	3–15	7.5YR	4/2	2.5/2	m	sh, s	sl				0.58
A2b	15–34	7.5YR	4/2	2.5/2	m	sh, s	ls				0.42
	34–53	7.5YR	4/2	2.5/2	m	sh, s	ls				0.41
A3b	53–67	7.5YR	4/2	2.5/2	m	s	ls				0.33
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				



fragments (Gile and Grossman, 1979, pp. 131, 133). This is because concentration of organic carbon into the small volumes between rock fragments would increase the values on a fine-earth basis and because numerous rock fragments would concentrate soil moisture and increase the abundance of plant roots.

Although the epipedon is easily dark enough for a mollic epipedon, organic carbon is marginal (Table 5). Upper horizons do contain some rock fragments, and with marginal values for organic carbon, the epipedon is considered mollic because organic carbon on rock fragments was not measured and would increase slightly the values shown in Table 5.

Site 6 also illustrates a thin water-laid deposit over a debris flow. The data suggest the possibility that some of the silt and clay in the water-laid deposit moved into the debris flow during deposition of the water-laid material, but that the effect was not great below 28 inches (Table 5).

Organ II ridge and Organ III scarp—site 7

Two study trenches were excavated across all or part of the main scarp (sites 7 and 8, respectively). The trench at site 7 (Figs. 4, 7, 14-16) extends up the main scarp and into the margin of the Organ II ridge. Figure 15 is a diagram showing elevations, subgroups, location of sampled pedons, and the skeletal and fine-earth zones. Table 5 gives soil characteristics at site 7.

FIGURE 13—Scarp colluvium (at right) between sites 2 and 6, looking to the south. The scarp is mantled with rock fragments. The Organ Mountains and foothills are on the skyline. The pickaxe at left is 3 ft high.

FIGURE 12—Landscape of the east (main) scarp and site 2, looking to the west from site 6 trench. Spoil of the site 2 trench is visible above the scarp at left center. The scarp is about 3.5 ft high. Organ III alluvium is in the foreground, and also extends upslope at the extreme right. The Organ Mountains are in the background. The pickaxe at left is 3 ft high.

A layer of skeletal colluvium occurs along the scarp, which cuts Organ II alluvium above it and therefore must be younger. Haplustolls formed in the scarp colluvium have thick Al horizons but lack B horizons, and are very similar to Haplustolls formed in Organ III sediments at sites 1 and 6. This pedogenic similarity and the younger surface indicate that the scarp colluvium and its soils are of Organ III age.

The landscape at site 7 contains three contrasting features that also differ in age (Figs. 14-16): moderately sloping alluvium of Organ II age, above the steep scarp; the scarp itself, of early Organ III age, mantled by cobbles and stones; and, below the scarp, moderately sloping sediments of late Organ III age, with a surface largely free of rock fragments. Sediments underlying the scarp and the area below it also differ: beneath the scarp, abundant rock fragments (termed skeletal zone in Fig. 15) occur throughout; beneath the surface below the scarp, fine earth (termed fine-earth zone in Fig. 15) dominates.

These zones of differing texture are thought to have originated as follows. The skeletal colluvium must have accumulated soon after displacement (will be discussed later). Skeletal material of scarps would be a favorable site for rapid accumulation of fine earth because of the scarp position below the crest, ten-

FIGURE 14—The study trench up the scarp at site 7. The dashed line marks the boundary between the skeletal scarp and the downslope alluvium, which is dominated by fine earth. Note the contrast between the scarp, with its numerous rock fragments and dense vegetation, and the area below the scarp, which has much fewer rock fragments and much less vegetation. The tape is at pedon 7a (see Fig. 16); pedon 7b (see Fig. 17) is at the extreme right. The Organ Mountains are in the background.

dency for erosion along the crest, and development of minute drainage lines across the crest to areas upslope. Occurrence of the scarp in the lee of westerly and southwesterly winds would tend to increase additions from dustfall. The numerous large rock fragments should expedite the entrapment of dustfall and its movement into the soil. As fine earth continued to accumulate in skeletal materials of the scarp, infiltration rate must have gradually decreased so that eventually some of the fine earth would begin to cross the scarp, initiating sedimentation in the fine-earth zone below the scarp. This process is still continuing in some areas where thin, stratified C-horizon material is at the surface (e.g., site 7; Table 5).

On the east end of the trench, the skeletal sediments do not slope downward from the scarp but instead rise to the east (Fig. 15). Thus, sediments on the east end of the trench could not have been derived from the scarp, and they are interpreted as deposits of North Arroyo as it swung down along the base of the scarp immediately after displacement. North along the scarp and east of it at site 2, a linear concentration of surficial cobbles is in line with these deposits at site 7 and could represent plugging of the arroyo channel as it gradually filled with sediments. Such channel-plugging would force North Arroyo eastward towards its present course, nearly straight out from its point of debouchement across the scarp (Fig. 4). Because terrace deposits of early Organ III cross this zone at the north end of the scarp (see Fig. 12), backfilling the channel and its abandonment must have taken place rapidly—possibly within a few years.

A difference in color of rock fragments in C horizons is additional evidence of a difference in origin of materials of the scarp and the zone just below it. Rock fragments in the C horizon of pedon 7b appear very clean and exhibit primary colors of the rocks—dominantly 10YR 8/1, 7/2, and 7/3, dry. But rock fragments in the C horizon of the scarp are slightly redder (dominantly 7.5YR 7/2 and 7/3, dry), which appears to reflect very slight staining with clay. This may be an inherited color reflecting the influence of the down-faulted, reddish Bt horizon on the scarp colluvium. The change in color exactly coincides with the change from the steep, skeletal scarp to the more gently sloping area just below it, supporting an interpretation of a different origin of rock fragments in the two landscape positions. Further evidence of such a former channel is presented at site 8.

Soils of three orders—Aridisols, Mollisols, and Entisols—are exposed in the study trench. Soils above the scarp are of Organ II age and have an argillic horizon, diagnostic for the Haplargids, in the Aridisols; soils along the scarp are of early Organ III age and have a mollic epipedon, diagnostic for the Mollisols; and soils below the scarp are of late Organ III age, have no diagnostic horizon other than an ochric epipedon, and are Entisols. As discussed in following sections, this occurrence of three soil orders in such a small space reflects differences in soil age, landscape, soil moisture, and the percentage of rock fragments on the surface and in the soils.

The study trench shows the effect of faulting on the soils because the Haplargid above the scarp (pe-

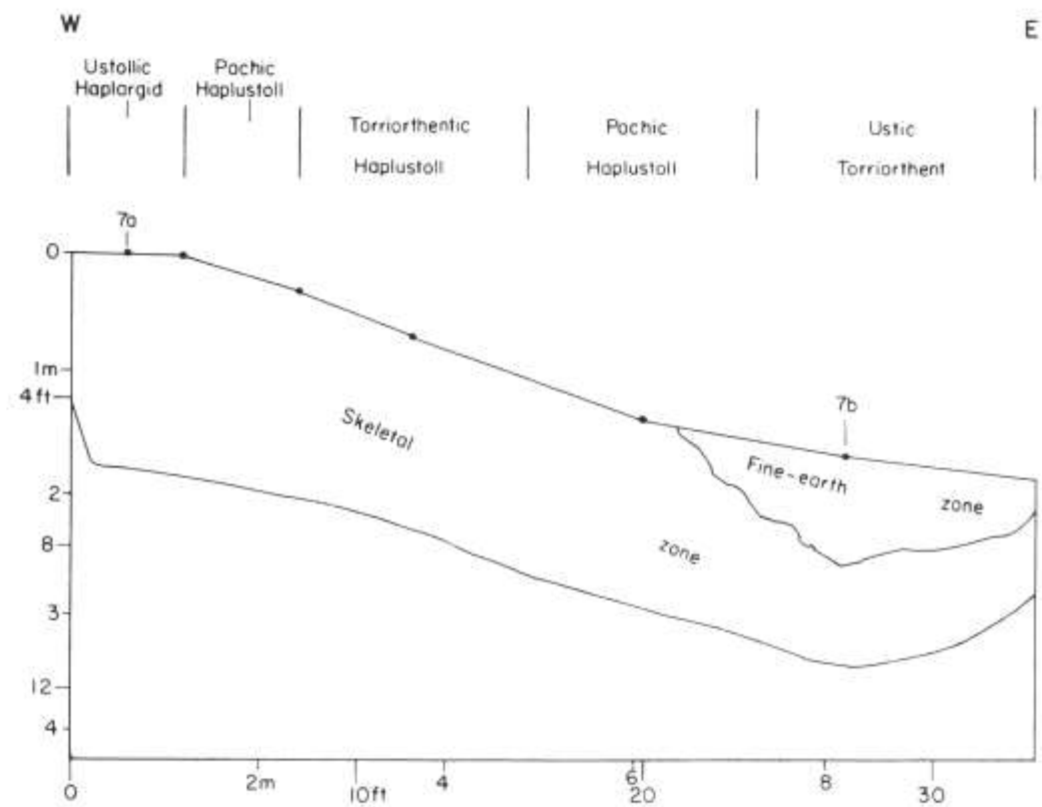


FIGURE 15—Diagram of the study trench at site 7, showing the location of pedons 7a and 7b, elevations, subgroups, and the skeletal and fine-earth zones. Dots at the surface mark points along the survey line on the north side of the trench.

don 7a, Fig. 16) has a distinct reddish Bt horizon that abruptly disappears below the top of the scarp. The Bt horizon has slightly higher chroma than the horizons at sites 2-5, all above the main scarp. The higher chroma is attributed to the location of pedon 7a, which occurs below the west scarp and also below an adjacent drain between the ridges at sites 2 and 3. Both the scarp and the drain would contribute runoff to Pedon 7a and increase the amount of water for clay movement in the soil.

Location of the fault plane (or initial scarp) is not certain because, as discussed earlier, its upper part must have been obliterated almost immediately by slumping in these skeletal, mostly coarse-textured materials. The fault plane would have been downslope (possibly on the order of a few feet) of the present point of disappearance of the Bt horizon along the scarp.

Ustollic Haplargids above the scarp

Pedon 7a (Figs. 14-16; Table 5) occurs in the 0-4-ft zone of the study trench (Fig. 15) and has an A horizon and a reddish Bt horizon that qualifies as an argillic horizon. At nearby sites 2-4, organic carbon decreases markedly below the thin A horizon, precluding a mollic epipedon (Table 3); this would also be expected at

FIGURE 16—Upper (west) end of trench at site 7. The Ustollic Haplargid, Holliday (pedon 7a), is at the tape. Scale in feet.

pedon 7a. Pedon 7a has the same distinct evidence of physical weathering noted at sites 2-5; parts of individual rock fragments are easily displaced with the finger. These weathered rock fragments are not present in soils of the scarp, which supports their being of Organ **III** age.

Pachic Haplustolls at the upper margin of the scarp

The 4-8-ft zone along the trench (Fig. 15) is the transition zone between soils above the scarp and soils along the scarp. Slope is greater than from 0-4 ft but less than the scarp below. Beneath the dark Al horizon is a reddish B horizon that is weaker than the Bt horizon of pedon 7a and that grades out to the east. Roots are more abundant and deeper because this zone has surface cobbles, in contrast to the largely cobble-free area just upslope. Because of moisture concentration by the cobbles, grass is common, shrubs are more numerous, and organic carbon and the low-chroma horizons are deeper than in pedon 7a.

The west boundary of the Pachic Haplustoll is abrupt because of faulting. The boundary is also related to the land surface, surficial rock fragments, and vegetation. The Pachic Haplustoll begins where the scarp-related slope starts to increase at the upper shoulder of the scarp. The point of slope increase is marked in the profile by a cobble that is partly above ground (Fig. 16). From this cobble eastward, rock fragments

FIGURE 17—Lower (east) end of study trench at site 7. The Ustic Torriorthent, Yana Variant (pedon 7b), is at the tape. Note scarcity of rock fragments on the surface and in the upper horizon of pedon 7b. The fine-earth and skeletal zones (cf., Fig. 15) differ considerably in particle size. Scale is in feet.

are common on the surface, and grass and shrubs are prominent between the rock fragments. Roots extend deeper and are much more common in this soil than in the Ustollic Haplargid at the left (Fig. 16).

Torriorthentic Haplustolls of the scarp

The mollic epipedon is 20 inches or more thick in the Pachic Haplustolls and less than 20 inches thick in the Torriorthentic Haplustolls. The boundary between the Pachic Haplustoll and the Torriorthentic Haplustoll downslope (Fig. 15) is marked by a subsurface boulder nearly 3 ft across in longest dimension (Fig. 16). Downslope from the boulder, the mollic epipedon is less than 20 inches thick, and the soil is a Torriorthentic Haplustoll. Another even larger boulder underlies the first. These large boulders must have helped to stabilize the slope after the faulting took place.

The scarp zone has ideal conditions for the development of a mollic epipedon. Most of the scarp is covered by cobbles; stones are consistently present but are less abundant. Surfaces between these larger fragments are generally occupied by pebbles, though there are occasional small patches, an inch or so in diameter, of surficial fine earth. Soil moisture and vegetation are concentrated between the numerous rock fragments; grass is common, and shrubs are quite large. Also, skeletal materials are abundant beneath

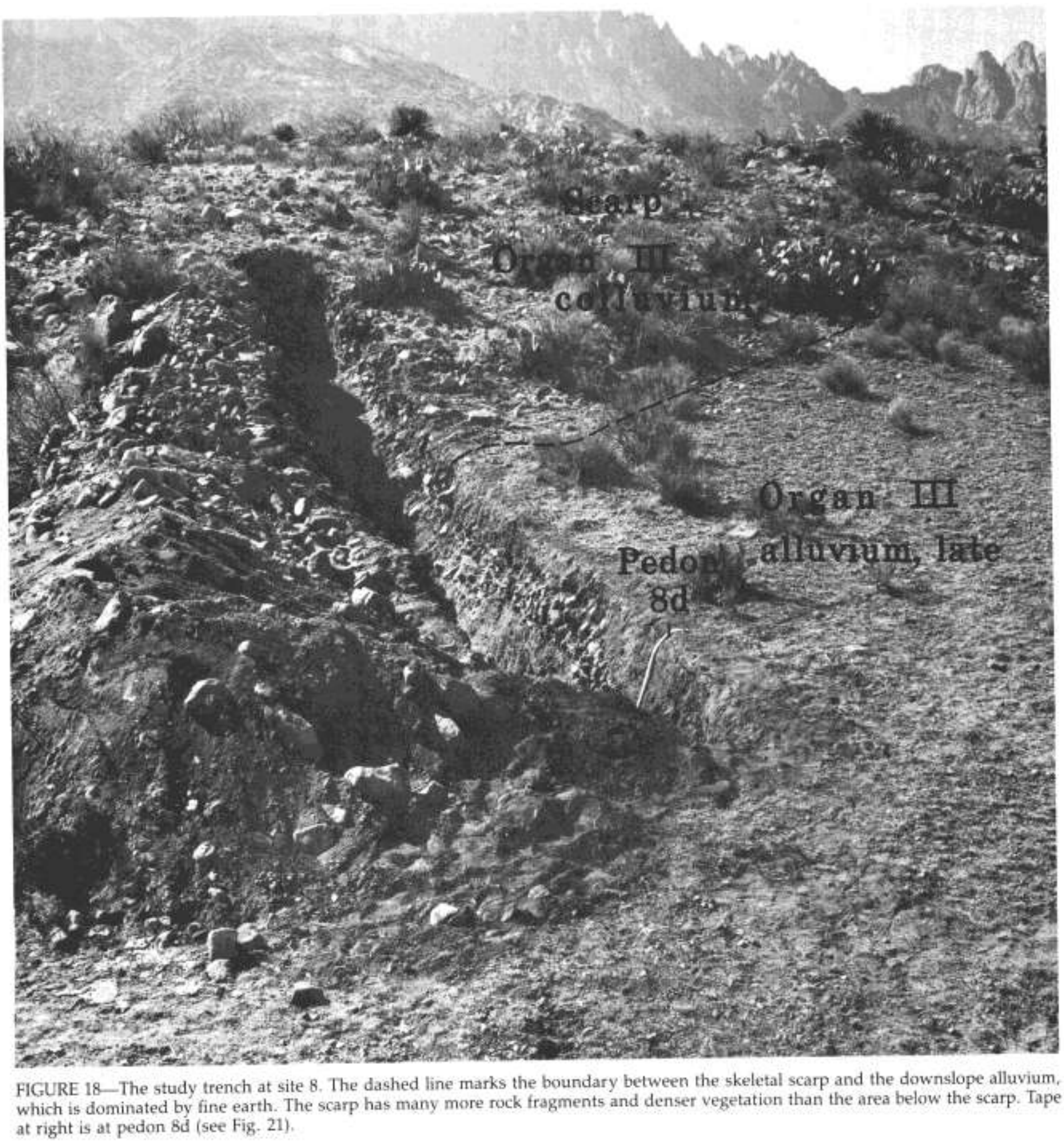


FIGURE 18—The study trench at site 8. The dashed line marks the boundary between the skeletal scarp and the downslope alluvium, which is dominated by fine earth. The scarp has many more rock fragments and denser vegetation than the area below the scarp. Tape at right is at pedon 8d (see Fig. 21).

the scarp, and the slope faces east. Higher percentages of organic carbon would be expected in these favorable circumstances.

Following are some of the general characteristics of a Torriorthentic Haplustoll at site 7. From 0-17 inches the Al horizon is dark enough and has enough organic carbon for a mollic epipedon. Texture is a medium sandy loam in the upper part of this zone and a light sandy loam in the lower part. Texture is a loamy sand from 17-25 inches; below 25 inches, texture is sand. The pedon is skeletal throughout.

Pachic Haplustolls of the lower part of the scarp

At the line between the Torriorthentic and Pachic Haplustolls (Fig. 15), the lower boundary of the mollic epipedon starts to dip below 20 inches in depth. This greater depth is in the lower part of the scarp, which appears to be a typical landscape position for the development of particularly thick A horizons and the Pachic Haplustolls because they occur in the same position at site 8. Occurrence of only Pachic Haplustolls on the lower part of the scarp is thought to be due to runoff from upslope, which moves the wetting front and organic carbon to greater depths than up-slope and deepens the zone of common rooting.

The boundary between the Pachic Haplustoll and the Ustic Torriorthent downslope (Fig. 15) is distinct, and is associated with a rise in the lower boundary of the dark A horizon. Change from the Haplustoll to the Torriorthent occurs in a lateral distance of about 12 inches, and is marked by a lateral change from a dark loamy sand to a lighter-colored sand.

Following are some of the general characteristics of a Pachic Haplustoll at site 7. From 0 to 26 inches the A horizon is dark enough and has enough organic carbon for a mollic epipedon. Texture is a sandy loam to 17 inches, a light sandy loam from 17 to 26 inches, a heavy sand from 26 to 35 inches, and a sand from 35 to 44 inches. The pedon is skeletal throughout.

Ustic Torriorthents below the scarp

Pedon 7b (Fig. 17) illustrates the Ustic Torriorthents. Pedon 7b is in materials that differ markedly in particle size and the fine-earth and skeletal zones (Figs. 15, 17). Although upper horizons are quite dark, organic carbon is too low for a mollic epipedon (Table 5). Enough organic carbon would probably be present for a mollic epipedon if upper horizons contained abundant rock fragments.

Organ III scarp—site 8

The scarp is steeper and higher at site 8 (Fig. 18) than at site 7, and the backhoe could not get to the top of the scarp. The landscape at site 8 contains only two of the three contrasting features at site 7: the steep scarp of early Organ III age, along which surficial cobbles are common; and the moderately sloping area of late Organ III age below the scarp, where the surface is largely free of rock fragments. As at site 7, materials beneath these landscape components differ: sediments beneath the scarp contain abundant rock fragments, whereas a fine-earth zone underlies the surface below the scarp. Fig. 19 shows elevations, subgroups, location of sampled pedons, and the skeletal and fine-earth zones at site 8. Soil characteristics are given in Table 6.

In contrast to site 7, where the surficial C horizon material was virtually continuous, its occurrence here is sporadic. Its absence in some areas is clearly due to development of slight drains that have concen-

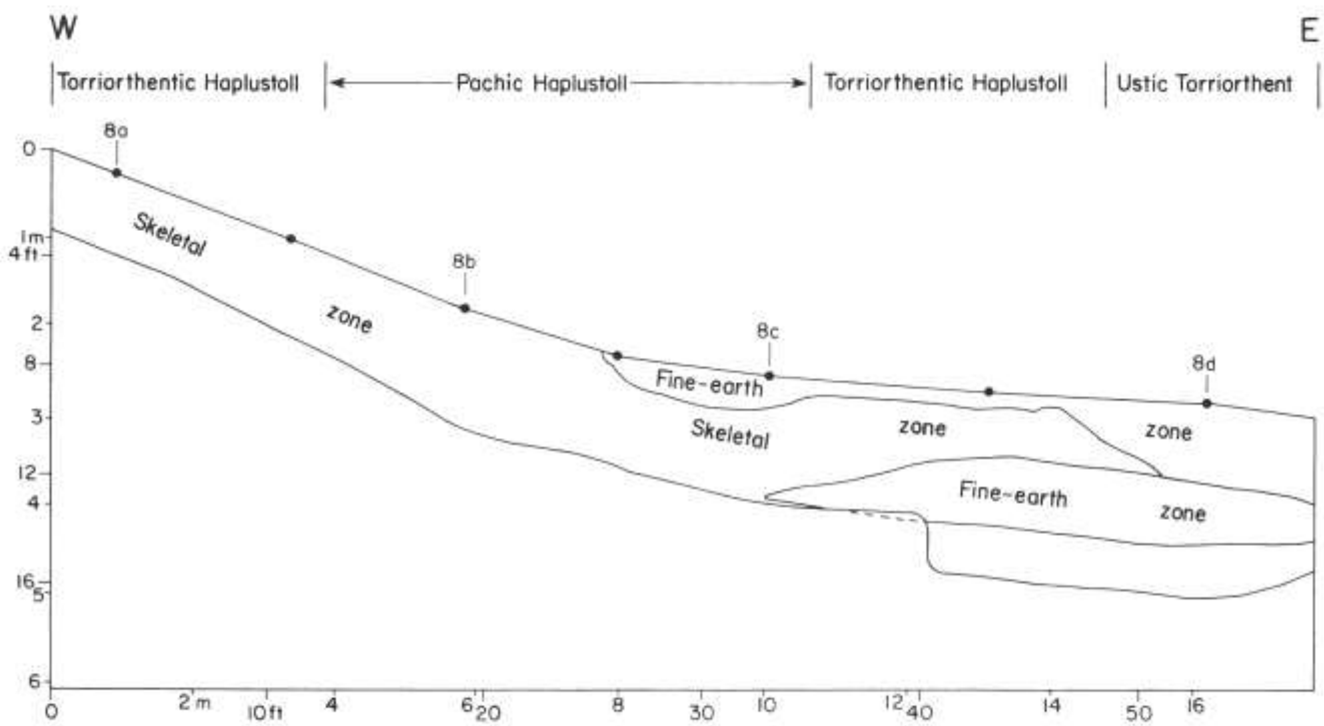


FIGURE 19—Diagram of the study trench at site 8, showing location of pedons 8a–8d, elevations, subgroups, and the skeletal and fine-earth zones.

TABLE 6—Soil characteristics at sites 8–10. The Bt horizon of pedon 10a was sampled in two parts according to hardness. Organic carbon for site 8 and sand, silt, and clay for site 10a were determined by the Soil and Water Testing Laboratory, New Mexico State University; for site 9, by Carol Taschek. Abbreviations are explained in Table 3 caption (p. 15).

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
								percent			
Torriorthentic Haplustoll at site 8a—Organ III, early											
A1	0–5	7.5YR	4.5/2	3/2	1cpl, m	s	vcsl				
A2	5–15	7.5YR	4/2	2/2	1f, msbk	sh, s	vcsl				
A3	15–31	7.5YR	4/2	2/2	1f, 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	1msbk	s	vcsl				
A3	17–39	7.5YR	4/2	2/2	1msbk	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	vcsl				
AC	92–130	7.5YR	4.5/3	3/3	m	s	vcls				
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	1msbk	sh	sl				0.69
A3	18–34	7.5YR	4/3	2.5/3	1msbk	sh	sl				0.73
2A4	34–55	7.5YR	4/3	2.5/3	1msbk	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				
Ustic Torriorthent at site 8d—Organ III, late											
C	0–4	7.5YR	4.5/3	3/3	1cpl, 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	1msbk	s	gsl				
3C1b	82–112	7.5YR	4.5/3	3/3	1msbk	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	1mpl, sg	s, l	sl	75	17	8	0.55
Bt1	4–24	7.5YR	4/3	2.5/3	1msbk	s	sl	74	18	8	0.36
Bt2	24–41	7.5YR	4.5/3	3/3	1msbk	sh, s	sl	73	16	10	0.32
2Bt3	41–74	7.5YR	4.5/3	3/3	1msbk	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
Ustollic Haplargid at site 10a—Organ I											
A1	0–4	7.5YR	5/3	3.5/3	1mpl, m	s	vcls	80	13	7	
A2	4–15	7.5YR	5/3	3/3	1m, csbk	sh	vcsl	75	16	9	
BAt1	15–36	5YR	4/3	3/3	1msbk	sh	vcsl	70	16	14	
BAt2	36–55	5YR	4.5/3	3/3	1f, msbk	sh	vcsl	70	14	16	
Bt	55–81	5YR	4.5/4	3/4	m	sh	vcsl	71	13	16	
Bt	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	1cpl	s	vcls				0.33
A2	7–19	6YR	4/3	2.5/3	1msbk	sh	vcsl				0.47
BAt1	19–37	5YR	4/3	2.5/3	1f, msbk	sh	vcsl				0.50
BAt2	37–52	5YR	4/3.5	3/3.5	1f, msbk	s, sh	vcsl				
Bt1	52–70	5YR	4/3.5	3/3.5	1f, msbk	s, sh	vcsl				
Bt2	70–89	5YR	4.5/3	3.5/3	1msbk	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				

trated moisture movement, precluding accumulation of sediments adjacent to the drains. Large size of the surface fragments controls disposition of this surficial C horizon material in some areas, causing it to accumulate on upper sides of some of the fragments but not below them.

Along the scarp, large size of many of the rock fragments, the near-platy character of some of them, and their close packing would seem to virtually preclude downslope movement of rock fragments after initial emplacement of the colluvium. Continuity of the thick A horizon also indicates a relatively long period of slope stability along the scarp.

Site 8 also differs from site 7 in having two fine-earth zones (Fig. 19). Although the upper fine-earth zone is generally continuous below the main scarp in the study area, extent of the buried fine-earth zone and its relation to the scarp are not known. Sediments of the buried fine-earth zone could have been deposited by an arroyo along the scarp base, or they may represent an earlier displacement. Further work is needed to demonstrate the origin of this zone. As at site 7, the skeletal zone rises to the east on the east end of the trench, suggesting an origin other than scarp colluvium for this part of the skeletal zone.

Soil occurrence at site 8 is similar to site 7 except that at site 8 a Torriorthentic Haplustoll occurs below (as well as above) the Pachic Haplustoll. This is apparently due to increased runoff from the higher, steeper scarp and presence of near-surface skeletal

FIGURE 20—The upper and central parts of the study trench at site 8. The Pachic Haplustoll, Santo Tomas (pedon 8b), is at the tape. Haplustoll (T) = Torriorthentic Haplustoll. Scale is in feet.

materials, which concentrate the organic carbon. The occurrence of soils that are skeletal throughout coincides with 1) the cobbly scarp, 2) the increase in slope at the scarp, and 3) the surficial expression of cobbles and stones. The A horizons qualify as a mollic epipedon for almost the full length of the trench. In the upper part of the trench the mollic epipedon is less than 20 inches thick, and the soil is a Torriorthentic Haplustoll; but downslope (as at site 7) the A horizon thickens and the soil is a Pachic Haplustoll. In the eastern part of the trench the soil is more arid because it is farther from the scarp and is an Ustic Torriorthent. The A horizons, although dark enough for a mollic epipedon, are not as dark as they are upslope, and organic carbon is too low for a mollic epipedon. All sediments are noncalcareous throughout except for the deepened east end of the trench, which will be discussed later.

Torriorthentic and Pachic Haplustolls

Pedon 8a (Fig. 19, Table 6) illustrates Torriorthentic Haplustolls of the scarp. The concentration of organic carbon in upper horizons and its gradual decrease with depth are reflected by lighter colors and coarser textures (Table 6). This is attributed to additions of fine earth from colluvium and dustfall. The abundant skeletal materials of the scarp surface constitute an efficient dust trap.

The boundary to the Pachic Haplustoll (Figs. 19 and 20) is distinct and is marked by increasing thickness

FIGURE 21—Lower and central parts of the study trench at site 8. The Ustic Torriorthent, Yana Variant (pedon 8d), is at the tape. At left of the tape, note the prominent buried fine-earth zone beneath the skeletal zone. Scale is in feet.

of the darker and finer part of the A horizon, so that the mollic epipedon is more than 20 inches thick. Pedons 8b and 8c (Table 6) illustrate the Pachic Haplustolls.

Downslope the boundary between the Pachic and Torriorthentic Haplustolls is similarly abrupt and slope-related; the finer, darker, upper part of the thick A horizon thins so that the mollic epipedon is no longer thick enough to be Pachic. As is shown in Fig. 19, the Pachic Haplustoll extends only a short distance east of the zone marked by 1) a decrease in slope, 2) disappearance of the surficial skeletal zone, and 3) appearance of the surficial fine-earth zone.

The western, steeper part of the trench was not deepened originally because of caving, but this western part of the trench was deepened to about 6 ft in depth just before the trench was filled. Loose, sandy, skeletal material was encountered for the entire deepened section (just west of the fine-earth zone; Figs. 18, 19).

Ustic Torriorthents

The thick skeletal zone at pedon 8c thins to the east. The mollic epipedon and the Torriorthentic Haplustoll continues eastward to where the skeletal materials thin markedly (Fig. 19). At this point, data for similar pedon 7b (Table 5) indicate that organic carbon would be too low for a mollic epipedon, although the horizons are dark enough (Table 6). This soil is an Ustic Torriorthent, illustrated by pedon 8d (Fig. 21).

Although color of upper horizons is lighter than it is upslope, accumulation of organic carbon is still the most evident pedogenic process in pedon 8d. The 2A4b horizon is the analogue of the thick skeletal zone at pedon 8c (Table 6). This horizon has scattered pebbles and less clay than adjacent horizons, and represents a discontinuity to the thick fine-earth zone beneath (Fig. 19). No evidence of pedogenesis is apparent in the buried fine-earth zone.

Materials beneath the buried fine-earth zone

The buried fine-earth zone is underlain by a more gravelly zone, represented by the 4C3b horizon in pedon 8d (Table 6). This horizon is underlain in turn by a low-gravel horizon, the 5C4b horizon, which is distinctly yellower and lighter colored (Table 6). More gravelly materials occur along the base of the trench, but they were not sampled.

Generally, pedon 8d and other sediments on the north side of the trench are noncalcareous to the bottom of the trench, where they are discontinuously calcareous. This may represent the most common depth of wetting at present. On the west end of the deepened section of the trench, a few carbonate filaments are present in the buried fine-earth zone.

On the south side of the trench, most of the sediments are also noncalcareous. However, near the east end of the trench and south of pedon 8d, a tongue of stage I carbonate, consisting of thin, mostly continuous carbonate coatings on pebbles, projects about 43 inches upward from the base of the trench. Texture of the tongue is loamy sand; some parts are nearly gravel-free and others are very gravelly. The stage I tongue is about 40 inches wide at the bottom, but narrows upward and is about 8 inches wide at the top. Fine earth between pebble coatings is also calcareous. Fine earth adjacent to the tongue is noncalcareous, with abrupt boundaries to the tongue.

About 24 inches east of this tongue is another, much smaller stage I tongue, which is about 6-8 inches wide and extends upward about 20 inches above the bottom of the trench. Between the two tongues are several small pebbles with carbonate coatings, but fine earth between them is generally noncalcareous. The tongues of stage I carbonate do not occur on the north side of the trench. Thus the tongues have considerable north—south relief as well as east—west.

Stage **I** carbonate is common in the soils of Organ I, south of Organ II deposits (Figs. 4 and 5; see site 10). The stage I tongues at site 8 are interpreted as a portion of the carbonate horizon of Organ I age, mixed with noncalcareous materials by faulting.

A large channel east of site 8

Evidence for a post-faulting arroyo channel along and near the base of the scarp was presented for site 7. A large channel, partly filled with Organ III sediments, is preserved just west of site 8 (Fig. 4), and constitutes a small interfan valley between fans from North and South Arroyos. The arroyo presently in this large channel is clearly much too small to erode it. Several factors indicate that streams of a post-displacement North Arroyo excavated the channel. The southern extremity of the channel is marked by a linear deposit of large boulders emplaced near the northern edge of the Organ II remnant. The upper drainage lines of the channel curve towards North Arroyo. Direction of these lines and evidence at site 7 indicate that, soon after displacement, North Arroyo swung south along the base of the scarp. Drainage into this deep channel from the scarp would have eroded the soil of downdropped Organ II alluvium, which was not found either at site 7 or 8. That this did in fact occur is also indicated by sediments of the area concerned; Organ **III** sediments occupy the whole area between the Organ II remnant and the scarp. Finally, accumulation of alluvium (from the channel and from drains above the scarp) plugged the channel in its upper reaches along the scarp, forcing North Arroyo northward to its present position. Little filling of this large channel has taken place, indicating that the abandonment was rapid.

Maximum amount of late Holocene displacement

The amount of late Holocene displacement apparently increases from north to south along the scarp. The north end of the scarp, which may be an area of minimum displacement, is also very likely the area of maximum sedimentation below the scarp because North Arroyo has by far the largest watershed of the two arroyos. Because of this a minimum displacement is difficult to estimate at the north end of the scarp.

The amount of maximum displacement can be more readily estimated at the south end because the scarp does not appear to have been buried, and a down-

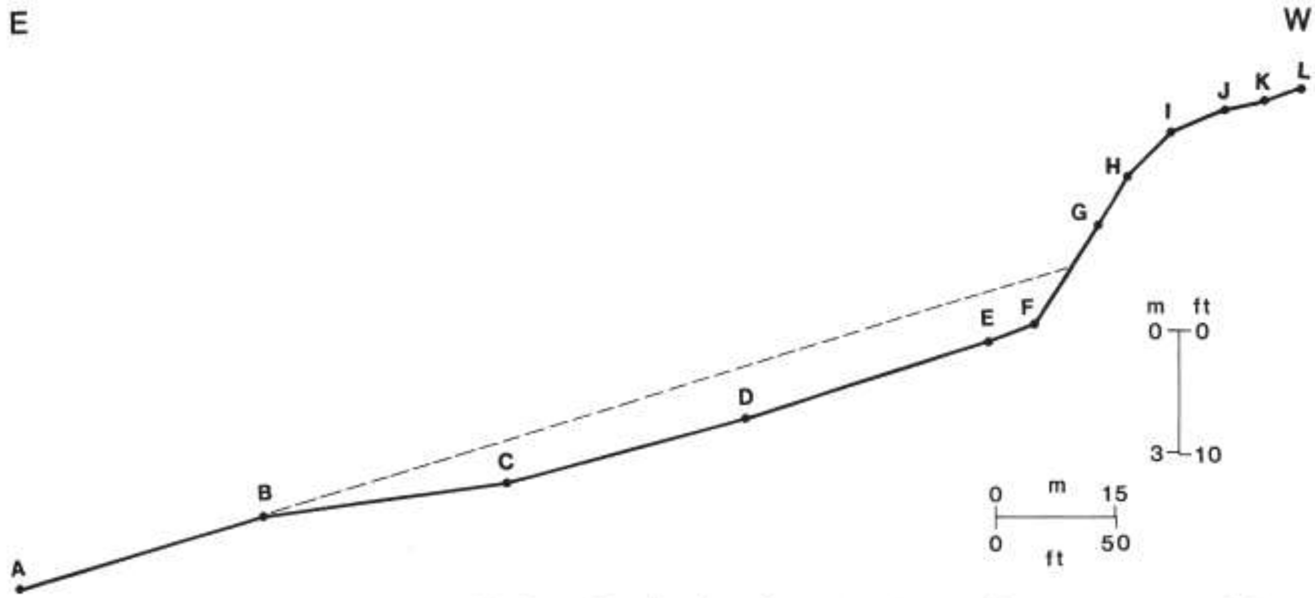


FIGURE 22—Diagram showing displacement of the Organ II surface along the east (main) scarp. The cross section extends from a remnant of the downthrown Organ II surface (line AB) to the upthrown Organ II surface (line LJ; see Fig. 4 for location of the cross section). The dashed line is a slope extrapolation from the downthrown remnant to the scarp. The solid line beneath the dashed line is the Organ III surface (see text discussion).

dropped remnant of Organ II is available for slope extrapolation. The estimation consists of two parts. First, slope is extrapolated across the west scarp along the site 5 survey line (Figs. 4-6). The extrapolation is made by using the soil surface on both the upthrown and downthrown sides of the fault because the soils are thought to be virtually the same age. The figure derived, 6 ft, is considered to be a minimum figure because a slight amount of fine earth appears to have accumulated below the west scarp.

For the east (main) scarp, estimating the amount of displacement is more complicated because, as discussed earlier at site 8, the downdropped soil has not been found near the scarp base. However, a remnant of the downdropped Organ II surface and its soils occurs about 300 ft east of the scarp. Organ III alluvium is lower than and inset against the remnant to the north and south (Fig. 4), indicating erosion of downdropped Organ II alluvium in at least part of these areas.

Soils of the downdropped remnant lack carbonate horizons and have Bt horizons with 5YR hue in part; thus, they are similar to Organ II soils above the scarp. Soils of the downdropped remnant do appear to have slightly less organic carbon than do the Organ II soils above the scarp, but this would be expected because of the trend towards increasing aridity downslope.

Elevations along a straight line from the downdropped remnant to the main scarp are given in Fig. 22. Slope along the remnant (line AB, Fig. 22) is about 6% to the east; slopes are about the same on interfluves just above the scarp zone. The extrapolation indicates a displacement of about 9 ft along the main scarp. Thus, the total displacement in the late Holocene is estimated to be about 15 ft. The extrapolated line, AB, crosses the scarp at a point about 4 ft above the apparent present base of the scarp. This is additional evidence of erosion of Organ II alluvium and its soils. Skeletal colluvium along the scarp may have accumulated during or shortly after this erosion.

Organ III fan—site 9

South Arroyo has a much' smaller watershed than North Arroyo, and the area of Organ III alluvium below the fault is also much smaller. Fans that debouch from South Arroyo below the fault may be traced eastward to where they are inset below the southern of the two Organ II remnants shown in Fig. 4.

Two ages of Organ III deposits occur below the scarp in the vicinity of South Arroyo. Site 9 (Fig. 4, Table 6) illustrates a soil of the highest and oldest of the two deposits. Soil materials at site 9 consist of a surficial zone dominated by fine earth, underlain by skeletal materials ranging in size from pebbles to boulders. Table 6 gives the soil characteristics.

Although upper horizons at site 9 are dark enough for a mollic epipedon (Table 6), organic carbon values are too low. They are barely high enough to qualify for Ustollic subgroups of Aridisols. However, if the upper materials were skeletal instead of dominantly fine earth, the soil would probably be a Haplustoll. Distinct Haplustolls have also been observed in skeletal materials of small late-phase Organ III terraces just south of the area shown in Fig. 4.

The Bt2 horizon of pedon 9 has a slight increase in silicate clay but not enough for an argillic horizon (Table 6), and the soil is an Ustollic Camborthid (Table 2). Although upper materials are primarily in fine earth, the control section averages loamy-skeletal. Weathered rock fragments, a distinct feature of Organ II alluvium (see sites 2-5 and 7a) are not present here, and this agrees with an interpretation of Organ III age for the deposits.

Soils of Organ I age—site 10

Site 10 is on a ridge of the Organ I surface (Figs. 4, 5, 23, and 24). A high Organ II terrace is inset against the ridge along its north edge (Figs. 5 and 23). Slight drains occur across the ridge in places, and one such drain occurs at site 10. The drain has very gently sloping sides and is only several inches deep and a few feet wide. The surface of the drain is in fine-earth sediments that are bordered by thick concentrations of rock fragments; both materials parallel the longitudinal slope of the interfluve. Thus, position of the drain is governed by position of the rock fragments. The drain contrasts with bordering areas not only in having few rock fragments but also in having much less vegetation because large fragments that concentrate moisture are scarce.

Initial investigations at site 10 consisted of a shallow hand-dug trench, which could not be deepened further by hand because of large rock fragments. Data for this pedon (site 10a) are given in Table 6. Different grades of consistence (slightly hard and hard) were encountered in the Bt horizon (Table 6). The hard material contains slightly more clay (Table 6) and is tightly packed between rock fragments, whereas the slightly hard material is readily removed.

Table 7 presents particle-size distribution for pedon 10a, including sand size. As at site 1, distinct accumulations of fine and very fine sand, as well as silt and clay, are in upper horizons. The percentages of fine sand, very fine sand, and silt are remarkably similar to those of the Organ III Haplustoll at site 1. The similarity suggests that input of these components from dustfall decreases markedly when their buildup in the soil reaches a critical level. But the clay percentages are substantially higher in the soil of Or-

FIGURE 23—Landscape at site 10, near the north edge of an Organ I ridge, looking to the northwest. Organ I alluvium is exposed in the trench and extends to the next lower level, a narrow Organ II terrace. The channel of South Arroyo cannot be seen, but is this side of the long line of boulders and stones in the middle ground. The long, east-sloping surface beyond the line of boulders and stones is the Organ II surface of the site 5 ridge (see Fig. 4). The Organ Mountains are in the background.

gan I, reflecting downward movement of clay in suspension as proposed by Thorp et al. (1959).

Later the small trench was enlarged with a backhoe, and two distinctly different soils became evident. One was adjacent to the drain, on the north side of the trench, and the other was in the drain, on the ends and south side of the trench. Both soils are Ustollic Haplargids.

Only the soil on the north side of the trench (pedon 10b, Table 6) was sampled for analysis. However, major horizons of a pedon on the south side of the trench (pedon 10c) were compared with analogous horizons of pedon 10b. Pedon 10b (adjacent to the drain) differs from pedon 10c (in the drain) in several important respects. Visually, the most apparent difference is in color of the Bt horizon. Hues and values are similar, but chroma of the Bt horizon of pedon 10c, in the drain, is 4.5 versus only 3 or 3.5 in the Bt horizon of pedon 10b. Another important difference is tightness of packing and difficulty of removal from the horizon. The Bt horizon of pedon 10b, adjacent to the drain, was not tightly packed and much of it caved when adjacent material was removed with the backhoe. In contrast, parts of the soil in the drain were tightly packed and held a near-vertical face without caving. The maximum degree of hardness in pedon 10b is slightly hard, and even it has some soft parts. In contrast, the Bt horizon of pedon 10c is hard throughout.

Structure also differs in the two soils. The Bt horizon of pedon 10c is so tightly packed that the material breaks out as massive chunks that show no development of peds. The packing is tight enough that it resists penetration by roots; only a very few roots are in the horizon. In contrast, the Bt horizon of pedon 10b has many roots, is not tightly packed, and weak subangular blocky and granular structure is apparent.

The high chroma, tightly packed material in the Bt

FIGURE 24—Profile of the Ustollic Haplargid, Holliday (pedon 10b), at site 10. Note the lack of visible stratification and the variety in the size of rock fragments throughout, which is typical of debris flows in the study area. Scale is in feet.

TABLE 7—Particle-size distribution at site 10a. Analyses by the Soil and Water Testing Laboratory, New Mexico State University.

		Particle-size distribution, mm, percent						
		Sand					Silt	Clay
Horizon	Depth cm	2–1	1–0.5	0.5–0.25	0.25–0.1	0.1–0.05	0.05–0.002	< 0.002
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

horizon of pedon 10c (in the drain) represents zones of maximum clay accumulation, which were emplaced by moisture derived both from direct precipitation and runoff from high parts of the drain. Once formed, the tightly packed material would tend to shunt clay-carrying soil water to adjacent, more pervious zones that are less tightly packed. The soil in the drain represents an intermediate stage in development (caused by extra moisture) to pre-Organ soils in which the Bt horizons are harder and less pervious in all soils.

Another difference between soils in and adjacent to the drain involves the carbonate horizon, which is present adjacent to the drain but not in the drain. The BCtk horizon (Table 6) is a stage I carbonate horizon. Cobbles in the BCtk horizon are discontinuously coated with carbonate, but most of the fine earth between the fragments is noncalcareous. This occurrence of carbonate represents the earliest morphological expression of the stage I horizon. Presence of the carbonate horizon in Organ I soils, but not in the younger soils, is attributed to more clay, which would reduce the depth of penetration of the wetting front. This would cause the dust-derived carbonate to precipitate at shallower depth; also, more carbonate would be expected in Organ I soils because they are older. But in the drain, extra moisture has moved carbonate to greater depths, so that it is not apparent in the exposure. In these noncalcareous parent materials the calcium must have been derived largely from dustfall (Gile et al., 1966).

As a further check on the morphological differences in and adjacent to the drains, the north side of the study trench was excavated an additional 3 ft to the north just before filling the trench. Soil morphology was the same as in pedon 10b, providing additional evidence of this kind of morphology between drains. However, more work is needed on the soils of Organ I.

Summary and discussion

Throughout the Southwest there is abundant evidence indicating episodes of climatically controlled erosion and deposition. Buried charcoal dated by "C gives chronological control for important episodes of erosion and deposition in the Desert Project area. The evidence indicates that late Holocene deposits dated at the Desert Project also occur at the Cox segment of the Organ Mountains fault, and that these sediments and their soils can be used to establish the approximate time of latest displacement at the Cox segment.

Most of the soil parent materials contain abundant rock fragments that range in size from pebbles to boulders and were deposited as debris flows. The debris flows are useful in studies of soils because, as soil parent materials, they tend to be relatively uniform. Thus the C horizon material beneath A and B horizons indicates the original character of the material in which the A and B horizons formed. The scarp colluvium was derived in large part from debris flows and similarly contains distinct C horizon material believed to be much like the materials in which the overlying thick A horizons formed. Other soil parent materials are water-laid, of which there are two main types, both of which are generally dominated by fine earth: 1) thin stream-flow deposits, derived from North and South Arroyos and their tributary streams, that bury the debris flows in places; and 2) alluvium just down-slope from the scarp colluvium, derived from streams that extended along the base of the scarp shortly after displacement, and, later, from small streams that descend the scarp.

Tables 3-7 illustrate soil properties that have chronological significance at the Cox segment. These properties are the accumulation of organic carbon, silicate clay, and carbonate, as well as soil color, consistence, and structure. These properties can be used to distinguish sediments of different ages when the morphological range of soils has been determined for a given sediment.

Dustfall additions to soils

Dustfall is a source of calcium for the carbonate horizons of Organ I soils as discussed previously. Evidence of dustfall additions of silicate clay to soils has been presented (Gile, 1970; Gile and Grossman, 1979). Dustfall also appears to have been a source of silt in some soils (Gile, 1977). Evidence presented in this paper indicates that, in skeletal materials, dustfall is not only an important source of silt and clay but of fine sand and very fine sand as well. Similarly, extensive areas of soils with skeletal upper horizons in other arid and semiarid regions would have been affected by such dustfall.

At sites 1-10 distinctly higher percentages of clay, silt, fine sand, and very fine sand occur above the C horizon than in it, indicating accumulations of these components since soil development began. Position of the accumulations above the C horizon, youth of the soils, and dust-trap studies at the Desert Project indicate that parts of these accumulations were derived from dustfall. The debris-flow materials, with abundant large rock fragments throughout, constitute a natural and efficient dust trap because the surficial fragments would help to trap the dustfall and because those deeper in the soil would concentrate the fine earth that is analyzed in the laboratory. Similar percentages of fine sand, very fine sand, and silt in soils of both Organ III and Organ I age suggest that input of these components from dustfall rapidly decreases when their buildup in the soil reaches a critical level. But clay content progressively increases in the soils of Organ III, II and I, indicating longer movement of dust-derived clay into the soils.

Judging from C horizon textures, the materials in which soil formation started must have been a skeletal sand with very little clay or silt. Presumably, large voids would have been present between some of the rock fragments, as suggested by presence of such voids in freshly deposited skeletal materials. Movement of dust-derived silt, fine sand, and very fine sand from the soil surface into the soil must have been by a gradual process of gravity, assisted by both the wetting front and by root growth. Movement of rock fragments and fine earth by frost would also be a contributing factor in upper horizons. Clay must have moved downward by these processes also, but in addition it would move downward by suspension in the soil solution, as indicated by the work of Thorp et al. (1959). Downward movement in suspension is reflected by development of the classic clay curves that show increasing clay with increasing age. Such curves show distinct maxima that reflect clay removal from the soil surface and upper horizon(s) and clay accumulation in deeper horizons as the wetting front slows its downward movement. The close relation of these curves to age has been shown for skeletal Argids of the Desert Project (Gile and Grossman, 1979, p. 180). A similar relation to age would also be expected in this area if older soils were fitted into the developmental scheme.

Soils of Organ III age (100-1,100 yrs B.P.—late phase)

These soils are the Haplustolls of the youngest Organ III terraces and the Haplustolls and Torriorthents below scarps (sites 7b, 8c, and 8d).

Organic carbon

Thick, dark A horizons are typical in the Organ III terraces. Presence of these horizons in sandy-skeletal debris flows of the Organ III terraces indicates that these horizons could not have formed by incremental accumulation of sediments during A horizon formation. Instead, thickness of the A horizon is due to the pervious parent materials and to the considerable depth of wetting of these soils. With these conditions of particle size and soil moisture, organic carbon can move to substantial depths in the soil (see sites 1 and 6).

Organic carbon is the first soil component to form a distinct horizon of accumulation in soils of the study area. Presence of thick, dark A horizons in Haplustolls of the lowest and youngest Organ III terraces is clear evidence that these horizons develop in a relatively short time, perhaps on the order of several hundred years. A factor that would expedite the development of thick, dark A horizons in pervious materials during the last several hundred years is the climatic shift to a cooler, moister interval, the Little Ice Age (Fritts, 1976; Neilson, 1986). According to Fritts (1976), the Little Ice Age began in the 1300's and brought cool, moist conditions to the southwestern United States early in the 17th century. Neilson (1986), writing about the climate of nearby Las Cruces (Fig. 1) and using high-resolution climatic analysis, interpreted the Little Ice Age as extending from about A.D. 1600-1900.

The Ustic Torriorthents have formed largely or wholly in alluvium dominated by fine earth, and are just downslope from the skeletal scarp colluvium. These Torriorthents have accumulations of organic carbon (Table 5), but generally lack mollic epipedons because of the low volume of rock fragments. A few pedons formed in this alluvium do have mollic epipedons (see pedon 8c). These pedons occur just below long slopes that would contribute runoff.

Texture

Haplustolls of stable terraces have accumulations of silt and clay in upper horizons; underlying C horizons contain very little silt and clay. Some of this silt and clay could have come from a water-laid deposit if one is present. But if a water-laid deposit is not present then the bulk of the silt and clay in upper horizons is attributed to dustfall.

The Ustic Torriorthents consist largely of fine earth and show little variation with depth; textural changes are due primarily to parent material differences. These soils are less pervious than the skeletal Haplustolls, and, because rock fragments are sparse in upper horizons, are less likely to receive maximum input of finer fractions from dustfall and water-laid deposits.

Soils of Organ III age (100-1,100 yrs B.P.—early phase)

These soils are the Haplustolls of scarps (sites 8a and 8b) and the Haplustolls (sites 1 and 6) and Camborthids (site 9) of the older Organ III terraces and fans.

Organic carbon and color

The accumulations of organic carbon are distinct, as indicated by comparison of C horizon colors and organic carbon values with those for the horizons above (see sites 1 and 6, Tables 3 and 5). At all sites there is prominent darkening of upper horizons, caused by the accumulation of organic carbon. The lower part of the scarp zone is a typical landscape position for especially thick, dark A horizons and the Pachic Haplustolls. This is attributed to runoff, which moves the wetting front and organic carbon to greater depths than upslope and deepens the zone of common rooting.

Texture, structure, and consistence

Particle-size data for pedons 1 and 6 and field texture for the other Haplustolls show that clay and silt have accumulated in upper horizons. However, morphological features of the Bt horizon and the clay increase required for the argillic horizon are not yet apparent. In Pachic Haplustolls on lower slopes of the scarp, the A horizons are commonly thicker and contain greater thicknesses of sandy loam texture than do the Torriorthentic Haplustolls higher on the slope. This is attributed to silt and clay contributed by runoff from slopes above. The Bt horizon of the Camborthid has a slight increase in silicate clay but not enough for an argillic horizon.

Consistence of the A horizon has changed only slightly from the parent materials and is dominantly soft, with small volumes of loose materials in some horizons. Structure has changed from single grain of the parent materials to massive or weak subangular blocky in the bulk of the A horizon and to dominantly platy in the thin surficial subhorizon. The latter horizon is very similar in soils of all ages, typically being mainly platy, with single grain and massive parts also occurring in some horizons.

Deeper in the soil, pedon 1 illustrates a common change in texture, consistence, and structure of Haplustolls formed largely or wholly in debris flows: a change from sand texture, single grain structure, and loose consistence in the C horizon to loamy sand texture, to massive structure and soft consistence in a thick zone of the overlying A horizon (Table 3). These changes are typical and significant because they illustrate the effect of dustfall additions on soil texture, consistence, and structure at considerable depth in the soil; enough clay and silt from dustfall have accumulated to slightly bind the soil materials together. Although these soils do not have B horizons, the distinct additions of silt and clay mark an important transitional stage to the older soils of Organ II age.

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

These soils are the Ustollic Haplargids (sites 2-4, and 7a) and Pachic Argiustolls (site 5) of the Organ II ridges.

The organic carbon anomaly

In Aridisols of the drier part of the Desert Project (between the mountains) organic carbon content commonly increases as clay content increases (Gile and Grossman, 1979, p. 131). But in areas transitional to the semiarid mountains and the Mollisols, the opposite situation is common: late Holocene Haplustolls have more organic carbon and less clay than adjacent Haplargids of both Holocene and Pleistocene age. Similarly, in this study the site 1 Haplustoll of the Organ III terrace has more organic carbon and less clay than adjacent Haplargids of Organ II age, despite having the same slope and parent materials. The anomaly is important in classification because the soils differ at the highest level: soil order (Aridisols versus Mollisols).

Soil erosion appears to be a major factor involved in the anomaly. The three Organ II Haplargids (at sites 2-4, Table 3) have evidence of soil erosion in the form of slight drains, and, on a few rock fragments, reddish stains that extend above the present ground surface. The reddish stains are interpreted as relicts of clay coatings in a Bt horizon, and thus would indicate erosion of overlying horizons. Such erosion would tend to locally increase slopes and consequently runoff, leading to reduced infiltration of organic carbon. In addition, the Organ II soils are finer than Organ III soils (Table 3), and this would tend to lower infiltration rates, soil permeability, and movement of organic carbon into the soil. Additional evidence of the significance of soil erosion in causing the anomaly is provided by the Argiustoll at site 5, which does have organic carbon values comparable to those of the Organ III Haplustolls (Table 3). Site 5 is a stable, boulder-protected site (Fig. 10) that lacks evidence of soil erosion at sites 2-4.

Color

Significant changes in color have taken place in the Organ II soils. Colors are not quite as dark as in the Organ III soils. In the Haplargids at sites 2-4, parts of the Bt horizon have 5YR hue whereas the C horizon has 7.5YR hue. Thus, pedogenic reddening from 7.5YR (and possibly from 10YR) to 5YR can occur in only 1,100 to 2,100 years. This agrees with pedogenic reddening from 7.5YR to 5YR in 1,000 to 2,000 years in soils of the Fillmore surface at the Desert Project (Gile, 1970, 1975). The reddening is attributed to weathering of biotite and hornblende (in the monzonite and andesite parent materials at the Cox segment) in the upper part of the A horizon and subsequent movement of iron, along with clay, into the B horizon (Gile and Grossman, 1979, p. 183).

The Bt horizon of the Pachic Argiustoll at site 5 is not as red as in other soils of Organ II. This is attributed to the stable, boulder-protected surface at site 5. Higher percentages of organic carbon at site 5 (Table 3) could tend to mask redder colors that might otherwise be visible. Also, shade provided by the boulders would tend to reduce temperatures in the upper part of the A horizon, and thus could retard weathering and the associated reddening of the Bt horizon discussed previously.

In most horizons, chromas have increased to 3 or 3.5, as compared to 2 for the Haplustolls on terraces and fans. However, the 2BCt1b horizon of pedon 7a, near the upper edge of the main scarp, has chroma of 4 (Table 5). This increase in chroma, as compared to pedons 2, 3, and 4, is attributed to the landscape position of pedon 7a: it is very near the west scarp and is located below a drain. Both the drain and the scarp upslope would contribute additional moisture to the pedon.

Texture, structure, and consistence

Particle-size data (Tables 3 and 5) indicate that more silt and clay from dustfall have accumulated in the soils of Organ II than in the soils of Organ III. In all Organ II soils, the clay difference between the A horizon and the horizon of maximum clay is enough for an argillic horizon. However, the clay increase is barely enough to qualify in the four soils of the Organ II ridges (a minimum clay increase of 3% is required in these soils). Only in the soil below the west scarp (pedon 7a, Table 5) is the clay increase more prominent, and this would be expected because of the pedon location, as noted in the preceding paragraph.

The thin A horizons of Organ II soils are very similar in consistence and structure to the surficial A horizons of Organ III soils. As with Organ III soils, a striking change in soil texture, structure, and consistence is evident from the C horizon to the pedogenic horizons above. In Organ II soils, however, the change from the loose, single-grain sand of the C horizon is more prominent because the soils are older and more of the finer fractions from dustfall have accumulated. The Bt horizons of Organ II soils are dominated by sandy loam texture, weak subangular blocky or massive structure, and slightly hard consistence. Transitional BC and CB horizons illustrate values in soil texture, structure, and consistence that are intermediate in morphological expression between the Bt and C horizons (Table 3).

Weathering of rock fragments, not shown in the tables of data, is another chronological feature of soil development in the soils of Organ II. Some rock fragments are easily taken apart with the finger—so easily that they would have been separated in transport before being deposited. Presence of this feature in soils of Organ II age, but not Organ III, indicates that it can form in a minimum time ranging from about 1,100 to 2,100 years (Table 1).

Organ II and III sediments and the time of latest displacement

The scarp colluvium is graded to deposits of a post-faulting channel of North Arroyo, which swung along the scarp base immediately after displacement. Because terrace deposits of early Organ III cross these post-faulting deposits of North Arroyo, the time that it occupied the scarp base must have been very short, possibly only a few years. Thus the age of the scarp colluvium must be essentially the same as the age of latest displacement along the fault.

Organ II sediments have been displaced along the fault; therefore, the latest displacement must be younger than some time within the age range of Organ II, namely, 1,100 to 2,100 yrs B.P. Just above the scarp, Organ II sediments have a distinct reddish (5YR hue) Bt horizon that abruptly disappears below the crest of the scarp and that does not occur in the scarp colluvium below. Weathered rock fragments, a distinct feature in the soils of Organ II alluvium, are also conspicuously absent from the scarp colluvium. Soils of the scarp colluvium are similar to soils of the Organ III terraces. This combination of soil and geomorphic evidence indicates that the displacement took place at somewhat less than the minimum time in the age range of Organ II, or less than about 1,100 yrs B.P.

Organ III sediments have a chronological range of 100 to 1,100 yrs. Extension of unfaulted early Organ III terraces across the fault zone indicates that the displacement must have taken place in earliest Organ III time, and for this reason the time of latest displacement is estimated to be about 1,000 yrs B.P.

Soils of Organ I age (2,200-7,000 yrs B.P.)

These soils are the Ustollic Haplargids of Organ I ridges. More work is needed on Organ I soils because only a small area of these soils occurs in the study area (Fig. 4). Work to date indicates that Organ I soils differ from Organ II soils in this study area in two main respects if the soils are not in drains: they have slightly more clay, and they have a stage I carbonate horizon. Horizons of carbonate accumulation, useful as chronological indicators in many soils of arid regions (Gile et al., 1966; Machette, 1978), in this moister area are not involved in distinguishing the younger soils of Organ age, but are useful in identifying the Organ I soils.

The study trench and landscape position indicate that soils of slight drains differ markedly from soils adjacent to the drains. The Bt horizon adjacent to the drain has soft and slightly hard consistence, has subangular blocky structure, has chroma of 3 or 3.5, and is easily removed from the horizon. In contrast, the Bt horizon in the drain is hard throughout, is massive, has chroma of 4.5, lacks a stage **I** carbonate horizon, is not readily removed from the horizon, and has slightly more clay. These differences are attributed to extra moisture received by the soil in the drain.

Further studies of Holocene displacement

The Organ Mountains fault is extensive, occurring on the east flanks of both the Organ and San Andres Mountains (Seager, 1981). Examination of aerial photographs at various places along the fault strongly suggest that the late Holocene displacement found in this study is common elsewhere along the fault. The fault itself is a useful chronological indicator once the times of displacement have been determined. Further studies of Holocene displacement(s) could well be aimed at discerning soil morphological changes that take place along the fault with changes in parent materials and topography. Of particular interest would be differences associated with changes to high-carbonate parent materials and to materials that have few or no rock fragments. Areas that lack, or are minimally affected by, drains that cross the scarp should be selected, because the complications caused by such drains would be avoided.

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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, 1980). 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 down-slope 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). See pp. 6 and 8 for other interpretations of the Altithermal.

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 0.1M HC1. 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 I carbonate horizon.*

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 which were moved there primarily by gravity and unconcentrated runoff.

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 the distance below the surface of the mineral soil or 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 and Haplustolls, it extends from 25 to 100 cm in depth; for the Ustollic Haplargids and Pachic Argiustolls, 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.

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.

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 (see cover and pp. 11 and 12 for further explanation).

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).

Interpluvials—See *pluvials.*

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.*

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 8 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 1 m^2.

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

Rock fragments—Particles 2 mm or larger in diameter. *Rock fragments* in the study area include gravel (diameter 2-7.6 mm), cobbles (diameter 7.6-25 cm), stones (diameter 2560 cm), and boulders (diameter >60 cm).

TABLE 8—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 coarse-loamy as defined for the coarse-loamy particle-size class.
Sandy	The texture of the fine earth is sand or loamy sand, but not loamy very fine sand or very fine sand; rock fragments are <35% by volume.
Coarse-loamy	The texture of the fine earth is loamy very fine sand, very fine sand, or finer; by weight, 15% 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% clay in the fine-earth fraction; rock fragments are <35% by volume.

Scarp—See *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 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 clay. 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

Four 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* horizons has not been truncated, the increase in clay to the argillic horizon must be at least 3% in soils of this study because the *eluvial* horizons have less than 15% clay (Soil Survey Staff, 1975). In addition to the clay increase, various kinds of evidences for clay *illuviation* 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.

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 I carbonate horizon—In *skeletal* materials, a horizon in which pedogenic carbonate occurs as thin coatings on *rock fragments* (Gile et al., 1966).

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; see also *particle size.*

Thermic soil temperature class—The mean annual soil temperature at 50 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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