CHAPTER 7. HAPLUSTALFS OF THE BIRDWELL SURFACE

The soils occur in mapping units E, F, G, and H (fig. 27).

PSAMMENTIC HAPLUSTALFS DOMINANT: MAPPING UNIT E, TEXICO FINE SAND

MAPPING UNIT COMPOSITION

Series or variant	Subgroup	Particle-size family	Percentage of mapping unit
TEXICO	PSAMMENTIC HAPLUSTALFS	SANDY	75
Farwell	Aridic Haplustalfs	Coarse-loamy	10
Circleback	Alfic Ustipsamments	Sandy	10
Other inclusions (Keeney, SND-1)			5

LOCATION, LANDSCAPE, SOIL OCCURRENCE, VEGETATION

Soils of unit E occur extensively in dunes in the central and southern part of the study area. Dune crests range from about 3 to 10 m higher than the adjacent depressions. Texico soils occur on most dune crests and on middle and upper sides (particularly east-facing) of dunes. Farwell soils occur on some of the broadest ridge crests, and, along with the Keeney soils, in narrow bands on lower sides of some dunes. Circleback soils occur on some of the strongly wind-eroded, west-facing upper sides of dunes, where the argillic horizon has been truncated or could not form. SND-1, Alfisols and Entisols undifferentiated, occurs in the bottom of gullies that have removed diagnostic horizons, exposing C horizon material or buried soils. These soils of Birdwell dunes and adjacent depressions constitute the striking textural sequence depicted in figure 8.

Vegetation observed in mapping unit E consists of snakeweed, hairy grama, sideoats grama, blue grama, wolftail, three-awn, wooly gaura, sand sagebrush, catclaw, dropseed, soapweed, and a small area of shinnery oak in the southwest part of the study area.

TYPICAL PEDON AND RANGES IN SELECTED PROPERTIES

See Mapping Unit C for a typical pedon and ranges of Texico.

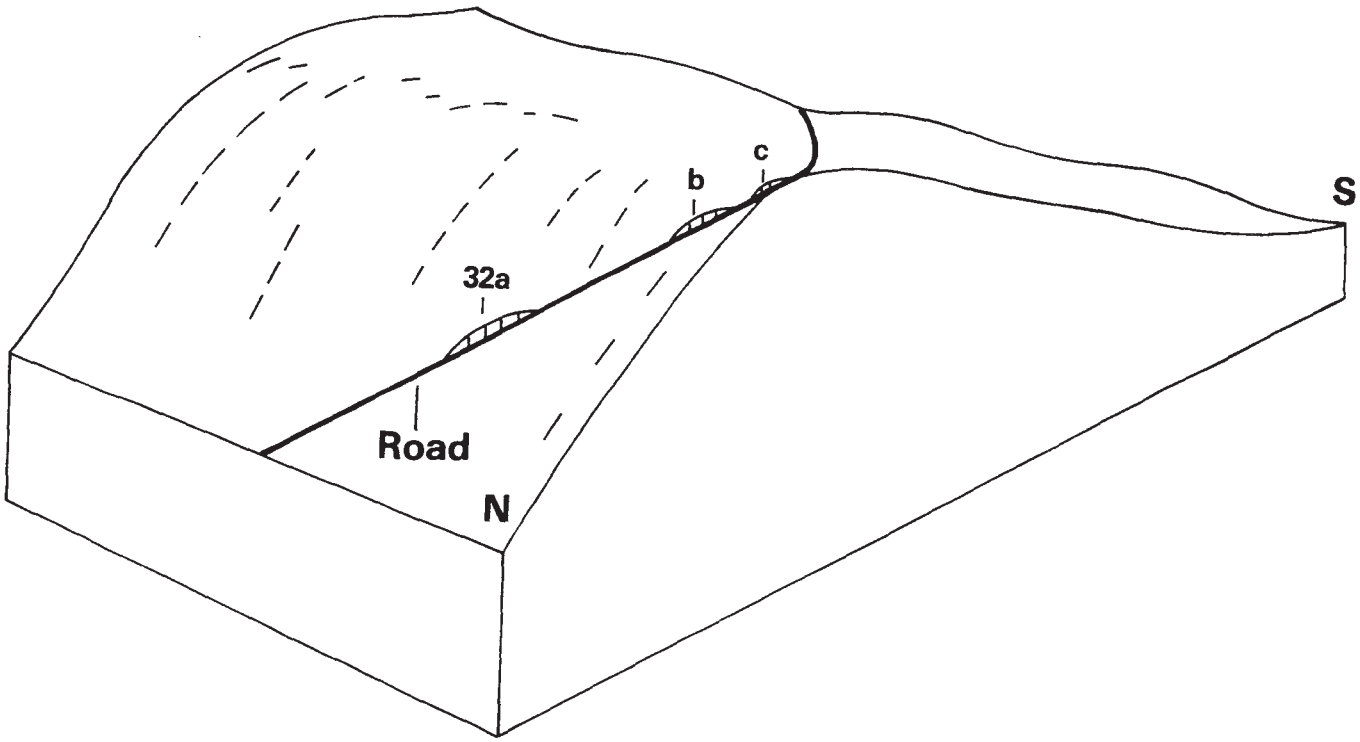
STUDY SITES

Site 32, landscape position and morphology of clay bands

Site 32 (figs. 75-77) consists of discontinuous exposures in the east bank of a road from a blowout up the adjacent dune (fig. 77). Presence of the windmill and water in the blowout (fig. 75; see Site 47) led to the development of a road and cattle trails, and to erosion and deposition of Fairview sediments. Figures 76 and 77 are aerial photographs taken in 1941, 1953, 1962, and 1970; they locate Sites 32, 47, and old trails that are associated with a windmill and water tank. The 1941 photograph shows a circular tank in the blowout, and faint traces of a diagonal road (fig. 76, arrow) from the blowout up the dune, but the adjacent soils and landscape show little evidence of erosion.

Figure 75. Above. Photograph of the blowout and dune shown in figures 76 and 77. Gullies are evident. Road at Site 32, not visible, is at right of area shown. Photographed December 1974.

Below. Diagram showing road ascending the dune and location of Sites 32a, 32b and 32c.



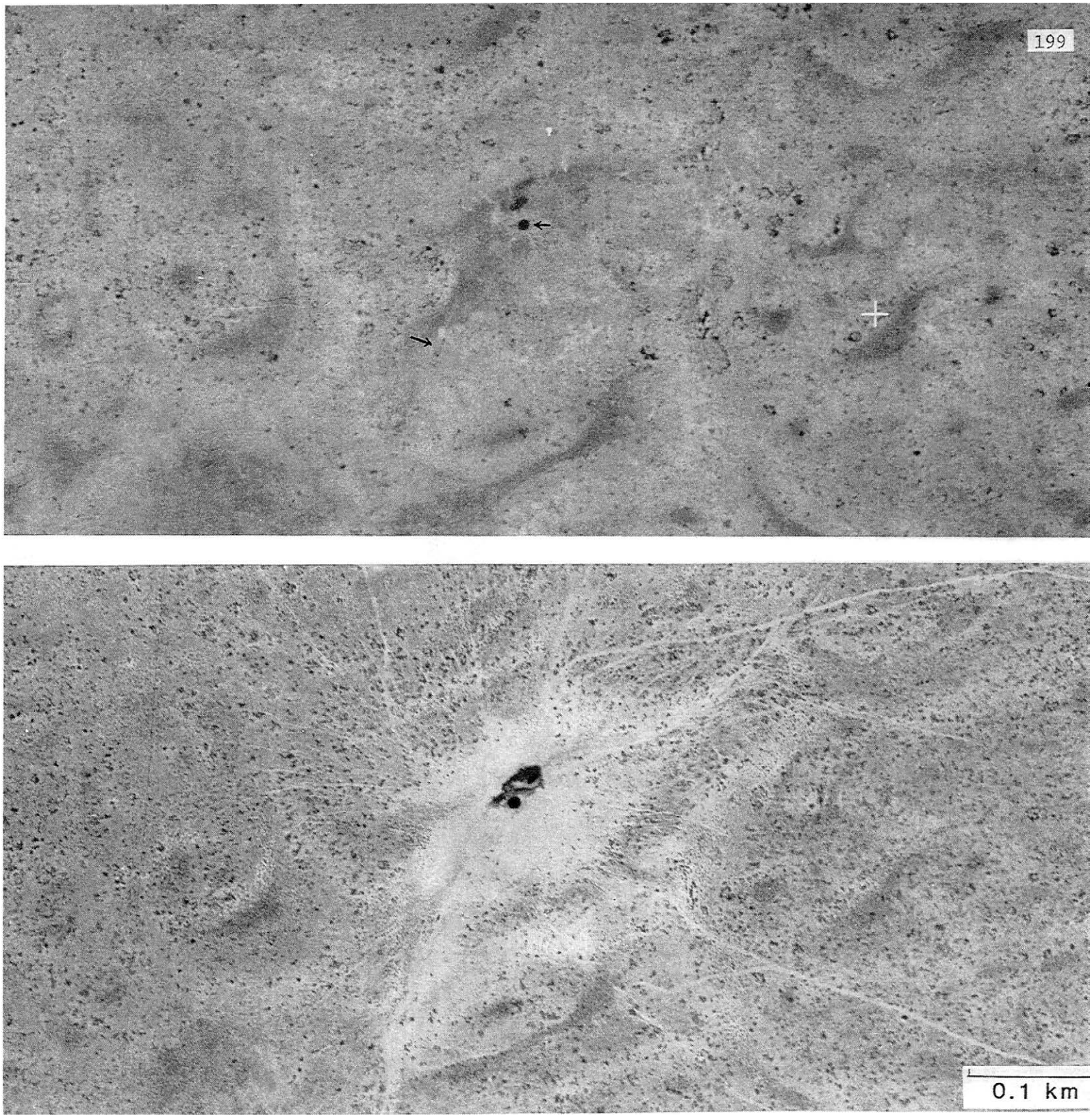


Figure 76. Upper. Aerial photograph taken August 3, 1941. Arrows point to water tank in blowout and faint trail up the dune just southwest; except for these features, little evidence of landscape alteration is apparent. Note changes with passage of time through 1970 (fig. 77, lower).

Lower. Aerial photograph taken February 25, 1953. Numerous cattle trails are apparent leading to the blowout and water tank. A band of Fairview sediments, derived from erosion of the road (arrow, upper) has accumulated and forms a light-colored band parallel to the road.

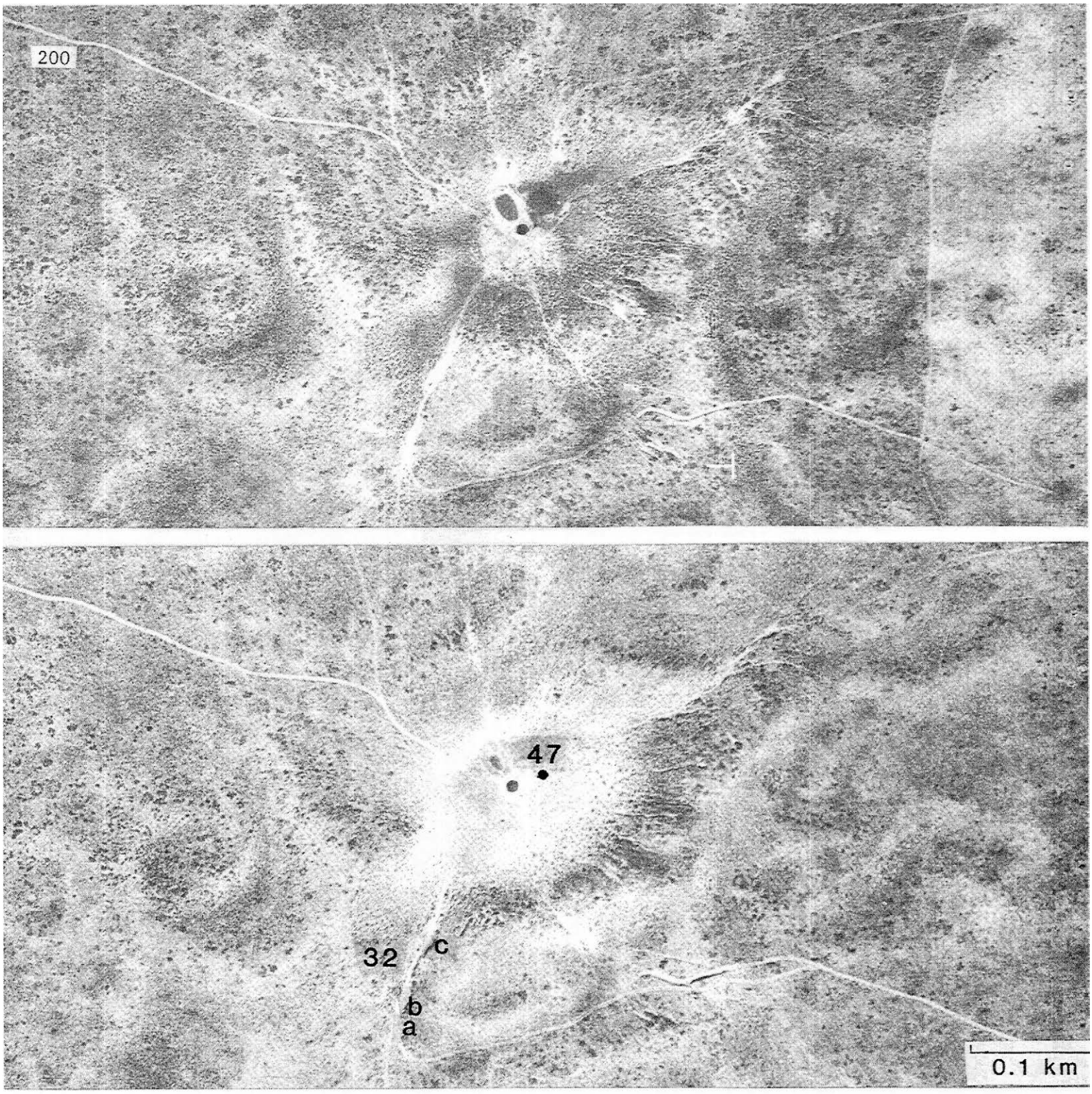


Figure 77. Upper. Aerial photograph taken October 31, 1962. Vegetation is visible in the Fairview deposit next to the road. Several new roads have been started since 1953.

Lower. Aerial photograph taken December 13, 1970. New gullies have formed in the dune south of the tank. Note that the north-south road, started before 1962, has been abandoned and is barely visible. Sites 47 and 32a,b and c are located.

The airphotos indicate progressive deterioration of the dune after 1941, particularly between 1941 and 1953; substantial numbers of cattle appear to have grazed in this general area during this time. The 1953 photograph shows the circular tank and also what appears to be an enlarged tank to the northeast. The diagonal road from the blowout shows evidence of much more use than in 1941; a light-colored strip occurs just east of, and parallel to the road. This strip represents a deposit of Fairview sediments, discussed later, that were emplaced as a result of wind erosion along the road, primarily between 1941 and 1953. Presence of water in the blowout must have contributed greatly to increased traffic by cattle, leading to the development of a number of trails on the dune, and to their subsequent erosion. A severe drought period that began in 1952 (table 2) probably contributed to the erosion.

In the 1953 photograph a number of distinct trails are apparent on the northwest-facing side of the dune (fig. 76). The 1962 and 1970 photographs show that these trails have enlarged and deepened into gullies (fig. 77). The gullies are visible in photographs taken on the ground in 1974 (fig. 75).

In the 1953 photograph, a road from the windmill may be seen heading southeast across the top of the dune and about at its center (fig. 76). By 1962 that road had been abandoned, presumably because of steepness and erosion, and the dune was again crossed by using the diagonal road (fig. 77). In 1979 the diagonal road was abandoned after construction of a new east-west fence that crossed the road. Before 1962 a new north-south road was established east of the blowout and dune (fig. 77, upper). The road was soon abandoned because it is barely visible in the 1970 photograph (fig. 77, lower). Thus the soil surface must have healed quite rapidly, as is typical in areas of minor disturbance in the sandhills. This contrasts with gullies in the heavily used cattle trails on steeper slopes of the high dune just east (fig. 77, lower).

Exposures in the diagonal road show the character of soils on the side and crest of the dune (Sites 32a, b, c; fig. 75). The post-1941 deposit of Fairview sediments, mentioned earlier, is continuous except where it has been stripped away by wind and by water erosion graded to the road (fig. 78). Pedon 32a, an Alfic Ustipsamment, occurs on the central side of the dune. Pedons 32b and 32c, both Psammentic Haplustalfs, occur on the upper side of the dune and the level crest of the dune, respectively. Pedon 32a (fig. 79) has a thick, prominent clay band horizon, with occasional thin, light-colored interband zones of A2 horizon material. In contrast, Bt material in Pedons 32b and 32c is virtually continuous, and their Bt horizons are much thinner. Table 39 gives soil characteristics.

Site 32a, central side of dune

Pedon 32a (figs. 78, 79) is the northernmost of the three pedons and is in the central part of the dune side. Slope is 11 percent to the west. As shown in figure 75, the exposure is not directly downslope from the dune crest, but cuts across the dune side at an angle. The west-facing roadside cut is exposed to both surface runoff and westerly winds and has undergone considerable erosion (fig. 78).

An A1 horizon and a thick, banded B horizon occur beneath the Fairview sediments. Most bands roughly parallel sedimentary strata. Although the

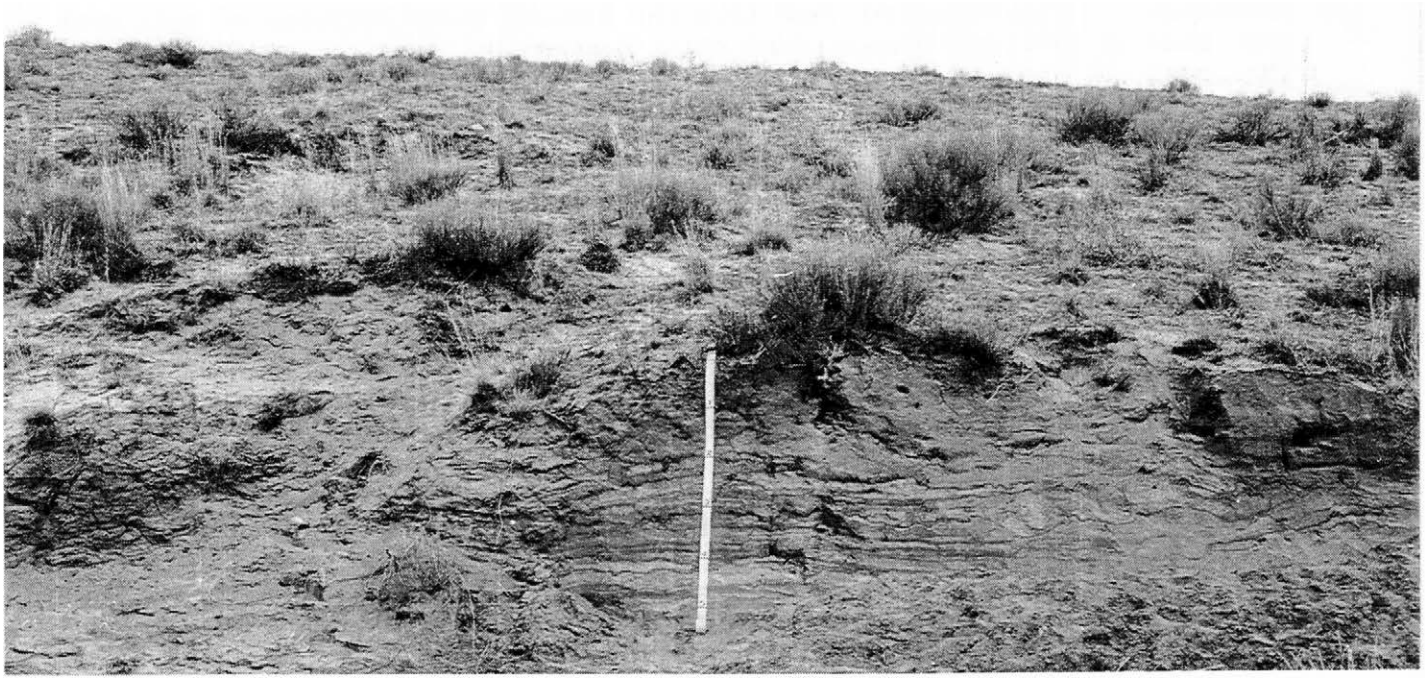


Figure 78. Landscape view along east bank of road at Site 32a. Fairview sediments are still preserved beneath the shrub at the tape, but both Fairview and underlying Birdwell sediments have been eroded nearby as indicated by drains graded to the road. Note the circular forms at 3 ft (0.9 m) depth, about 6 ft (1.8 m) to the right of the tape (see fig. 80). Photographed March 1981. Scale is in feet.

clay bands are prominent, they do not contain enough clay in a horizon thick enough for an argillic horizon (table 39), and Pedon 32a is an Alfic Ustipsamment. Only a very small amount of clay -- several percent -- can cause prominent changes in color and consistence (table 39, fig. 79).

Most of the clay bands are continuous laterally. In places an individual band bifurcates into two bands. The boundary to the bands is commonly abrupt and smooth. Light-colored zones between some of the bands are quite continuous and consist of sand grains virtually free of clay. Their light color, close association with clay bands, and thickness of bands suggest a substantial amount of lateral movement of water downslope along the bands, and associated stripping of clay from the interband zones. This clay stripping would cause the light color of the interband zones.

Figure 79. The Alfic Ustipsamment, Circleback, at Site 32a. Note prominent clay bands; compare with clay bands on dune side of Longview age at Site 3. Scale is in feet.

Table 39. Characteristics of Haplustalfs and an Ustipsamment at Site 32[1/]

Sediment	Horizon	Depth, cm	Hue	Value/chroma Dry	Value/chroma Moist	Structure	Dry consistence	pH	Lower boundary	Textural class	Sand 2.0-0.05 mm	Silt 0.05-0.002 mm	Clay < 0.002 mm
Alfic Ustipsamment, Circleback, on central side of dune: Pedon 32a[2/]													
F	C	0-29	6YR	5.5/4	4/4	m	s	7.4	as	s	95.1	0.2	4.7
B-I	A1b	29-38	7.5YR	5/3	3.5/3	m	s	7.4	as	s	94.0	0.8	5.2
	B11tb	38-46	5YR	5/4	3.5/4	m	sh	7.2	as	s	92.9	0.4	6.7
	B12tb	46-58	5YR	5/4	4/4	m	sh	7.2	as	s	93.9	0.9	5.2
	B21tb	58-62	2.5YR	4/6	3.5/6	1msbk	h	7.0	as	s	90.5	0.8	8.7
	B22tb	62-71	5YR	6/5	4.5/5	m	sh,h	7.0	as	s	92.5	0.8	6.7
	B23tb	71-73	2.5YR	4.5/6	4/6	1msbk,m	vh	7.0	as	ls	87.5	0.7	11.8
	B24tb&A2	73-94	2.5YR	4.5/6	4/6	1msbk	h,sh	6.8	as	s	94.0	0.8	5.2
	B25tb	94-96	2.5YR	4.5/6	4/6	1msbk	vh	7.0	as	s	91.8	0.6	7.7
	B31tb	96-110	5YR	6.5/5	5/5	m	sh,h	7.0	as	s	94.8	0.6	4.6
	B32tb	110-122	5YR	6.5/5	5/5	m	vh,h	7.0	as	s	93.4	0.4	6.2
	A2b	122-126	5YR	6.5/5	4/5	m	s	7.0	as	fs	96.2	0.7	3.1
	B33tb	126-129	4YR	5/6	4.5/6	m		7.0		s	92.6	1.4	6.0
Psammentic Haplustalf, Texico, on upper side of dune: Pedon 32b													
F	C	0-28	5YR	5/4	3.5/4	m	s	7.0	as	fs	92.2	3.4	4.4
B-I	A1b	28-43	5YR	5/3	4/3	m	s,sh	7.0	cw	fs	91.9	3.1	5.0
	B1tb	43-56	4YR	5/4	3.5/4	m	sh	7.0	cw	s	89.3	2.7	8.0
	B21tb	56-68	4YR	5/5	3.5/5	1msbk	sh	6.8	cw	s	91.0	0.5	8.5
	B22tb	68-89	4YR	5/5	3.5/5	1msbk	sh,h	6.8	as	ls	88.9	1.6	9.5
	B23tb	89-107	5YR	5.5/5	4/5	1msbk	sh	6.8	cw	ls	87.7	2.3	10.0
	B3tb	107-139	5YR	6/5	4.5/4	m	s	7.0	cw	s	93.6	2.5	3.9
	C1b	139-160	6YR	6/4	4.5/4	m	s	7.0	cw	fs	97.5	0.1	2.4
	C2b	160-174	6YR	6/4	4.5/4	m	s	7.0		fs	99.3	0.3	0.4
Psammentic Haplustalf, Texico, on crest of dune: Pedon 32c[3/]													
F	C	0-17	5YR	5/4	3.5/4	m	s	7.0	as	fs			
B-I	A1b	17-23	6YR	5/3	3.5/3	m	sh	7.0	cw	fs			
	A2b	23-33	5YR	5.5/4	4/4	m	sh	7.0	cw	fs			
	B1tb	33-45	5YR	5.5/5	4/5	1csbk	h	6.8	cw	fs			
	B21tb	45-59	2.5YR	5.5/6	4/6	1csbk	vh	6.8	aw	lfs			
	B22tb	59-74	5YR	5.5/5	4/5	1csbk	vh	6.8	cw	lfs			
	B31tb	74-99	5YR	5.5/5	4/5	1csbk	h	6.6	as	fs			
	B32tb	99-112	5YR	5.5/5	4/5	1csbk	sh	6.6	as	fs			
	B33tb	112-131	5YR	5.5/5	4/5	m	sh	6.8	as	s			
	B34tb	131-147	5YR	6/4	4.5/4	m	s	7.0	cw	s			
	Cb	147-165	7.5YR	6/4	4.5/4	m	s	7.0		fs			

1/ Subordinate colors and other characteristics are footnoted to pertinent soils. Sediments are identified as F = Fairview, B-I = Birdwell I.

2/ B11tb: remnant of large band is present; it is slightly darker and redder, and has more clay than rest of horizon. B12tb: interband area, but has some illuvial clay. B21tb: band. B22tb: mostly interband, but has one fairly distinct band, included in sample. B23tb: mostly one thick band, but in places there are light-colored interband zones, 1-3 mm thick. B24tb&A2: A2 parts are 5YR 6.5/4, dry, and lower in clay. B25tb: band. B31tb: mostly interband, but has one band, about in center. B32tb: has 3 bands, but less clay than above. A2b: light-colored and low in clay. B33tb: band.

3/ B21tb: parts 6/5, dry. B22tb: bands 2.5YR 4/6, dry. B32tb: bands 2.5YR 4.5/6, dry.

The most prominent clay bands are in the upper part of the Bt horizon and do not have light-colored zones above them. But this upper part of the Bt horizon is very near the surface and should be subject to some clay accumulation from vertical as well as lateral movement of soil water. Some of the clay in this upper zone could also be due in part to accumulation late in soil history, because the abundant clay bands, once formed, would tend to slow vertical downward movement of the wetting front.

Site 32a also shows different depths to the same clay bands. For example, on the south end of the exposure a band is 44 cm below the top of the buried A horizon; the same band near the north end of the cut is at about 90 cm depth.

Clay bands of large, roughly circular shape occur upslope of Pedon 32a (figs. 78, 80). These bands are interpreted as clay accumulations along the margin of crotovinas that formed early in the history of the soil. This is indicated by shape similarity to a modern crotovina that is filled with dark fine earth instead of light-colored sand. A number of nearby smaller circular clay bands along the exposure are also thought to represent ancient crotovinas.

Some of the bands and interband zones in the upper part of the B horizons were thick and distinct enough that they were sampled separately. The bands are thinner and less distinct in the lower part of the B; some of these were grouped together in sampling. Excavation with a shovel below the bottom of the exposure showed that distinct clay bands continue to at least another 30 cm.

The clay bands are thicker and more numerous than they are in soils on the sides of Longview dunes. These prominent bands occur only on the sides of dunes that are favorably situated for their development and preservation, and are not found on such west-facing dunes as the long dune at Sites 35 and 36. The dune side at Site 32c not only faces northwest instead of west, but also has been protected from westward wind erosion by another Birdwell dune just to the west. Toward the dune crest, the prominent bands of dune sides grade to horizons with thinner, less numerous bands and with clay throughout the Bt instead of being mostly in the bands.

This occurrence of Birdwell clay bands on the dune side, and their greater number and thickness as compared to Longview, is supporting chronological and morphological evidence for their proposed mode of formation by lateral movement of water and its suspended clay downslope. This difference in clay band expression between dune crest and sides is similar to that in soils of Longview age (Site 3); the bands are thicker and more numerous in Birdwell sediments because the process has been going on for a longer period of time than in Longview sediments.

Site 32b, upper side of dune

Pedon 32b (fig. 75) is the central of the three pedons sampled at Site 32, and on the upper side of the dune. Slope is 6 percent to the west. The clay increase in the Bt horizon is enough for an argillic horizon and Pedon 32b is a Psammentic Haplustalf. The B21t horizon has no clay bands. The B22t horizon has two, from 3-5 mm thick, that are undulating and generally continuous. The B23t horizon has two discontinuous bands, 1-2 mm thick. There are none below.

Figure 80. Crotovinas of different ages and sizes (see fig. 78) at Site 32a. Crotovinas at left, and the lower portion of one at right, are old enough that prominent clay bands have formed around them. Younger crotovinas lack the prominent bands, but clay bands have started to form around crotovinas of intermediate age (see fig. 80a). Penny in crotovina at right gives scale.

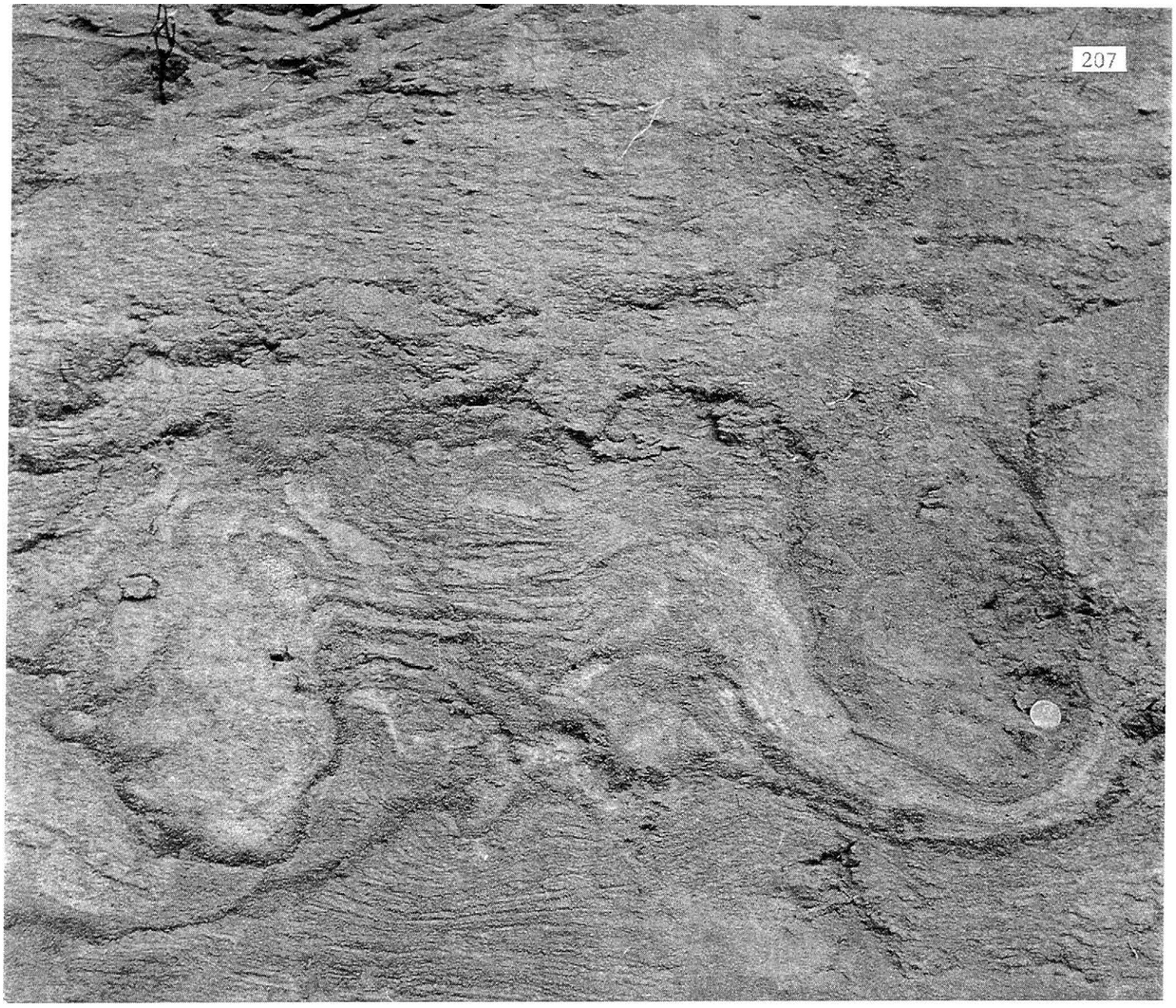


Figure 80a. Closer view of crotovinas shown in figure 80. The central part of crotovina at right is filled with darker material, and discontinuous clay bands have started to form around it; this central part represents a later excavation by rodents, and subsequent filling. Outlines of the younger part can be traced upward, where the crotovina narrows considerably; this apparently represents an access tunnel. The youngest crotovina is the small one at top center. It has no clay bands, and is the type found in much younger soils (of Muleshoe age; see fig. 41). Penny gives scale.

The abrupt smooth boundary at the base of the B22t horizon marks the contact of stratified sediments on unstratified sediments. Sedimentary strata are apparent only in the lower part of the B22t horizon. The C1 horizon has crotovinas of reddish material like that in the B horizon above. The crotovinas are circular in cross section, 6-8 cm in diameter, appear quite young, and lack the prominent coatings of clay seen at Site 32a.

Site 32c, dune crest

Pedon 32c (fig. 81), also a Psammentic Haplustalf, is in the center of the dune crest. Although the dune crest is nearly level and is the stablest position on the dune, note the strong evidence of wind erosion shown in the photograph (fig. 81). Up to about 1 m of soil has been eroded at the left of Pedon 32c. Since the site is on the very crest of the dune, the bulk of the erosion must have been by wind. Significance of wind erosion is also indicated by the belt of eolian sediments that parallels the diagonal road (fig. 76).

Clay bands are more distinct in this pedon than in Pedon 32b. The B21t horizon has one band. It is about 1 cm thick and is continuous across the exposure, though there is some undulation; the band dips down several cm to the left of the sample site. The B22t horizon has one clay band; it is ½ - 1 cm thick. This band also dips down to the left of the sample site, and bifurcates to the right. The upper bifurcation then rises in part and joins the top clay band. The bifurcations are about ½ cm thick. The B23t horizon has two thinner, discontinuous bands, 2-3 mm thick. Faint, discontinuous bands also occur at lower boundaries of the B21t, B32t, and B33t horizon, but there are none between.

Buried soils

Auger samples between Sites 32b and 32c showed the following materials.

0 - 8 ft (0 - 2.4 m): Birdwell sediments.

8 - 10 ft (2.4 - 3 m): Roosevelt sediments, with a sandy clay loam B2t horizon, 5YR 3.5/4, moist.

10 - 11 ½ ft (3 - 3.5 m): sand.

11 ½ - 15 ft (3.5 - 4.5 m): Hale sediments, with a sandy clay loam B2t horizon, 2.5YR 4/6, moist, in the upper part. In the lower part of this zone, color is less red (about 4YR 5/6, moist), with a few parts lighter and less red.

Due south of the water tank, by the road that ascends the dune (fig. 76), the exposed edge of a buried Bt horizon was observed about midway up the side of the dune. The Bt horizon has hue of 2.5YR and texture of sandy clay loam, and is noncalcareous. Auger samples indicate that the Bt horizon is underlain by at least 1 m of sand. The Bt horizon may represent a pre-Roosevelt buried soil that is younger than soils of Hale and Bailey age. The Bt horizon is thinner than typical Hale, and may represent a pre-Tahoka interpluvial deposit. The distribution of Muleshoe and Longview sediments (fig. 19) shows that evidence of some periods of less severe climatic stress may be found only in certain areas susceptible to wind erosion. Surficial materials particularly resistant to erosion appear to preclude significant

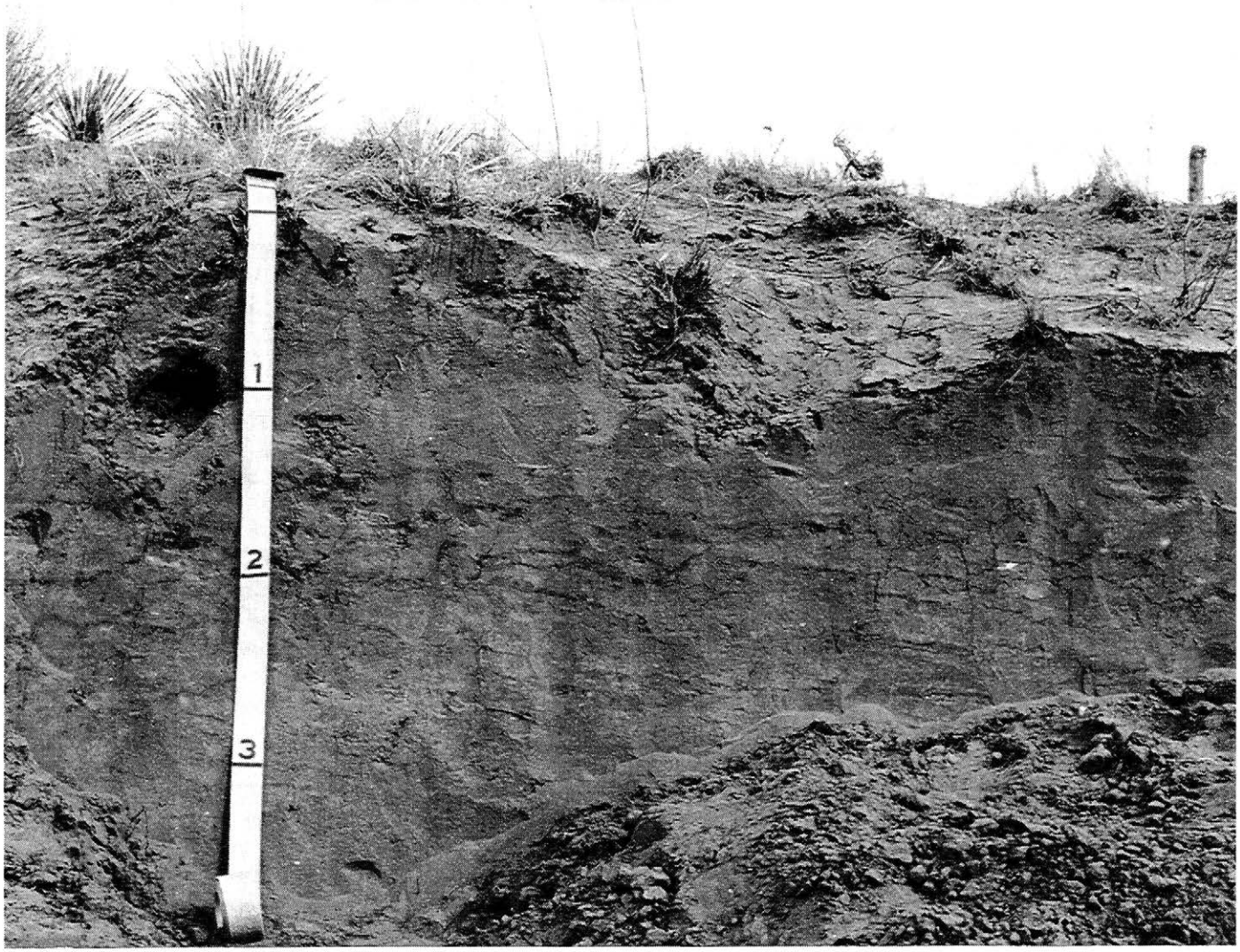


Figure 81. Upper. Landscape of the Birdwell dune at Site 32c, on the ridge crest. Strong erosion has taken place even on the ridge crest. The view is east. Photographed March 1981.

Lower. The Psammentic Haplustalf Texico, at Site 32c. Clay bands are apparent in the B horizon, but are much less numerous than on the side of the dune (fig. 79). Scale is in feet.

erosion and deposition during these periods.

Thus substantial deposits of a minor erosive episode would be expected only to the lee of areas that had an ample supply of sediments for erosion. The dune at Site 32 and the large dune at Sites 35-39 may have potential for further investigations of the period before the Tahoka pluvial, but after the time represented by the start of soil development in Hale time. These and similar large dunes could in fact hold much of the stratigraphically demonstrable sedimentary and pedologic evidence of this interval, because erosion that accompanied the severe post-Tahoka climatic change may have removed deposits of this age between dunes. Such investigations could also yield valuable information about sediments of Hale and Bailey age.

Origin of whitish lenses and smooth surface crusts

At first it was thought that lenses of whitish sand in eolian deposits (see Sites 1a, 36, 37c, and 41) were caused by brief periods of surficial weathering during halts in sedimentation (Gile, 1981, p. 20, 21). While this may be true in some instances of some very thin, discontinuous lenses, further study indicates that most of the whitish lenses were derived from concentrations of whitish sand deposited by small streams arising in the sides of the dunes. Such concentrations of whitish sand can presently be seen on lower sides of dunes after rains. Examination of Site 32a in October 1982 showed evidence of a ready source of whitish grains for wind erosion and deposition. The slope below Site 32a was an uneven surface mantled by spoil after deepening and cleaning the exposure in March 1981. But by October 1982 the surface had been cut by water, and sediments derived primarily from the exposure had been deposited below it (fig. 82). Two components of the surface are apparent: deposits of whitish sand in and below slight channels, and a smooth crust adjacent to some of the channels (fig. 82). The whitish sand appeared very fresh and must have been emplaced during the latest rainstorm. Apparently, the clay coatings on sand grains are readily removed by stream action. Also, some of the grains in the profile itself were light-colored before their erosion.

Similarly, deposits of whitish sand were found on much of the slope below exposures at Sites 32b and 32c, and in the road adjacent to the exposures. Examination of lobes of alluvium below gullies in the dunes showed similar discontinuous deposits of fresh whitish sand, and adjacent smooth crusts as observed at Site 32a.

Whitish sand grains have also been found scattered over other parts of the dunes, and apparently were caused by surface weathering. But the alluvial deposits below gullies are much thicker. From the foregoing it seems likely that the primary source of whitish sand in the major deposits of the sandhills (i.e., Muleshoe and older) consisted of the deposits of small streams arising in the sides of dunes. Alluvium below gullies in cattle trails has been a source of eolian sediments in the past several decades, and these eolian sediments also contain whitish lenses (see Site 37c).

If the whitish sand was blown in, conditions would be required that would permit little mixing with the redder sand. Loose whitish sand at the surface should be first to be picked up during a dry, windy episode; nearby areas with a crust would be more resistant to erosion and sand grains in these areas would be picked up later. This mechanism would explain

Figure 82. Site 32a, photographed in October 1982 (see figs. 78,79) . Erosion since March 1981 has affected both the roadcut and the slope just below it. Microledges have formed along the more resistant clay bands in the exposure, and some of the sandier, less resistant material has been eroded, furnishing sediment for the alluvium below. Most of the surface this side of the roadcut is covered with fresh sand.

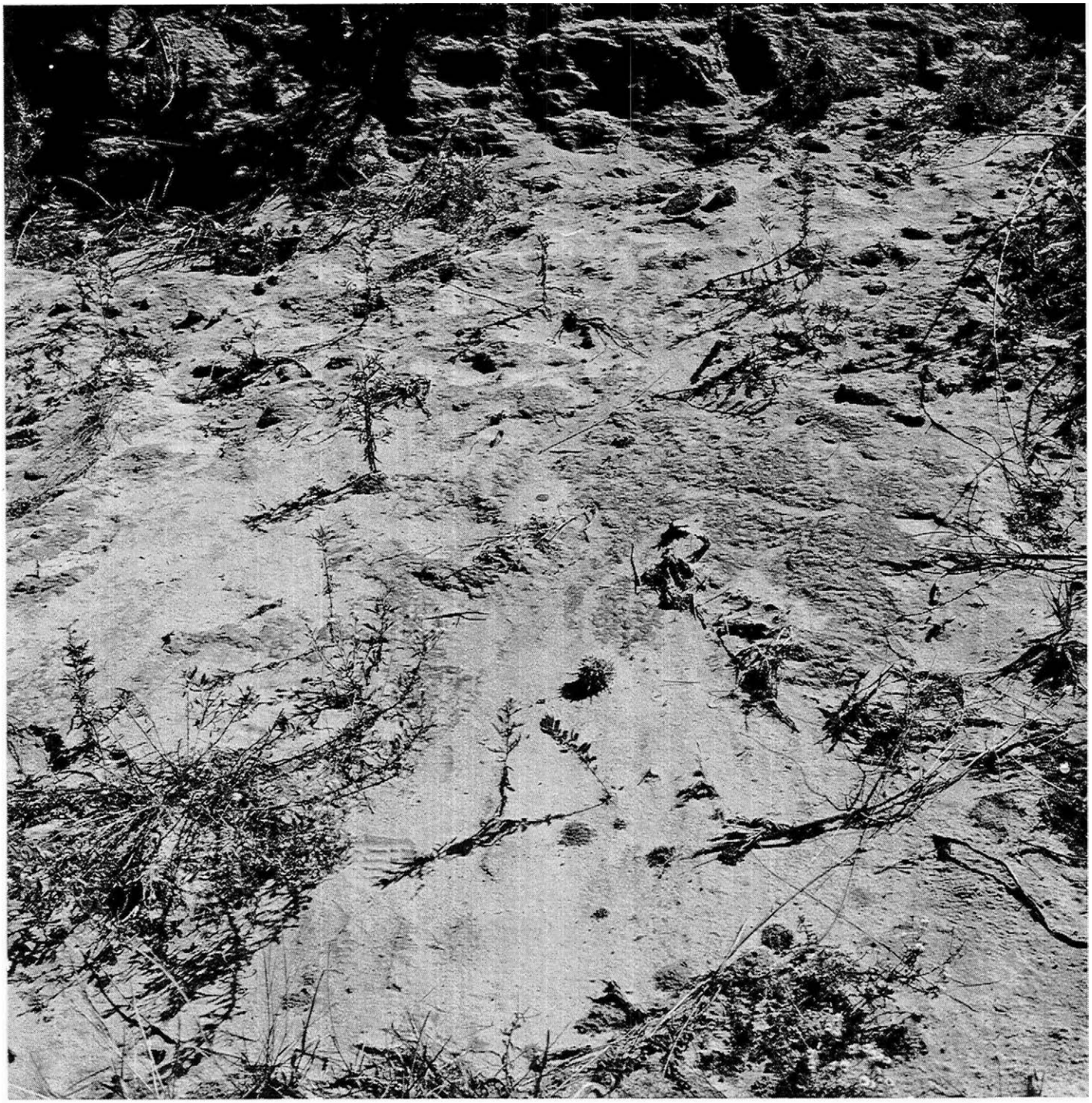


Figure 82a. Closer view of the fresh deposit of whitish sand that covers most of the slope below the cut at Site 32a, and of the smooth surface crust at right center. Penny at left of smooth crust gives scale, as does a heel print at lower left; the top of the heel print is 8 cm across.

concentration of the whitish grains. Since whitish lenses commonly constitute only a minor part of a deposit and are not always present, such localized occurrence would not be out of place for this origin.

Concerning the smooth surface crust, similar crusts have been found at the surface of desert soils in southern New Mexico (Gile and Grossman, 1979, p. 109-110):

> In low-gravel materials with little clay a smooth crust, usually less than 1 mm thick, is common at the very surface of the soil.... It may be partly breached during dust storms but seems to reform quickly. It is thought to be due to drying of surface water following torrential rains, when the infiltration rate is exceeded and water is standing or moving slowly over the soil surface. When the water dries, the fine particles it contains settle on the surface, forming a smooth film. The film and adhering fine earth constitute the crust. . . . Polygonal cracks form on surfaces of materials with more clay.

Similarity of crusts in the two areas suggests that crusts of this study area have similar origin.

A surface crust apparently does not form on the whitish lenses, as indicated by its general absence from their tops whether at the land surface or buried. Lack of clay coatings could tend to prevent crust formation. Clay stripping from the grains during water transport probably contributes to the crust nearby and beneath the whitish lenses. Some of the whitish lenses are underlain by thin, more clayey lenses, but many are not. This is additional evidence for the primary character of the whitish grains -- the grains must have been whitish when deposited. Some of the whitish lenses have shades of light red or pink, suggesting only partial stripping of clay from the sand grains.

Site 33, texture sequence and colluvium, south aspect

Figures 83 and 84 are aerial photographs taken in 1941, 1953, 1970, and 1981; they locate Sites 33, 40, 41, 53-55, and trails in the southwestern part of the study area. Only a few faint cattle trails are apparent in the 1941 photograph. But in the 1953 photograph, trails showing in the 1941 photograph are more prominent and appear to have started gullying; in addition, new trails have been formed. This trend continues in the later photographs.

Site 33 consists of a trench dug in a south-facing dune side and in the adjacent depression. Figure 85 shows soil occurrence, stratigraphy and the slope and location of the sampled pedons. Table 40 gives soil characteristics.

Side of dune

Pedon 33a (fig. 86, table 40) illustrates the Psammentic Haplustalfs of the Birdwell dune crest and upper side of the dune, which are typically finer than the Haplustalfs in the central sides of the dunes. The loamy fine sand Bt horizon of Pedon 33a gradually coarsens downslope due to post-Birdwell erosion, and grades to a fine sand Bt horizon in Pedon 33b discussed later. Table 40 gives particle size data. Note that although the

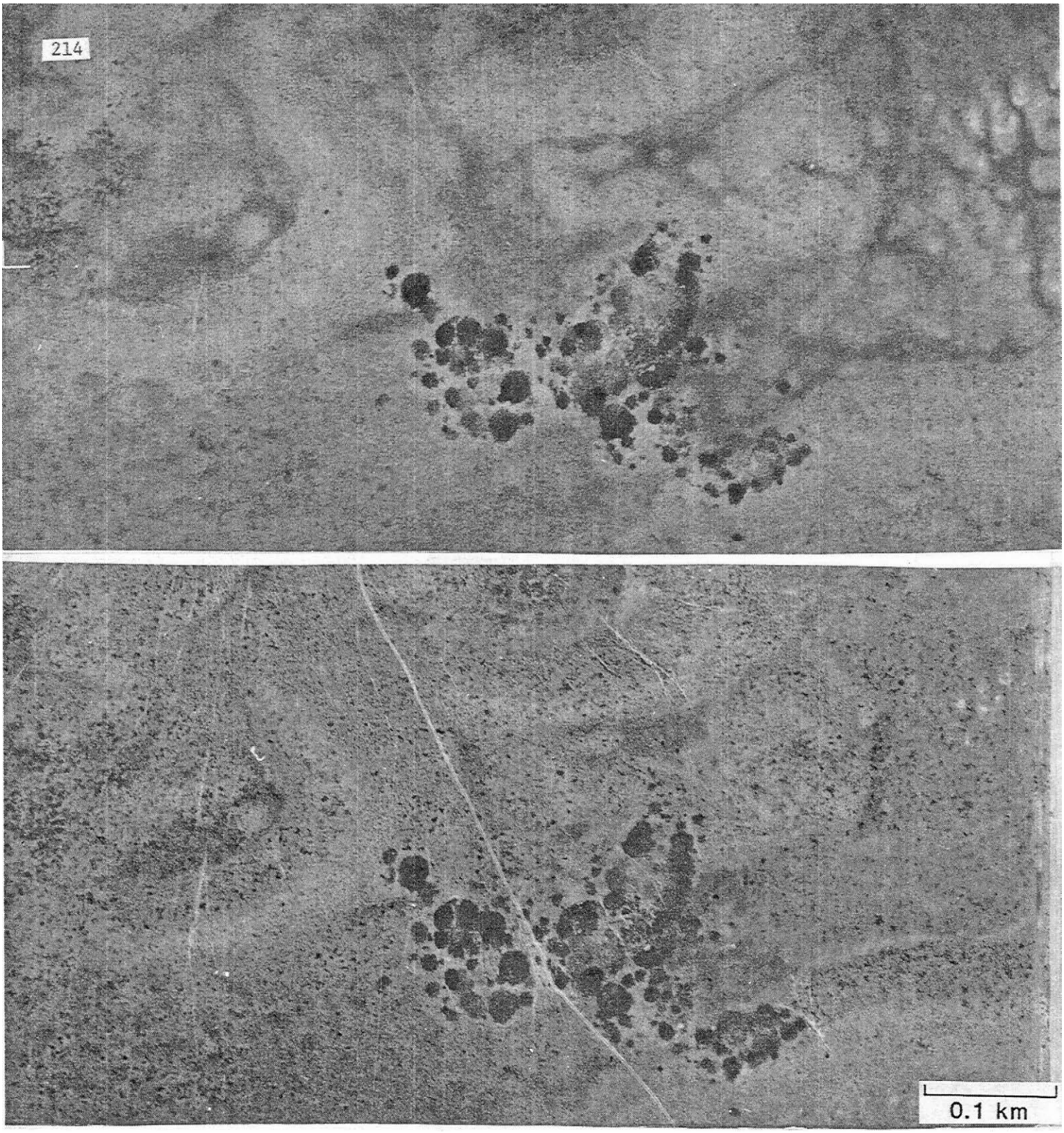


Figure 83. Upper. Aerial photograph taken August 3, 1941. 1941 was a year of record rainfall (see text discussion), and the dark colors suggest moist conditions. Lightest colors, at top right, are shallow high-carbonate horizons that occur in small knolls. Other light-colored, rounded shapes nearby represent slight topographic highs in the blowout. Darker, roughly linear patterns between the highs are drainageways that head in the large dune at lower right. The dark rounded forms at lower left are shinnery oak, which here occurs primarily on Psammentic Haplustalfs of Birdwell age; for an exception, see Site 55.

Lower. Aerial photograph taken February 25, 1953. Roads have been added and some of the oak clumps have enlarged.

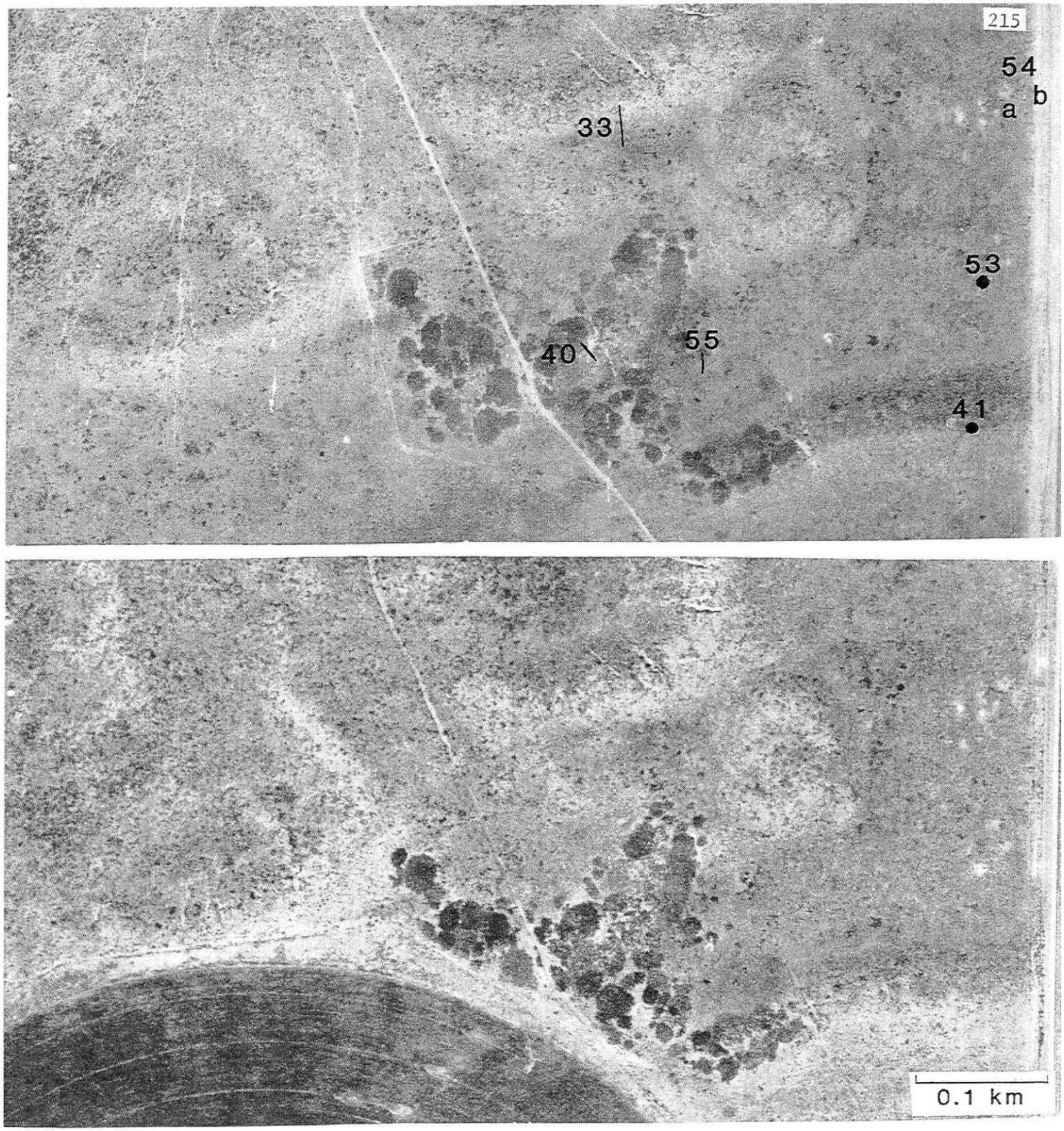


Figure 84. Upper. Aerial photograph taken December 13, 1970. Sites 33, 40, 41, and 53-55 are located.

Lower. Aerial photograph taken November 26, 1981. Rounded form at left is an irrigated area. Note that the oak clump at Site 40 has not enlarged (due to lack of sufficient thickness of surficial sand) although others have. Note the light spot at Site 53 (see upper) caused by high-carbonate material in the trench fill.

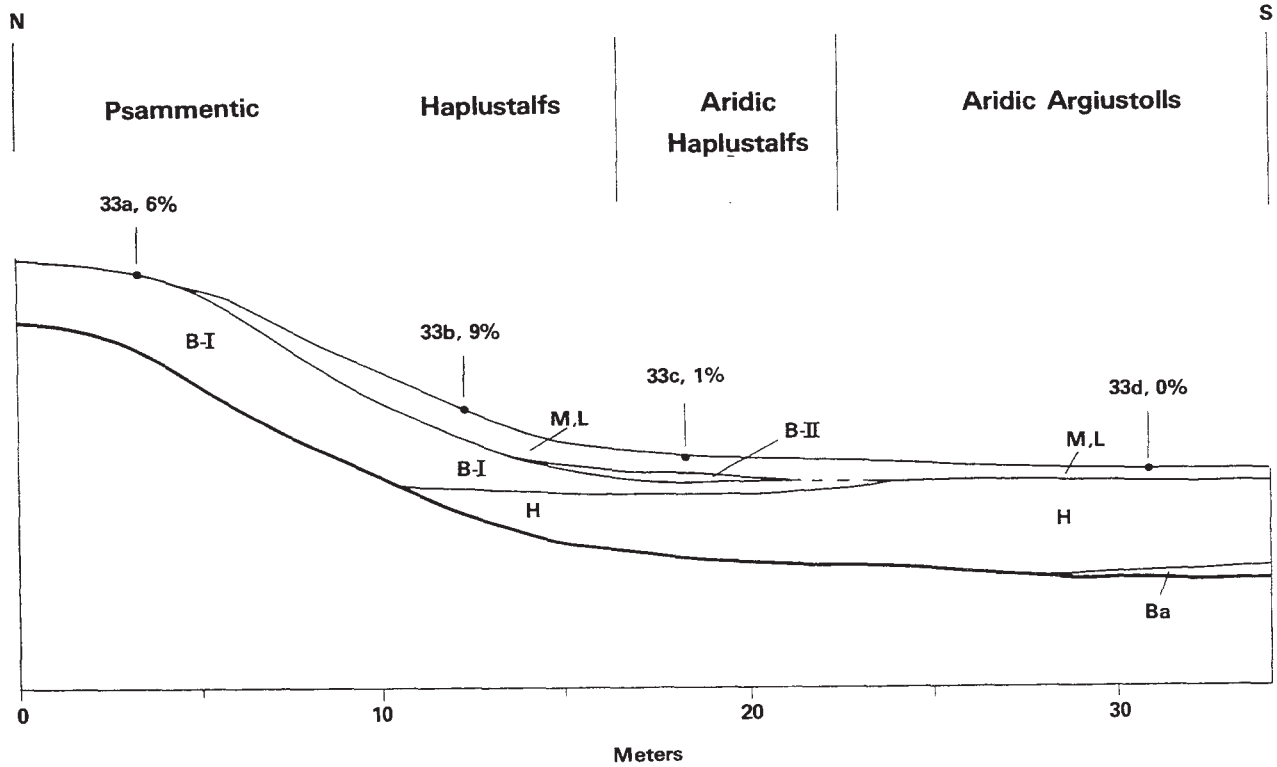


Figure 85. Diagram of study trench at Site 33, showing stratigraphy, subgroup, slope and location of sampled pedons. M = Muleshoe, L = Longview, B-I = Birdwell I, H = Hale. No vertical scale (see table 40 for thickness of sediments and horizons). The heavy lower line represents the bottom of the trench.

pedon has a distinct maximum in silicate clay and that clay content is fairly high compared to the Psamments, texture of the Bt horizon is only loamy fine sand. This is because of the very low amount of silt.

A sandy surficial deposit starts just south of Pedon 33a and thickens downslope (figs. 85, 86).

Pedon 33b (fig. 85, table 40) is a Psammentic Haplustalf on the central side of the dune, and is located about in the middle of the sandy deposit of Muleshoe and Longview age. The B22t horizon has two prominent clay bands, about 2 cm thick, that in places join; one or two bands occur continuously along most of the dune side. Usually the material between bands is distinctly stratified. The B3tb horizon and Birdwell sediments rest abruptly on the red Bt horizon of Hale age all along the side of the trench exposure.

Table 40. Characteristics of Haplustalfs and Argiustolls at Site 33[1/]

Sediment	Horizon	Depth, cm	Hue	Value/chroma Dry	Value/chroma Moist	Structure	Dry consistence	pH	Lower boundary	Textural class	Sand 2.0-0.05 mm	Silt 0.05-0.002 mm	Clay < 0.002 mm
Psammentic Haplustalf, Texico, on upper side of dune; Pedon 33a													
B	A1	0-7	6YR	5/4	3.5/4	m	s	7.0	cw	fs	90.4	3.6	6.0
	B21t	7-20	5YR	5/4	3.5/4	1csbk	h	7.2	cw	1fs	85.7	2.9	11.4
	B22t	20-32	4YR	5/6	4/6	1csbk	h,vh	7.0	cw	1fs	83.9	3.1	13.0
	B23t	32-46	4YR	5/6	4/6	1csbk	vh	7.0	cw	1s	85.0	2.3	12.7
	B3t	46-72	4YR	5/6	4/6	1csbk	sh,h	7.0	cw	s	90.5	2.4	7.1
	C	72-94	5YR	5/6	4/6	m	s,sh	7.0		1s	88.9	1.7	9.4
Psammentic Haplustalf, Texico, on central side of dune; Pedon 33b[2/]													
M, L	A11	0-10	7.5YR	5.5/4	3.5/4	m	s,sh	7.0	cw	fs	93.3	3.0	3.7
	A12	10-38	6YR	5.5/4	4/4	m	sh	7.0	aw	fs	94.7	2.1	3.2
B	B21tb	38-51	5YR	6/6	5/6	1csbk	h	7.2	aw	1fs	86.9	6.5	6.6
	B22tb	51-72	5YR	6/6	5/6	1csbk	vh	7.0	aw	1fs	89.6	0.3	10.1
	B3tb	72-102	5YR	6/6	5/6	m	vh	7.0	as	1s	89.0	1.7	9.3
H	Btb2	102-117	2.5YR	5/6	4/6	1cpr-1csbk	vh	6.8		scl	73.1	0.5	26.4
Aridic Haplustalf, Keeney, on lower side of dune; Pedon 33c[3/]													
M, L	A11	0-10	7.5YR	5.5/3.5	3.5/3.5	m	s	7.2	as	fs	92.6	4.1	3.3
	A12	10-24	7.5YR	5/3.5	3/3.5	m	s	7.0	aw	fs	93.2	3.5	3.3
B	Ab	24-33	7.5YR	5/4	3.5/4	m	sh	7.2	cs	fs	92.9	3.3	3.8
	B1tb	33-46	5YR	4.5/4	3.5/4	1msbk	h,vh	7.2	as	fs	88.9	3.8	7.3
	2B21tb	46-58	5YR	5.5/6	4/6	2mpr-1csbk	vh	7.2	as	scl	73.6	5.7	20.7
	2B22tb	58-67	5YR	4.5/5	3.5/4	1mpr-1csbk	vh	7.0	cw	scl	58.3	13.1	28.6
H	3B21tb2	67-94	2.5YR	5/6	4/6	2cpr-1csbk	vh	7.0	cw	scl	71.3	2.8	25.9
	3B22tb2	94-118	2.5YR	5/6	4/6	1cpr-1csbk	vh,h	7.0		fsl	79.7	3.2	17.1
Aridic Argiustoll, Newell, in trough; Pedon 33d[4/]													
M, L	A11	0-9	7.5YR	4/2	2/2	m	sh	6.8	as	fsl	77.4	12.2	10.4
	A12	9-24	7.5YR	4.5/2.5	3/2.5	m	sh	7.0	as	1fs	84.5	6.6	8.9
H	B1tb	24-32	5YR	4.5/2.5	3/2	1cpr-1csbk	vh	6.8	cw	fsl	70.9	9.8	19.3
	B21tb	32-48	2.5YR	5/6	4/6	2cpr-1csbk	vh	6.6	cw	scl	74.5	4.7	20.8
	B22tb	48-74	2.5YR	5/6	4/6	2cpr-1csbk	vh	6.6	cw	scl	73.3	3.9	22.8
	B23tb	74-112	2.5YR	6/6	5/6	1cpr-1csbk	vh	6.8	cw	fsl	80.9	3.6	15.5
	B3tb	112-132	4YR	6/6	5/6	1cpr-1sbk-m	vh	6.8	aw	1fs	83.6	3.9	12.5
Ba	K2b2	132-144	10YR	8/2	7/3	m	eh			fsl	64.5	18.2	17.3

1/ Subordinate colors and other comments are footnoted to pertinent soils. M = Muleshoe, L = Longview, B = Birdwell, H = Hale, Ba = Bailey.

2/ B22tb: clay bands range from 1 to 2 cm thick, are 4YR 4/6, dry.

3/ B1tb: few parts have slightly higher chroma. 2B21tb: some parts 5YR 4.5/4, dry. 2B22tb: some parts 5YR 6/6, dry.

4/ B1tb: spots of 5YR 5/6, dry, are scattered throughout. B21tb: prisms coated with dark organic carbon. K2b: parts 10YR 9/1, dry.

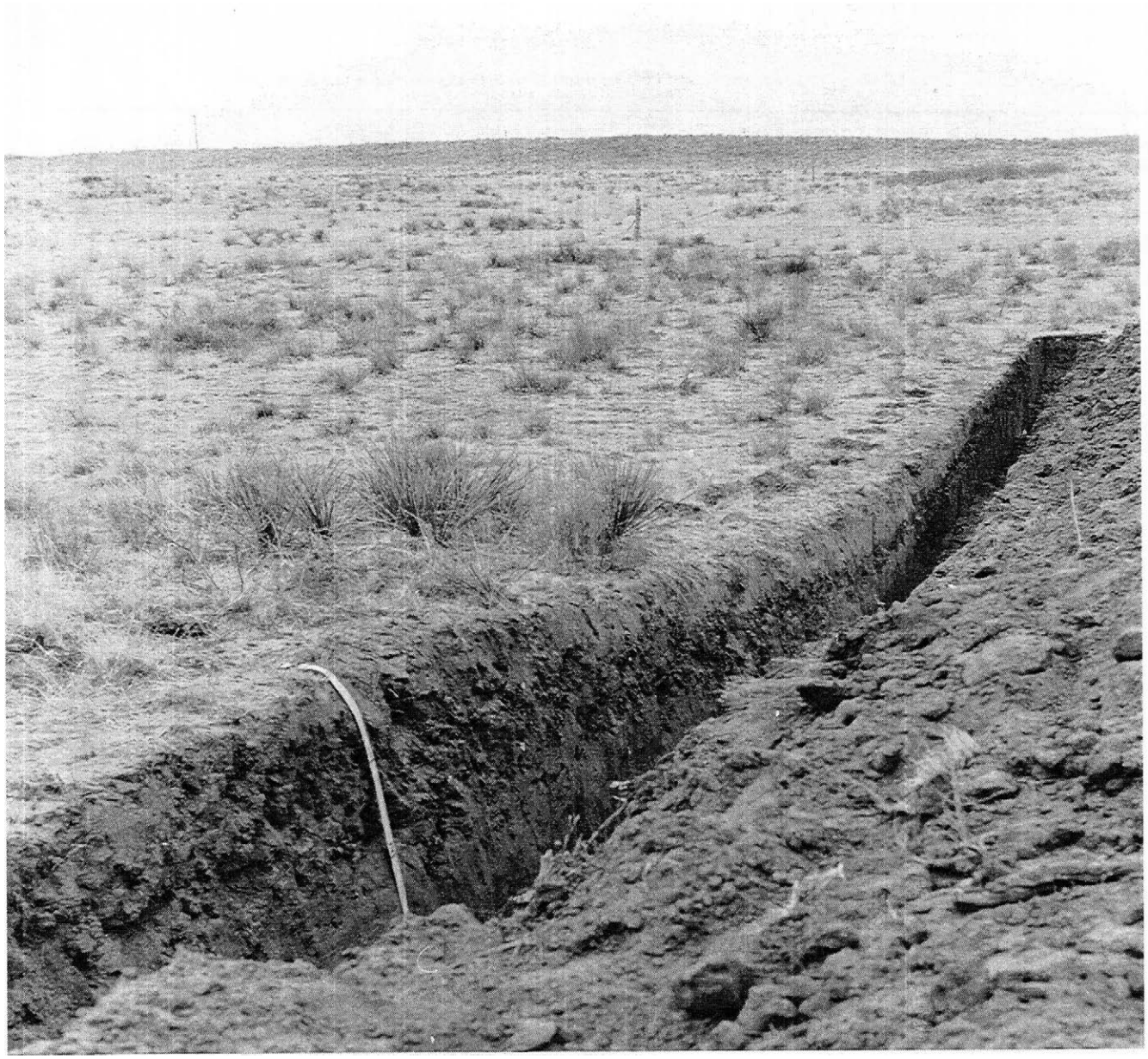


Figure 86. View of study trench at Site 33. The foreground dune is Birdwell, with a thin deposit of Muleshoe and Longview sediments on the dune side. The trough (at far end of trench) is in sediments of the Hale surface. At left is the Psammentic Haplustalf Texico, at Site 33a. Scale is in feet. The view is south. Photographed March 1977.

Texture of the Bt horizon gradually becomes finer downslope, a typical feature of Birdwell dunes as discussed below.

Texture sequence and colluvium

Pedon 33c (fig. 85, table 40) occurs on the lower part of the dune side, and illustrates a soil formed partly in colluvium. This soil forms part of a characteristic textural sequence in soils of many Birdwell dunes and adjacent depressions. Commonly, texture of the Bt horizon grades from loamy fine sand on the crest and upper sides of dunes, to fine sand in the central side of the dune. Clay increases downslope to a fine sandy loam and then to a sandy clay loam on lower sides of dune and then to a sandy clay in some of the adjacent depressions.

The following evidence indicates that the increase in clay is due primarily to colluviation.

(1) The slope-related changes in clay content occur on slopes facing in all directions -- north, south, east, and west. This indicates sediments deposited by water, not wind.

(2) In the process of sedimentation from water moving downslope, clay content would be expected to increase as slope decreases, which is what happens. The finest member of the textural sequence occurs in depressional areas that are either level or nearly level.

(3) The Bt horizon (in which the textural sequence occurs) is in the same stratigraphic position, overlying Birdwell or pre-Birdwell eolian sediments.

(4) On lower sides of dunes and in depressions, the finest-textured subhorizon of the Bt horizon overlies Birdwell or pre-Birdwell eolian sediments, and has abrupt boundaries to coarser materials above and below. This subhorizon shows a distinct decrease in sand, and an increase in silt and clay, as compared to adjacent horizons (table 33; see also Sites 34, 35, and 39). These factors and those previously discussed suggest another origin (deposition from water) as compared to eolian origin of adjacent sediments.

(5) Holocene colluvium is a common feature on sides of ridges in arid regions (Gile, 1975) and might also be expected on sides of some ridges in semiarid regions.

(6) Some of the clay increase in the texture sequence may be due to increased clay illuviation, since additional water from runoff would be available for pedogenesis on lower slopes and in depressions. But if clay in the Bt horizon were due primarily to clay illuviation, in these sandy materials the clay maximum would have extended to greater depths, as it does elsewhere in soils of Birdwell age. The Bt horizon is thinner and closer to the soil surface (despite greater moisture on lower slopes and in depressions) than it is in sandy parent materials of similar age elsewhere. These factors suggest a parent material change to sediments of finer texture.

(7) Less clayey colluvium is presently accumulating in the youthful Muleshoe depressions, where the uppermost part of the A horizon contains more silt and clay than in the adjacent slopes (e.g., loamy fine sand in

depressions vs. fine sand of slopes). Thus, colluvium would be expected in Birdwell sediments, and it is more prominent because it is older. In Birdwell sediments, the colluvium has been in place long enough for a Bt horizon to have formed in it, and for clay to have moved from the upper part of the colluvium into its lower part and below.

But since little illuvial clay extends below the sedimentary contact, colluviation probably began shortly after Birdwell sedimentation stopped and before much clay illuviation had occurred.

The colluvium must have been derived by erosion of Birdwell dunes after Birdwell sedimentation stopped. Slopes of some foreset beds are substantially steeper than present slope of dunes (see Site 1). This suggests that after active eolian sedimentation ends there may be a period of erosion and slope reduction. Birdwell colluvium could have accumulated during this period of slope reduction.

Some lateral movement of clay downslope along the sedimentary contact could have taken place within the soil as well as on the surface, and could cause some of the clay increase. This would be similar to the postulated thickening of clay bands downslope due to lateral movement of clay in the soil water.

Trough

Below Pedon 33c, the A11 horizon in Muleshoe sediments continues south along the exposure and grades into the A11 horizon of Pedon 33d (fig. 87). Also downslope, the colluvium and its Bt horizon become less apparent and grade into the lower part of the A horizon of the Argiustoll in the trough.

Pedon 33d, an Aridic Argiustoll, has a dark A horizon and a thick, red Bt horizon, and thus differs greatly from the younger soils of the dune. Most of the B1tb horizon has low value and chroma (table 40) as is typical of prominent A1 horizons in the area. But its finer texture and scattered redder, high-chroma spots (5YR 5/6, dry), which occur regularly throughout, suggest clay illuviation in the B1tb horizon at the present time. The B1tb horizon is interpreted as a former A1 horizon of the underlying B2tb horizon at an earlier period (possibly during the late Pleistocene) of soil development. Later, younger sediments were deposited at the surface and now function as the A horizon.

Silicate clay content of the thick, red Bt horizon decreases with depth well above the carbonate maximum (table 40), and the K2 horizon has an abrupt upper boundary even though it is not indurated. These facts and evidence presented earlier (see Stops 8 and 9, Gile, 1981) suggest a deposit of Hale sediments on a wind-eroded K2 horizon of Bailey age.

Site 34, texture sequence and colluvium, north aspect

Figures 88-91 are aerial photographs taken in 1941, 1953, 1970, and 1981. They locate Sites 34-39, 42, and 48-52, and show the development of gullies in cattle trails to be discussed later (Site 37). Site 34 consists of a study trench dug in the north-facing side of a dune and in the adjacent trough. Figure 92 shows soil occurrence, stratigraphy, and location and slope of the sampled pedons. Table 41 gives soil characteristics.

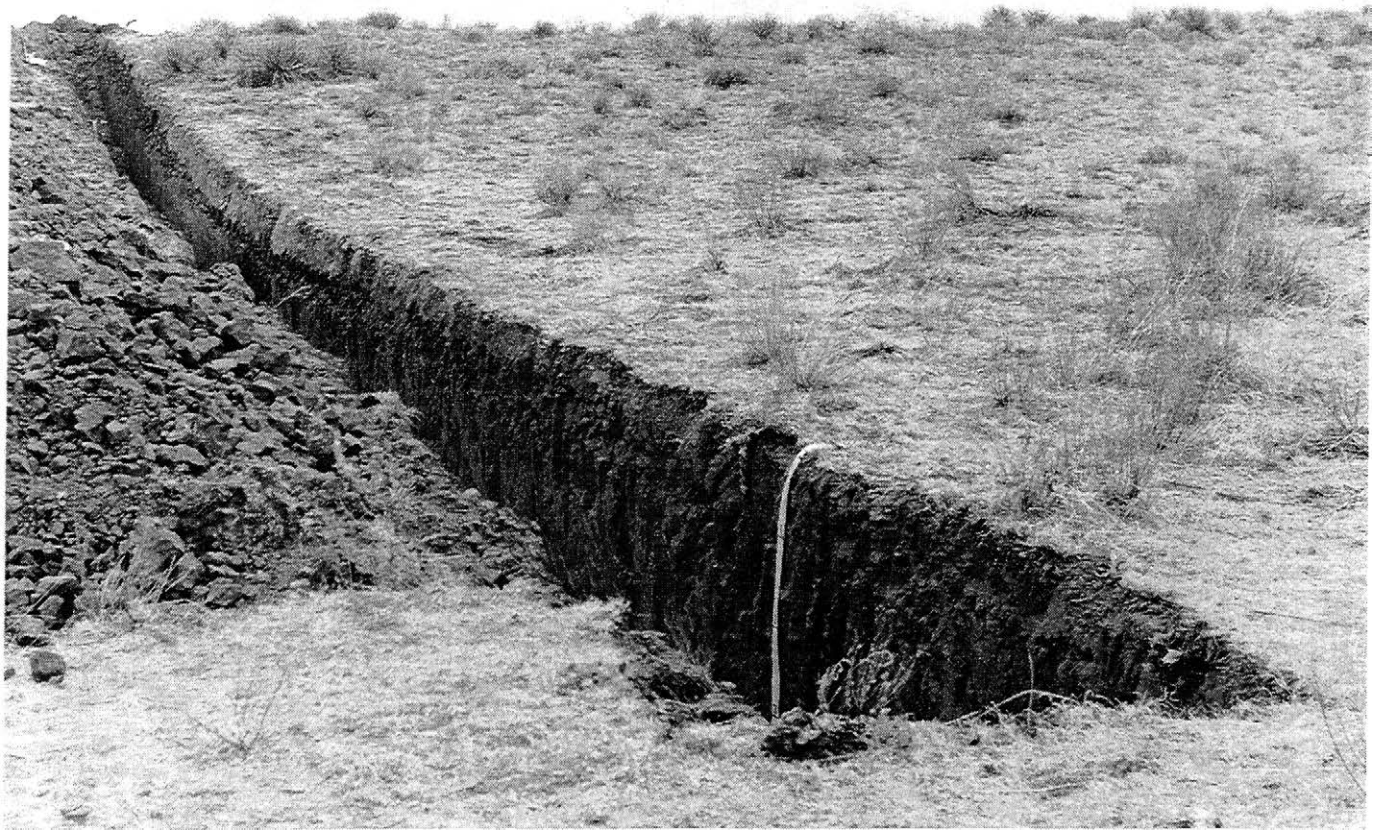


Figure 87. The Aridic Argiustoll, Newell, Pedon 33d, in the trough at the tape. The Alfisol-Mollisol boundary occurs at the margin of the trough, which receives run-in from the dune. Scale is in feet. The view is north. Photographed March 1977.

The trench illustrates some of the prominent changes in morphology and classification that take place on the lower side of many Birdwell dunes and adjacent depressions regardless of dune aspect. Texture of the clay maximum in the Bt horizon grades from fine sandy loam in the central side of the dune to sandy clay in the trough (fig. 92, table 41). This increase in clay and greater moisture in the trough cause these changes in classification downslope: Psammentic Haplustalfs - Aridic Haplustalfs - Aridic Argiustolls.

The thin deposit of Muleshoe and Longview sediments found at Site 33 was also found here. A buried Bt horizon of undetermined age was observed at the bottom of the trench. The stratigraphy at depth was not determined at this site, because the main purpose was to document the presence of the textural sequence on the north aspect of Birdwell dunes.

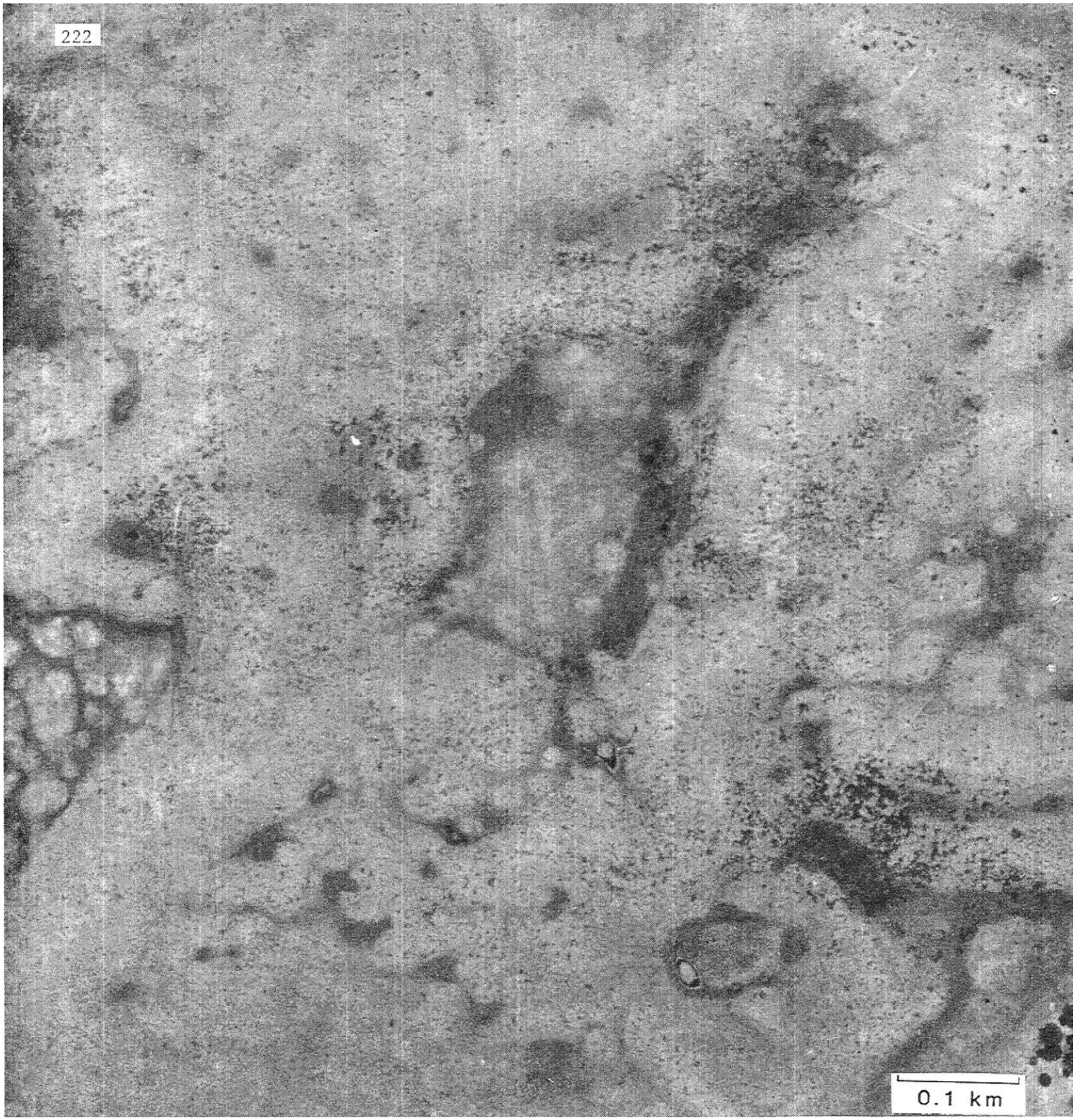


Figure 88. Aerial photograph taken August 3, 1941. North-south lines crossing the high dunes at left are traces of the old XIT trail, which are also visible in all later photographs. Heavy rains fell in 1941, and the dark areas, which are in depressions, represent moist soil. The small, roundish areas in the depression represent small, very slightly higher (about 1-2 m or less) areas of drier, coarser-textured soils that contribute to the complexity of soil patterns in the depressions. Note the large dune at upper right; little evidence of gullying is apparent in the dune.

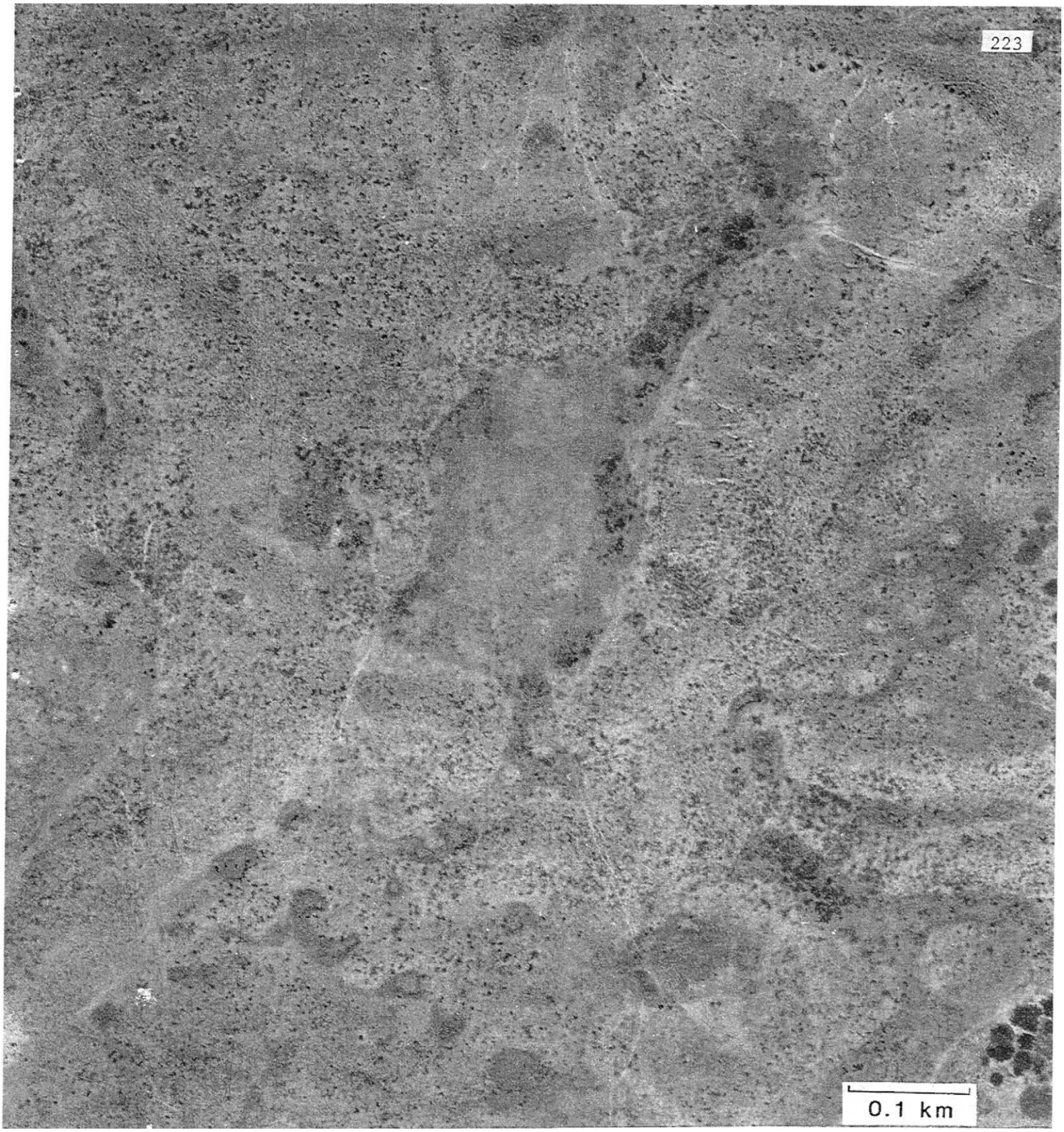


Figure 89. Aerial photograph taken February 25, 1953. A number of gullies are apparent in the west-facing side of the large dune at upper right. Note that the trails in the upper center head toward the gullies; to the north, the trails connect to a water tank (see Sites 32 and 47).

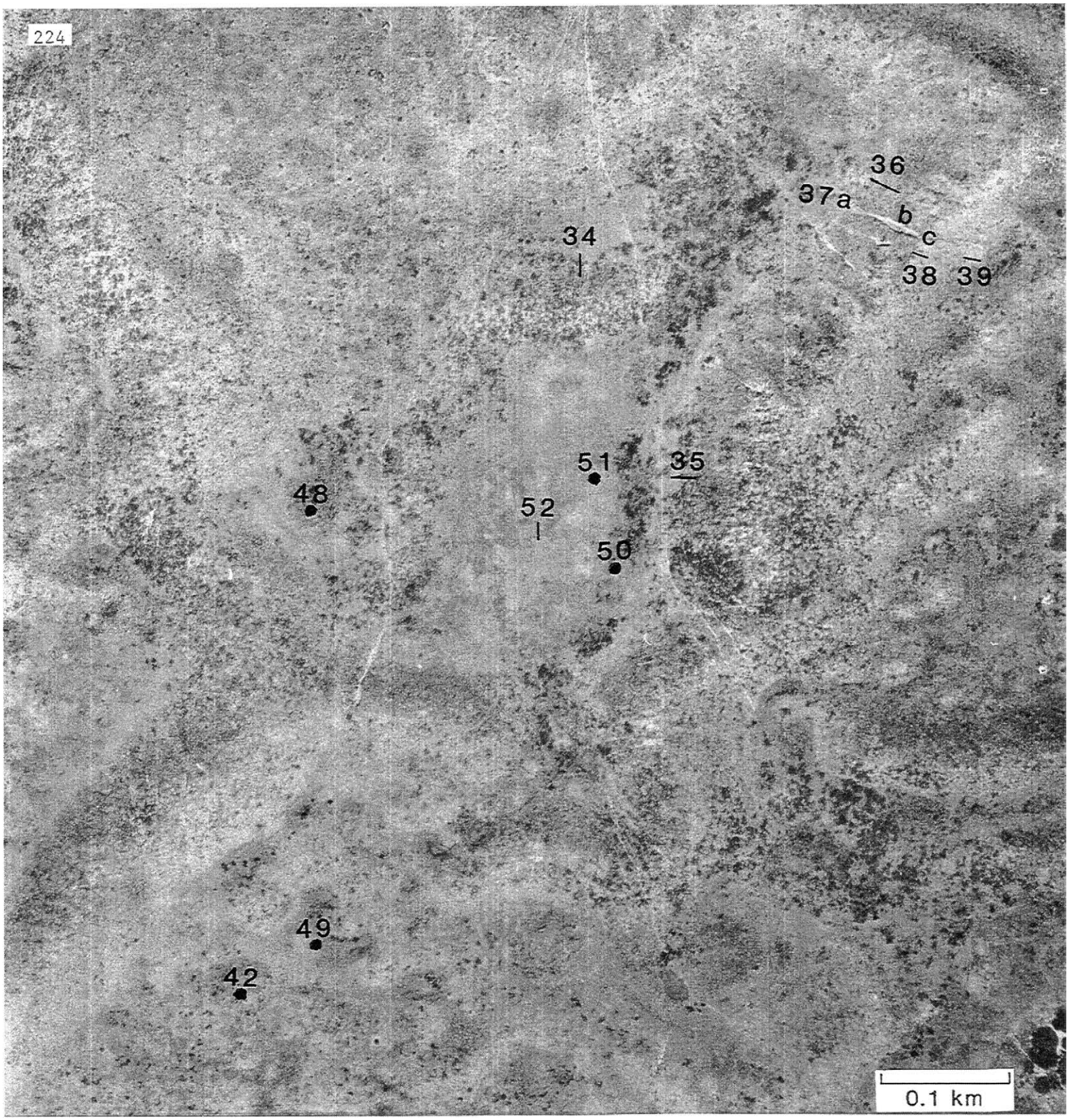


Figure 90. Aerial photograph taken December 13, 1970. Sites 34-39, 42 and 48-52 are located. Most gullies have enlarged since 1953. A small gully has formed in a north-facing dune side at left center.

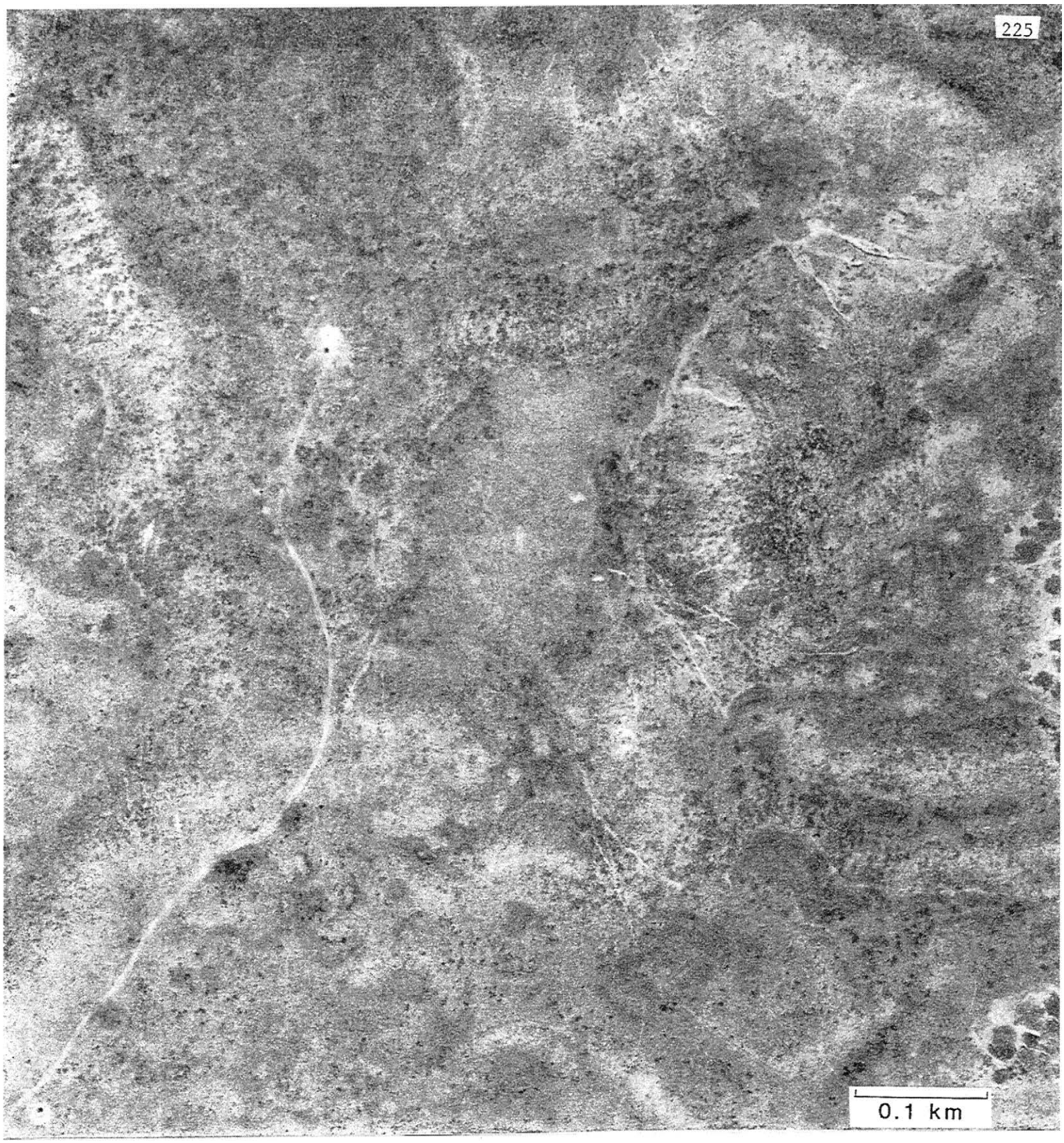


Figure 91. Aerial photograph taken November 26, 1981. Gullies have enlarged and extended headward since 1970. Road at left leads to a new tank and cattle feeding station. Light spots at Sites 50-52 reflect high-carbonate material in the trench fills (see fig. 90).

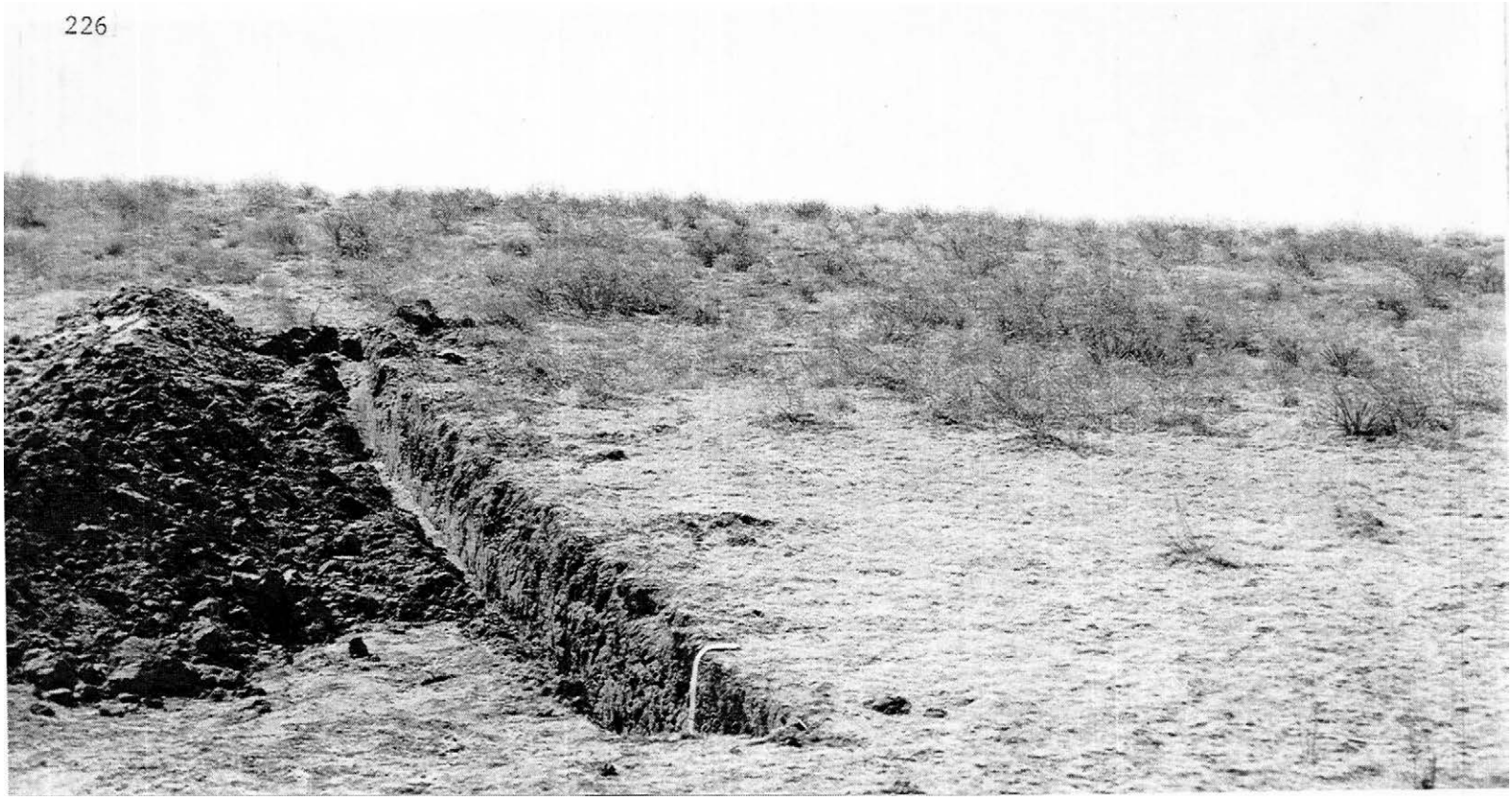


Figure 92. Above. View of Birdwell trough and dune at Site 34. The tape marks the location of the Aridic Argiustoll, Newell, Pedon 34c. Although the study trench is short, it displays prominent changes in soils. The view is south. Photographed March 1976.

Below. Diagram of study trench at Site 34, showing stratigraphy, subgroup, and slope and location of sampled pedons. M = Muleshoe, L = Longview, B = Birdwell. No vertical scale (see table 41 for thickness of sediments and horizons). The heavy lower line represents the bottom of the trenches.

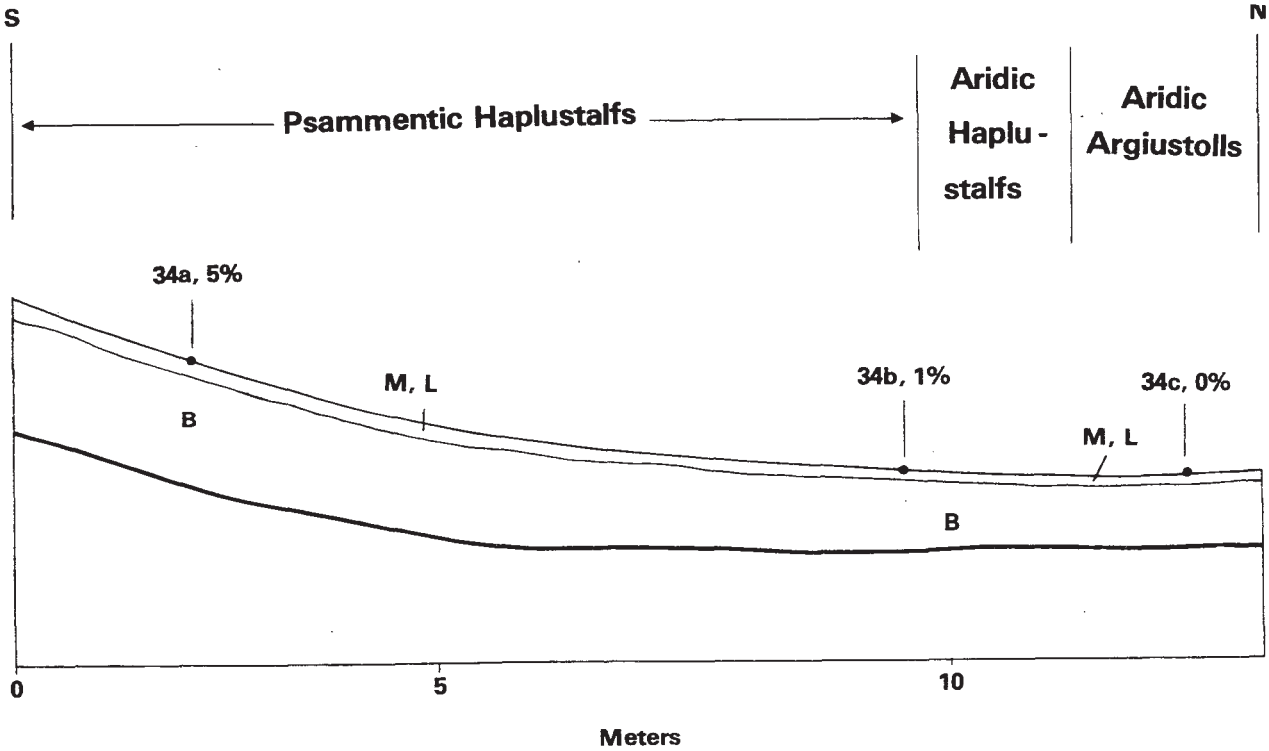


Table 41. Characteristics of Haplustalfs and an Argiustoll at Site 34[1/]

Sediment	Horizon	Depth, cm	Hue	Value/Chroma Dry	Value/Chroma Moist	Structure	Dry consistence	pH	Lower boundary	Textural class	Sand 2.0-0.05 mm	Silt 0.05-0.002 mm	Clay < 0.002 mm
Psammentic Haplustalf, Texico, on central side of dune; Pedon 34a													
M, L	A11	0-5	7.5YR	5/3	3/3	m,lmpl	s	6.8	aw	lfs	82.6	10.6	6.8
	A12	5-17	6YR	5/3	3.5/3	m	s	6.8	cw	fs	89.2	4.5	6.3
B	A1b	17-35	6YR	5/3.5	3.5/3.5	m	sh	7.0	aw	fs	90.1	3.1	6.8
	B21tb	35-46	4YR	5/5	3.5/5	lcsbk	h	7.0	as	lfs	87.0	3.2	9.8
	B22tb	46-65	4YR	5/5	3.5/5	lcsbk	vh	7.2	cw	fsl	78.7	5.3	16.0
	B31tb	65-79	5YR	5/6	3.5/6	m	sh	7.2	cw	fs	88.9	1.6	9.5
	B32tb	79-104	5YR	5/4	4/4	m	s	7.2	cw	fs	88.8	4.4	6.8
?	Btb2	104-not sampled											
Psammentic Haplustalf, Texico, on lower side of dune; Pedon 34b[2/]													
M, L	A1	0-5	7.5YR	5/4	3/4	lmpl,m	sh	6.4	as	lfs			
B	A1b	5-23	5YR	5/3	3.5/3	lcpr	s	6.8	as	fs			
	B2tb	23-34	4YR	4.5/6	4/6	2mpr	vh	7.0	as	fsl			
	B31t	34-51	4YR	5/5	4/5	lcpr	h	7.4	cw	ls			
	B32t	51-88	5YR	5/4	3.5/4	m	s,sh	7.2		s			
?	Btb2	88-not sampled											
Aridic Argiustoll, Newell, in trough; Pedon 34c[3/]													
M, L	A1	0-5	7.5YR	5/3	3/3	lmcpl	sh	6.4	as	fsl	73.3	16.9	9.8
	B1	5-17	5YR	5/3	3/3	lmsbk	sh	6.8	as	lfs	81.1	8.6	10.3
B	2B2tb	17-25	4YR	5/5	4/5	2mpr-2msbk	eh	7.2	as	sc	51.0	13.4	35.6
	3B31tb	25-46	2.5YR	5/6	4/6	lcsbk	vh	7.6	as	fsl	78.1	3.3	18.6
	3B32tb	46-54	4YR	5/5	4/4	m	sh	7.0	as	fsl	78.6	4.9	16.5
H	3B2tcab2	54-75	5YR	5/4	4/4	lcsbk	vh	7.6		scl	70.6	8.6	20.8

1/ Subordinate colors and other comments are footnoted to pertinent soils. Sediments identified as: M = Muleshoe, L = Longview, B = Birdwell, H = Hale.

2/ B2tb: parts 5YR 4/4 and 5YR 5/4, dry. B31tb: parts 5YR 6/6, dry.

3/ 2B2tb: some ped surfaces and some ped interiors are stained with dark organic carbon. 3B2tcab2: a few carbonate filaments. Most of the horizon is noncalcareous.

Pedon 34c, in the trough, illustrates Mollisols in the depressions, and how close some of the Mollisols are to Alfisols because of chroma and depth to pedogenic carbonate. Several aspects of the definition of the mollic epipedon are involved in applying the definition for these soils with respect to chroma and depth to carbonate. First, the upper 18 cm of soil must be mixed (individual horizons are weighted) before the determination is made. And, although organic carbon may be ample for a mollic epipedon, if chromas are too high the epipedon is not mollic. If depth to pedogenic carbonate present as filaments, soft coatings or soft nodules is >75 cm, the mollic epipedon must be >25 cm thick (Soil Survey Staff, 1975, p. 16). But if depth to pedogenic carbonate is 75 cm or less, as it is in Pedon 34c, the mollic epipedon can be as thin as 18 cm. For Pedon 34c, the weighted average of chroma is 3.1. Since this is closer to 3.0 than 3.5, the epipedon is classified as mollic.

Site 35, texture sequence and colluvium, west aspect

Site 35 (figs. 90, 93; table 42) consists of a short trench in the margin of a blowout, and a larger trench in an adjacent dune. The sediments and soils are of Birdwell and Bailey age. This contrasts to the blowout just west, where only Bailey sediments are present due to strong wind erosion (see Site 51). Figure 93 shows soil occurrence, stratigraphy, and location and slope of the sampled pedons. Table 42 gives soil characteristics.

Blowout

Pedon 35a is in the margin of the blowout. The soils receive runoff from the adjacent dune, and organic carbon is high. Although upper horizons are dark-colored, chromas are too high for a mollic epipedon, which must be more than 25 cm thick because depth to pedogenic carbonate is >75 cm. The soil is a fine-loamy Aridic Haplustalf, and is in the Extee series because the calcic horizon is within 90 cm depth.

Note the remarkably thin, but more clayey B21t horizon; this is in the western, blowout end of the texture sequence that extends from the blowout up the side of the dune. The base of the colluvium is the base of the 2B21t horizon, and clay content drops markedly in the 2B22t horizon. Some of the clay in the 2B23t and 2C horizons is also clearly inherited, but is in eolian sediments derived from the west, instead of colluvium derived from the dune to the east.

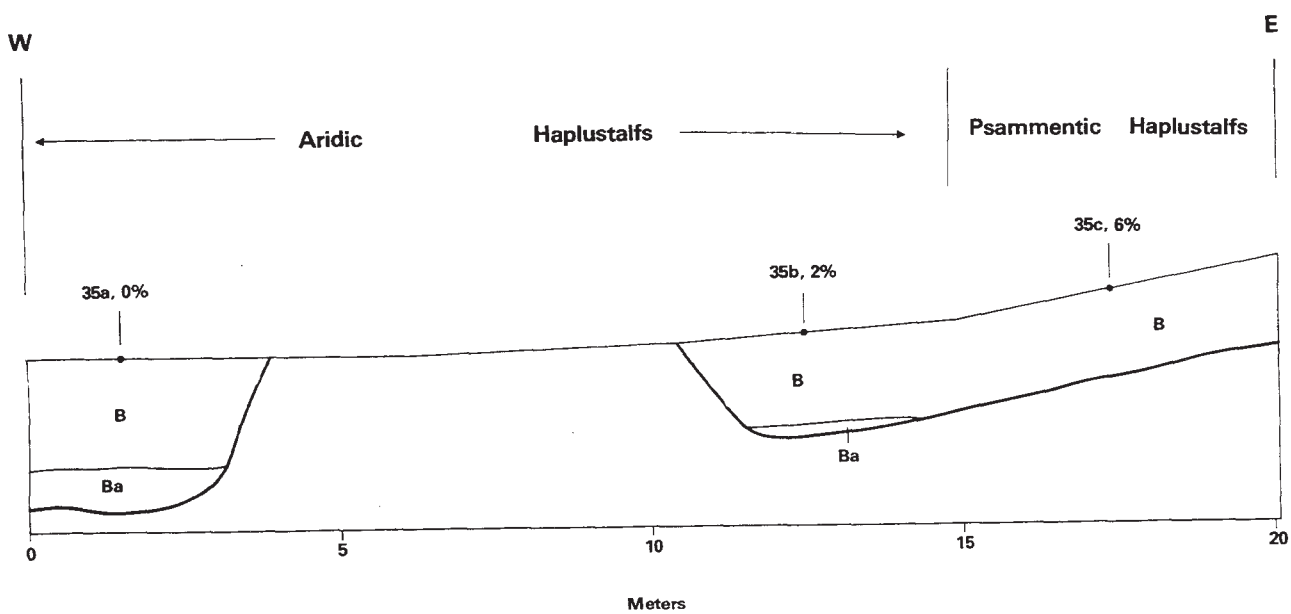


Figure 93. Diagram of study trench at Site 35, showing stratigraphy, subgroups, and slope and location of sampled pedons. B = Birdwell, Ba = Bailey. No vertical scale (see table 42 for thickness of sediments and horizons). The heavy lower line represents the bottom of the trenches.

Eolian sedimentary strata are clearly visible below the finer-textured colluvium, and their top marks the abrupt smooth boundary between the two deposits. An abrupt smooth boundary also occurs between prominently stratified sands in the Bt horizon and finer sands in the C horizon. This distinctive boundary also occurs in Pedon 35b upslope, is common elsewhere in this physiographic-stratigraphic position, and typically marks the base of prominent Birdwell sedimentation. But sedimentary strata are visible in the C horizon, which shows no evidence of A or B horizon development, and for these reasons it is considered to be in fact a C horizon.

The faintly stratified C horizon material is thought to have been deposited at the onset of Birdwell sedimentation, during the transition from the pluvial to the interpluvial period. Prominent sedimentary strata are absent because they typically do not occur or are sparse in the less severe erosive episodes (see Muleshoe sediments). But with the onset of the severe drought of the erosive episode, strong winds caused erosion and then deposition of the coarser stratified sands above the C horizon.

The C horizon rests abruptly on the B2tb horizon, which appears to be of Bailey age and to have formed in the same deposit as the underlying K horizon. This is suggested by a reddish pipe, about 30 cm wide, which descends into the K horizon. The pipe has similar texture as the Bt horizon and appears to be a normal pipe, the same age as the adjacent carbonate horizon, and not an eolian groove filling.

Lower side of dune

Pedon 35b (figs. 93, 94, table 42) is on the lower side of the dune. The pedon is similar to Pedon 35a and has the same general stratigraphy. The soil of Bailey age rises from Site 35a and appears to represent a dune of Bailey age, indicating that the dune was already in existence when Birdwell sedimentation began.

Pedon 35b has dark upper horizons although it is slightly higher than the blowout. This indicates that runoff has influenced soil moisture and vegetation on the lower side of the dune as well as in the blowout. The epipedon does not quite qualify as mollic because of high chroma, but calculations show how close it is to a mollic epipedon. Since pedogenic carbonate is at 48 cm depth, the mollic epipedon must have a minimum thickness of only 18 cm. The weighted values of moist chroma (table 42) to 18 cm depth average 3.3. Since 3.3 is closer to 3.5 than 3.0, the epipedon is classified as ochric.

The colluvium is distinct and its base is at 25 cm depth. The Birdwell sedimentary strata are prominent and their contact to the C horizon is abrupt. As at Pedon 35a, clay appears to be "hanging" in the stratified sediments. This is the common situation with prominently stratified sediments and would be expected as discussed at Site 1.

The stratified zone of the 2B3t horizon consists of sandy strata separated by strata with more clay. Some of the strata are quite clayey; one about 1 cm thick has clay texture. Occasional tongues of clay descending into the 2B3t horizon indicate some clay illuviation in the 2B3t horizon at times. Most of the upper part of the stratified zone is non-calcareous, but there are occasional thin strata that are calcareous, and in

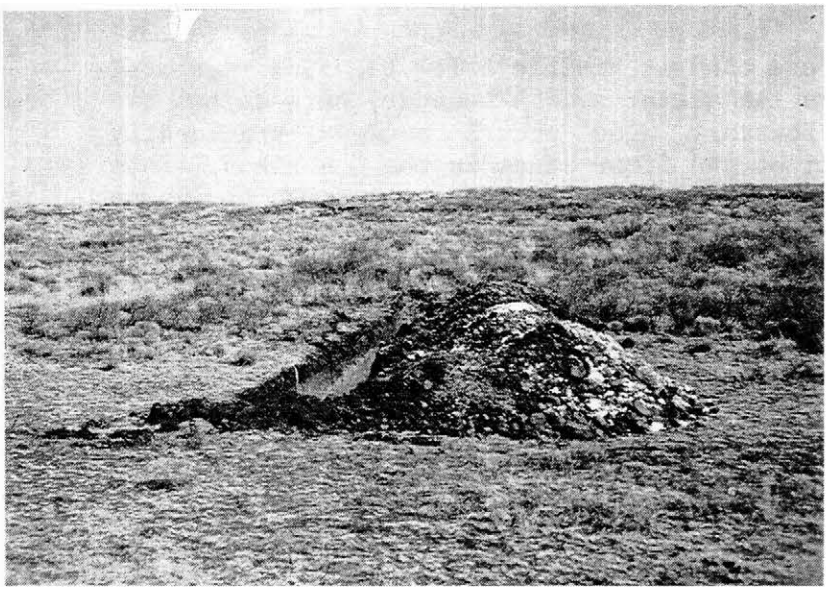
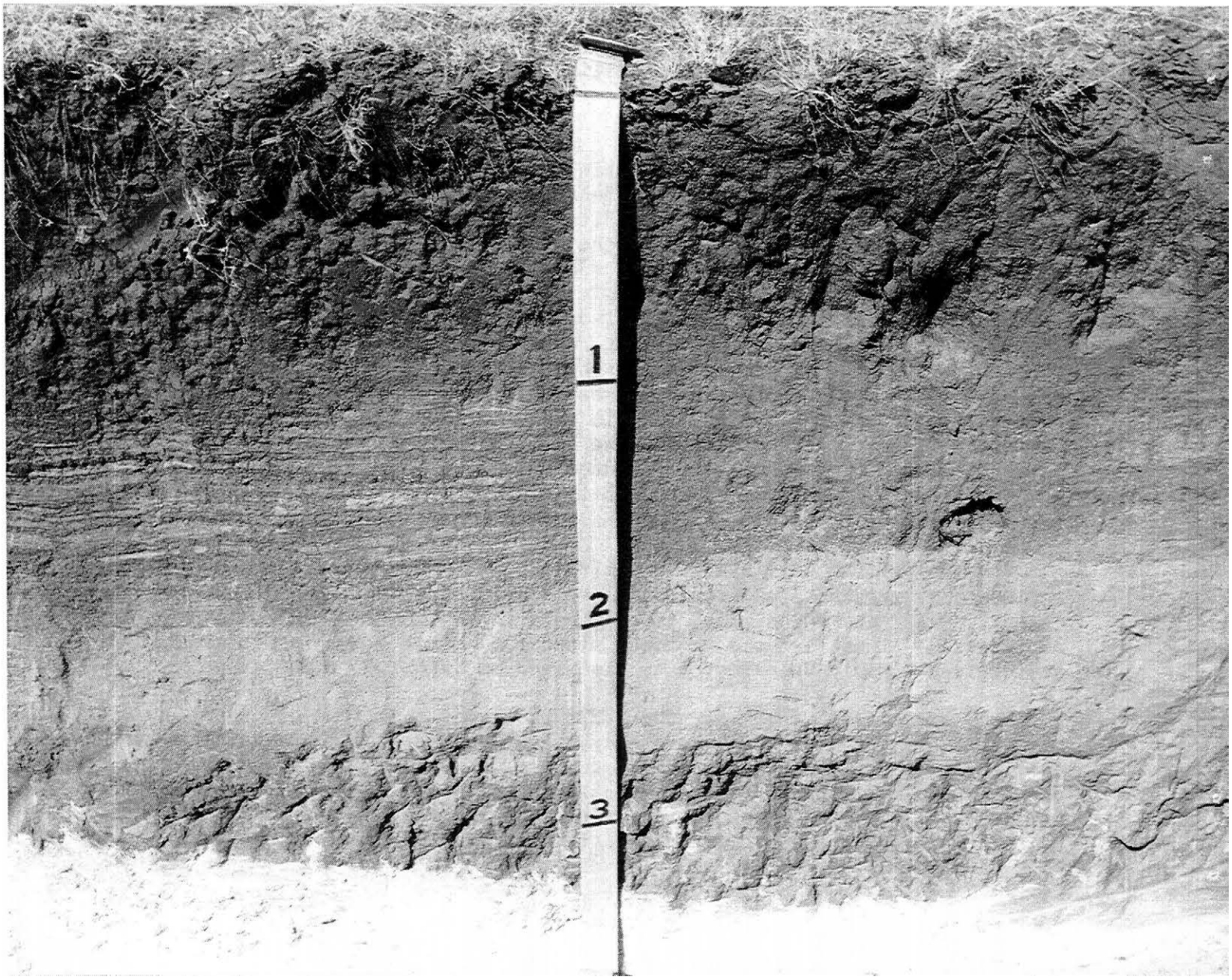


Figure 94. Left. Landscape view of Birdwell surface on lower side of dune at Sites 35b and 35c. The view is east. Photographed March 1976.

Below. The Aridic Haplustalf, Extee, Pedon 35b. The lower boundary of the B2t horizon, at slightly less than 1 ft (0.3 m), represents a major shift in origin of soil parent materials, from colluvium derived from upslope (parent materials of the B2t horizon) to eolian deposits.



places there are sand-size grains of white, high-carbonate material in the 2B32t and 2B33tca horizons.

Colluviation must have started very soon after Birdwell eolian sedimentation stopped. Pedogenic evidence indicates that clay descending from the 2B2t horizon was emplaced after the colluvium was deposited. Some carbonate has been leached from the carbonate grains and has accumulated as coatings and soft filaments below them (the 2B33tca horizon, table 42).

That the stratified sediments are in fact eolian sediments, derived from the blowout to the west and not by water erosion from the dune upslope, is indicated by the presence of these carbonate grains. The only source of these grains is the thick, old carbonate horizon in the soil of Bailey age in the blowout just west, since the analogous horizon at Site 35 is progressively more deeply buried to the east, upslope in the dune.

Only a few strata are apparent in the 2C horizon. As at Site 35a, this is attributed to less severe erosive conditions at the beginning of Birdwell sedimentation.

Texture of the B2t horizon becomes coarser upslope, to fine sandy loam, then a loamy fine sand and then sand at Pedon 35c (fig. 93). Depth to the buried horizon of Bailey age was not determined at Pedon 35c.

Site 36, low bench and adjacent high dune

Sites 36-39 (fig. 95) illustrate several features associated with many Birdwell dunes of Unit E: dunes as low benches (Site 36); gullies and associated eolian and alluvial deposits (Site 37); post-Birdwell I wind erosion and deposition (Sites 37, 38); and colluviation (Site 39).

Bench

Occasional low benches occur at scattered places along the lower margins of high Birdwell dunes. Soils of a bench and adjacent high dune were studied at Site 36 to determine their morphology and chronological relation to each other. The west end of the bench is about 1 m higher than the adjacent blowout. Figure 95 shows stratigraphy, soil occurrence, and location and slope of the sampled pedons. Table 43 gives soil characteristics.

Pedon 36a (figs. 95, 96) is on the west end of the bench. The A horizon is thin, as is commonly the case in soils of the Birdwell surface. The Bt horizon has a distinct maximum in silicate clay (table 43), as is typical of Birdwell I sediments at stablest sites. Occasional well-preserved sedimentary strata at fairly shallow depth (fig. 96) reflect the relative youth and thinness of these soils of Birdwell age. Strata are prominent in the B3t horizon. The contact of prominently stratified Birdwell sediments on the underlying C horizon is smooth and abrupt as is the case all along the study trench (see fig. 96). Commonly an accumulation of reddish clay is associated with the contact, either on it, or just above it and diffused throughout a thickness of one to several centimeters. The clay accumulation is attributed to illuviation at times of deepest wetting in these stratified sediments.

The C horizon is not as red as the overlying B2t horizon, and has only

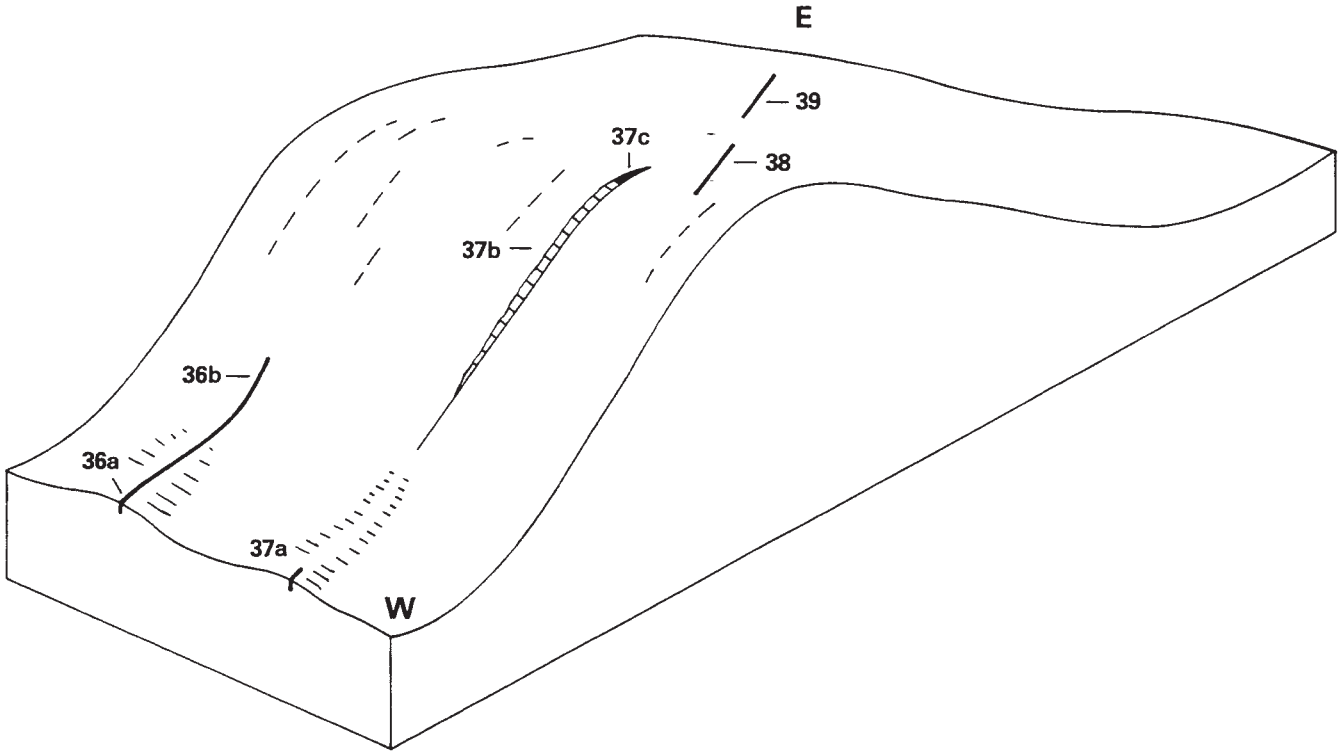


Figure 95. Above. Diagram of portion of dune at Sites 36-38. Site 36 is a bench (36a) and upslope dune of Birdwell age. Site 37 consists of deposits exposed by and related to a gully. Sites 38 and 39 are on the crest and east-facing dune side.

Below. Diagram of study trench at Site 36, showing stratigraphy, subgroup, and slope and location of sampled pedons. B = Birdwell. No vertical scale (see table 43 for horizon thickness). The heavy lower line represents the bottom of the trench.

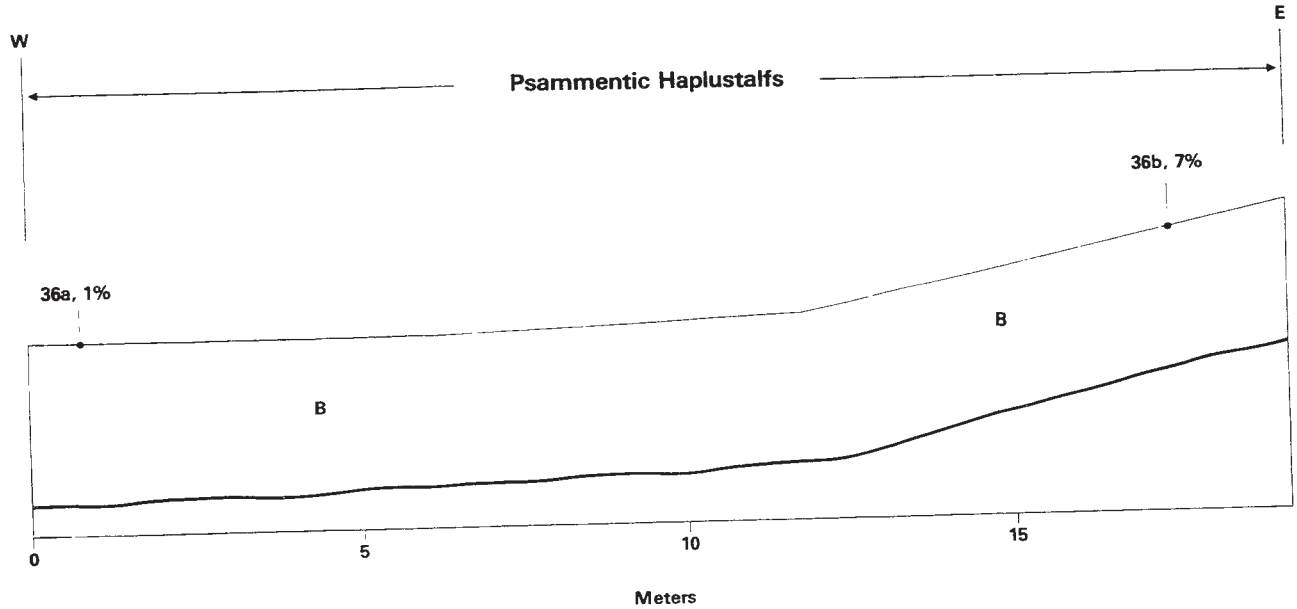


Table 42. Characteristics of Haplustalfs at Site 35[1/]

Sediment	Horizon	Depth, cm	Hue	Value/chroma Dry	Value/chroma Moist	Structure	Dry consistence	pH	Lower boundary	Textural class	Sand 2.0-0.05 mm	Silt 0.05-0.002 mm	Clay < 0.002 mm
Aridic Haplustalf, Extee, in blowout; Pedon 35a[2/]													
B	A11	0-4	7.5YR	5/2	3/2		sh	6.8	as	fsl			
	A12	4-10	7.5YR	4.5/2	2.5/2	m	sh	6.8	as	lfs			
	B21t	10-20	4YR 5YR	5/5 4/3	4/5 3/3	2mpr- 1msbk	vh	7.0	as	scl			
	2B22t	20-38	4YR	5/5	4/5	1cpr- 1csbk	vh	7.2	as	fsl			
	2B23t	38-50	4YR	5/6	4/6	1cpr- 1msbk	h	7.6	as	scl			
	2C	50-61	5YR	6/4	4.5/4	1csbk	sh,h	7.6	as	lfs			
Ba	2B2tb	61-85	4YR	5.5/5	4.5/5	1crp- 1csbk	vh		aw	scl			
	2K2b	85-96	7.5YR	8/2	7/4.5	1msbk	h,eh			scl			
Aridic Haplustalf, Extee, on lower side of dune; Pedon 35b[3/]													
B	A1	0-6	7.5YR	5/3	3/3	m	sh	6.8	as	lfs	80.0	14.0	6.0
	B1t	6-12	6YR	5/3	3/3	1cpr- 1msbk	h	7.0	as	fsl	75.6	14.3	10.1
	B2t	12-25	5YR	5/4	4/4	2mpr- 2msbk	vh	7.4	as	scl	55.3	15.4	29.3
	2B31t	25-35	5YR	5/6	4/6	m	s,sh	7.6	as	ls	83.8	3.2	13.0
	2B32t	35-48	2.5YR	5/6	4/6	m,sh	s,l	7.6	as	sl	83.1	3.4	13.5
	2B33tca	48-58	2.5YR	5/6	4/6				as	sl	78.0	4.2	17.8
	2C	58-73	5YR	6/5	5/5	m,sg	s,sh	7.6	as	fs	90.0	3.8	6.2
Ba	2B2tcab	73-89	5YR	5/5	4/5	1csbk	h,vh	7.6	as	scl	71.4	9.0	19.6
	2K1b	89-97	7.5YR	7/3	6/4		h,vh			scl	56.3	15.8	27.9
Psammentic Haplustalf, Texico, on side of dune; Pedon 35c													
B	A1	0-14	7.5YR	5/3	3/3	m	s	6.8	cw	s			
	B1tb	14-29	5YR	5/3.5	3.5/4	m	sh	7.0	cs	s			
	B21tb	29-44	4YR	5/6	4/6	1csbk	h	7.6	cs	s			
	B22tb	44-57	4YR	5/6	4/6	1csbk	sh,h	7.4	cw	s			
	B3tb	57-66	5YR	6/5	4/5	1csbk	s,sh	7.4	cw	s			
	Cb	66-98	5YR	6/4	5/4	m	s,sh	7.6		fs			

1/ Subordinate colors and other comments are footnoted to pertinent soils. Sediments identified as: B = Birdwell, Ba = Bailey. Several centimeters of Muleshoe and/or Longview sediments may be present at the surface.

2/ B21t: colors given are approximately equal in amount. 2B23t: many parts are noncalcareous, but there are common grains of carbonate, 1 to 3 mm diameter, that are redder and darker than the matrix, and that appear to consist largely of illuvial clay. 2K2b: parts 7.5YR 9/2, dry and 5YR 7/4, dry.

3/ 2B32t: a few carbonated-cemented grains of primary origin. 2B33tca: has many primary grains of carbonate. Some carbonate has been moved from these grains and occurs as short filaments and grain coatings.

Table 43. Characteristics of Psammentic Haplustalfs, Texico, in Birdwell sediments at Site 36[1/]

Horizon	Depth, cm	Hue	Value/chroma Dry	Value/chroma Moist	Structure	Dry - consistence	pH	Lower boundary	Textural class	Sand 2.0-0.05 mm	Silt 0.05-0.002 mm	Clay < 0.002 mm
On bench; Pedon 36a[2/]												
A1	0-5	7.5YR	5/3	3.5/3		s	7.0	as	lfs	84.1	9.2	6.7
B21t	5-17	5YR	5/6	4/6	lcpr-m	sh,h	7.2	cw	lfs	84.7	4.1	11.2
B22t	17-28	2.5YR	5/6	4/6	lcpr-lcsbk	h	7.4	cw	lfs	84.9	3.1	12.0
B23t	28-43	2.5YR	5/6	4/6	lcpr-lcsbk	vh	7.6	cw	lfs	83.9	2.6	13.5
B24t	43-66	2.5YR	5.5/6	4/6	lcpr-lcsbk	h	7.6	cw	lfs	84.3	2.7	13.0
B3t	66-112	2.5YR	6/6	4.5/6	m	s	7.6	as	lfs	88.3	2.1	9.6
C	112-126	5YR	6.5/5	5/5	m	s	7.6		fs	94.8	1.3	3.9
On lower side of dune; Pedon 36b[3/]												
A11	0-8	7.5YR	5/3	3.4/3		s	7.0	cw	lfs			
B11	8-23	5YR	5/3.5	3.5/3/5	m	s	7.0	cw	fs			
B12	23-42	5YR	5/4	3.5/4	m	sh	7.0	cw	fs			
B2t	42-56	2.5YR	5/6	4/6	m	h	7.2	as	ls			
B31&Bt	56-76	4YR	5/4	4/4	m	h	7.2	as	s			
B32&Bt	76-91	4YR	5/6	4/6	m	sh	7.2	as	s			
C	91-107	5YR	6/5	5/5	lcsbk	sh	7.2		lfs			

1/ Subordinate colors and additional characteristics are footnoted to pertinent soils.

2/ B22t: one discontinuous clay band occurs from 27-28 cm.

3/ B2t: parts 5YR, dry; and bands colored 5YR 5/4, dry. B31&Bt: primary strata, 1 to 3 mm thick, are visible. Two main colors: 5YR 6/4, dry, low in clay; and 4YR 5/4, dry, has a bit more clay. Main clay bands are at least 1 cm thick and contain distinctly more clay than the remainder of the horizon. B32&Bt: parts 2.5YR 4/6, dry, mostly in banded forms that contain more clay than adjacent areas.

faint sedimentary strata. The C horizon is largely noncalcareous, although there are a few calcareous spots.

The bench-high dune transition and whitish lenses

The sedimentary strata roughly parallel the land surface. From the west end of the trench toward the high dune the strata gradually steepen and are continuous with strata of the high dune. Studied sediments of the bench and dune are clearly of the same (Birdwell) age.

Thin lenses of whitish sand are distinct features in the B3t horizon on the west end of the trench (fig. 96). The whitish color is the color of the primary grains and is due to lack of clay coatings on the grains (see sites 32a and 37c for discussion of origin of the whitish lenses). In places, the lenses have a slight reddish tinge due to presence of very thin clay coatings. Maximum thickness of the whitish lenses is about 1 cm. Several of the lenses are continuous for as much as 5 m. Commonly they occur between strata that are distinctly darker and redder, and that have more clay. The whitish lenses do not occur above a depth of about 50 cm anywhere along the exposure, because they have been obliterated by clay illuviation and biotic mixing above that depth.

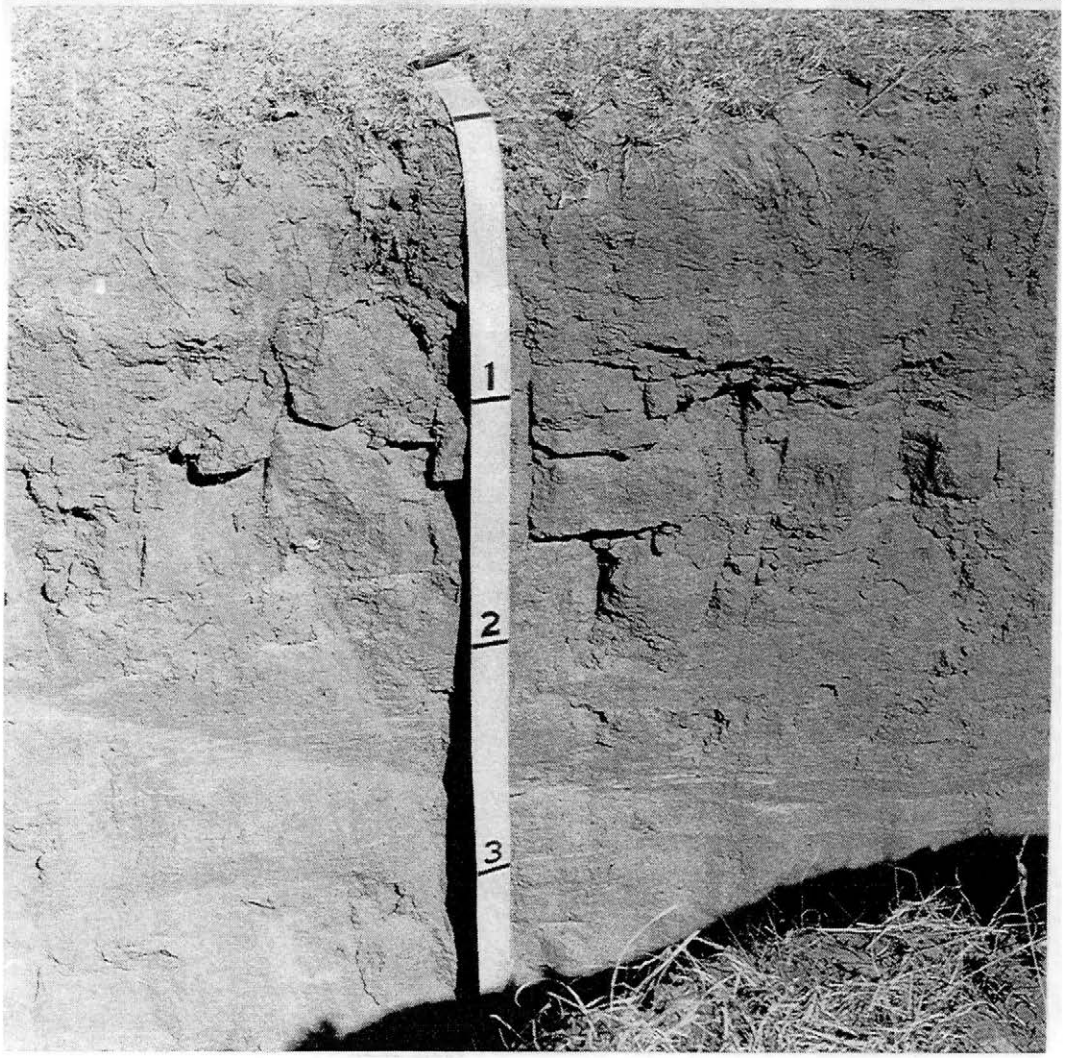
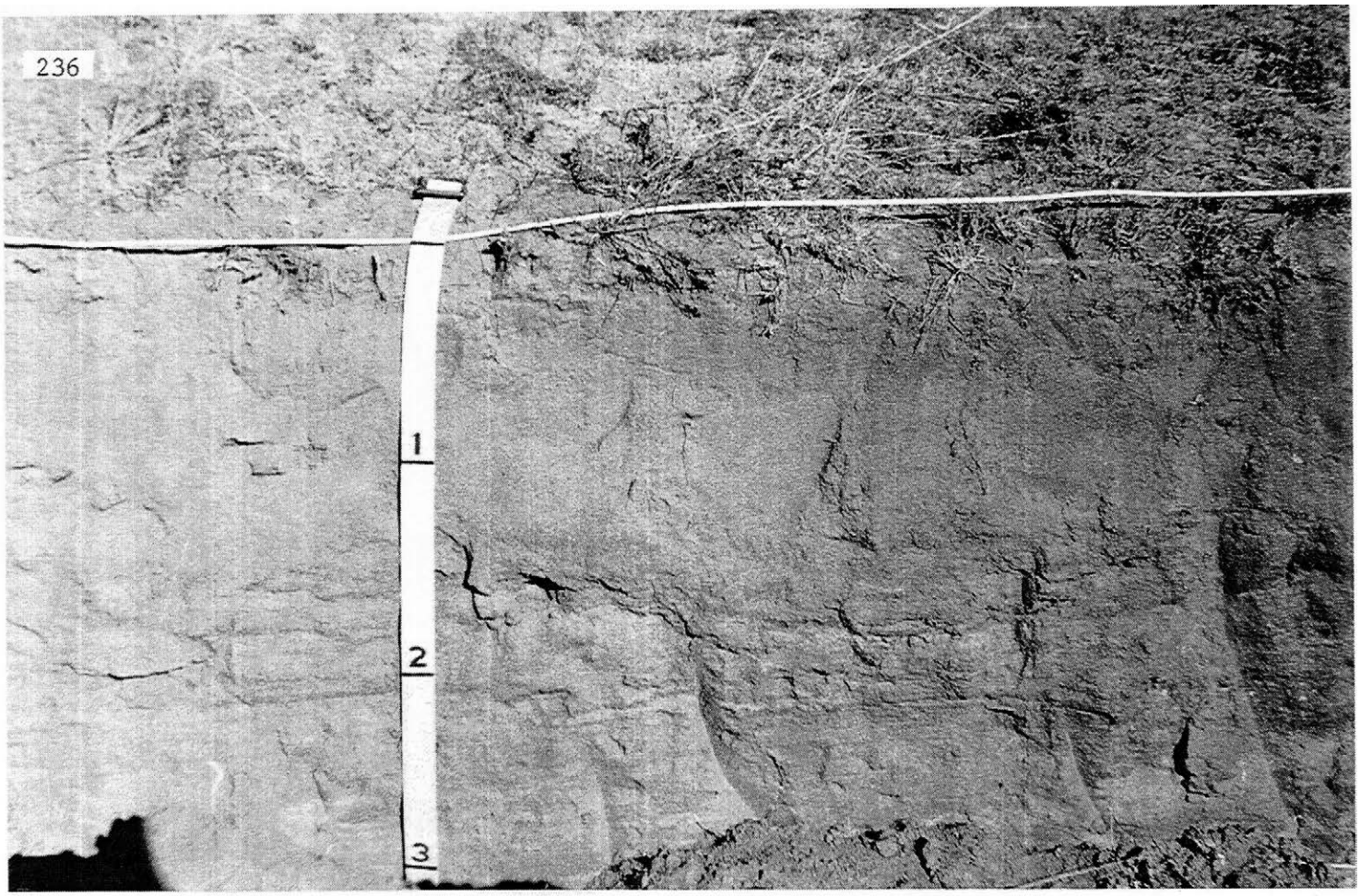


Figure 96. Upper. Landscape view of Birdwell bench and side of dune at Site 36. The view is east. Photographed October 1977.

Lower. The Psammentic Haplustalf, Texico, at Site 36a. Note whitish lenses, just above 2 ft (0.6 m) to below 3 ft (0.9 m), not obliterated by pedogenic processes. Scale is in feet.



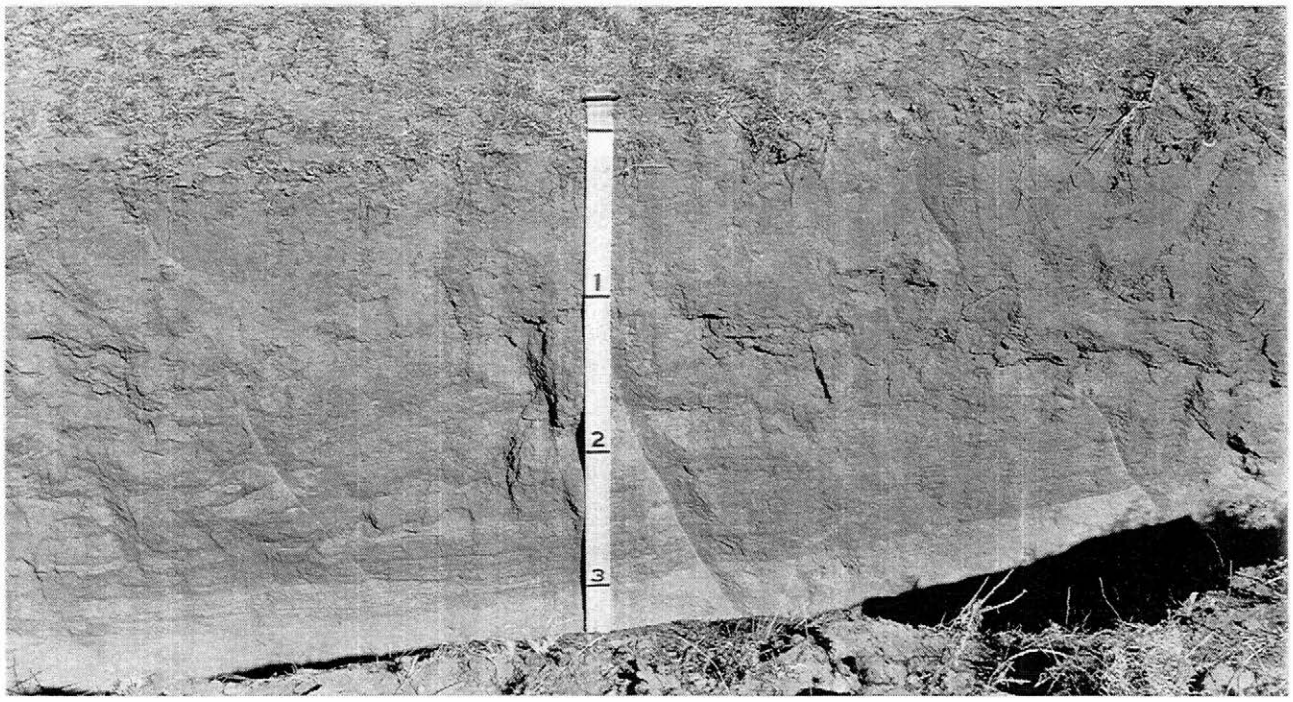


Figure 97. Upper. The Psammentic Haplustalf, Texico, at about 13 m (fig. 95). Clay bands along whitish lenses are thicker than at Pedon 36a, but whitish parts of the lenses are still preserved. Photographed October 1977. Scale is in feet.

Lower. The Psammentic Haplustalf, Texico, at Site 36b. Clay bands are more numerous and thicker in this upslope, steepest part of the trench than they are downslope. Note the prominent contact between stratified and unstratified sediments at the 3 ft (0.9 m) mark.

Expression of the whitish lenses is related to clay band development in the study trench as a whole. The whitish lenses are most prominent in the western part of the trench, where they have little or no clay and clay bands are only discontinuously present. But clay bands become more distinct toward the high dune, and are quite prominent about midway of the trench (fig. 97). The western edge of these prominent bands is about 10.4 m along the study trench (fig. 95), where one band 1 cm thick is at 41-42 cm depth and another ½ cm thick is at 56-56 ½cm depth. At 11 m (fig. 95) another band begins between these two, and 11.7 m there are four bands, at these depths: 38-39 cm; 51-52 cm; 54-55 cm; and 63-64 cm. The bands trace continuously eastward, where in places the lower one splits into two bands.

The clay bands continue to thicken upslope, and in Pedon 36b (figs. 95, 97) the upper two are each 2 cm thick. Bands occupy these depths: 46-48 cm; 53-55 cm; 67-68 cm; 74-75 cm; and 79½ -80 cm. Material between the bands is prominently stratified and slightly reddened with illuvial clay. A discontinuous clay band occurs along the top of the C horizon; in places, illuvial clay visibly penetrates the C horizon, which seldom happens downslope.

Thus the expression of whitish lenses is clearly related to illuvial clay and the development of clay bands. The clay bands are prominent on steeper slopes, as discussed at Sites 3 and 32; this is because of lateral movement of clay-carrying water downslope along strata (and along the clay bands after they had started to form), and deposition of clay as the water dried. As sand grains in the whitish lenses became coated with clay, the lenses were partly to completely changed to reddish clay bands. But with decreasing slope (to 1% on the west end of the bench), lateral movement of water was considerably reduced, and the whitish lenses largely retained their original character.

No evidence of Birdwell colluvium (see Sites 33-35 and 39) was found, possibly because of surface drainage, which splits to the north and south at the contact between the bench and the high dune.

Site 37, gully exposure and associated deposits

Site 37 consists of 37a, a trench in alluvium below a gully in a Birdwell dune; 37b, an exposure in the north bank of the gully; and 37c, an exposure of a Fairview eolian deposit on the south side of the gully, at its eastern end. Figure 95 locates the alluvium, gully and eolian deposit.

Gullies, discussed earlier at Site 32, have also formed in cattle trails on west-facing slopes of large Birdwell dunes, but are generally absent or slight on east-facing slopes. Strong erosion on west-facing slopes has resulted in thinner soils with less clay and more sand (see Site 37b); this may have been a major reason for gully development primarily on west-facing slopes. Soils of west-facing slopes would also tend to be hotter and droughtier than soils of east-facing slopes because they face the sun more directly and more often. Vegetation is denser on east-facing slopes and would tend to protect them from erosion. Thin lobes of alluvium occur downslope from the gullies, and have been emplaced long enough that vegetation has become well established in the alluvium.

Comparison of aerial photographs taken between 1941 and 1981 (figs. 88-91) establish the time of gully development at Site 37. A trail was

present in 1941, but a gully and its deposit are not evident. The gully had started to form by 1953, when alluvium is visible below it, and had enlarged to nearly its present size by 1962 (1962 aerial photograph not shown). The 1970 and 1981 photographs show that some gullies have extended headward and deepened since 1970. The 1970 and 1981 photographs also show dark areas in the gully at Site 37. These are vegetated areas that have been observed on the ground (fig. 98).

Eolian sediments derived from the gully and the alluvium below occur on the upper sides of the gully and its head (see Site 37c). Eolian sediments on the gully sides are not visible in the aerial photograph, but are faintly visible at the head of the gully (on the east-facing upper side of the dune).

It is of interest to compare evidence of post-1941 erosion of west-facing dunes of the old XIT trails (figs. 88-91). These trails are most apparent where they cross steep dunes; even in the 1941 photography, the trails are only sporadically visible in the adjacent, more gently sloping terrain. Presumably the north-south XIT trails have been little used by cattle since abandonment by the XIT, because they do not accord with the trends of later trails. Although the continuity and number of the trails suggests that they were heavily used by the XIT, only slight evidence of gullying (light-colored streaks along trails) is apparent in the 1941 aerial photograph. This may be due to their north-south, rather than east-west orientation. The trails appear to show slightly more evidence of erosion and gullying in photographs after 1941, possibly because of severe drought years after 1941 (see Climate section).

Site 37a, alluvium below the gully

Pedon 37a (table 44, figs. 98, 99) is in alluvium below the gully and in an underlying buried soil which was at the land surface before deposition of the alluvium. The alluvium must have accumulated primarily during the summer rainy season. Table 44 gives soil characteristics. No horizons have formed in the youthful material of the alluvium, although it has been emplaced long enough for the development of plant roots. The deposit consists of varying thickness of stratified, whitish to reddish sediments that range in texture from fine sand to sandy clay loam, but averages sand (table 44). The lower part tends to contain more clay than the upper part. Stratification is still visible in the upper part that contains roots, reflecting youth of the sediments.

The young mantle is 52 cm thick, thus is thick enough (50 cm or more) that the upper boundary of the "soil that we classify" is at the land surface (Chapter 3). Thus the soil is an Entisol. It is a Fluvent because organic carbon decreases irregularly with depth: the sand C horizon is underlain by a fine sandy loam A horizon, and organic carbon generally increases as clay content rises (Gile and Grossman, 1979).

The buried soil has a dark A horizon and the thick, red Bt horizon that is typical of Hale age. The soil of Bailey age is probably buried beneath Hale sediments because it was found with the auger upslope, as discussed in the following section.

Table 44. Characteristics of a Typic Ustifluvent, Tivoli, thin variant #2 in and beneath gully alluvium at Site 37a[1/]

Horizon	Depth cm	Hue	Value/chroma Dry	Value/chroma Moist	Texture	Structure	Dry consistence	pH	Lower boundary
C1	0-13	5YR	6/4	4.5/4	s	m	s	6.4	cw
C2	13-52	5YR	6/4	4.5/4	s	m	s	6.8	as
2A11b	52-58	5YR	4/2	3/2	fsl	m	sh,h	6.4	cw
2A12b	58-75	5YR	4.5/2	3/2	fsl	m	sh,h	6.6	cw
2B1tb	75-81	5YR	5/3.5	4/4	fsl	m	h	6.8	cw
2B21tb	81-91	2.5YR	5/6	4/6	fsl	2cpr	vh	6.8	cw
2B22tb	91-116	2.5YR	5/6	4/6	scl	2cpr	vh	7.4	cw
2B23tcab	116-140	2.5YR	5.5/6	4.5/6	scl	1cpr	vh	7.6	cw
2B24tcab	140-178	2.5YR	5.5/6	4.5/6	scl	1cpr	vh	7.6	

1/ Subordinate colors and other characteristics follow. C1, C2: parts 5YR 5/4, dry, that are stratified with, and are more clayey than, the materials colored 5YR 6/4. 2A11b: parts 5YR 5/3.5, dry. 2B23tcab: few carbonate filaments on prism faces. 2B24tcab: common carbonate filaments on prism faces. Fairview sediments occur from 0 to 52 cm, and Hale sediments from 52 to 178 cm.

Site 37b, gully exposure

Pedon 37b (fig. 100) is on the north-facing side of the gully. Strong wind-blasting of west-facing sides of dunes was mentioned earlier. Figure 100 shows photographs of Pedon 37b taken in November 1975 and in March 1977, after the exposure had been strongly eroded by wind and sand in dust storms. Distinct strata, very near the surface, have not been obliterated by soil formation. The strata slope from left to right and are downwind, suggesting erosion of crest deposits (see McKee, 1979, p. 126). Table 45 gives soil characteristics.

The Bt horizon is sandy (table 45), as is typical of upper ridge sides of Birdwell ridges, and has less clay than soils of stablest sites (e.g., nearby Sites 36a and 38a). This factor and landscape position (west-facing, upper side of dune) indicate strong wind erosion. This is thought to have happened in Birdwell II time, as indicated by evidence at nearby Site 38, to be discussed. This wind erosion and water erosion, which contributed to the colluvium downslope, are thought to be the reason for lack of a silicate clay maximum in the B horizon (table 45). The soil does have clay bands of pedogenic origin, and is therefore classified as an Alfic Ustipsamment.

The C horizon actually contains more clay than the B horizon (table 45). This is not unusual and is due to origin of the parent materials partly from the thick Bt horizon of Hale age.

Two deep auger borings provide information on the pre-Birdwell sediments and buried soils. Below Pedon 37b, the C horizon extends to 13 ft (4 m) depth. Below 13 ft (4 m) there is a buried Bt horizon in Roosevelt

Figure 98. Landscape view of study trench at Site 37a, foreground, and upslope gully at Site 37b. Note vegetation in gully bottom. Site 37a is in a lobe of alluvium derived from the gully. The view is east. Photographed March 1977.

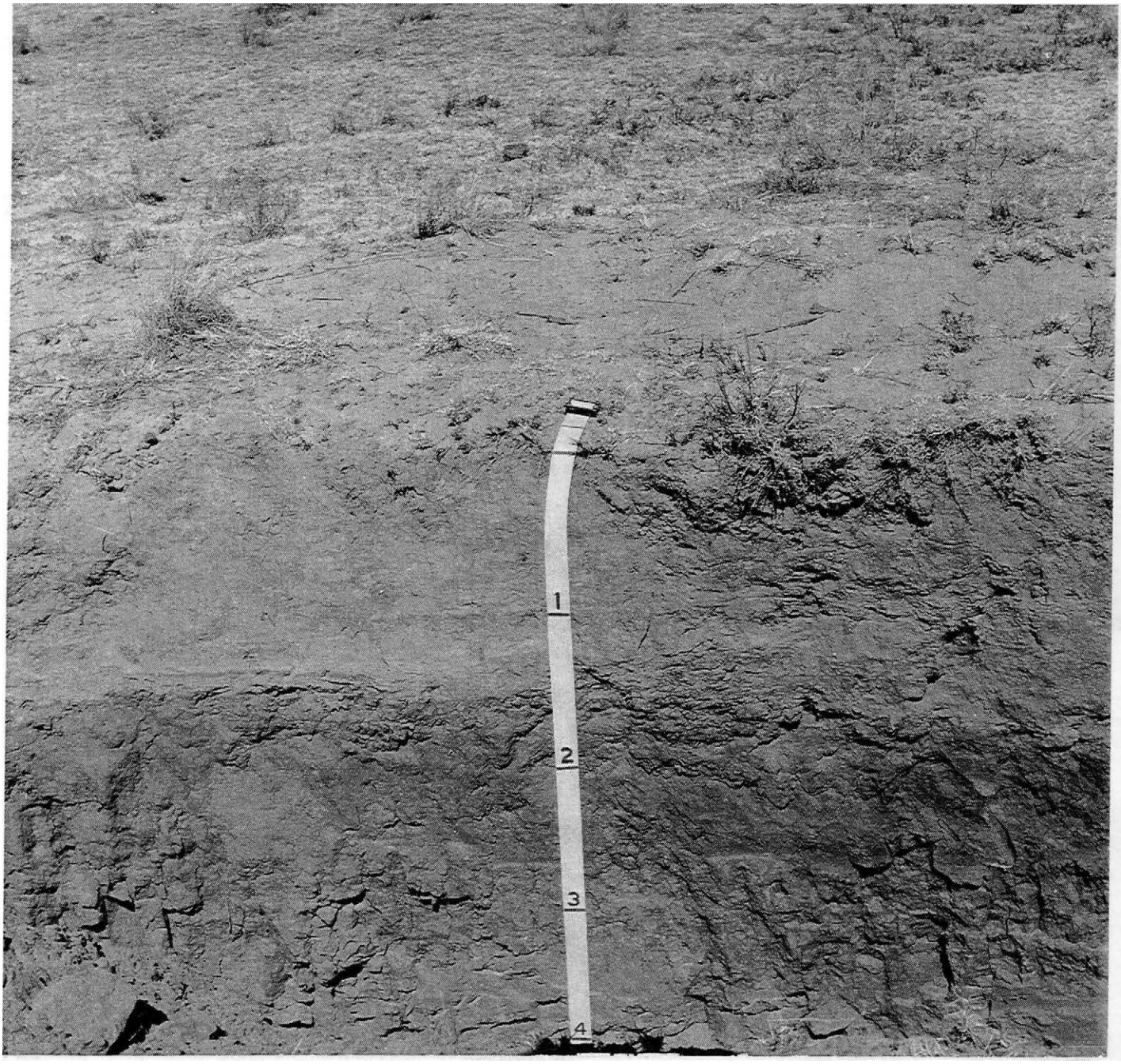
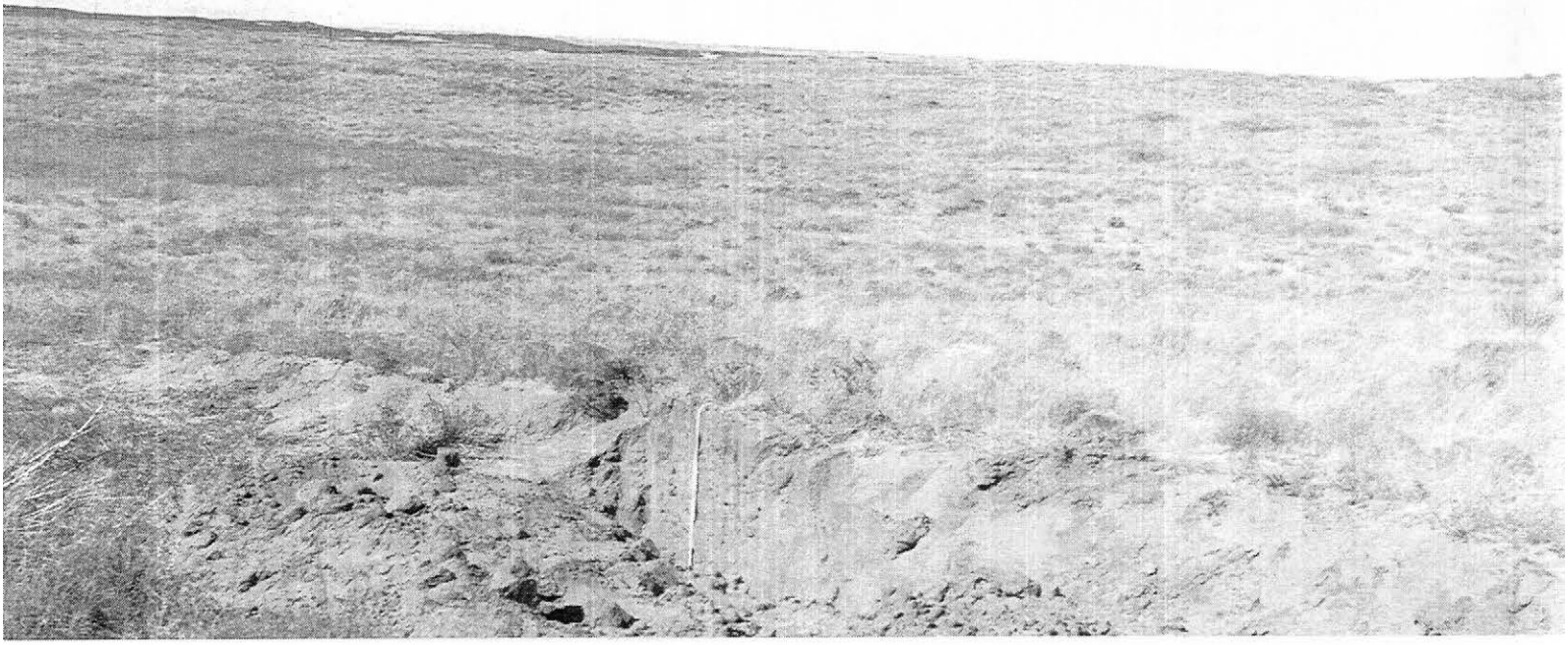
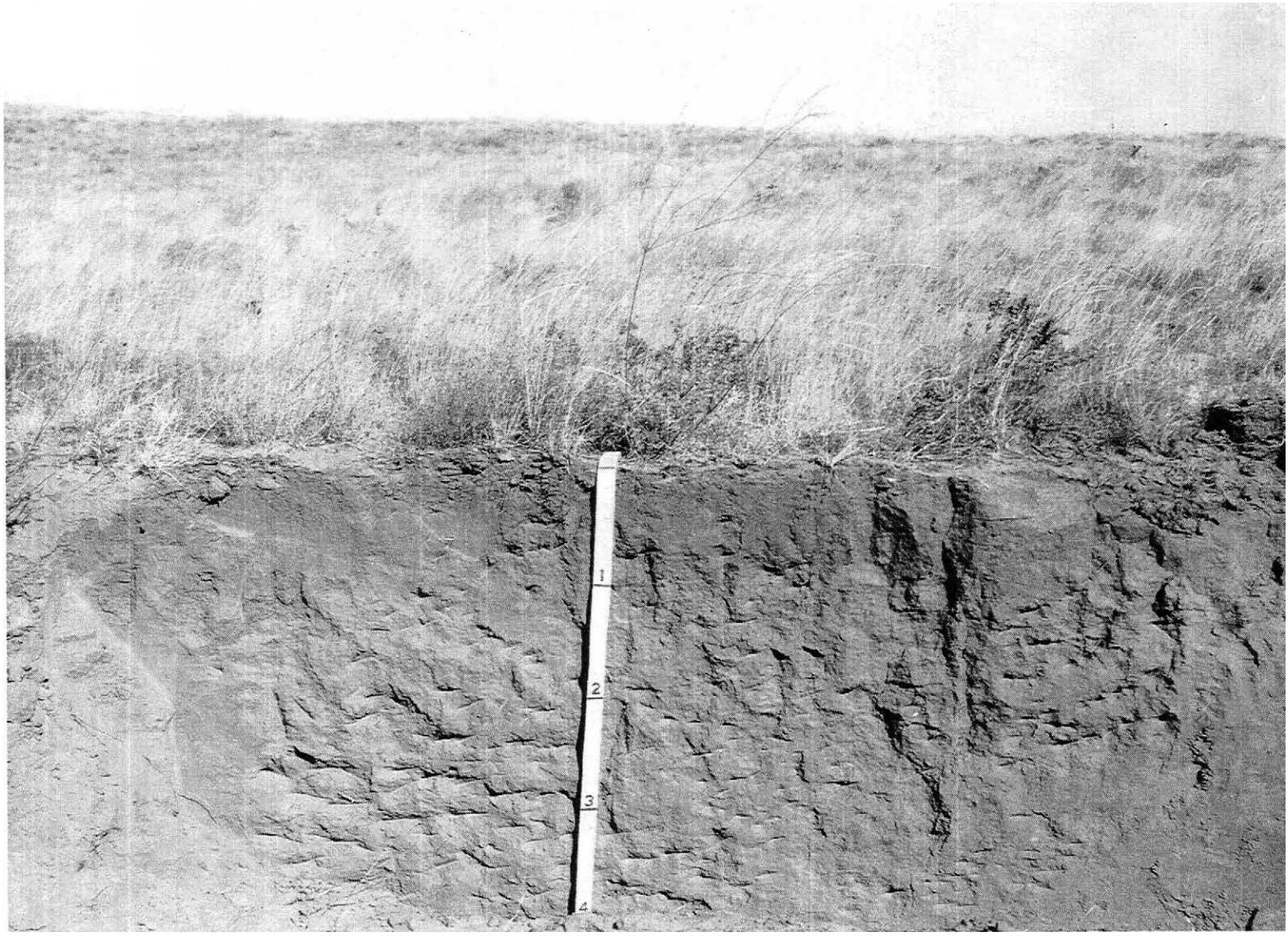


Figure 99. The Typic Ustifluvent, Tivoli, thin variant #2, at Site 37a. The alluvium is fresh-appearing and faintly stratified, but has been in place long enough for growth of plants. Scale is in feet.

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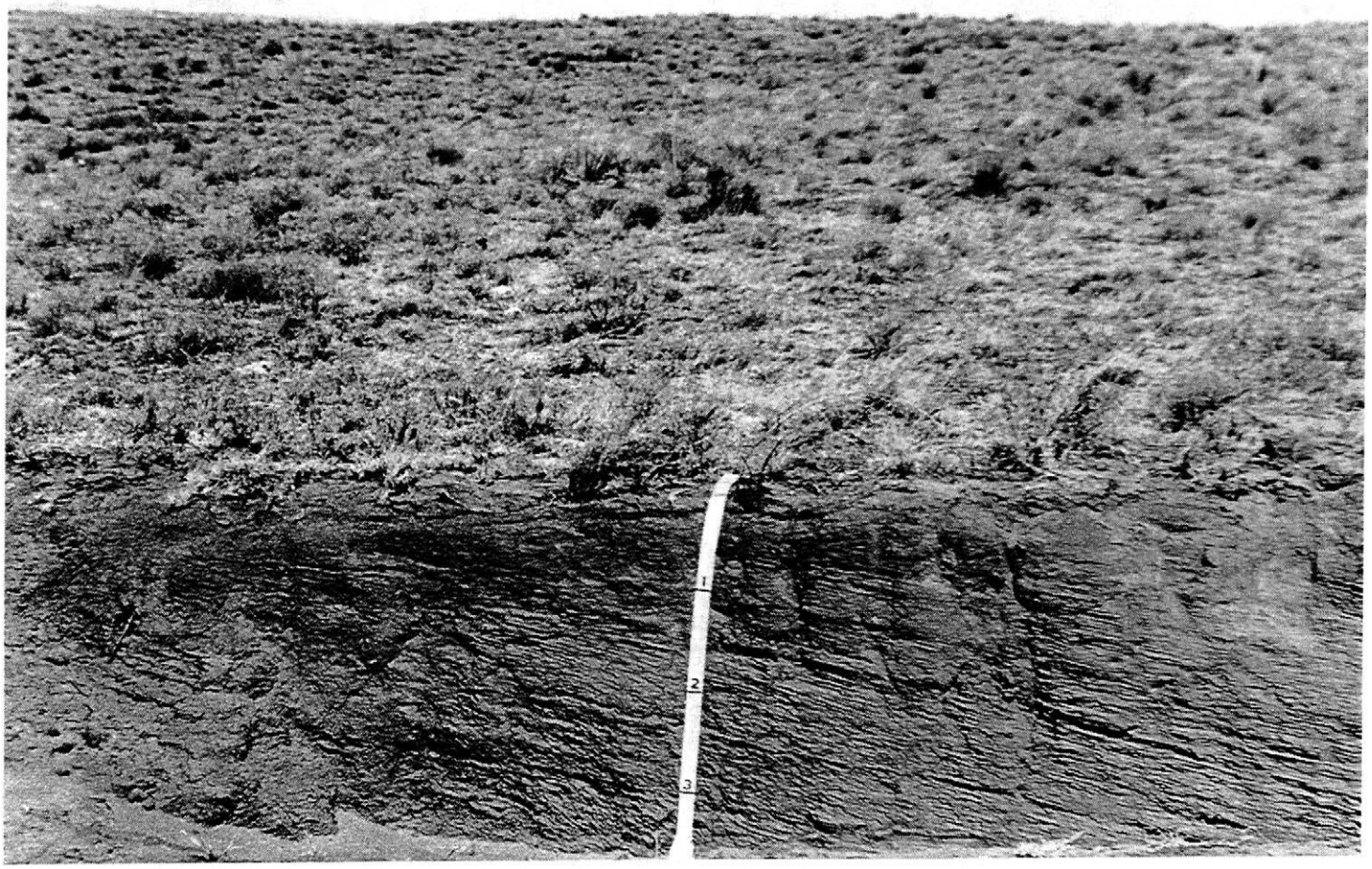


Figure 100. Opposite page, upper. Landscape view of Birdwell II surface on west-facing dune side at Site 37b. The tape is in the north wall of the gully (see fig. 98). Note that the gully wall is rounded except where straightened with the backhoe, and that the gully bottom is vegetated (left). The view is west. Photographed November 1975.

Opposite page, lower. The Alfic Ustipsamment, Circleback, at Site 37b, in eroded Birdwell I sediments. Scale is in feet.

Above. Site 37b after spring dust storms. Note the distinct sedimentary strata, evidence that the soil is younger than Birdwell I. Clay bands have formed along some of the primary strata. Photographed March 1977. Scale is in feet.

Table 45. Characteristics of the Alfic Ustipsamment, Circleback, on upper side of Birdwell dune at Site 37b

Horizon	Depth, cm	Hue	Value/chroma Dry	Value/chroma Moist	Structure	Dry consistence	pH	Lower boundary	Textural class	Sand 2.0-0.05 mm	Silt 0.05-0.002 mm	Clay < 0.002 mm
A1	0-7	6YR	5/4	3.5/4	lm,cpl	s	6.8	as	ls	88.6	4.0	7.4
B1t	7-14	4YR	5/5	4/5	m	sh	7.0	as	s	90.1	1.3	8.6
B2t	14-34	4YR	5/5	4/5	lcpr-m	sh	7.0	as	lfs	88.9	2.3	8.3
B3t	34-45	2.5YR	5/6	4/6	m	sh,h	7.0	as	s	91.3	0.1	8.6
C1&Bt	45-60	2.5YR	5/6	4/6	m	sh	7.0	as	s	90.1	1.3	8.6
C2&Bt	60-69	4YR	5.5/5	4/5	m	h	7.0	as	lfs	85.7	1.5	12.8
C3&Bt	69-91	2.5YR	5/6	4/6	m	sh	7.2	as	lfs	88.3	1.0	10.7
C4&Bt	91-124	2.5YR	5.5/6	4/6	m	sh	6.8		ls	89.4	1.3	9.3

sediments, 7.5YR 4/3, moist, underlain by a fine sand, 7.5YR 6/5, dry. At about 17 ft (5.2 m) depth, the color reddens to 5YR 6/8, moist, and texture is fine sandy loam. This is interpreted as an upper subhorizon of the thick soil of Hale age.

Ten m downslope, the following horizons were encountered with the auger. At 5 ½ ft (1.7 m) depth the Bt horizon in Roosevelt sediments (texture sandy clay loam, color 5YR 4/6, moist) was found. The color reddens with depth until at 8 ft (2.4 m) depth it is 2.5YR 4/6, moist, and texture is a fine sandy loam. From 8½-11½ ft (2.6-3.5 m) there is a fine sand. Sand (5YR 6/6, moist), continues to about 15 ft (4.6 m), where a noncalcareous sandy clay loam (4YR 4/6, moist) was encountered. This continues to 17 ft (5.2 m), where a prominent calcic horizon was found. This shows that the old soils of Bailey age continue beneath considerable thickness of younger sediments.

Site 37c, gully-related eolian deposit of Fairview age

The Fairview eolian sediments derived from the gully and the alluvium below it occur in two general landscape positions: bordering the north-south margins of the gully, and in a lobe just east of the gully head, on the east-facing upper side of the dune. The bulk of these deposits must have accumulated during the spring dusty season after times of maximum gully incision in the rainy summer season.

Pedon 37c (fig. 101) occurs near the dune crest, on the south bank of the gully, where Fairview sediments and underlying Birdwell sediments are exposed for a distance of about 23 m west of the crest. The young Fairview deposit is readily identified because it is prominently stratified and rests abruptly on the soil of Birdwell age. At its downslope, western edge the Fairview deposit is only several centimeters thick. It gradually increases in thickness upslope, being thickest (35-50 cm) in the lobe on the east-facing upper side of the dune. Slope at Pedon 37c is 3 percent to the west.

The upper 28 cm of Pedon 37c consists of Fairview sediments (table 46). Distinct strata are apparent in the Fairview sediments but not in the underlying Birdwell sediments (fig. 101). Note dominance of short, undulating strata instead of the long, uniformly sloping strata typical of stratified older sediments. The difference is attributed to a lack of vegetation during deposition of the long, uniformly sloping strata, and to the presence of clumps of vegetation during deposition of the short, undulating strata.

Table 46. Characteristics of the Psammentic Haplustalf, Texico, and overlying eolian deposit at Site 37c[1/]

Horizon	Depth cm	Hue	Value/chroma Dry	Value/chroma Moist	Texture	Structure	Dry consistence	pH	Lower boundary
C	0-28	4YR	5/6	4/5	fs	m	sh,s	7.2	as
B21tb	28-34	4YR	4.5/5	3.5/5	lfs	lmsbk	h,vh	7.0	cw
B22tb	34-48	4YR	5/5	4/5	lfs	lmsbk	h	7.2	cw
B23tb	48-68	4YR	5.5/6	4/6	fs	lmsbk	h	7.2	

1/ Subordinate colors and other characteristics follow. C: parts 5YR 6/4 and 7/4, dry ("whitish lenses"). Whitish lenses are soft; reddish parts are slightly hard. The C horizon is of Fairview age; remainder is Birdwell.

Whitish lenses, dark lenses and lenses of intermediate whiteness are apparent (fig. 101). The differing degree of lightness reflects their origin in alluvium below the gully (see Sites 37a and 32). Lower strata show more undulations and irregularities than upper strata, possibly because vegetation may have been thicker when deposition began. The whitish lenses are underlain by redder, darker lenses, at the very top of which is a thin (1 mm or less) discontinuous band. The band is interpreted as a thin surface crust that formed during the rainy season, and that was buried by eolian sediments during the spring dusty season.

Site 38, Birdwell II eolian deposit

Strong evidence of post-Birdwell I erosion was shown at Site 37b. Conclusive evidence of post-Birdwell I wind deposition is shown at Site 38. Three pedons were sampled: Pedons 38a and 38b, on the crest of the dune, and Pedon 38c, on the east-facing side of the dune. Figure 102 shows stratigraphy, soil occurrence, and the location and slope of the sampled pedons. Table 47 presents soil characteristics.

West edge of dune crest

Pedon 38a (figs. 102-104) illustrates a Psammentic Haplustalf on the dune crest. Less wind and water erosion would be expected here than at strongly eroded Site 37b; hence, the Bt horizon of Pedon 38a contains more clay (table 47). But the A horizon is very thin and the horizon with

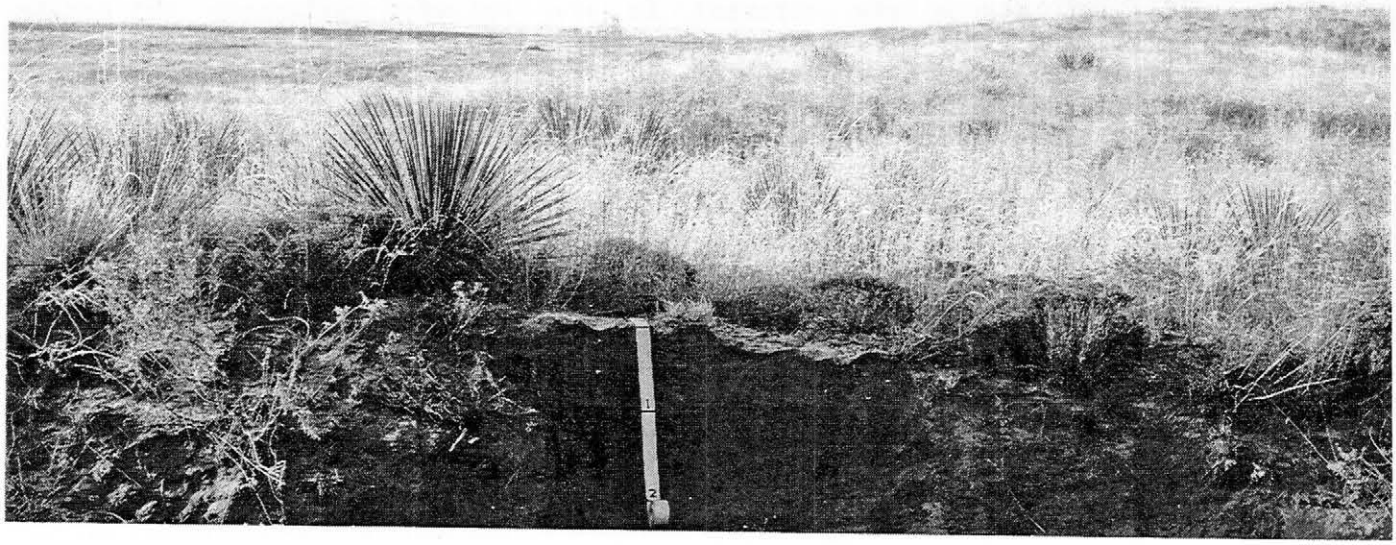
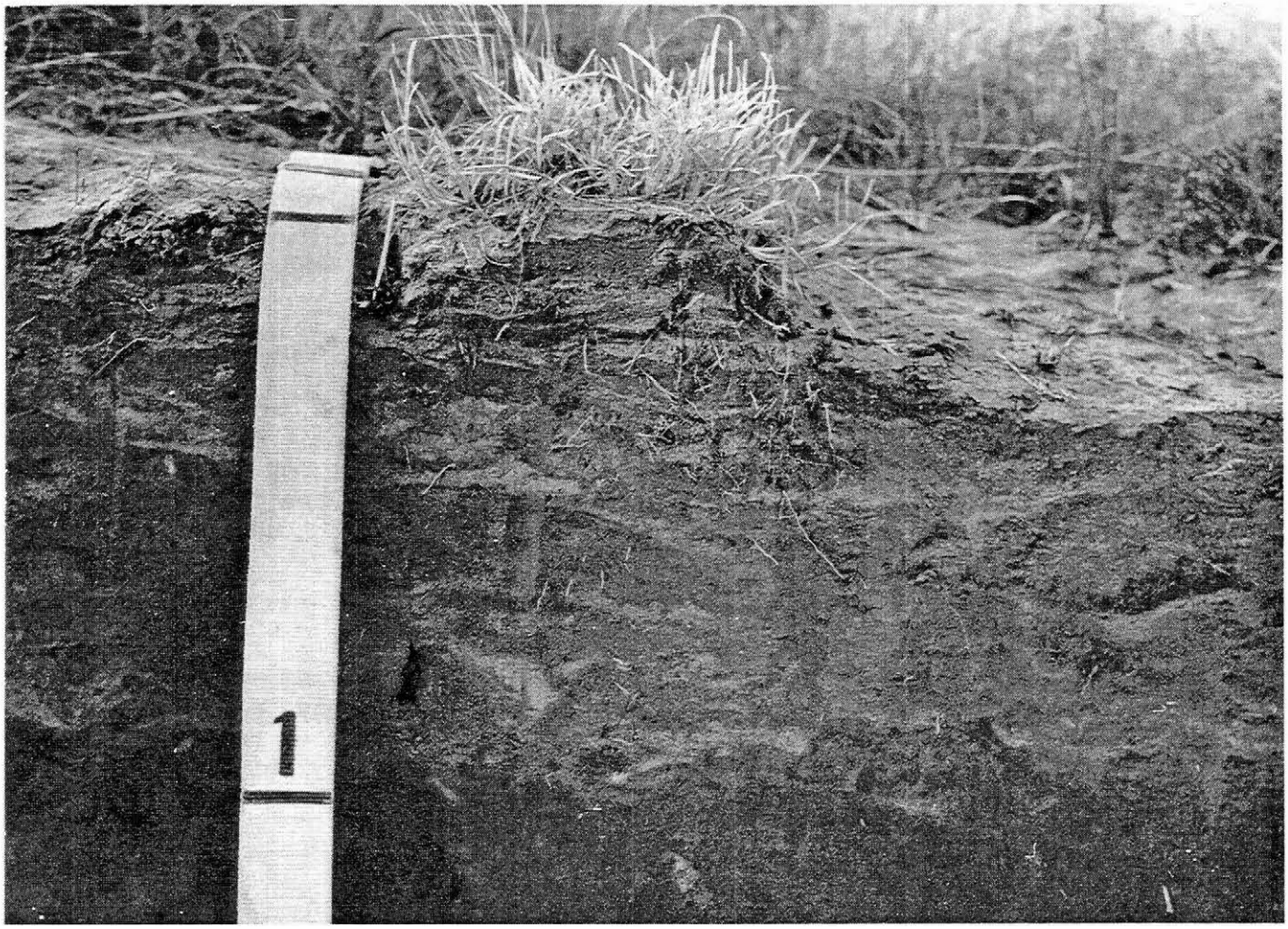


Figure 101. Above. Landscape view of post-gully, Fairview eolian sediments on south bank of gully, near crest of dune at Site 37c. The view is south. Photographed October, 1982. Scale is in feet.

Below. The post-gully sediments extend to about 1 ft (0.3 m) depth, where they overlie the Psammentic Haplustalf, Texico. Note that some of the whitish lenses are short and undulating. This is attributed to deposition around clumps of vegetation.



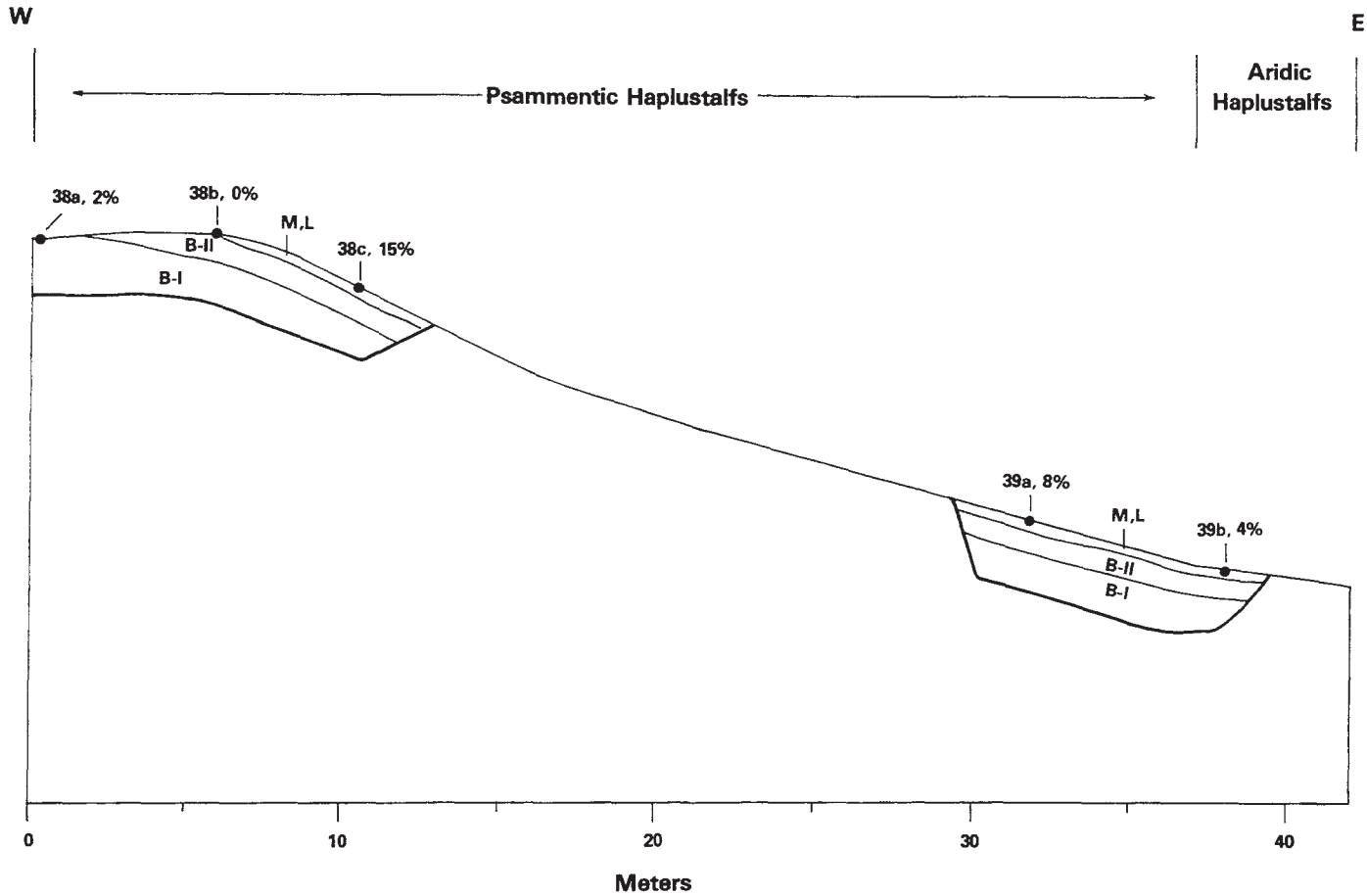


Figure 102. Diagram of study trenches at Sites 38 and 39, showing stratigraphy, subgroup, and slope and location of sampled pedons. M = Muleshoe, L = Longview, B-II = Birdwell II, B-I = Birdwell I. No vertical scale (see tables 47 and 48 for thicknesses of sediments and soils). The heavy lower lines represent the bottoms of the trenches.

Table 47. Characteristics of Psammentic Haplustalfs, Texico, at Site 38[1/]

Sediment	Horizon	Depth, cm	Hue	Value/chroma Dry	Value/chroma Moist	Structure	Dry consistence	pH	Lower boundary	Textural class	Sand 2.0-0.05 mm	Silt 0.05-0.002 mm	Clay < 0.002 mm
Dune crest; Pedon 38a													
B-I	A1	0-3	6YR	5/4	3.5/4		s	6.8	as	lfs	87.7	5.0	7.3
	B21t	3-14	2.5YR	4.5/5	4.5/4	lmsbk	sh,h	7.0	cw	fsl	83.2	2.0	14.8
	B22t	14-34	2.5YR	5/6	4/6	lcsbk	sh,h	7.2	cw	lfs	83.1	3.6	13.3
	B23t	34-53	2.5YR	5.5/6	4.5/6	lcsbk	sh,h	7.2	cw	ls	85.4	1.8	12.8
	B24t	53-74	2.5YR	5.5/6	4.5/6	lcsbk	sh,h	7.4	cw	fsl	83.0	2.4	14.6
	B3t	74-91	2.5YR	5.5/6	4.5/6	m	sh	7.4	cw	lfs	85.7	2.9	11.4
	C1	91-104	2.5YR	5.5/6	4.5/6	m	sh	7.4	cw	lfs	88.8	1.7	9.5
	C2	104-126	2.5YR	5.5/6	4.5/6	m	sh	7.4		ls	85.8	3.3	10.9
Dune crest; Pedon 38b[2/]													
B-II	A	0-4	6YR	4.5/3	3.5/3	m	sh	7.0	as	fs			
	B21t	4-13	4YR	4.5/4	3.5/4	lcsbk	h	7.2	cw	lfs			
	B22t	13-29	2.5YR	5/6	4/6	lcsbk	h,sh	7.2	cw	lfs			
	B3t	29-53	4YR	5.5/4	4.5/4	lmsbk	sh	7.2	cw	fs			
B-I	Ab	53-75	5YR	5.5/5	4/5	m	sh	7.2		fs			
Upper side of dune: Pedon 38c[3/]													
M, L	A11	0-14	7.5YR	5/3	3.5/3	m	sh	7.0	cw	fs			
	A12	14-31	6YR	5/4	3.5/4	m	sh	7.0	cw	fs			
B-II	B1tb	31-42	4YR	5/5	4/5	lcsbk	sh	6.8	cw	fs			
	B2tb	42-60	2.5YR	5/6	4/6	lcsbk	sh,h	7.0	cw	lfs			
	B3tb	60-79	2.5YR	5/6	4/6	lcsbk	sh,h	7.2	cw	lfs			
B-I	Ab2	79-92	5YR	5.5/5	4/5	lcsbk	h	7.2	cw	fs			
	B1b2	92-110	4YR	5.5/6	4.5/6	lcsbk	h	7.0	cw	lfs			
	B21tb2	110-130	4YR	5.5/5	4.5/5	lcsbk	h	7.0	cw	lfs			
	B22tb2	130-153	4YR	5.5/5	4.5/5	lcsbk	h	7.0	cw	lfs			
	B3tcab2	153-175	4YR	5.5/5	4.5/5	m	sh	7.6	cw	fsl			
	Cb2	175-189	4YR	5.5/5	4.5/5	m	s	7.6		lfs			

1/ Subordinate colors and additional characteristics are footnoted to pertinent soils. Sediments identified as: M = Muleshoe, L = Longview, B-II = Birdwell II, B-I = Birdwell I.

2/ Ab: has a few darker parts.

3/ Ab2: has a few darker parts. B1b, B21tb, B22tb: have variable amounts of material that is 5YR 5.5/4, dry. B3tcab: calcareous throughout; scattered white high-carbonate grains, and a few patchy carbonate bridges between grains.

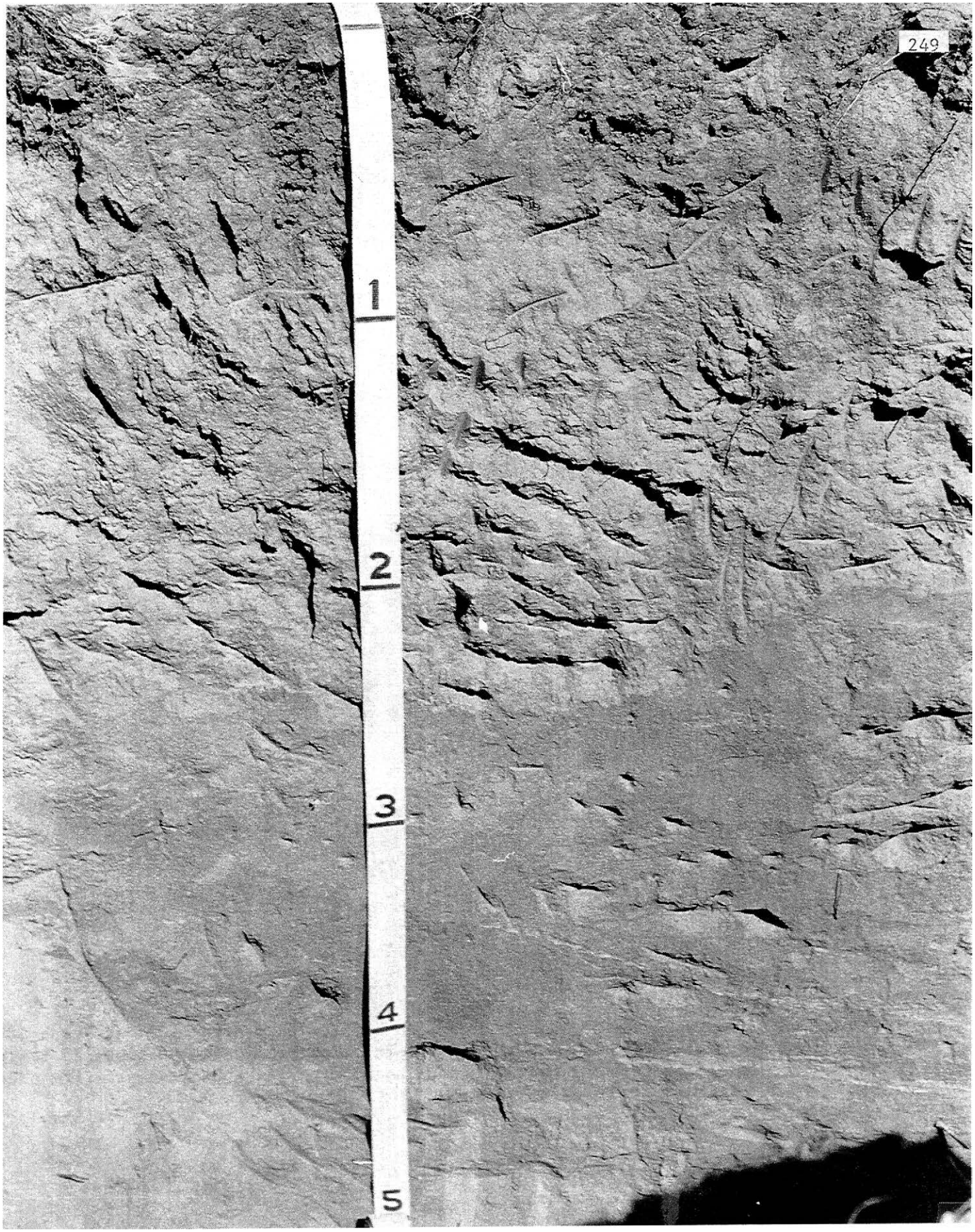


Figure 103. The Psammentic Haplustalf, Texico, at Site 38a, in Birdwell I sediments at the dune crest. Note presence of primary strata in the C horizon at about the 4 ft (1.2 m) mark, right of tape. Photographed March 1977. Scale is in feet.

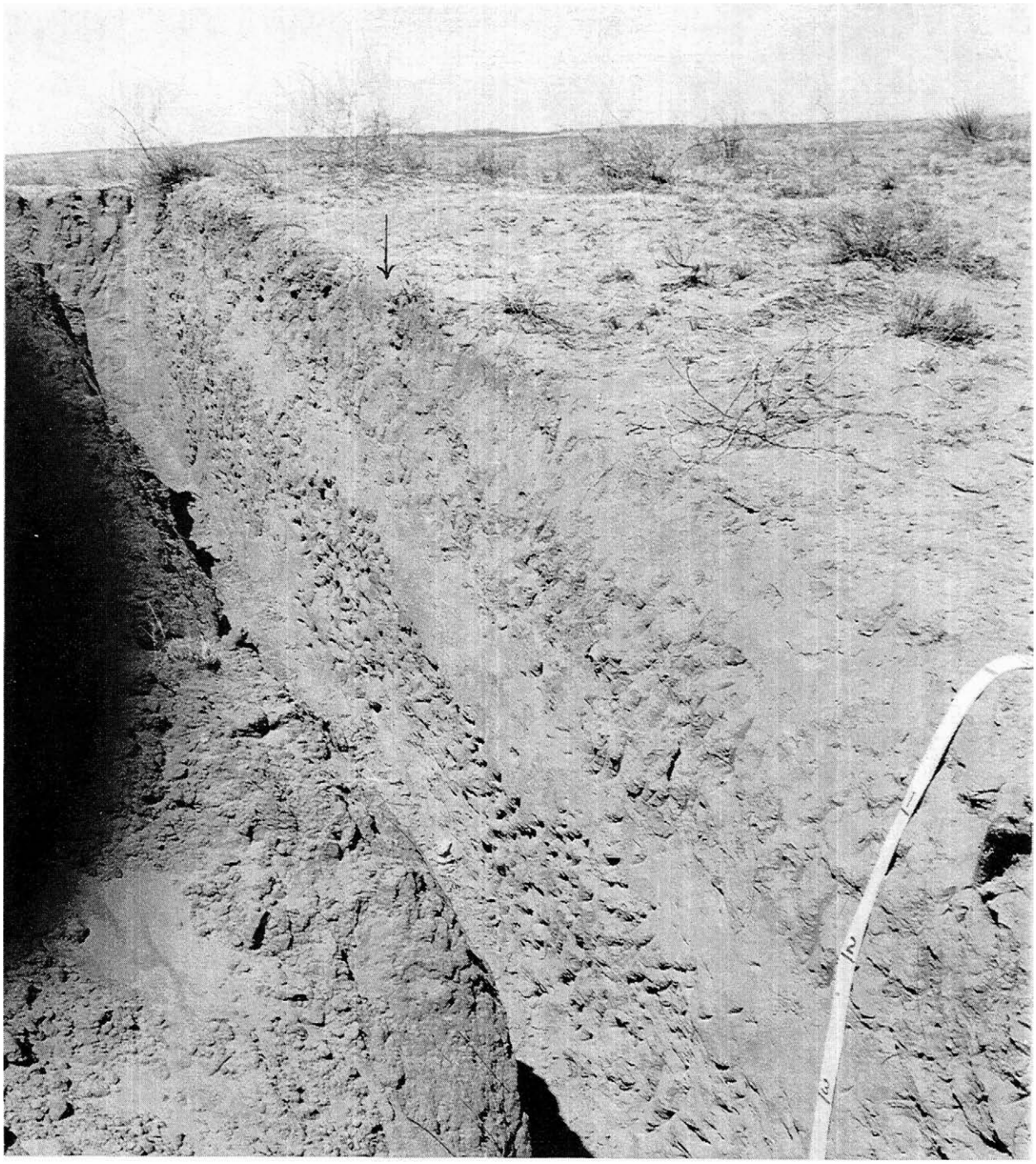


Figure 104. Westward view along study trench at Site 38. Arrow locates Pedon 38b (see also fig. 23). Pedon 38a is at upper left. The Psammentic Haplustalf, Texico, Pedon 38c, is at the tape. Note the buried soil, with its A horizon starting below the 2 ft (0.6 m) mark. Photographed March 1977. Scale is in feet.

maximum clay is very shallow (3 to 14 cm), indicating some soil truncation on the west-facing margin of the dune crest. Although two subhorizons of the argillic horizon are fine sandy loam (table 47), the control section (from 3 to 53 cm) averages sandy; the pedon is therefore a Psammentic Haplustalf.

Just east of Pedon 38a, the analogue of Pedon 38a dips below the younger, Birdwell II eolian deposit (fig. 102). Here the buried A horizon is so near the surface that reddish illuvial clay from Birdwell II sediments is emplaced in it. Illuvial clay is not present in the buried A horizon downslope, where the Birdwell II deposit thickens and a Bt horizon has formed in it. Clay bands are usually present in the Bt horizon. They are best expressed about midway between Pedons 38a and 38b where the bands are at about 21, 25, 33, 37, and 40 cm depths. The three upper bands are about ½ cm thick and the lower two are 1 to 2 mm thick. In places, a thin band occurs discontinuously in the buried A horizon.

East edge of dune crest

Only the horizons in Birdwell II sediments and the buried A horizon were sampled in this pedon (see Pedon 38c for morphology of the buried soil in Birdwell II sediments).

The Bt horizon is very near the surface just left of the tape (figs. 23, 104). The A horizon of Pedon 38b, at the tape, is about 4 cm thick. About ½ m to the right of the tape, the Bt horizon dips beneath a thicker A horizon, about 10 cm thick, that increases in thickness downslope. Also at the tape, slope also increases markedly, to 15 percent (fig. 102). The A horizon has been strongly eroded on the dune crest but has been buried and preserved by eolian sediments on the lee side of the dune crest.

The lower part of the B3t horizon is stratified, but not the Ab horizon beneath. This supports the interpretation of a buried A horizon since strata would tend to be obliterated during soil development. The Ab horizon has scattered dark volumes of organic carbon.

Upper side of dune

Pedon 38c is similar to Pedon 38b, but the Bt horizon is much deeper than in Pedon 38b (table 47). The increasing thickness of materials downslope above the Bt horizon is thought to represent an eolian and colluvial deposit of Muleshoe and Longview age, emplaced on an A horizon of Birdwell II age. However, the latter horizon could not be readily distinguished, so it was included in the A12 horizon (table 47). The eolian component of the deposit would have been emplaced mainly during windy, dry times, and the colluvium primarily during rainy seasons. This deposit is common on east-facing slopes of Birdwell dunes.

The B3tb horizon has white carbonate grains that appear to be a feature of the parent materials, and that must have been derived from the thick carbonate horizon of Bailey age in the blowout to the west, as at Site 35 discussed earlier. Sedimentary strata are visible in the lower part of the Btb horizon, but not in the upper part or in the A horizon below.

Site 39, texture sequence, east aspect

Site 39 consists of an east-west study trench below Site 38, in the lower side of the Birdwell dune (figs. 102, 105, 106). As at Site 38, sediments of four ages are present: Muleshoe, Longview, Birdwell II and Birdwell I. Two pedons were sampled at Site 39: Pedon 39a, in the upslope part of the trench, and Pedon 39b, in the downslope part. Figure 102 presents soil occurrence and stratigraphy, and the slope and location of the sampled pedons. Table 48 gives soil characteristics.

Site 39a

The eolian-colluvial accumulation of Muleshoe and Longview age has preserved the buried A horizon in Birdwell II sediments. The Ab horizon has scattered reddish crotovinas, round or elliptical in cross section. Both Birdwell I and II sediments have colluvium-containing Bt horizons that are distinctly finer than soils in Birdwell I and II sediments upslope.

Sedimentary strata are not visible in the 2B22tb horizon and above (apparently, many strata were largely obliterated by soil formation) but are present in places along the trench in horizons below. Although there is no intervening C horizon material between soils of Birdwell I and II age to demonstrate soil burial, several factors indicate it. Discontinuous strata beneath the 2Btb horizon at various places along the trench indicate sedimentation following a time of soil development beneath. Sedimentary strata also occur in the lower part of the Bt horizon at Site 38 upslope. The total thickness of A and Bt horizons is considerably greater than at Birdwell sites that lack buried soils. This also suggests soil burial.

Sedimentary strata occur discontinuously both in the lower B horizon and in the C horizon, but the strata differ markedly. The 3Cb2 horizon has faint strata that are long and that have slopes that do not vary. In contrast, strata in the 3B3tcab2 horizon are short, and vary in thickness and slope. The boundary between the two kinds of strata is thought to mark the boundary between the wind-deposited material (in the 3Cb2 horizon) and the colluvium-containing material (in the 3B3tcab2 horizon).

Visible carbonate does not occur in Pedon 39a and there is no effervescence with HCl. However, scattered carbonate filaments do occur in the lower B and in the C horizon on both sides of Pedon 39a. Downslope, a weak stage I carbonate horizon occurs discontinuously along the trench, and always in the same general position: in the lower B and/or in the C horizon.

Site 39b

Downslope toward 39b, major horizons of Pedon 39a can be continuously traced all along the trench. The 2Btb horizon gradually becomes darker in part, as clay increases downslope. Birdwell I and II sediments thin eastward as slope decreases, and consequently depth to the C horizon material of Birdwell I is less in downslope Pedon 39b than in Pedon 39a.

The A1 horizon contains more silt than any horizon below (table 48), supporting the interpretation of the late Holocene as being a time of silt accumulation. The colluvial zone contains substantial clay, both in Birdwell II and in Birdwell I sediments (table 48). Had the trench been extended to gentler slopes, even finer textures would probably have been

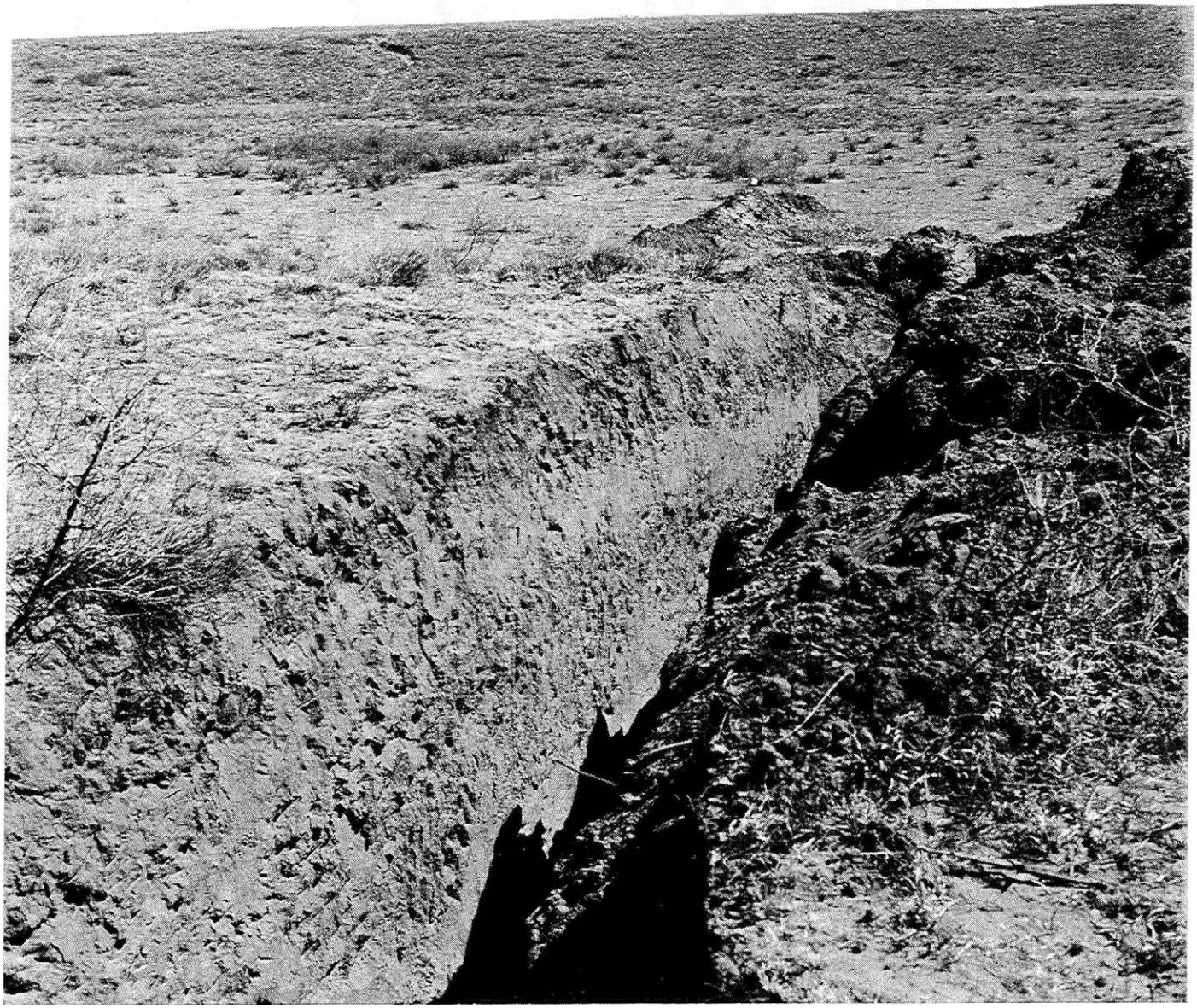


Figure 105. Landscape view of Site 38, foreground, and Site 39, on slope beyond Site 38. The view is east. Photographed March 1977.

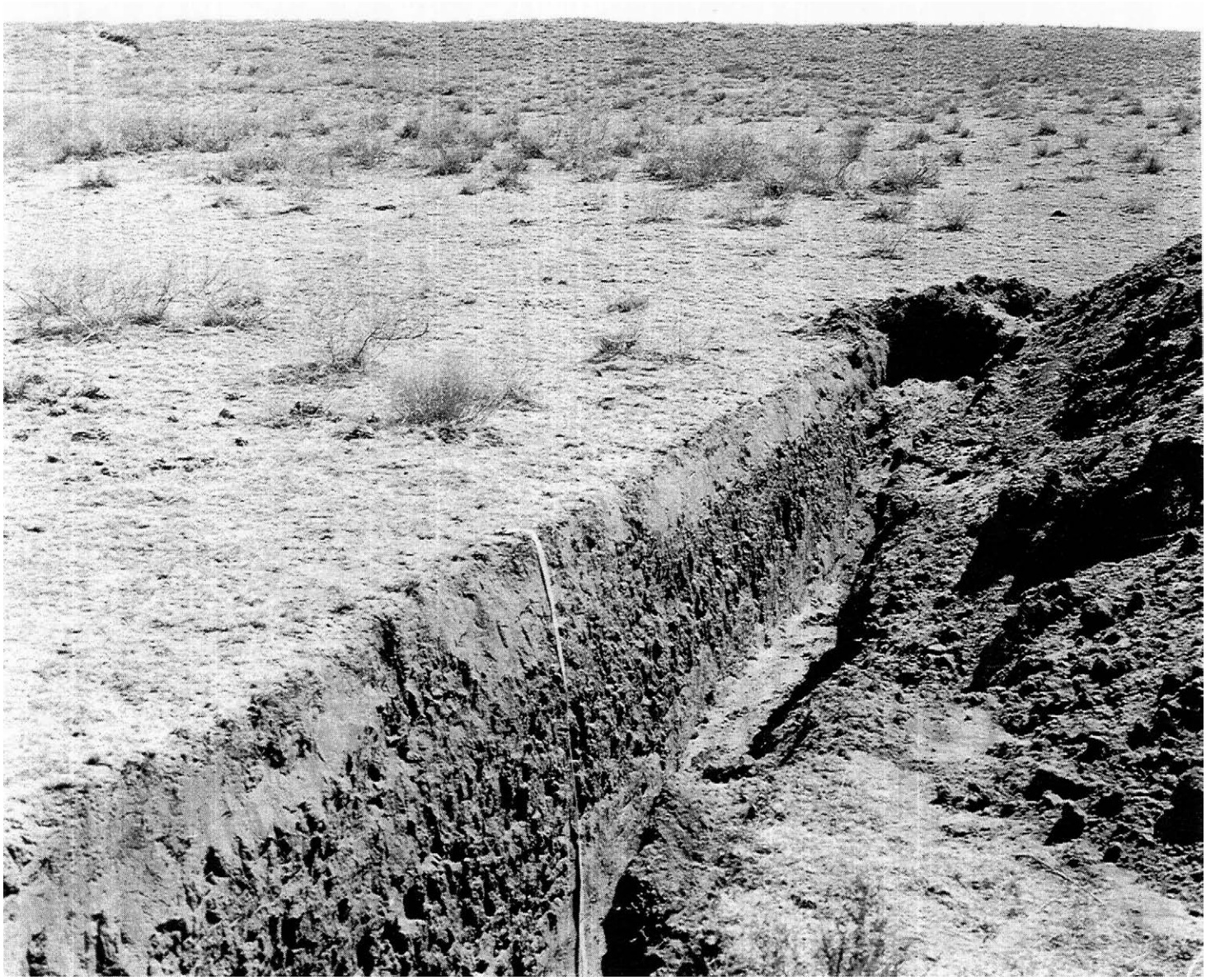


Figure 106. The study trench at Site 39. The tape is at the Psammentic Haplustalf, Texico, at Site 39a. Scale is in feet.

Table 48. Characteristics of Haplustalfs on lower side of dune at Site 39[1/]

Sediment	Horizon	Depth, cm	Hue	Value/chroma Dry	Value/chroma Moist	Structure	Dry consistence	pH	Lower boundary	Textural class	Sand 2.0-0.05 mm	Silt 0.05-0.002 mm	Clay < 0.002 mm
Psammentic Haplustalf, Texico; Pedon 39a[2/]													
M, L	A11	0-4	7.5YR	5/3	3.5/3	m	s	6.8	cw	fs			
	A12	4-20	6YR	5/3	3.5/3	m	s	7.0	cw	fs			
B-II	Ab	20-33	6YR	5/3	3.5/3	m	s	7.0	as	fs			
	B1tb	33-43	5YR	5/4	4/4	m	sh	7.0	as	lfs			
	B21tb	43-55	5YR	5/4	4/4	lmpr-lcsbk	sh	7.0	as	lfs			
	2B22tb	55-64	4YR	5/4	4/4	lmpr-lcsbk	h,vh	7.2	cw	fsl			
B-I	2B21tb2	64-85	2.5YR	5/6	4/6	lmpr-lcsbk	h	7.2	cw	fsl			
	2B22tb2	85-102	2.5YR	5/6	4/6	lmpr-lcsbk	h,vh	7.4	cw	scl			
	2B23tb2	102-114	2.5YR	5/6	4/6	lmpr-lcsbk	vh	7.4	cw	scl			
	2B24tb2	114-125	3YR	5.5/6	4.5/6	lmpr-lcsbk	sh,h	7.4	cw	fsl			
	3B31tb2	125-146	4YR	5.5/5	4/3	m	sh	7.6	cw	lfs			
	3B32tb2	146-165	5YR	5.5/3	4/3	m	s	7.6		fs			
	3Cb2	165-184	6YR	5.5/3	4/3	m	s	7.6		fs			
Aridic Haplustalf, Keeney; Pedon 39b[3/]													
M, L	A11	0-4	7.5YR	5/2.5	3.5/3		sh	6.8	as	lfs	79.2	11.9	8.9
	A12	4-24	7.5YR	5/3	3.5/3	m	sh	6.8	cw	fs	91.9	2.2	5.9
B-I1	Ab	24-34	6YR	5/3.5	3.4/3.5	m	sh	7.0	as	fs	89.7	2.4	7.9
	B1tb	34-45	5YR	5/4	3.5/4	m	h	7.0	cw	lfs	86.5	2.6	10.9
	2B21tb	45-57	5YR	5/4	4/4	lmpr	vh	7.2	cw	scl	72.8	5.2	22.0
	2B22tb	57-71	2.5YR	5/6	4/6	lmpr	vh	7.2	cw	scl	71.6	2.4	26.0
B-I	2B21tb2	71-88	3YR	5/6	4/6	lmpr	vh	7.4	cw	scl	69.0	4.9	26.1
	2B22tb2	88-100	4YR	5/6	4/6	lmpr	h	7.4	cw	fsl	80.6	1.3	18.1
	2B23tcab2	100-109	4YR	5/5	4/5	lmpr	h	7.6	cw	scl	65.7	7.2	27.1
	3B3tcab2	109-134	5YR	5/5	4/5	m	sh	7.6	cw	fsl	83.5	2.0	14.5
	3Cb2	134-149	5YR	6/4	4.5/4	m	s	7.6		fs	95.3	0.9	3.8

1/ Subordinate colors and additional characteristics are footnoted to pertinent soils. Sediments identified as M=Muleshoe, L=Longview, B-II=Birdwell II, B-I=Birdwell I.

2/ Ab: few parts have 5YR hue and 4 chroma. B21tb: few parts 5YR 6/4, dry. 3B22tb: few parts 4YR 6/4, dry.

3/ 2B21tb: parts high in organic carbon, range from 5YR 4/2, dry to 5YR 2.5/2, dry and occur as prism coatings and as bodies from 1 mm to 1½ cm across, within prisms. 2B23tcab2 and 3B3tcab2: a few carbonate filaments, mostly on faces of peds.

encountered, as is common in such areas. Discontinuous strata are visible in the 2B22tb2 horizon, and some continuous strata are visible in underlying horizons. The same two kinds of strata noted at Site 39a also are present at Site 39b, and their contact apparently marks the boundary between wind-deposited and colluvium-containing material.

The evidence at Sites 38 and 39 shows the presence of two ages of Birdwell sediments and of post-Birdwell sediments on east-facing sides of dunes. The deposit may be best developed and thickest only on the lee sides of the highest dunes. Work with the auger indicates that the deposit is also present on the east side of other north-south dunes of Birdwell age.

Site 40. The oak-nonoak transition on a dune of Birdwell age

Oak is most common on the very sandy soils of Muleshoe and Longview age, but in places it also occurs on older soils. In these situations, a surficial sandy layer is critical for the presence of oak. This is illustrated by Site 40 (figs. 84, 107; table 49).

The study trench extends from an oak clump across a nonoak area to another oak clump. A sandy A horizon is at the surface in the oak, but in the nonoak area the A horizon has been eroded and the much harder B horizon is at or very near the surface. The B22t horizon is mainly a loamy fine sand, with clay bands; in places, sedimentary strata are preserved between the bands. There is good gradation to C horizon material beneath the Bt horizon. The C horizon rests abruptly on pre-Birdwell sediments all along the trench (fig. 107).

Table 49. Characteristics of a Psammentic Haplustalf, Texico, on crest of a Birdwell dune at Site 40[1/]

Horizon	Depth cm	Hue	Value/chroma Dry	Value/chroma Moist	Texture	Structure	Dry consistence	pH
A1	0-12	5YR	5/3.5	4/3	fs		s,sh	7.0
B2t	12-30	2.5YR	5/6	4/6	fs	1csbk	h,vh	6.8
B31t	30-64	2.5YR	5/6	4/6	s	1csbk	h	6.8
B32t	64-82	3YR	5.5/5	4/5	s	1msbk	h,sh	6.6
C1	82-107	4YR	5.5/5	4/5	fs	m	s	6.8
C2	107-129	4YR	5.5/5	4/5	fs	m	s	7.0

1/ Subordinate colors and additional characteristics follow. B2t: parts 5YR 6/6, dry. B31t: parts 5YR 6/4, dry, that are lower in clay than the redder parts.

Figure 107. View of Site 40, in Birdwell sediments and the Psammentic Haplustalf, Texico. Oak plants occur in the vicinity of the tape, where about 12 cm of fine sand is at the surface. Beyond the tape the surficial sand is virtually absent, and the Bt horizon is at the surface; oak is not present until sand again thickens at the far end of the trench.Photographed March 1977.

Site 41, dune crest

Site 41 is in a moisture exclosure on the crest of a Birdwell dune. Table 50 summarizes some of the laboratory data (see Appendix for a pedon description and complete data). A photograph of this soil has been presented (Gile, 1981, p. 69).

The narrow crest of the dune and the thin A1 horizon (table 50) indicate strong erosion. Note the high proportion of fine to total clay in the Bt horizon (table 50). The fine clay is similar in amount to fine clay in the buried Bt horizon of Hale age at Site 43, discussed earlier, and is attributed primarily to origin from a thick Bt horizon of Hale age.

Some of the C horizon material is relatively high in clay (table 50), that is also attributed primarily to the parent material source. Primary, sand-size carbonate grains occur in the C horizon, and were apparently derived from high-carbonate horizons at shallow depths in the blowout to the north and northwest (see Sites 53 and 54). Filamentary carbonate in the B3tca horizon was derived from such primary carbonate grains.

The C1&B33t horizon, 94-95 cm, is a distinct whitish lens (table 50). Some of the sand grains in the lens have very thin coatings of clay; this is the redder, Bt part of the horizon. Whitish lenses of sand grains that are free, or nearly free of clay are a feature of parent materials as discussed at Sites 1, 32 and 37.

Table 51 gives mineralogical information for Pedon 41. The pedon is borderline to siliceous mineralogy, for which the definition reads "... more than 90 percent by weight of ...". Since the definition is given in whole numbers and since 90.3 percent rounds to 90 percent, the pedon has mixed mineralogy.

PSAMMENTIC AND ARIDIC HAPLUSTALFS DOMINANT: MAPPING UNIT F, TEXICO-FARWELL COMPLEX

MAPPING UNIT COMPOSITION

Series or variant	Subgroup	Particle-size family	Percentage of mapping unit
TEXICO	PSAMMENTIC HAPLUSTALFS	SANDY	60
FARWELL	ARIDIC HAPLUSTALFS	COARSE-LOAMY	30
Other inclusions (Keeney, Tivoli, Circleback)			10

LOCATION, LANDSCAPE, SOIL OCCURRENCE, VEGETATION

Soils of unit F occur in the southern part of the study area, on a gently undulating landscape, consisting of low dunes, level or nearly level areas, and occasional slight depressions. Commonly, one or more buried argillic horizons occur within 1 m depth. Texico soils are dominant, and occur where the control section averages sandy. Farwell soils occur in three ways: where the soil in the Birdwell sediments contains enough silt and clay to qualify as coarse-loamy; in scattered places where the soil in Roosevelt sediments is at or very near the surface; and as a member of the textural sequence along the margin of low dunes. Keeney soils occur in some of the slight depressions and along the margins of dunes. A few minor areas

Table 50. Data for the Psammentic Haplustalf Texico, S75TX-17-1, at Site 41 1/

Sediment	Horizon	Depth	Particle size distribution, mm: Sand 2-1	Sand 1-0.5	Sand 0.5-0.25	Sand 0.25-0.1	Sand 0.1-0.05	Silt 0.05-0.002	Clay < 0.002	Clay < 0.0002	Carbonate < 2	Carbonate < 0.002	Organic C	Ext. Fe	Bulk density	pH	Textural class	Dominant dry color
		cm	%												g/cc			
Birdwell I	A1	0-4	0.2	2.2	13.5	56.1	16.6	6.6	4.8	4.1	0		0.47	0.3		7.2	fs	5YR 3/4
	B1t	4-17	tr	1.9	11.5	51.3	19.8	4.8	10.7	10.2	0		0.53	0.4	1.61	7.2	lfs	5YR 3/3
	B21t	17-37	tr	3.3	11.0	42.8	25.5	5.1	12.3	11.3	tr		0.33	0.5	1.62	7.4	lfs	2.5YR-5YR 5/6
	B22tca	37-54	0.1	2.3	7.8	48.1	23.7	4.8	13.2	11.1	tr		0.16	0.5	1.59	8.2	fsl	5YR 5/6
	B31tca	54-78	0.1	1.0	4.4	52.8	25.7	3.4	12.6	11.4	tr		0.24	0.5	1.56	8.1	lfs	5YR 5/6
	B32tca	78-94	0.1	0.8	7.6	53.8	18.0	3.5	11.2	10.5	tr		0.11	0.4	1.63	8.3	lfs	5YR 5/6
	C1&B33t	94-95														8.2	fs	7.5YR 8/6
	C2 2/	95-130	0.1	1.9	9.5	45.4	24.5	5.3	13.3	11.2	tr		0.01	0.5	1.58	8.1	fsl	5YR 5/6
		95-130	tr	3.6	18.1	47.6	15.5	3.6	11.6	9.9	tr		0.10	0.4	1.68	8.2	lfs	5YR 5/6
	C3	130-160	0.1	10.3	26.6	42.3	10.0	3.1	7.6	6.9	tr		0.09	0.3		8.1	fs	5YR 5/6

1/ Particle-size distribution is by method 3A1 (Soil Conservation Service, 1972); organic carbon, method 6A1a; extractable Fe, method 6C2b; bulk density, method 4A1h; pH, method 8C1a (1 : 1 H_2O).

2/ The C2 horizon consists of material (first line) that lacks macroscopic stratification and that is dominant in the upper and lower parts of the horizon, and material (second line) that has macroscopic stratification and that is dominant in the central part of the horizon.

Table 51. Sand and clay mineralogy, and resistant minerals of Pedons 41, 43 and 53

Site, laboratory pedon number, and horizon	Sand 1/ Fine QZ	Fine FD	Fine CB	Very fine QZ	Very fine FD	Very fine CB	Percent resistant minerals 2/	Clay 3/
Pedon 41 (S75TX-17-1)								
B21t, 17-37 cm	82	7		81	14		90.3	MM 3, MI 2, KK 2
C3, 130-160 cm				88	8			
Pedon 43 (S75TX-17-2)								
B2t, 57-76 cm	96	4		88	10		93.0	MI 4, MM 3, KK 3
B2tb, 120-142 cm				85	12			MI 4, KK 2, MM 3, MC 1
K3b2, 238-265 cm				66	11	19		MT 3, CA 3, MI 2, KK 2
Pedon 53 (S75TX-17-3)								
B2tca, 19-42 cm	66	4	30	57	10	31	89.8	CA 3, MM 2, MI 2, KK 1
Bca, 181-197 cm				82	14	1		MT 3, MI 3, KK 2, QZ 1, FD 1, CA 1
B22tcab, 250-286 cm				86	9	3		MT 4, MI 3, KK 2, MC 1, QZ 1, CA 1

1/ QZ = quartz (includes some chalcedony), FD = feldspar, CB = carbonate aggregates.

2/ Weighted average resistant minerals in .02-2 mm fraction. Assume resistant minerals in medium and coarser fractions are the same as in the fine sand; resistant minerals in coarse silt are the same as in the very fine sands.

3/ MI = mica, MT = montmorillonite, MM = montmorillonite-mica, MC = montmorillonite-chlorite, KK = kaolinite, CA = calcite. Relative amounts are indicated as 4 = abundant, 3 = moderate, 2 = small, 1 = trace.

of Tivoli and Circleback soils occur discontinuously in Muleshoe and Longview sediments, respectively, in the northern part of the mapping unit.

Vegetation observed in mapping unit F consists of blue grama, hairy grama, sideoats grama, sand dropseed, sand sagebrush, catclaw, soapweed, and wolftail.

TYPICAL PEDON AND RANGES IN SELECTED PROPERTIES

A typical pedon and ranges of Texico are given in mapping unit C. Pedon 42 is a typical pedon for Farwell. See table 52 for characteristics of Pedon 42. Ranges in color and texture follow; underlined entries are typical.

The A horizon has hue of 7.5YR through 10YR, value of 4.5 through 5.5 (5) dry, 2.5 through 3.5 (3) moist, and chroma of 3 through 4. It is loamy fine sand or fine sandy loam.

The Bt horizon has hue of 5YR through 2.5YR, value of 4.5 through 5.5 (5) dry, 4 through 5 (4.5) moist, and chroma of 4 through 6 (5). It is fine sandy loam, commonly with subhorizons of loamy fine sand and/or sandy clay loam, but averaging less than 18 percent clay in the control section.

The C horizon has hue of 5YR through 7.5YR, value of 5 through 7 (6) dry, 4 through 6 (4.5) moist, and chroma of 4 through 6 (5). It is fine sand, sand, or loamy fine sand.

STUDY SITE

Site 42, thinning of major sediments

The stratigraphy in Unit F is the same as in the high Birdwell dunes, but in Unit F the Birdwell sediments are very thin and a buried Bt horizon is at shallow depth. Site 42 illustrates. Figure 108 shows the soil and landscape. Table 52 gives soil characteristics.

The A horizon has the characteristic, relatively smooth feel of many A horizons at stable sites, and reflects the slightly higher silt that accumulates in the upper horizon at such sites. The argillic horizon is thin (15 cm) because the A horizon is relatively high in clay, and only the B21t horizon increases sufficiently in clay to qualify as an argillic horizon (table 52). If the A horizon had less clay, the B1t and B22t horizons would qualify as argillic and the soil would be a Psammentic Haplustalf instead of an Aridic Haplustalf.

The contact of Birdwell sediments on Roosevelt sediments is remarkably abrupt and smooth, as in exposures along Farm Road 1731 (Gile, 1981). The occurrence of Roosevelt on Hale sediments, typical of most of the roadside cuts, is also the situation here. A difference from some of the roadside cuts is that here the buried soil of Hale age has no A2 horizon.

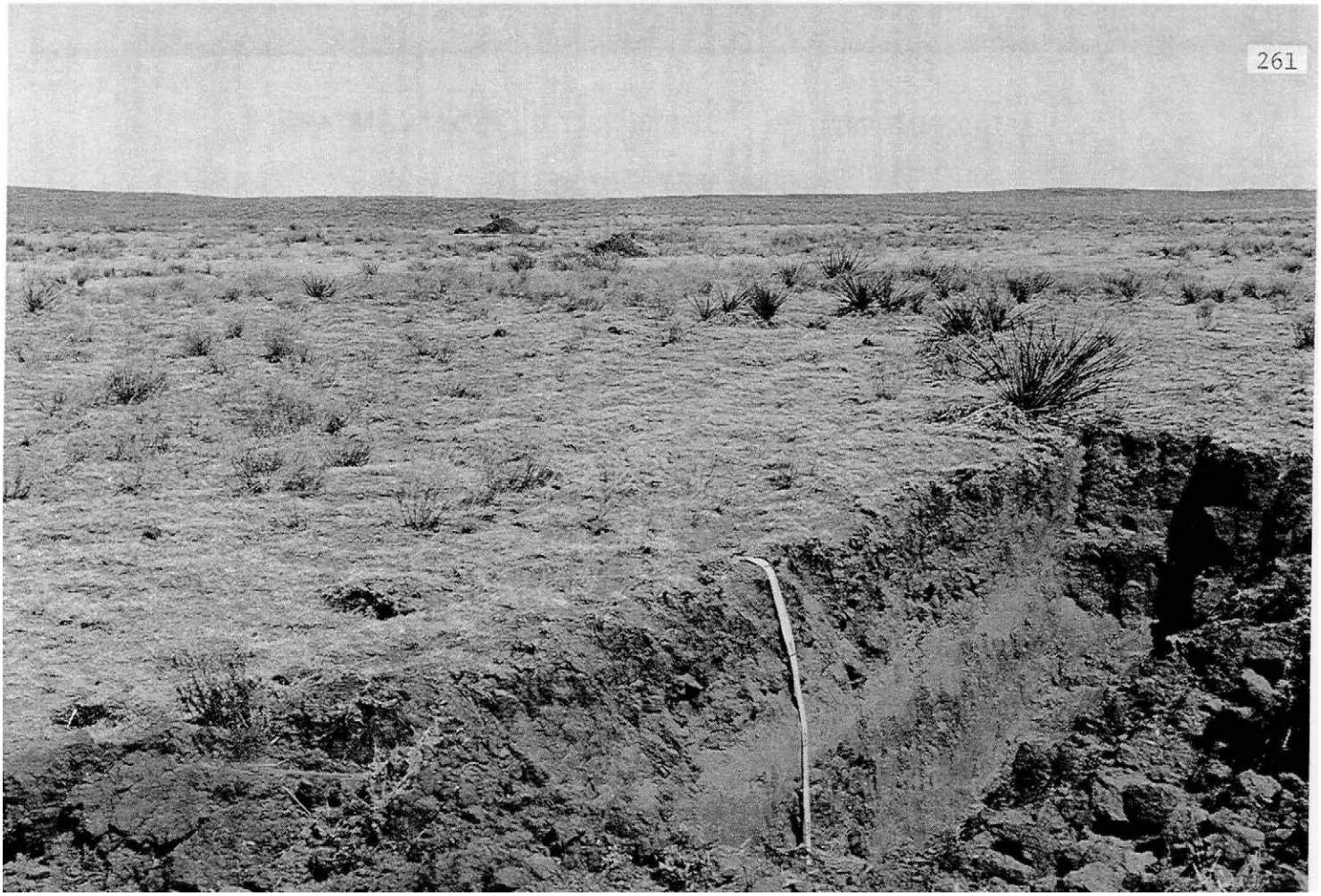


Figure 108. View of the Birdwell surface, study trench, and the Aridic Haplustalf, Farwell, at Site 42. The light-colored band at about 2 ft (0.6 m) is C horizon material of Birdwell age, and overlies Roosevelt sediments. The view is northeast. Scale is in feet. Photographed March 1977.

Table 52. Characteristics of the Aridic Haplustalf, Farwell, at Site 42

Sediment	Horizon	Depth, cm	Hue	Value/chroma Dry	Value/chroma Moist	Structure	Dry consistence	pH	Lower boundary	Textural class	Sand 2.0-0.05 mm	Silt 0.05-0.002 mm	Clay < 0.002 mm
B-I	A1	0-4	7.5YR	5/4	3/3		s	6.8	as	lfs	80.9	10.5	8.6
	B1t	4-14	5YR	5/4	3.5/4	lmsbk	sh	7.0	as	lfs	80.9	8.6	10.5
	B21t	14-29	4YR	5/6	4/6	lmsbk	sh,h	7.0	cw	fsl	79.8	7.2	13.0
	B22t	29-42	5YR	5.5/6	4.5/5	lcsbk	sh	7.0	cw	lfs	84.7	5.0	10.3
	B3t	42-56	5YR	5.5/5	4/5	lcsbk	sh	7.0	cw	fs	90.6	3.0	6.4
	C	56-66	5YR	6/5	4.5/5	m	s,sh	7.0	as	fs	93.4	1.6	5.0
R	B1tb	66-77	5YR	5.5/4	4/4	m	s,sh	7.0	cw	lfs	85.5	4.9	9.6
	B21tb	77-93	5YR	5/4	4/4	lcpr-lcsbk	vh	7.0	cw	fsl	72.9	8.8	18.3
	B22tb	93-131	5YR	5.5/4	4/4	lcpr-lcsbk	vh	7.0	cw	fsl	72.2	10.8	17.0
H	B21tb2	131-151	2.5YR	5/6	4/6	lcpr-lcsbk	vh	7.6	cw	fsl	76.1	4.7	19.2
	B22tcab2	151-175	2.5YR	5/6	4/6	lcpr-lcsbk	vh	8.2		scl	73.6	4.0	22.4

1/ Subordinate colors and additional characteristics follow. B21tb2: parts effervesce weakly. B22tcab2: a few carbonate filaments; effervesces weakly. Sediments identified as: B-I = Birdwell I, R = Roosevelt, H = Hale.

ARIDIC HAPLUSTALFS: MAPPING UNIT G, FARWELL VARIANT

MAPPING UNIT COMPOSITION

Series or variant	Subgroup	Particle-size family	Percentage of mapping unit
FARWELL, THIN VARIANT	ARIDIC HAPLUSTALFS	COARSE-LOAMY	95
Farwell	Aridic Haplustalfs	Coarse-loamy	5

LOCATION, LANDSCAPE, SOIL OCCURRENCE, VEGETATION

Soils of unit G are in one small delineation in the southwestern part of the study area. The southern part of unit G is virtually level. Slope increases northward and the northern part of unit G slopes about 1 percent to the south. The thickness of Birdwell sediments increases northward towards unit F, and in places C horizon material occurs between the Bt horizons of Birdwell and Hale age; these are the Farwell soils.

Vegetation observed in mapping unit G consists of buffalo grass, blue grama, snakeweed, hairy grama, zinnia, three-awn, catclaw, soapweed, side-oats grama, and sand sagebrush.

TYPICAL PEDON AND RANGES IN SELECTED PROPERTIES

Pedon 43 is typical of Farwell, thin variant. See table 53 for characteristics of Pedon 43. All soils in the small area of this unit are similar to Pedon 43.

STUDY SITE

Site 43, sediment coalescence into a thick pseudoPaleustalf

Site 43 (fig. 109) is on the northern margin of a broad, nearly level plain that is in marked contrast to the duned terrain to the north. For a photograph of the soil and landscape at Site 43, see Gile (1981, p. 72, 73). Data are in table 53. Figure 110 is a sketch of the soils and sediments at Site 43 and at Sites 41 and 53 to the north.

South of Site 41 (fig. 110) the soils of Hale and Bailey age, deeply buried beneath Birdwell sediments at Site 41, rise towards the land surface. The vertical arrangement of the land-surface and buried soils is of interest because of genetic implications for soil classification as the buried soils approach the surface. A probe transect between Sites 41 and 43 indicates that the Birdwell sediments are not confined to the high dune at Site 41 but instead continue southward to Site 43. At Site 43 the Birdwell sediments are so thin the the Bt horizon of Birdwell age rests directly on the thick Bt horizon of Hale age; there is no intervening C horizon material as at Site 41. If the stratigraphic relations were not known, it might be possible to mistake Pedon 43 as a Paleustalf since clay does not decrease by more than 20 percent of the maximum within 1.5 m of the soil surface. However, below 76 cm the clay distribution is a feature of the buried soil

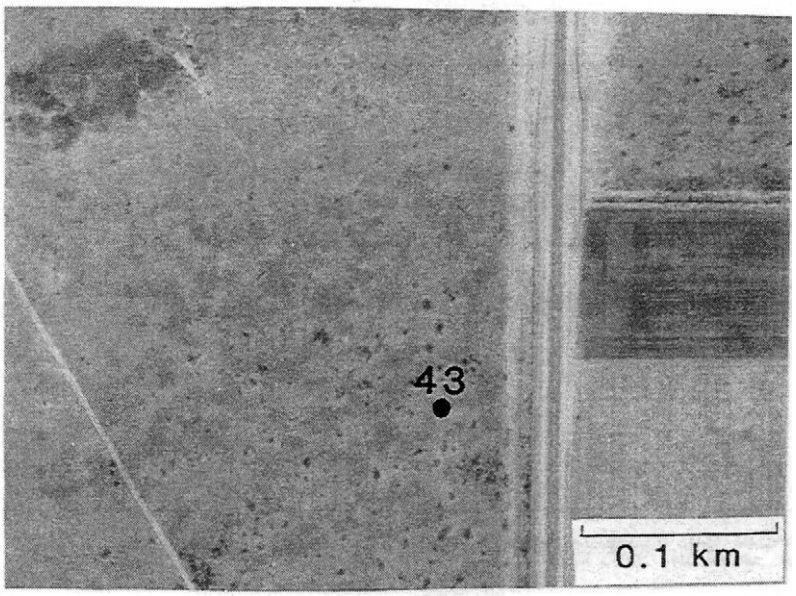


Figure 109. Location of Site 43. Farm Road 1731 is at right. 1970 aerial photograph.

instead of the land surface soil (table 53). Clearly, this pedon -- in which the control section is wholly in the youthful horizons of Birdwell age -- does not belong in the "Pale" great group, and it is classified as an Aridic Haplustalf.

The control section in these soils is the upper 50 cm of the argillic horizon, the top of which is at 15 cm depth (table 53). This thickness averages less than 18 percent clay. Thus Pedon 43 is coarse-loamy. These soils are designated Farwell, thin variant, to distinguish them from Farwell soils in thicker Birdwell sediments in which a C horizon underlies the Bt horizon (e.g., Site 42).

The silicate clay data also suggest soil burial (table 53). Instead of a single clay maximum as is the usual case in soils formed in parent materials of the same age, table 53 shows two distinct maxima above the K horizon -- one in the B2t horizon of Birdwell I age, and the other in the B2t horizon of Hale age. The third maximum shown in the clay column (table 53) is in the K horizon, but this value represents some carbonate clay since carbonates were not removed before the determination was made.

Carbonate content is high in the soil of Bailey I age, and percentages of very coarse and coarse sand increase in the K horizon (table 53). These higher percentages are undoubtedly due to carbonate-cemented aggregates that resisted dispersion during particle size analysis. This reflects the high degree of carbonate cementation that accompanies the high carbonate content.

Table 53. Data for the Aridic Haplustalf Farwell, thin variant, S75TX-17-2, Site 43[1/]

Sediment	Horizon	Depth	Particle size distribution, mm: Sand 2-1	Sand 1-0.5	Sand 0.5-0.25	Sand 0.25-0.1	Sand 0.1-0.05	Silt 0.05-0.002	Clay < 0.002	Clay < 0.0002	Carbonate < 2	Carbonate < 0.002	Organic C	Ext. Fe	Bulk density	pH	Textural class	Dominant dry color
		cm	%												g/cc			
Birdwell I	A1	0-15	0.1	2.4	11.0	48.2	22.2	10.0	6.1	4.1	tr		0.54	0.3		7.1	lfs	7.5YR 5/3
	B11t	15-32	tr	2.8	10.5	46.7	22.4	7.0	10.6	8.1	tr		0.44	0.4	1.57	7.0	lfs	5YR 5/4
	B12t	32-57	tr	2.8	9.0	37.6	22.0	11.6	17.0	13.2	tr		0.45	0.6	1.56	7.2	fsl	5YR 5/4
	B2t	57-76	tr	2.6	8.4	35.0	22.2	12.8	19.0	14.6	0		0.38	0.6	1.65	7.1	fsl	6YR 5/4
Hale	B11tb	76-96	0.1	2.8	9.3	37.4	22.2	11.9	16.3	12.5	0		0.23	0.5	1.70	7.2	fsl	5YR 5/4
	B12tb	96-120	0.1	3.1	9.6	38.8	23.8	7.7	16.9	13.5	tr		0.17	0.5	1.70	7.3	fsl	3.5YR 5/6
	B2tb	120-142	0.1	3.0	8.9	38.9	21.8	6.6	20.7	17.3	tr		0.16	0.6	1.70	7.5	scl	2.5YR 5/6
	B3tcab	142-159	0.1	3.7	8.9	38.4	23.3	6.7	18.9	14.1	tr		0.14	0.6	1.71	7.8	fsl	2.5YR 5/6
Bailey I	K21b2	159-187	13.9	8.4	6.3	14.2	11.1	22.6	23.5	1.7	67	15	0.15	0.1		8.1	scl	7.5YR 8/4
	K22b2	187-238	2.3	4.9	5.9	17.4	13.9	28.2	27.4	2.3	62	20	0.11	0.1		8.3	scl	7.5YR 9/4
	K3b2	238-265	1.3	4.5	6.6	25.1	16.2	22.6	23.7	4.3	39	13	0.06	0.2		8.5	scl	7.5YR 8/4

1/ Particle-size distribution is by method 3A1 (Soil Conservation Service, 1972); organic carbon, method 6A1a; extractable Fe, method 6C2b; bulk density, method 4A1h; pH, method 8C1a (1 : 1 H_2O).

SOUTH OF THE SANDHILLS

An important question is how soils and sediments of the sandhills are related to soils and sediments of the very extensive parts of the High Plains outside the sandhills. Exposures along the margin of the inner Portales Valley, about 1 km south of the study area (front flyleaf), provide information about a nearly level plain that extends to the margin of the valley. One exposure is provided by a caliche pit and two others by nearby trench silos. The exposures give good control on soil morphology on this part of the plain; and because the exposures are along the margin of the valley, they also show effects of valley entrenchment on soil morphology. The exposures have only been briefly examined to date, and deserve further study. They are on the southern margin of the nearly level plain on which Pedon 43, discussed in the previous section, occurs.

Several factors indicate that correlation of valley-margin sediments and sediments of the sandhills must be considered tentative. The stratigraphy has not been determined between the valley margin and the study area to the north. Also, highly calcareous lacustrine sediments occur in the floor of the inner Portales Valley, and more carbonate may have occurred in parent materials and in dustfall along the valley margin than in the study area. For the surficial deposits, an additional factor concerns site stability. Even the stablest portions of the exposures (closest to the plain) slope about 1 percent toward the valley, as compared to the extensive, level or nearly level plain to the north. Thus it seems questionable that soils on the slope represent a stable situation for the accumulation and preservation of the later eolian sediments (i.e., Birdwell and post-Birdwell).

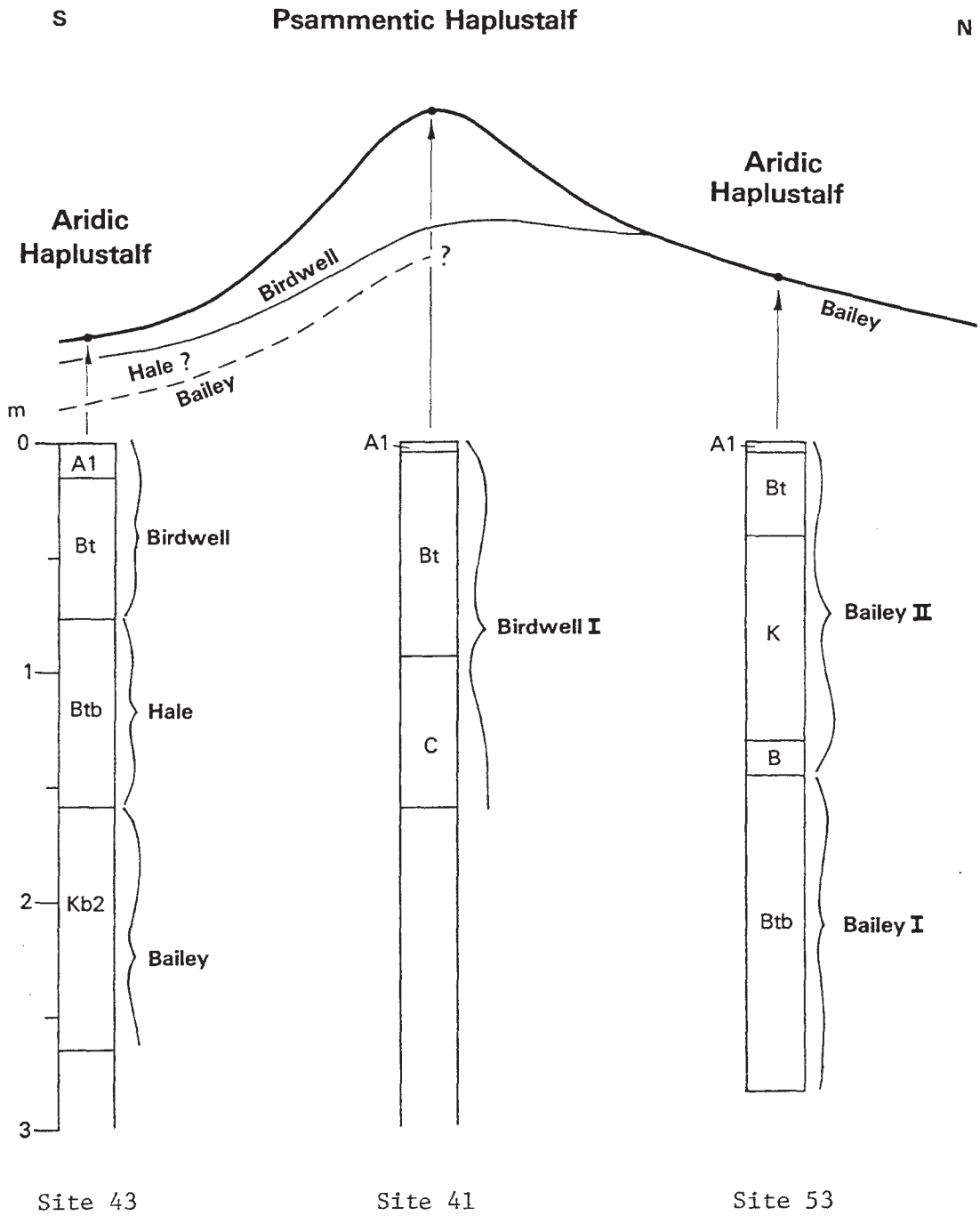


Figure 110. Upper. Sketch of cross section from Sites 43, 41 and 53 west of Farm Road 1731. Birdwell sediments continue southward from the high dune to Site 43 and possibly beyond. Bailey sediments also had dune form, indicating that the dune started to form in mid-Pleistocene time or earlier. No scale.
Lower. Summary of soil horizons and sediments at Sites 43, 41 and 53. Horizon designations are generalized. No horizontal scale.

The caliche pit exposure

The caliche pit exposure (fig. 111) is on the eastern edge of Farm Road 1731, along the margin of the nearly level plain. The exposure shows a reddish Bt horizon that becomes thinner with increasing slope into the valley, and an underlying thick K horizon. No C horizon material is apparent anywhere in the exposure. Pedon BP-1 (table 54) illustrates a soil on the stablest, least-eroded part (the north end) of the caliche pit exposure.

The Bt horizon of Pedon BP-1 is similar in color and texture to the Bt horizon in Hale sediments at Site 43 discussed earlier except that the Bt horizon in the borrow pit exposure has more carbonate (table 54), has more carbonate at shallow depth, and color above the K horizon is slightly less red. These differences may be due to increased carbonate in the parent materials and in dustfall. The Bt horizon is thought to have formed largely in Hale sediments. A thin deposit of post-Hale sediments may be present at the surface; but comparative studies at stablest sites on the plain would be required to demonstrate this. The thick K horizon is thought to have formed in Bailey sediments as discussed later.

Pedon BP-1 is a fine-loamy Aridic Haplustalf that falls within the range of the Keeney soils of the study area (table 4). The pedon does not qualify as a Paleustalf because silicate clay decreases by more than 20 percent of its maximum within 1.5 m of the soil surface. Pedon BP-1 has three general zones of carbonate accumulation: a thin upper zone in the Btca horizon, a middle zone in the underlying K horizon, and a thick lower zone in the Kb2 horizon.

The upper carbonate zone and the Hale-Bailey boundary. The stage I filamentary carbonate in the Btca horizon (table 54) is interpreted as being of middle and late Holocene age. Carbonate in the B22tca horizon constitutes a distinct maximum that decreases with depth until the stage III (K2) horizon is encountered. Does the top of the K2 horizon represent a discontinuity and the top of a buried soil? Several factors suggest so. The boundary between the reddish Bt horizon and the light-colored K2 horizon is abrupt all along the exposure. Occasional groove-like undulations (30-50 cm deep, into which the Bt horizon descends) are thought to represent either eolian grooves eroded before the Hale sediments were deposited, or small watercut drains leading into the inner Portales Valley (these undulations need further study). The abrupt boundary and undulations suggest a discontinuity and emplacement of a younger deposit. Additional evidence of soil burial is discussed in the next section.

The middle carbonate zone, and Bt engulfment by carbonate. Did carbonate in the K2 horizon (table 54) accumulate while the Bt horizon in Hale sediments were developing, or did it accumulate before Hale sediments were deposited? If both the stage I and III carbonate had accumulated during development of the Hale Bt horizon, in these relatively fine materials a distinct morphological connection (e.g., carbonate nodules) would be expected between the two accumulations in arid regions. But in this semiarid area, penetration of the wetting front may have been so much deeper in the Pleistocene than at present that no morphological connection formed, though this seems questionable, given the minor pluvials that occurred since the Tahoka pluvial. An alternative explanation is that the upper maximum was caused by deposition of post-Hale sediments on top of the

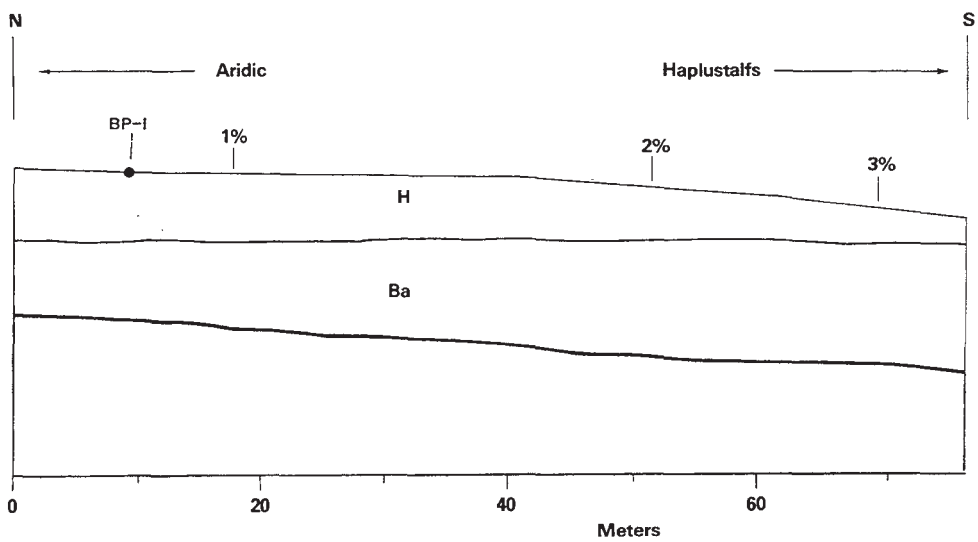


Figure 111. Diagram of caliche pit exposure along the margin of the inner Portales Valley. No vertical scale (see table 54 for horizon thicknesses for Pedon BP-1, located at left). Sediments tentatively identified as H = Hale, Ba = Bailey. A reddish Bt horizon is in Hale sediments and a thick K horizon is in Bailey sediments. Heavy lower line marks bottom of exposure.

Table 54. Characteristics of an Aridic Haplustalf, Pedon BP-1, at the borrow pit exposure[1/]

Horizon	Depth, cm	Hue	Value/chroma Dry	Value/chroma Moist	Structure	Dry consistence	Eff. w/HCl	Textural class	Sand 2.0-0.05 mm	Silt 0.05-0.002 mm	Clay < 0.002 mm
A1	0-3	5YR	4.5/5	3/5/5		s	nc	fsl	79.0	6.6	14.4
B1t	3-10	2.5YR	4.5/5	3/5/5	1csbk	vh	nc	fsl	67.4	14.2	18.4
B21t	10-31	2.5YR	5/6	4/6	1cpr-2csbk	vh	nc	scl	76.9	2.7	20.4
B22tca	31-56	2.5YR	5/6	4/6	1cpr-2csbk	h,vh	e	fsl	75.5	8.1	16.4
B23tca	56-86	4YR	5/6	4/6	1cpr-2csbk	h	e	fsl	80.4	5.2	14.4
B3tca	86-107	4YR	5/6	4/6	1msbk	h	e,nc	fsl	79.0	6.6	14.4
K2	107-127	5YR	8.5/2	7/3	1msbk	h,vh	es	scl			
K3	127-155	5YR	7/4	6/4	1msbk	h	es	scl			
K1b	155-181	5YR	9/2	7.5/3	1msbk	h	es	scl			
K21b	181-184	5YR	9/2	8/3	1msbk	eh	es	vgscl			
K22b	184-209	5YR	9/2	8/3	1csbk	vh	es	scl			

1/ Subordinate colors and other characteristics follow. A1: few parts effervesce weakly. B22tca, B23tca: common carbonate filaments. B3tca: few carbonate filaments and coatings on prisms, prism interiors commonly noncalcareous. K2: also 5YR 6/4, dry. K3: also 5YR 6/4, dry and 5YR 8/2, dry. K21b :also 8/3, dry. Gravels are indurated nodules, ½ - 3 cm diameter, some of which have laminar fabric. K22b :also 5YR 8/3, dry; some indurated blocks.

Hale sediments. Such deposition would effectively lift the zone of carbonate accumulation in Hale sediments. In view of the above questions, the K2 horizon is not designated as buried because some of the carbonate in it, and possibly a substantial amount of carbonate, may have been emplaced while the Bt horizon was developing in the overlying Hale sediments.

Beneath the light-colored K2 horizon is the K3 horizon, which is darker and has higher chroma than the K2 (table 54). When the K3 horizon is traced downslope, in places it grades into a reddish brown Bt horizon that is only slightly carbonate-impregnated. The overlying K2 horizon also is darker and has higher chroma in places. Thus it appears that the top of the K2 horizon represents the top of a former Bt horizon now masked by carbonate accumulation. Buried Bt horizons markedly slow penetration of wetting fronts that pass through overlying horizons (see also Site 54). Thus carbonate could have accumulated on and in the buried Bt horizon, forming the K2 and K3 horizons. Even in pluvials, the buried Bt horizon must have slowed the wetting front, thus "trapping" moisture and carbonate that would have penetrated to considerable depths if the Bt horizon in Hale sediments were underlain by more pervious materials. Carbonate accumulation in a buried Bt horizon would explain the lack of pipes in the K horizon: the relatively fine texture and uniform character of the Bt horizon prevented their formation.

Carbonate accumulations of this magnitude (the K2 and K3 horizons) were not found associated with Hale sediments in the sandhills. As noted earlier, this may be due to increased carbonate in the parent materials and in dustfall, and to the presence of buried Bt and K horizons to hold up the wetting front. But carbonate in the K2 horizon may have accumulated in another manner: the carbonate may have been emplaced in the buried Bt horizon through a post-Bailey, pre-Hale sediment that was largely eroded before Hale sediments were deposited. However, the weight of present evidence seems to suggest that the carbonate accumulated in the K2 horizon while the Bt horizon in Hale sediments was developing. More work is clearly needed on this problem.

The lower carbonate zone. The lower, more prominent zone of carbonate accumulation (the Kb horizon, table 54) appears to have formed during development of the Bailey Bt horizon before it was impregnated with carbonate. Pipes occasionally penetrate the upper part of the Kb horizon, differing markedly in this respect from the K2 horizon above. Because of the considerable thickness of the Kb horizon, this soil as a whole -- consisting of the now carbonate-impregnated Bt horizon (the present K2 and K3 horizons) and the underlying Kb horizon -- is thought to be of Bailey I age. The Kb horizon is considered to be the analogue of the Kb2 horizon at Site 43, where the Bailey I Bt horizon was apparently removed by strong erosion before Hale sediments were deposited.

Downslope from Pedon BP-1, slope increases and in places the K21b horizon is sufficiently cemented for a petrocalcic horizon. Farther downslope the Kb horizon rises towards the land surface and on the lower part of the slope is the shallow K horizon of the land-surface soil. This area, which is just south of the area diagrammed in figure 111, is mantled with spoil and the nature of undisturbed horizons above the K horizon was not determined.

As material above the K horizon thins near the downslope margin of the

exposure, the horizon becomes less hard and generally does not qualify as a petrocalcic horizon. This may be due in part to the numerous pipes that occur on this part of the slope; carbonate needed for plugging the K horizon and development of the petrocalcic horizon has gone down the pipes.

The Birdwell trench silos

Two large trench silos occur on the Birdwell Ranch, just east of the borrow pit and approximately parallel to it. Taken together, the two trenches provide a cross section very similar to the caliche pit exposure. Figure 112 shows the eastern trench and the abrupt boundary between the Bt horizon and the underlying K horizon. As in the caliche pit exposure, a carbonate maximum is common in the Btca horizon. In places, the Btca horizon is underlain by a noncalcareous B3 horizon that rests on the prominent K horizon.

The Bt horizon gradually becomes thinner towards the south and reflects the beginning of steeper slopes that lead into the inner Portales Valley. Pipes are not apparent except for a few on the southeast, downslope part of the trench. Pipes are common, however, in the southern part of the western trench, which was open for viewing and extends farther down the ridge side. This position parallels the lower part of the borrow pit exposure, where pipes are also common.

Figure 112. The eastern of the two Birdwell trench silos, at edge of the nearly level plain at the margin of the inner Portales Valley, beyond the trench. Note the abrupt boundary of the darker Hale sediments on the light-colored sediments of Bailey age. The bottom of the trench is in the thick K horizon. The view is south. Photographed October 1982.

Discussion

The absence of blowouts and dunes, the presence of the carbonate-engulfed Bt horizon beneath Hale sediments, and its continuity along the exposures suggest that the nearly level plain may have undergone relatively little erosion in Birdwell and Hale time as compared to the sandhills. The main process seems to have been the accumulation of eolian sediments as postulated by Brown (1956) for origin of caliche on the northeastern Llano Estacado in Texas. Brown believed that the sheets of eolian sediments were derived from the west or southwest, from the Pecos Basin and possibly from arid areas west of the Pecos.

Brown's hypothesis of eolian aggradation is supported by studies of buried soils that have formed in broad sheets of eolian sediments (Allen and Goss, 1974), who point out that some deposition from northern sources likely occurred. The area studied by Allen and Goss is away from the sandhills, and seems to have been affected mainly by deposition and less by erosion. Presumably the same general intervals of deposition took place in the sandhills, but there the sediments appear to have been dominated by materials derived from the sandhills. Further work is needed to determine the relation of the sandhills deposits to deposits of the High Plains outside the sandhills.

PSAMMENTIC AND ARIDIC HAPLUSTALFS DOMINANT: MAPPING UNIT H, TEXICO COMPLEX

MAPPING UNIT COMPOSITION

Series or variant	Subgroup	Particle-size family	Percentage of mapping unit
TEXICO	PSAMMENTIC HAPLUSTALFS	SANDY	60
KEENEY	ARIDIC HAPLUSTALFS	FINE-LOAMY	20
Newell	Aridic Argiustolls	Fine-loamy	10
Farwell	Aridic Haplustalfs	Coarse-loamy	10

LOCATION, LANDSCAPE, SOIL OCCURRENCE, VEGETATION

Soils of unit H occur in depressions that are located primarily in the central part of the study area. Texico soils are dominant, with Farwell and Farwell, fine-loamy variant in areas of finer texture. Some soils have dark A horizons, but surficial textures are too coarse for a mollic epipedon. However, in some areas next to ridges that contribute runoff, textures are suitable for a mollic epipedon and Newell soils occur. Buried argillic horizons are common within a depth of 1 m.

Vegetation observed in mapping unit H consists of catclaw, blue grama, side-oats grama, hairy grama, sand dropseed, soapweed, sand sagebrush, and three-awn.

TYPICAL PEDON AND RANGES IN SELECTED PROPERTIES

A typical pedon and ranges from Texico are given in mapping unit C. Pedon 49 is a typical pedon for Keeney. See table 57 for characteristics of Pedon 49. Ranges in color and texture follow; underlined entries are typical.

The A horizon has hue of 7.5YR through 10YR, value of 4 through 6 (5) dry, 2.5 through 3.5 (3) moist, and chroma of 2 through 3. It is fine sandy loam or loamy fine sand.

The B2t horizon has hue of 2.5YR through 7.5YR, value of 4 through 6 (5) dry, 3.5 through 4.5 (4) moist, and chroma of 4 through 6. It is heavy fine sandy loam or sandy clay loam, except for thin horizons of sandy clay or clay in some pedons.

Many of these soils (e.g., Pedon 49) have formed in Hale sediments and are underlain by buried soils of Bailey age. High-carbonate calcic horizons of Bailey age occur in some pedons at depths greater than 90 cm. Hale sediments thicken to the north and a sandy C horizon is present beneath the Bt horizon; but in that area these soils are usually buried by younger sediments and their soils. Other Keeney soils have formed in Birdwell colluvium that is thick enough that the argillic horizon averages fine-loamy (e.g., Pedon 44b).

STUDY SITES

Sites 44-46, depressions

Sites 44-46 (figs. 113-115) illustrate soils that occur in blowouts but that do not qualify as Mollisols. Chromas are too high for a mollic epipedon in Pedons 45a, 45b, and 46 (table 55), but it is estimated that all five pedons have too little organic carbon to qualify. This is because upper horizons contain very little clay (table 55); since the percentage of organic carbon is generally related to the percentage of clay, as previously discussed, all five pedons are thought to contain too little organic carbon for a mollic epipedon.

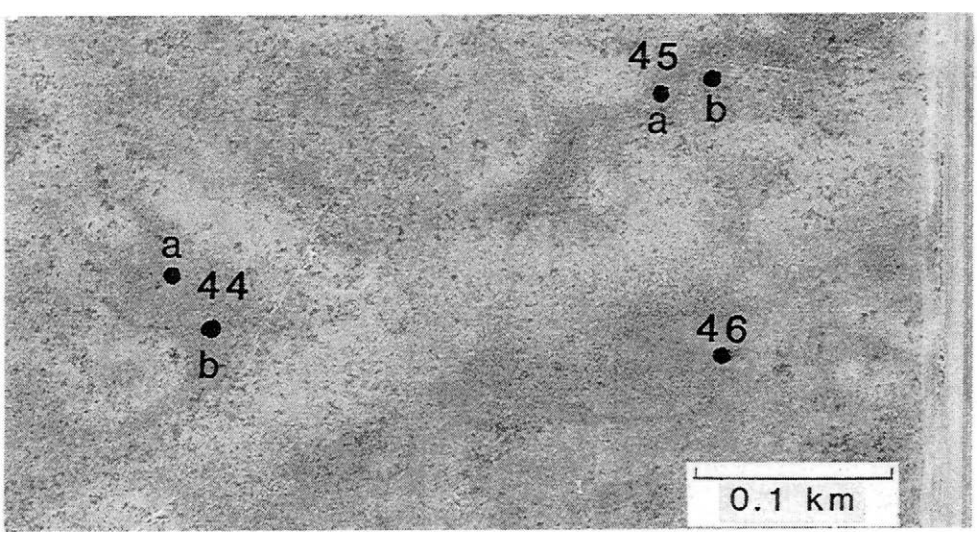


Figure 113. Location of Sites 44-46. Farm Road 1731 is at right. 1970 aerial photograph.

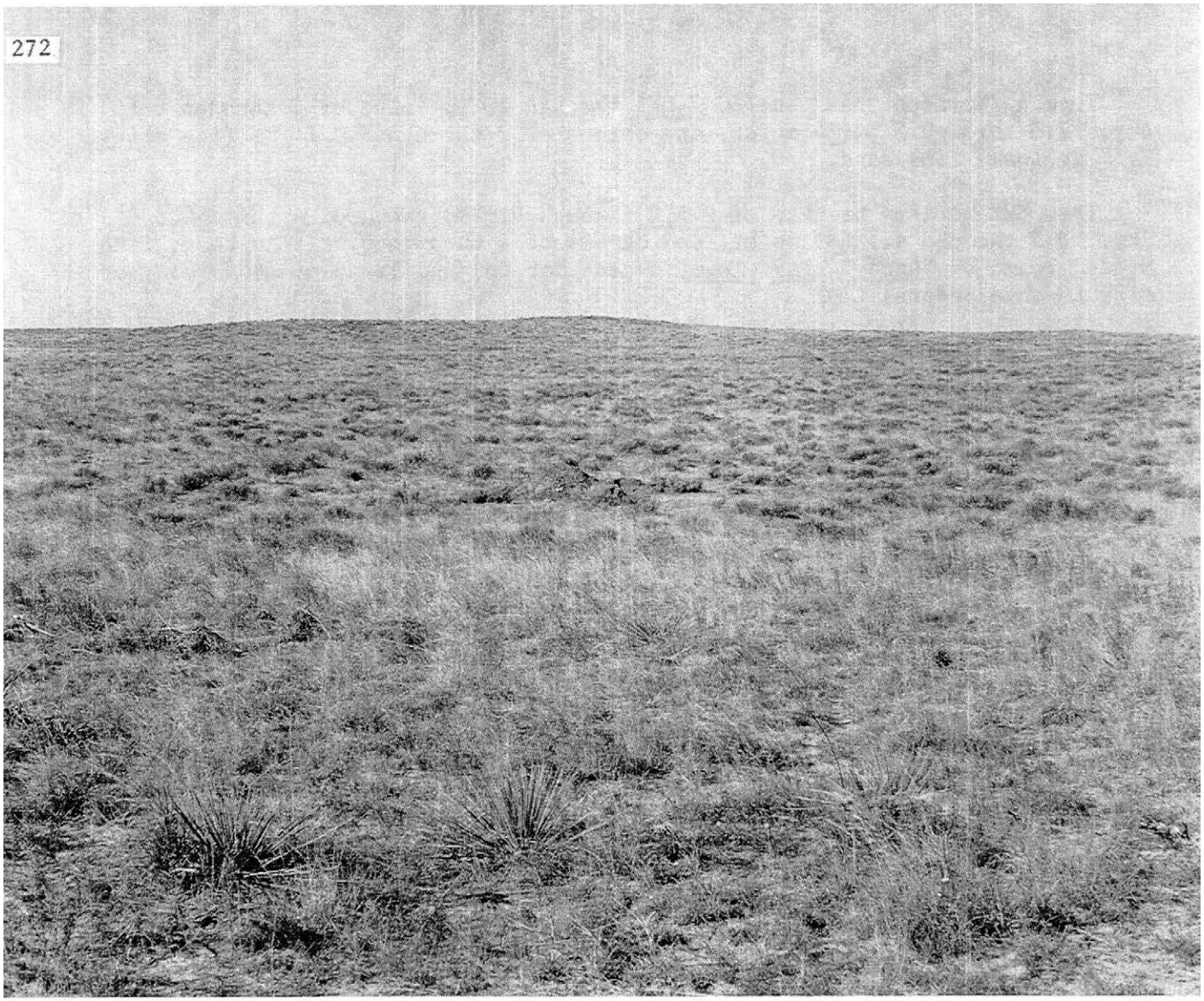


Figure 114. Landscape view of Birdwell surface in a topographic low at Site 44b, adjacent to slight dune, to which the slope in the foreground leads. The view is northwest. Photographed November 1976.

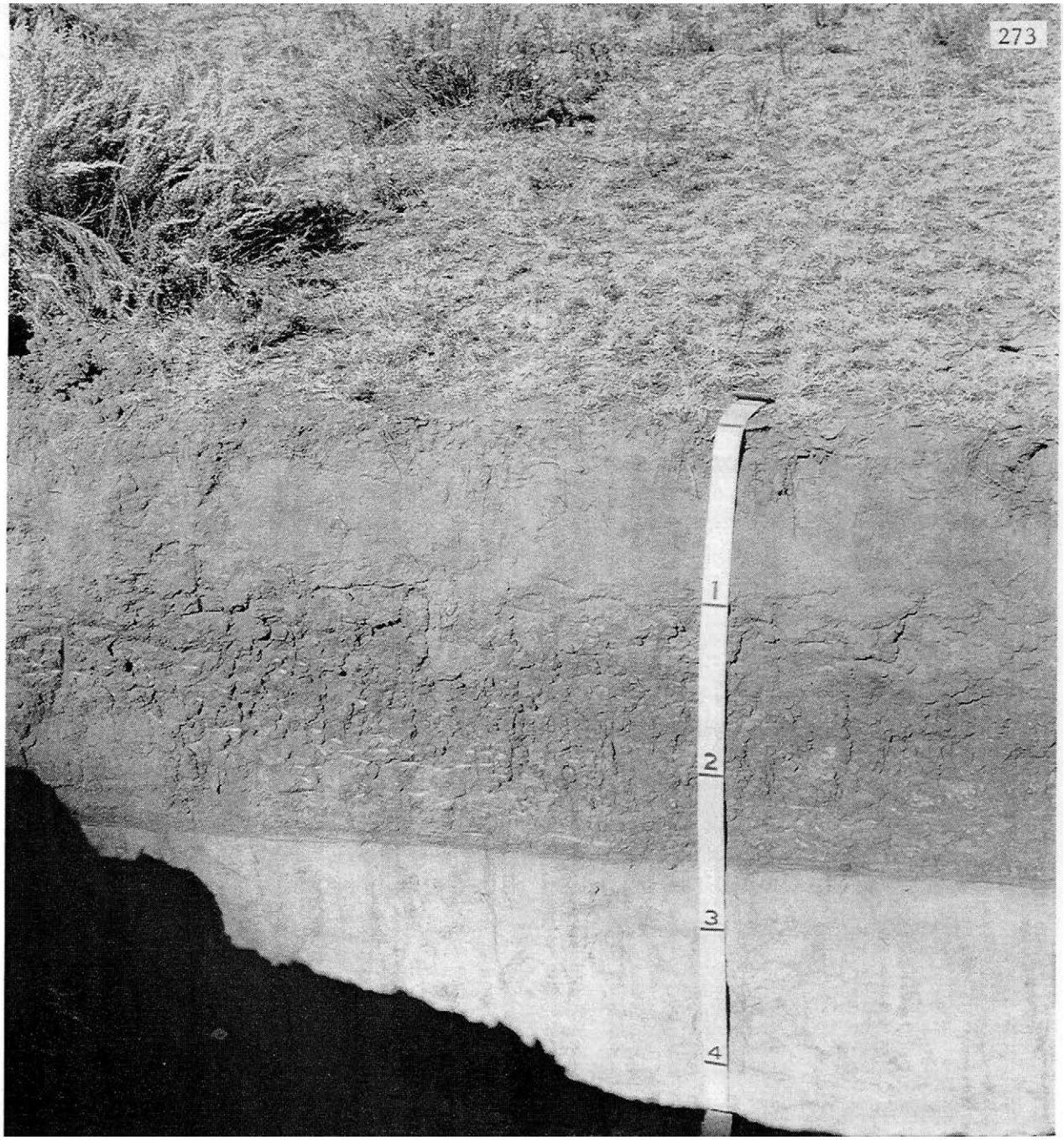


Figure 115. The Aridic Haplustalf, Keeney, at Site 44b. The prominent sedimentary contact at about 2½ ft (0.8 m) is the common basal contact of Birdwell I sediments. Scale is in feet.

Table 55. Characteristics of Haplustalfs in depressions at Sites 44-46[1/]

Sediment	Horizon	Depth, cm	Hue	Value/chroma Dry	Value/chroma Moist	Structure	Dry consistence	pH	Lower boundary	Textural class	Sand 2.0-0.05 mm	Silt 0.05-0.002 mm	Clay < 0.002 mm
Psammentic Haplustalf, Texico; Pedon 44a[2/]													
B-I	A11	0-9	7.5YR	5/4	3/3	m,cr	s	6.8	as	lfs	85.7	8.5	5.8
	A12	9-21	7.5YR	5/5	4/3	m	s	6.8	as	fs	91.7	4.0	4.3
	B1t	21-29	5YR	5/5	4/4	m	s	6.8	cs	fs	88.7	4.2	7.1
	B21t	29-35	2.5YR	5/6	4/6	lcsbk	h	7.0	cs	fsl	82.5	2.9	14.6
	B22t	35-45	2.5YR	4/6	3/6	lcsbk	vh	7.2	cs	ls	83.9	2.8	13.3
	B23t	45-67	5YR	6/6	5/6	lcsbk	vh	7.2	as	fsl	83.3	2.9	13.8
	B3t	67-101	5YR	6/6	5/6			7.2		ls	85.2	2.8	12.0
Aridic Haplustalf, Keeney; Pedon 44b[3/]													
M,L	A11	0-5	7.5YR	5/3	3/3	m	s	6.6	as	fsl			
	A12	5-20	7.5YR	5/4	3/3	m	s	6.8	as	fs			
B-II	A1b	20-28	7.5YR	4.5/4	3/3	m	s	6.8	as	fs			
	B2tb	28-39	6YR	4.5/4	3/4	lmsbk	h	6.8	as	fsl			
B-I	A1b2	39-43	7.5YR	3/2	2/2	2mpr	h	7.0	as	fsl			
	2B21tb2	43-54	5YR	4/4	3/4	2fpr	vh	7.4	as	scl			
	2B22tb2	54-66	3YR	4/4	3/4	2fpr	vh	7.4	aw	clay			
	2B31tb2	66-74	2.5YR	5/6	4/6	lmpr	h	7.4	as	scl			
	3B32tb2	74-76	2.5YR	5/6	4/6	m	sh	7.4	as	ls			
	3C1	76-92	7.5YR	7/6	6/6	m	h	7.4	cw	s			
	3C2	92-116	10YR	8/3	7/3	m	vh	7.6		s			
Psammentic Haplustalf, Texico; Pedon 45a[4/]													
B-I	A11	0-10	7.5YR	5/3	3/3	m	s	6.8	as	fs	88.6	7.1	4.3
	A12	10-24	7.5YR	5.5/4	3.5/4	m	s	6.8	as	fs	92.4	3.1	4.5
	B1t	24-32	5YR	5.5/4	4/4	lmsbk	sh	6.8	aw	fs	91.6	2.9	5.5
	B21t	32-43	7.5YR	4/4	3/4	lcpr-lcsbk	vh	7.0	as	fsl	82.1	2.5	15.4
	B22t	43-56	2.5YR	5/6	4/6	lcpr	vh	7.0	as	fsl	82.8	1.7	15.5
	B31t	56-73	2.5YR	5/6	4/6	lcpr	vh	7.0	cw	lfs	86.0	1.5	12.5
	B32t	73-105	4YR	6.5/6	5/6	lcpr	h	7.2		lfs	88.1	0.8	11.1
Psammentic Haplustalf, Texico; Pedon 45b													
B	A11	0-7	7.5YR	5/3	3/3	m	s	6.4	as	lfs			
	A12	7-34	7.5YR	5/4	3/4	m	s	6.8	cs	fs			
	B1t	34-49	5YR	5/4	3/4	lcsbk	h	6.8	cw	fs			
	B21t	49-73	4YR	5/5	4/5	lmsbk	h	7.0	cw	s			
	B22t	73-82	2.5YR	5/5	4/5	lmsbk	h	7.0	aw	s			
	B31&Bt	82-113	5YR	6/6	4.5/6	m	sh	7.0		s			
	B32&Bt	113-140	5YR	6.5/6	5/6	m	sh	7.2		s			
Psammentic Haplustalf, Texico; Pedon 46													
B-I	A11	0-9	7.5YR	5/3	3/3	m	s	6.8	as	lfs	82.3	9.7	8.0
	A12	9-27	7.5YR	5/4	3/4	m	s	6.8	cw	fs	90.0	4.6	5.4
	B1t	27-38	5YR	5/4	4/4	m	sh	6.8	cs	lfs	87.2	5.2	7.6
	B21t	38-51	4YR	5/4	4/4	lcsbk	vh	6.8	cs	fsl	73.6	8.7	17.7
	B22t	51-69	5YR	5/5	4/5	lcsbk	vh	7.0	cs	lfs	82.8	4.7	12.5
	B3t	69-83	5YR	5/5	4/5	lcsbk	h	7.0	cw	lfs	88.6	3.0	8.4
	C	83-120	5YR	5/5	4/5	m	sh	7.0		s	91.5	2.7	5.8

1/ Subordinate colors and other characteristics are footnoted to pertinent soils. Sediments identified as: M = Muleshoe, L = Longview, B = Birdwell, B-II = Birdwell II, B-I = Birdwell I.

2/ B21t: parts 5YR 4/4, dry. B3t: clay linings, 2.5YR 4/6, dry in pores. The horizon grades to a mottled zone on west end of trench, colored 10YR 8/3, 7.5YR 7/8, and 2.5YR 4/6, dry, texture loamy sand.

3/ A1b: parts 6YR 4/4, 7.5YR 2/2 and 7.5YR 2/1, dry. 3B32tb2: parts 2.5YR 4/6, dry. 3C2: a few clay bands, about 1 mm thick, are 7.5YR 7/8, dry.

4/ B21t: parts 2.5YR 5/6, dry. B22t: parts 2.5YR 4/4, dry.

Site 44

Site 44 (fig. 113) consists of two study trenches, Sites 44a and 44b, that illustrate the significance of nearby slopes to occurrence of colluvium. Pedon 44a, without nearby slopes, has formed in Birdwell eolian sediments without colluvium.

Particle size analyses for Pedon 44a (table 55) show a distinct clay maximum, but because of low silt the soil is in the sandy family and the Psammentic Haplustalfs. The analyses also show more silt and clay in the A11 horizon than in the A12 horizon. This is common at stable sites, and indicates addition of clay and silt from dustfall after soil development started.

Pedon 44b, closer to a dune, has the thin, but distinctive Bt horizon that is typical of colluvium-containing deposits (see also Sites 33-35 and 39). The upper horizon of Birdwell I is a distinct buried A horizon. Intermixed in it are reddish, light-colored parts (table 55) that were apparently derived from the Bt horizon formed in the overlying younger sediments. These parts were apparently introduced into the A1b2 horizon after its burial, a phenomenon observed elsewhere (e.g., see Pedon 33d).

Site 45

The two soils at Site 45 (table 55) illustrate soils of Birdwell sediments in narrow troughs. The Birdwell accumulation is a part of the near-continuous blanket of Birdwell sediments in this area (fig. 19). Particle-size analyses (table 55) show Pedon 45a to fall easily into the sandy family and to be a Psammentic Haplustalf. The marked increase in silt in the A11 horizon indicates additions from dustfall. Pedon 45b, not analyzed, also is a Psammentic Haplustalf.

Site 46

Pedon 46 (table 55) is in a larger depression than at Sites 44 and 45. The argillic horizon (table 55) is nearly, but not quite in the coarse-loamy family, and the soil is a Psammentic Haplustalf. As with the other pedons at Sites 44-46, a distinct increase in silt is apparent in the surface horizon, and Pedon 46 also has an increase in clay.