CHAPTER 4. SOILS AND SEDIMENTS EXPOSED IN A LARGE ACTIVE BLOWOUT

The large light-colored area east of Farm Road 1731 (fig. 28) is an active blowout, the origin of which was discussed in Chapter 1. The extensive exposure in the blowout provided an opportunity to study the soils and sediments, examined at Sites 1-3 (fig. 28). Sites 1a through 1d are on the large south-facing dune remnant on the east side of the blowout. Site 2 is in a small Muleshoe remnant between Sites 1 and 3. Sites 3a through 3g are in a north-south exposure along the western margin of the blowout. Table 11 gives soil characteristics at Sites 1 and 2.

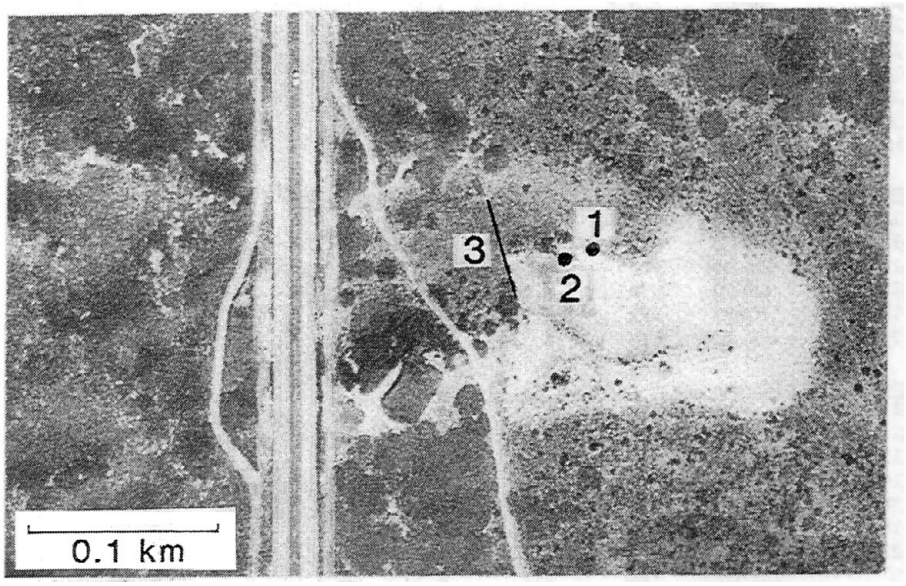


Figure 28. Location of Sites 1-3 in the active blowout (1970 photograph).

SITE 1, USTIPSAMMENTS OF THE EAST REMNANT

Site 1 is on a large dune remnant on the east side of the blowout. Figure 29 shows the dune remnant and locates Sites 1a, 1b, 1c, and 1d. Erosion on the south face of the remnant has resulted in good exposures in an east-west direction (fig. 29). The exposures are deep enough that they reveal two distinctly different sets of sedimentary beds. Beds of the upper

Table 11. Characteristics of Ustipsamments at Sites 1 and 2[1/]

Sediment	Horizon	Depth, cm	Hue	Value/chroma Dry	Value/chroma Moist	Tex-ture	Struc-ture	Dry consis-tence	pH	Lower boundary
Typic Ustipsamment, Tivoli, on central side of dune[2/]										
Fairview	C1	0-18	5YR	6/4	4.5/4	fs	m,sg	s,l	6.8	cw
	C2	18-51	5YR	6/4	4.5/4	fs	m	s	7.0	cw
	C3	51-87	5YR	6/4	4.5/4	fs	m	s,sh	6.8	cw
	C4	87-122	5YR	6/4	4.5/4	fs	m	s,sh	6.8	cs
Longview II	A1b	122-137	7.5YR	5.5/4	4/4	fs	m	s,sh	6.8	
Typic Ustipsamment, Tivoli, on crest of dune: Pedon 1b[3/]										
Fairview	C1	0-14	7.5YR	6.5/4	5/4	fs	m	s	7.0	gw
	C2	14-30	7.5YR	6.5/4	5/4	fs	m	s,sh	7.0	gw
	C3	30-40	7YR	6.5/4	5/4	fs	m	s,sh	7.0	cw
Muleshoe	A1b	40-54	7.5YR	5/3	4/3	fs	m	sh	7.0	cw
	A2b	54-66	7.5YR	6.5/3.5	5/4	fs	m	s	7.0	aw
Longview II	A1b2	66-80	7.5YR	6/4	4.5/4	s	m	s,sh	7.0	cw
	B11b2&Bt	80-93	5YR	6/4	5/4	s	m	sh	7.2	as
	B12b2&Bt	93-114	5YR	6/4	5/4	s	m	sh	7.2	as
	B2b2&Bt	114-132	5YR	6/4	5/4	s	m	sh	7.2	as
	B3b2&Bt	132-174	5YR	6.5/4	5/4	s	m	sh	7.0	cs
	Cb2	174-194	6YR	6.5/4	5/4	fs	m	s,sh	6.8	
Alfic Ustipsamment, Circleback, on central side of dune: Pedon 1d[4/]										
Longview II	A11	0-13	7.5YR	5.5/3.5	4/3	s	m	sh	6.8	cw
	A12	13-28	6YR	6/4	4.5/4	s	m	sh	6.8	cw
	A13	28-46	5YR	6.5/4	4.5/4	s	m	sh	6.8	cw
	B11	46-70	5YR	6.5/5	4.5/5	fs	m	sh	6.8	as
	B12&Bt	70-91	5YR	6.5/5	5/5	fs	m	sh	6.8	as
	B2&Bt	91-114	5YR	6.5/5	5/5	fs	m	sh	6.8	
Typic Ustipsamment, Tivoli, on dune remnant at Site 2[5/]										
Fairview	C1	0-15	5YR	6/4	4.5/4	fs	m	s	7.0	cw
	C2	15-33	5YR	6/4	4.5/4	fs	m	s	7.0	cw
Muleshoe	A11b	33-54	7.5YR	5/3	3.5/3	fs	m	s	7.4	cw
	A12b	54-70	5YR	5/3	3.5/3	fs	m	s	7.4	cw
	A3b	70-91	5YR	6/4	4.5/4	fs	m	sh	7.4	cw
	B1b	91-117	5YR	6/4	4.5/4	fs	m	sh	7.4	ab
	B2b&Bt	117-141	5YR	6/4	4.5/4	fs	m	sh	7.4	ab
	Cb	141-167	5YR	6/4	4.5/4	fs	m	s	7.4	

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

2/ This soil has now been removed by erosion.

3/ A1b: some parts 7.5YR 6/4, dry. B11b2&Bt: clay-enriched splotches, of irregular shape, 5YR 5/4, dry. B12b2&Bt, B2b2&Bt, B3b2&Bt: clay bands 5YR 5/4, dry.

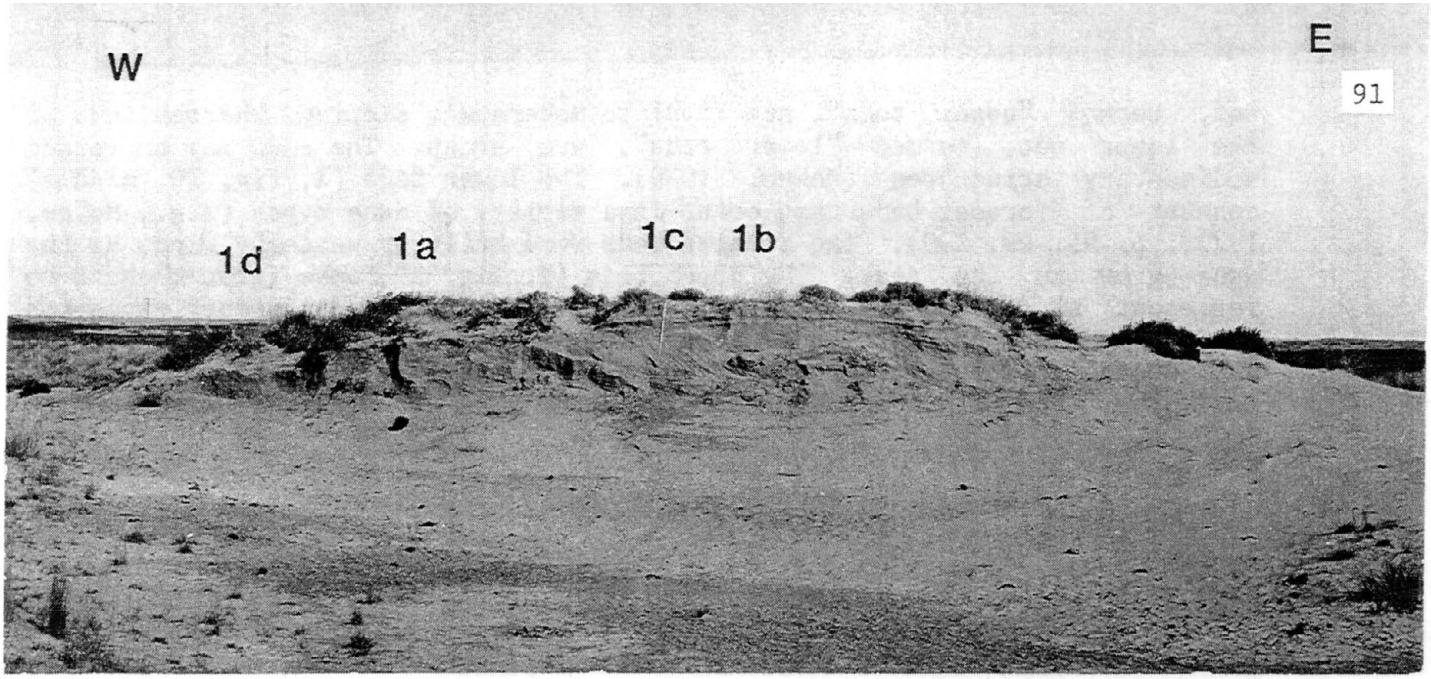
4/ A11: a few parts slightly darker. B12&Bt, B2&Bt: clay band and occasional bits of clay-enriched material colored 5YR 5/4, dry.

5/ A3b: parts 5YR 5/3, dry.

Figure 29. Opposite page. Upper. The east remnant and location of Sites 1a, 1b, 1c, and 1d. The tape is at Site 1c. The view is north. Photographed October 1982.

Middle. Closer view of the dune crest. The tape is at Site 1b. X = lower, steep beds; Y = upper, level to moderately sloping beds. The top of the buried A1 horizon in Muleshoe sediments is at a depth of slightly less than 1½ ft (0.5 m) at the tape. Scale is in feet.

Lower. The same area photographed March, 1983. Erosion since October 1982 has exposed a deeper section. Hammer gives scale.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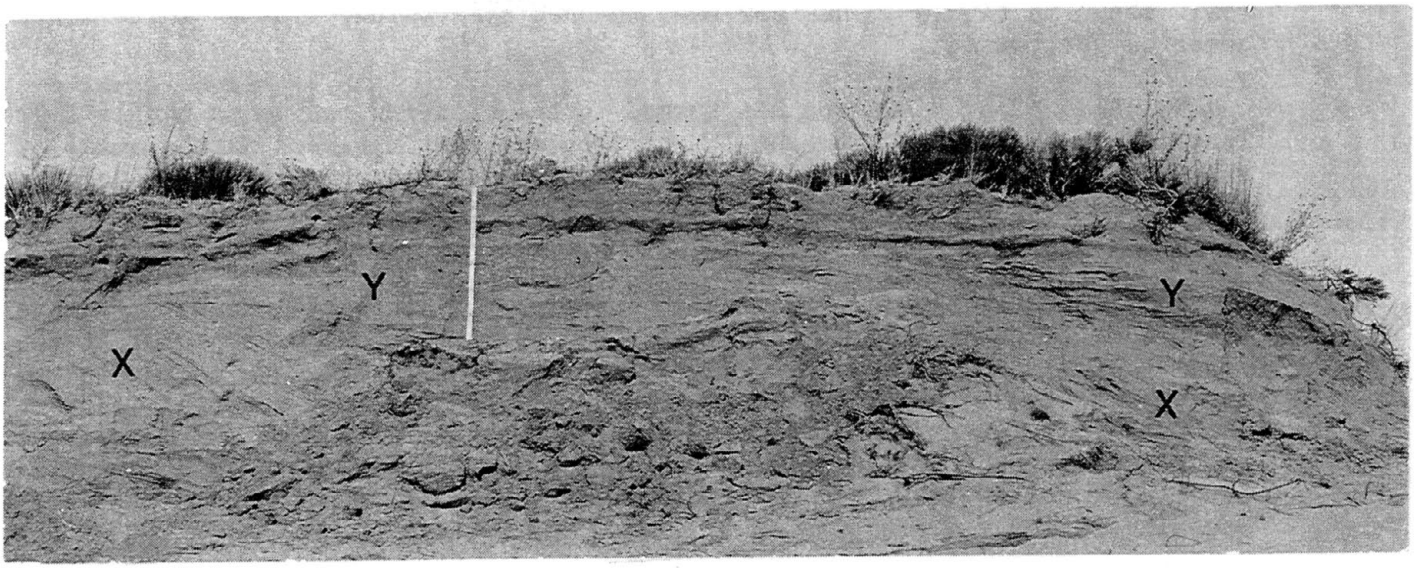
1d
1a
1c
1b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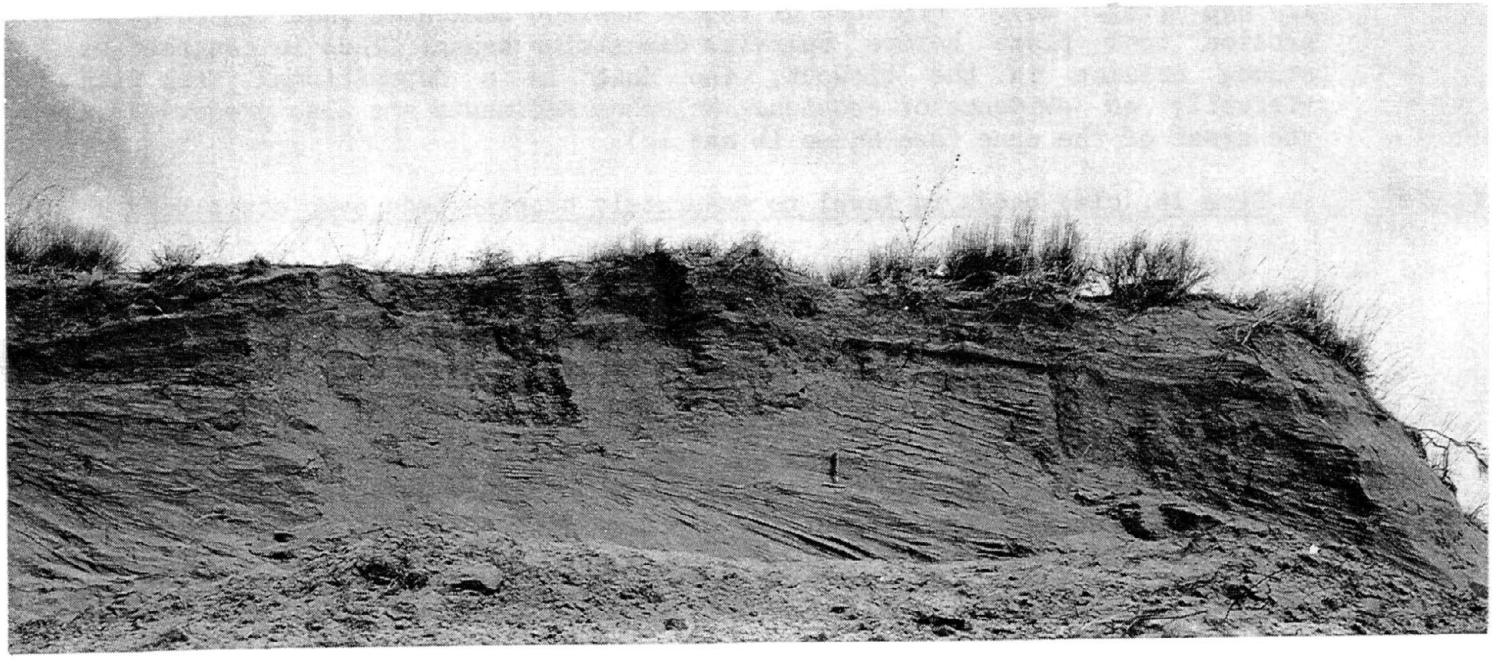
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set, termed "upper beds", are level to moderately sloping, whereas beds of the lower set, termed "lower beds", are steep. The beds may be termed sedimentary structures (McKee, 1979). The lower beds (X, fig. 29, middle) consist of foreset beds that occur in a variety of dune types (e.g., McKee, 1979, p. 95, 99, 100). The foreset beds were built by westerly winds as the dune grew to the east. The upper beds (Y, fig. 29) were first thought to represent a cut and fill structure (Gile, 1983). But deeper exposures caused by erosion between October 1982 and March 1983 (fig. 29) show that the dominant slope in the upper beds is to foreset beds on the east side of the dune, and it now appears that the upper beds are crest deposits (McKee, 1979, p. 126).

Site 1a, pedogenesis in Fairview sediments

Pedon 1a (fig. 20) is in a thick deposit of Fairview sediments. Sediments of the Fairview surface are thick enough ($\geq$50 cm) to be considered in the soil classification system only in a few areas. The area adjacent to the large blowout (fig. 19) contains the largest and thickest deposit of Fairview sediments in the study area. A soil near the tape (fig. 20) is discussed below; table 11 gives some of its characteristics. Although the soil shown in figure 20 has now been removed by erosion, similar soils still occur on the remnant.

No A1, A2 or B horizon has formed in the Fairview sediments (table 11). Instead, subdivisions of the C horizon are distinguished on the basis of such features as zones of root concentration and characteristics of the parent materials. Texture is fine sand throughout (table 11) as is typical of Fairview deposits.

In places, Fairview sediments contain whitish sand lenses that range from 1 mm to about 1 cm in thickness. The whitish color is the color of the sand grains, which are virtually free of coatings. Presence of the lenses in the Fairview deposits shows that they are a parent material feature. Some whitish lenses are still preserved in the lower B and in the C horizons of older soils (Sites 36, 41) but in many places the lenses have been partly or completely obliterated by subsequent accumulations of pedogenic clay. See Site 32 for a discussion of origin of the whitish lenses.

The Fairview deposit rests abruptly on a buried A1 horizon of Longview II age (fig. 20). Presence of the A1 horizon indicates that little or no erosion took place before Fairview deposition began. Thus in contrast to strong erosion in the blowout, the dune is a depositional area with virtually no evidence of erosion. Muleshoe sediments are also preserved on the crest of the dune (see Sites 1b and 1c).

Site 1b, clay bands in level to moderately sloping beds over steep beds

The pedon at Site 1b (figs. 29, 30; table 11) is in Fairview, Muleshoe, and Longview II sediments. Both Muleshoe and Longview sediments are in an area of general Muleshoe and Longview sedimentation (fig. 19), so deposits of these ages would be expected in the dune. Horizons like the upper part of Longview I at Site 3a, to be discussed, have been observed at the base of the blowout near Site 1d. Longview I sediments are presumed to underlie Longview II sediments at Site 1, but this aspect needs more study. The blowout exposures provide an opportunity to study pedogenic expression in thick Longview II deposits and to compare it with that in thin deposits of

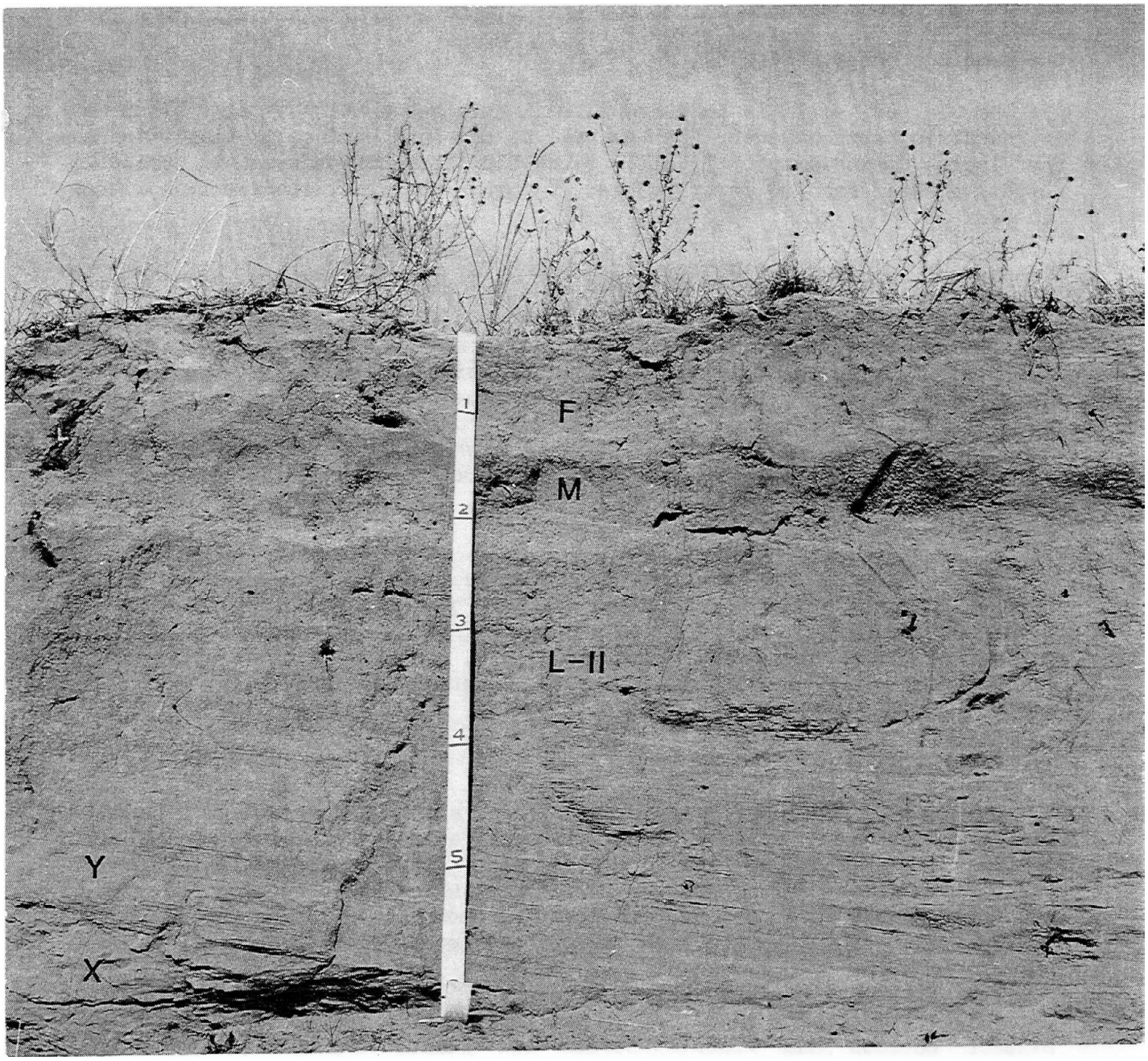


Figure 30. Closer view of Site 1b. Sediments identified as F = Fairview, M = Muleshoe, L-II = Longview II. The contact between the lower steep beds and the upper beds is at lower left. The upper beds (Y) are level or nearly level at right but increase in slope at left. Scale is in feet.

the same age nearby (Site 3).

The buried soil in Longview II sediments has continuous clay bands and is an Alfic Ustipsamment. But the soil at the land surface is classified as the Typic Ustipsamment, Tivoli, since the Alfic Ustipsamment is buried to depths greater than 50 cm by younger sediments that lack diagnostic horizons (Chapter 3).

Horizons in Muleshoe sediments

The A1 and A2 horizons in Muleshoe sediments are distinct. The A1 horizon, in particular, is characteristic in soils of Muleshoe age, and will also be seen in a thicker Muleshoe deposit at Site 2. Tracing eastward across the exposure shows that the Muleshoe sediments occur continuously, but that the A1 horizon of Longview II age gradually thins eastward and then disappears on the east margin of the crest, where the A1 horizon of Muleshoe age has formed partly in the clay band horizon of Longview II age. This must reflect soil erosion in Muleshoe time, since the clay band horizon at stable sites is well below the A horizon.

Muleshoe sediments must have covered much of the dune crest before the blowout formed. This is indicated by their persistence through a number of cycles of sediment spalling from the south face of the exposure as the dune gradually eroded northward since March 1978, when the presence of A1 and A2 horizons in Muleshoe sediments above Longview II sediments was first recorded on the crest of the dune.

Horizons in Longview II sediments

The buried soil of Longview II age has a thin A horizon and a banded B horizon over a C horizon with virtually no pedogenic clay. Below the A horizon are the upper and lower beds that differ considerably in slope as previously discussed. The upper beds, in which the B horizon and most of the clay bands are formed, are level to moderately sloping (about 25 percent). The lower beds are much steeper and commonly slope about 50 percent.

The B11b2&Bt horizon has scattered, small, clay-enriched zones of irregular shape, 5YR 5/4, dry, but no visible sedimentary strata. The B12b&Bt horizon has visible strata and faint, very thin (1 mm and less) discontinuous clay bands from about 1 mm to 1 cm apart. The bands show little undulation, and occur along the strata. The B2b2&Bt horizon is distinctly stratified. It has four continuous bands ranging from 1 to 2 mm thick and from about 1 to 5 cm apart, and also has thinner bands like those in the B12b2&Bt horizon. Clay bands decrease in thickness and number in the B3b2&Bt horizon. The lower boundary of the B3b2&Bt horizon is marked by a clay band. The boundary coincides with the boundary between the upper and lower beds, and a change from sand to fine sand texture (table 11). Such discontinuities are often marked by clay accumulation because water tends to "hang" along the contact.

The A-B1-B2-B3-C horizon arrangement; gradual increase, then decrease in expression of clay bands; and virtual absence of clay in the C horizon, all indicate that clay in the clay bands is primarily to wholly of illuvial origin. Some of the illuvial clay may have been derived from thin clay coatings that are common on sand grains in many freshly deposited sandy sediments. Some sand-size aggregates of clay could have been present, also.

But the bulk of the clay is thought to have been derived from dust deposited on the soil surface following dust storms.

Site 1c, clay bands in steep, shallow beds

Changes in slope and soils take place west of Pedon 1b. Slope of the land surface increases to about 3 percent to the west, as slope of the upper beds continues at about 25 percent to the east. These slope differences cause important changes in soils, as illustrated by Pedon 1c (not sampled, but shown in fig. 31).

Effects on surface proximity on strata and clay bands

West of the moderately sloping upper beds (in which clay bands of the B&Bt horizon have formed), individual sedimentary strata gradually disappear as they approach the A1 horizon. Also toward the A1 horizon, clay bands gradually become less distinct and finally disappear altogether. This is a typical effect of proximity to the soil surface on expression of clay bands: the combined effect of soil biota and percolating water prevents development of the bands. Similarly, if clay bands formed in B position and upper horizons were later truncated, bands nearest the land surface are eventually obliterated by percolating water and soil biota.

Effects of surface proximity on clay bands along the contact between beds of differing slope

The cross section from Site 1b to Site 1c shows the effect of a contact between beds of differing slope and the depth to that contact on the accumulation of illuvial clay. Thus at Pedon 1b (fig. 30) the contact between the moderately sloping and steep beds is about 1 m below the Longview II surface, but at Pedon 1c the contact is about 30 cm below the Longview II surface. From Pedon 1b towards Pedon 1c, one to several clay bands that have formed along and near the contact gradually become more prominent as they approach the surface. But in the vicinity of Pedon 1c, as clay bands along the contact come even closer to the surface, the bands first become discontinuous and then are obliterated altogether (left of tape, fig. 31).

An associated phenomenon involves clay illuviation in the steep, lower beds. From Pedon 1b nearly to Pedon 1c, virtually no illuvial clay occurs in these steep beds. But where both the moderately sloping beds and the contact to steep beds are absent, the analogue of clay that accumulated in these two positions has accumulated instead in the steep beds. This is shown near the tape at Pedon 1c (fig. 31), where steep beds are directly beneath the A1 horizon. Below the tape, illuvial clay may be traced to a depth of about 130 cm below the Longview II surface — deeper than in the moderately sloping upper beds. This is additional evidence of illuvial origin of the clay bands: where the moderately sloping strata and underlying sedimentary contact are not present to hold up the wetting front, clay in the soil solution descends to greater depths. The extension of clay down these strata explains why there is very little clay just beneath the A horizon; because of this highly pervious avenue for moisture movement, the deeply penetrating wetting front has moved clay to substantial depths.

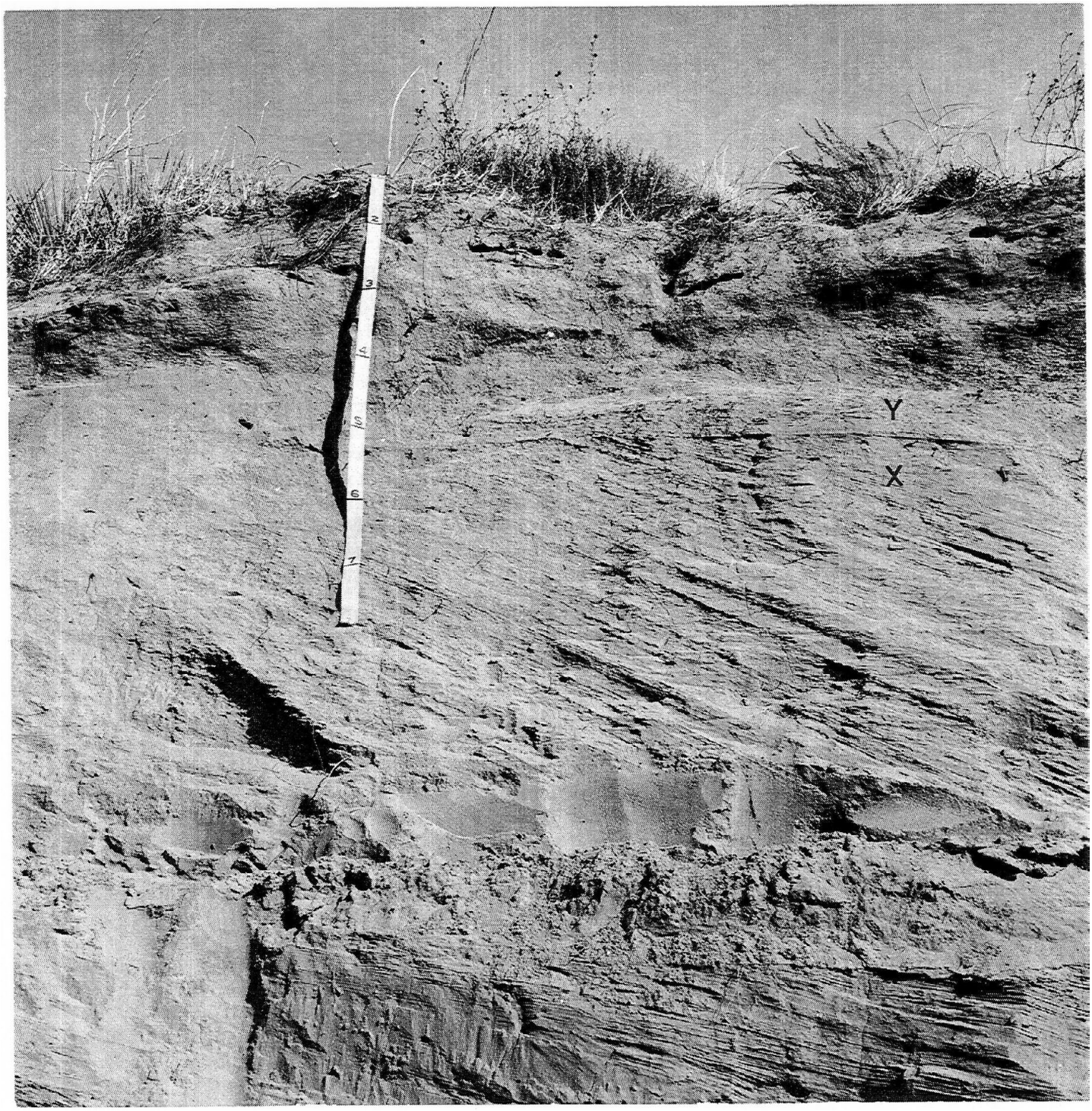


Figure 31. Site 1c. Here the land surface slopes to the west, beds slope to the east, and the contact between lower beds (X) and upper beds (Y) rises toward the surface. The clay band along the contact (just below the 5 ft mark at tape) is distinct at right of tape. But at left of tape the clay band first becomes discontinuous and then disappears altogether as it approaches the buried A1 horizon. Scale is in feet.

Site 1d, clay bands in level or nearly level beds beneath sloping surface

Site 1d (fig. 32, table 11) occurs on the northwestern edge of the dune remnant, on the lower part of the exposure. In March 1981, this soil, an Alfic Ustipsamment in Longview II sediments, was buried by Fairview sediments. But by October 1982, erosion had stripped away the Fairview sediments and exhumed the buried soil.

Site 1d illustrates soil development in Longview II sediments under still another slope combination of land surface and sedimentary strata. Down the side of the dune and northwest of the steep beds discussed in the previous section, clay bands along level or nearly level strata gradually disappear as they near the surface, which slopes 15 percent to the northwest. The disappearing bands are replaced by bands that at first are at greater depth than those they replace, but that in turn approach the surface further downslope.

The clay bands become thicker and more numerous downslope (fig. 32). This is the usual situation and is attributed to increased moisture on the lower side of the dune. Soil moisture moving vertically downward is augmented by lateral movement downslope along the bands, as discussed later at Site 3.

Sites 1b-1d illustrate the strong control exerted by slope of sedimentary beds, a parent material feature, on position and slope of developing clay bands, a pedogenic feature. Where the beds are at an angle to the land surface, the clay bands tend to form along individual strata of the beds. Thus instead of approximately paralleling the land surface (the usual situation) the clay bands have formed at an angle to it.

Site 1 and Site 3, to be discussed, well illustrate the effects of differing thickness of sediments and slope of sedimentary beds on clay illuviation. An important difference between Sites 1 and 3 is the much greater thickness of stratified Longview II sediments at Site 1. At Site 3, the stratified sediments of Longview II are thin and the slope and depth complications at Site 1 cannot form because the clay is confined to a stratified zone in which all beds are gently sloping and in one direction only.

SITE 2, USTIPSAMMENTS OF THE MIDDLE REMNANT: DISCONTINUOUS CLAY BANDS

A remnant of the Muleshoe surface (fig. 19) is preserved in the northwest margin of the blowout, between Sites 1 and 3, and has been previously illustrated (Gile, 1981, fig. 6). Because sediments of Muleshoe, Fairview, and Longview age are nearby,the remnant is important in a reconstruction of the geomorphic and pedogenic history of the blowout area.

No A or B horizons are evident in the Fairview sediments (table 11). The Muleshoe sediments are thought to have been partly derived from the area of Site 3 to the west since there is evidence of Muleshoe erosion there as discussed later. The buried soil slopes gently to the north, and the Muleshoe deposit was apparently emplaced on the flank of the Longview dune that is exposed both to the east (Site 1) and to the west (Site 3).

No sedimentary strata are visible. The A1 horizon of the Muleshoe soil is well preserved beneath the thin deposit of Fairview age. A similar A1

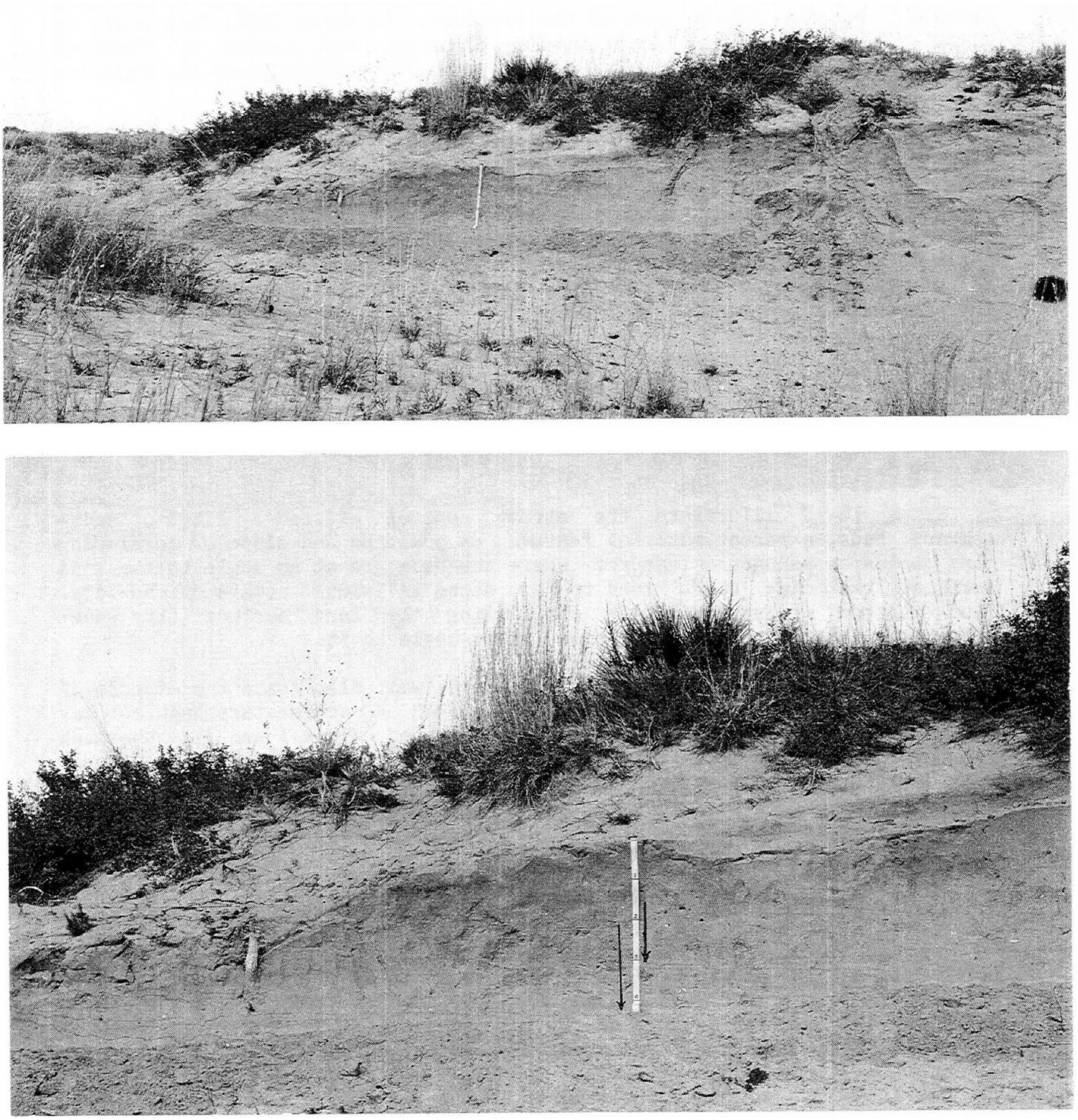


Figure 32. Upper. Landscape view of Site 1d. Fairview sediments are on the skyline except at far left. The once-buried soil of Longview II age is at the tape and crops out along the exposure, sloping downward from right to left.

Lower. Site 1d, at tape. Arrow at right of tape locates the ends of clay bands that are continuous to the right. Arrow at left of tape locates the beginning of a clay band that is continuous to the left. Note increasing prominence and number of clay bands at left. Scale is in feet.

horizon is also prominent at Sites 1 and 3 and may have been continuous across the landscape before the blowout formed.

The thin, discontinuous clay bands present in many soils of Muleshoe age also occur at Site 2. Although only one discontinuous band was visible in the B2b&Bt horizon of the sampled pedon, several discontinuous bands were encountered in digging the sampling pit. The Cb horizon lacks bands and underlies the banded zone. The banded B horizon typical of Longview sediments was encountered with an auger at a depth of about 3 m. Thus the Muleshoe deposit represents a substantial thickness of these sediments.

SITE 3, USTIPSAMMENTS, HAPLUSTALFS AND ARGIUSTOLLS OF THE WEST REMNANT AND ADJACENT TROUGH

Site 3 occurs along the western margin of the blowout (fig. 28). Site 3 consists of an exposure of the north side of a dune, and a trench dug to connect the exposure to the adjacent trough. See Gile (1981, p. 23) for a photograph of the dune exposure. Thin deposits of Fairview and Muleshoe sediments occur on much of the ridge side. Figure 33 shows the stratigraphy, soil occurrence, slope and location of the sampled pedons.

The C horizon material beneath the clay bands is thicker in the crest and upper side of the dune, where soils of pre-Longview II age are deeply buried. Table 12 gives characteristics of Pedons 3a and 3b. In both pedons, Fairview sediments are fine sands and Longview sediments are dominated by sands (for particle size distribution of sands for Pedon 3b, see Pedon 78-3, Appendix).

Site 3a, clay bands underlain by C horizon

Pedon 3a (fig. 34) is a Typic Ustipsamment. The pedon is thus classified because the young mantle without diagnostic horizons (Fairview sediments) is $\geq$50 cm thick; in these cases classification is based on the mantle and not on the buried soil (Chapter 3). A light-colored A2b horizon of Muleshoe age occurs between the Fairview sediments and the A1 horizon of Longview age. In places along the exposure, the A2b horizon is overlain by a thin, discontinuous A1 horizon. Vegetation is dominantly oak; figure 34 shows the enlarged oak patch located in the 1941 aerial photograph (fig. 13).

There are six main clay bands in the B2b2&Bt horizon. They range from 2 to 4 mm thick and all are generally continuous. There are also several thinner discontinuous bands, and several very thin clay bands are faintly visible in the B3b2&Bt horizon. Most bands show little undulation and tend to parallel primary strata of the dune. Primary strata are visible mostly in the lower part of the B and in the C horizon, but are more apparent further down the side of the dune.

Thin sections were made of clay bands from the B2b2&Bt horizon. Nearly all of the clay in the bands occurs as coatings of oriented clay on the sand grains. Occurrence of the coatings in the clay maximum is evidence that the clay in the coatings is primarily of illuvial origin. According to Brewer's terminology these coatings are simple free grain argillans (Brewer, 1964, p. 207). Thin sections were also made of thicker clay bands of Birdwell age. The same micromorphological feature was found, the only difference being

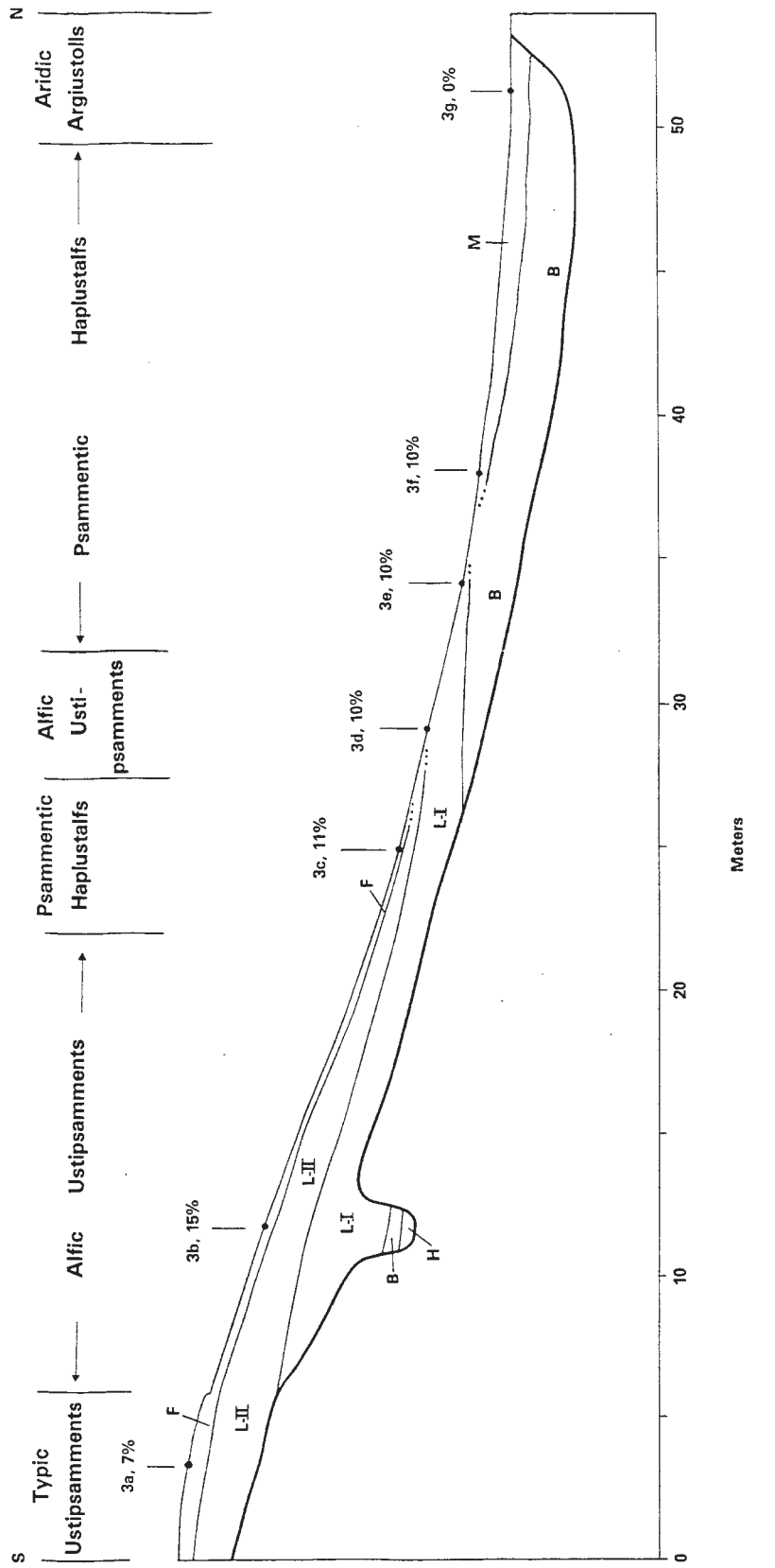
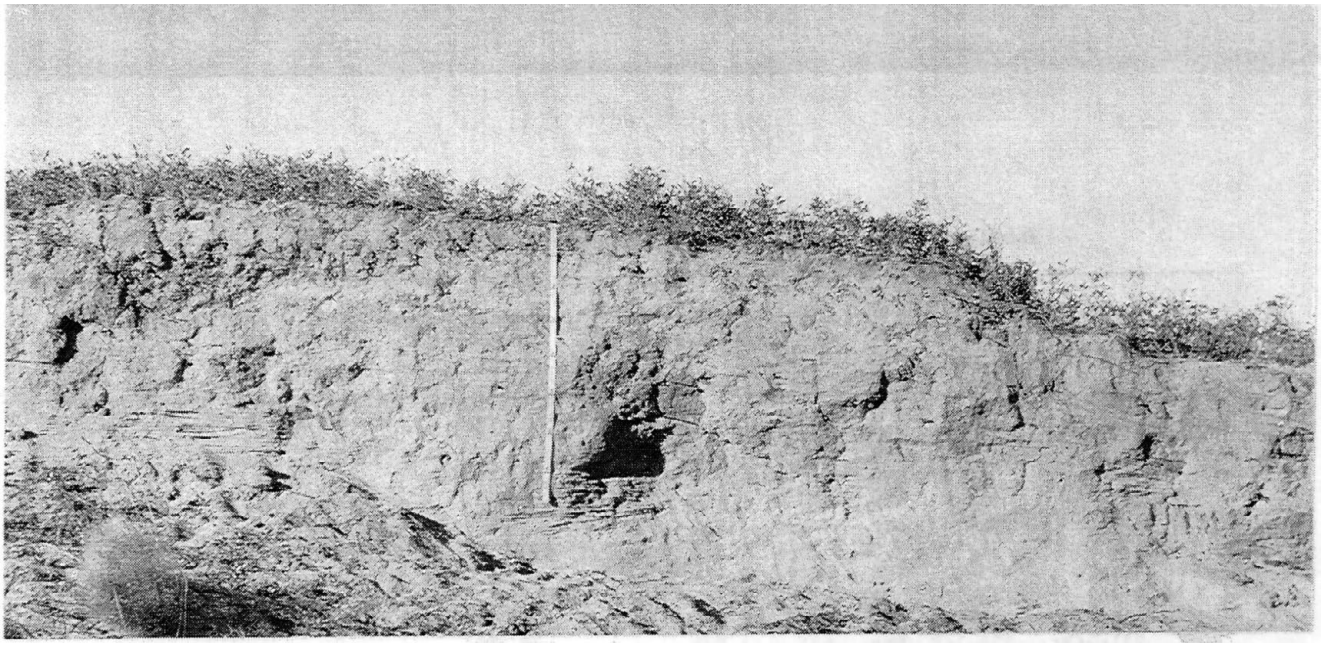


Figure 33. Diagram showing stratigraphy, soil occurrence, and the location and slope of the sampled pedons at Site 3. No vertical scale.



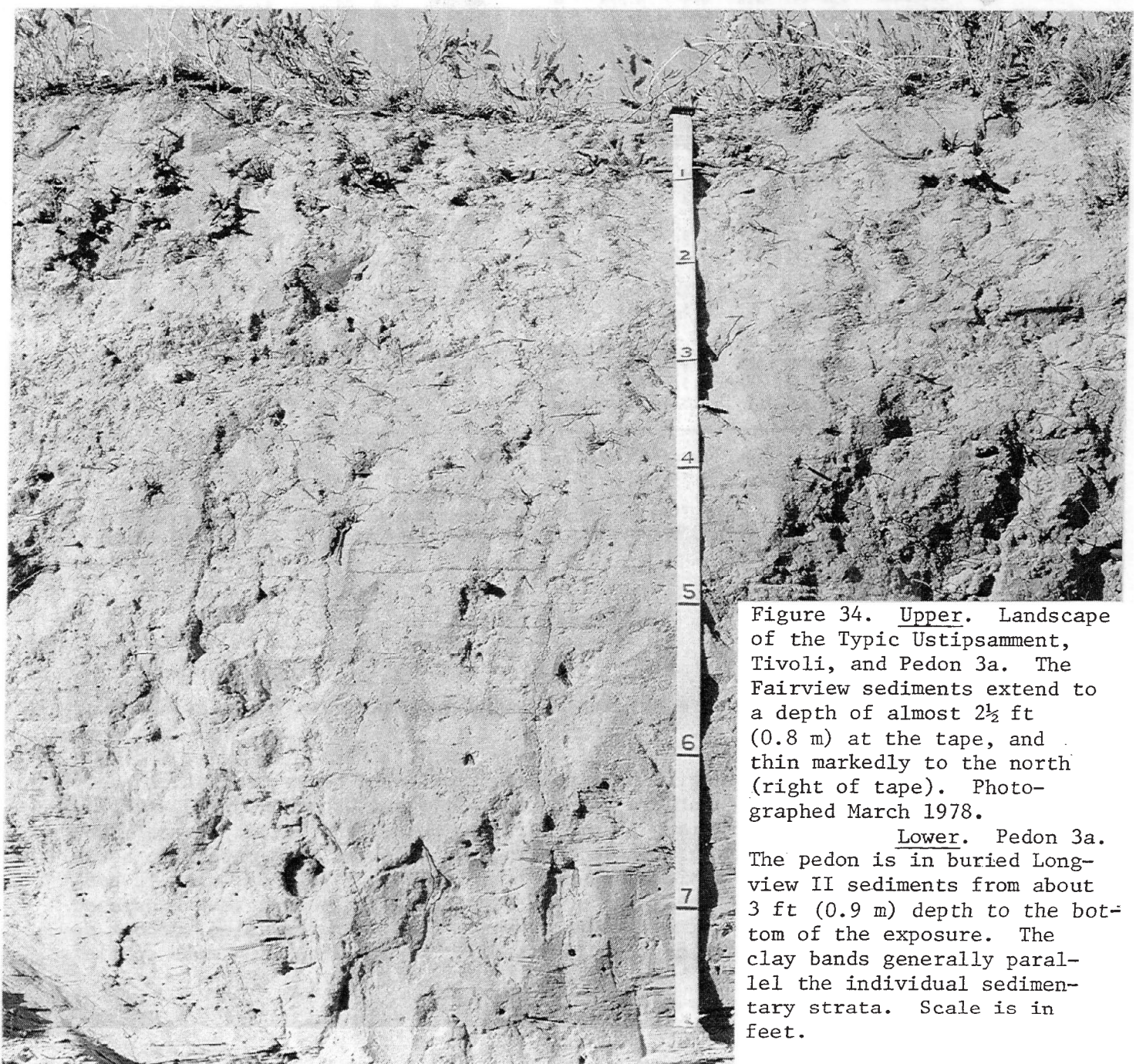


Figure 34. Upper. Landscape of the Typic Ustipsamment, Tivoli, and Pedon 3a. The Fairview sediments extend to a depth of almost 2½ ft (0.8 m) at the tape, and thin markedly to the north (right of tape). Photographed March 1978.

Lower. Pedon 3a. The pedon is in buried Longview II sediments from about 3 ft (0.9 m) depth to the bottom of the exposure. The clay bands generally parallel the individual sedimentary strata. Scale is in feet.

Table 12. Characteristics of Ustipsamments on upper side of dune at Site 3 [1/]

Sedi-ment	Horizon	Depth, cm	Hue	Value/chroma Dry	Value/chroma Moist	Struc-ture	Dry consis-tence	pH	Lower bound-ary	Tex-tural class	Sand 2.0-0.05 mm	Silt 0.05-0.002 mm	Clay < 0.002 mm
Typic Ustipsamment, Tivoli: Pedon 3a													
F	C1	0-8	6YR	6/4	4.5/4	m	s	6.4	cw	fs			
	C2	8-25	5YR	6/4	4.5/4	m	s	7.0	cw	fs			
	C3	25-52	5YR	6/4	4.5/4	m	s,sh	7.0	cw	fs			
	C4	52-72	5YR	6/4	4.5/4	m	s,sh	6.8	as	fs			
M	A2b	72-83	7.5YR	6.5/4	4.5/4	m	s	6.8	as	fs			
L-II	A11b2	83-103	5YR	6/4	4.5/4	m	s,sh	6.8	cw	fs			
	A12b2	103-118	5YR	6/4	4.5/4	m	sh	6.8	cw	fs			
	B1b2	118-130	5YR	6/4	4.5/4	m	sh	6.6	as	s			
	B21b2&Bt	130-147	5YR	6/4	4.5/4	m	sh	6.6	as	s			
	B22b2&Bt	147-175	5YR	6.5/4	5/4	m	sh	6.6	as	s			
	B31b2&Bt	175-190	5YR	6.5/4	5/4	m	sh	6.6	cw	s			
	B32b2&Bt	190-218	5YR	6/4	5/4	m	sh	6.6	cw	s			
	Cb2	218-269	6YR	6.5/4	5/4	m	sh	6.6	as	fs			
L-I	Ab3	269-280	7.5YR	6/4	4.5/4	m	sh	6.6		fs			
Alfic Ustipsamment, Circleback: Pedon 3b													
F	C	0-20	7.5YR	6/4	4.5/4	m	s	7.0	aw	fs	96.2	2.2	1.6
L-II	A1b	20-46	8YR	5.5/3	4/3	m	sh	7.0	cw	fs	95.9	2.5	1.6
	B1b&Bt	46-66	7.5YR	6/4	4.5/4	m	sh	7.0	aw	s	93.7	1.9	4.4
	B21b&Bt	66-84	5YR	6/4	4.5/4	m	sh	6.8	aw	s	94.3	1.7	4.0
	B22b&Bt	84-101	5YR	6/4	4.5/4	m	sh	6.8	as	s	95.4	1.0	3.6
	B3b&Bt	101-127	5YR	6.5/4	5/4	m	sh	6.6	as	s	95.7	1.5	2.8
L-I	Ab2	127-150	7.5YR	6.5/4	5/4	m	s	6.6	as	fs	98.2	0.6	1.2
	[2/]												
L-I	Ab2	168-218	7.5YR	6.5/4	5/4	m	s	6.6	gw	fs			
	B21b2&Bt	218-257	7.5YR	6.5/4	5/4	m	s	6.6	gw	fs			
	B22b2&Bt	257-290	7.5YR	6.5/4	5/4	m	s	6.6	gw	fs			
	B3b2	290-315	7.5YR	4/6	4.5/6	m	s	6.6	gw	fs			
B	B1tb3&A2	315-330	5YR	5/4	4/4	m	sh,h	6.6	cs	fs			
	B2tb3	330-386	5YR	5.5/4	4/4	lcsbk	vh	6.4	cs	lfs			
H	A2b4&Bt	386-424	6YR	6.5/4	5/4	m	sh	6.2		fs			

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

2/ The horizons below were sampled from an earlier excavation, but near the horizons above, and were not analyzed in the laboratory. Overall horizonation was similar in both profiles. B1tb3&A2: also 7.5YR 7/3, dry. A2b4&Bt: also 5YR 5/4, dry.

that the clay coatings were thicker and more continuous in the clay bands of Birdwell age.

Simple free grain argillans also have been found to be typical of sandy loam Bt horizons in southern New Mexico (Gile and Grossman, 1979, p. 171, 173), and in desert regions of northern New Mexico and Nevada (unpublished information, L. H. Gile). These coatings of oriented clay appear to be an important and extensive micromorphological feature of illuvial clay in both arid and semiarid regions. The oriented coatings, although best expressed in the younger soils with sandy or sandy loam textures, also support an illuvial origin for some of the clay in older Bt horizons with more complex

micromorphologies (e.g., see Gile and Grossman, 1979, p. 174, 175). Presumably these older soils passed through a similar stage of development at an earlier time in their history.

The transition to the Cb2 horizon is marked by the disappearance of clay bands and a change to slightly less red and lighter color. An occasional discontinuous clay band along the contact to the Ab2 horizon or just below it suggests occasional deep penetration of soil water and its suspended clay.

Site 3b, clay bands underlain by buried soil

The thickness of Fairview sediments decreases abruptly downslope towards Pedon 3b (figs. 33-35). Pedon 3b (fig. 5, Gile, 1979) is classified as an Alfic Ustipsamment since the mantle of Fairview sediments is less than 50 cm thick. Here the Longview II sediments are so thin that the clay band horizon rests directly on the buried soil of Longview I age.

Most clay bands below the B1b&Bt horizon are continuous and colored 5YR 5/4, dry. The B1b&Bt horizon has two discontinuous clay bands, 3 to 5 mm thick. There are three bands, from 3 to 5 mm thick, in the B21b&Bt horizon; four bands, from 1 to 3 mm thick, in the B22b&Bt horizon; and five bands, from 1 to 2 mm thick, in the B3b&Bt horizon. There are also scattered much thinner bands (<1 mm thick) in all subhorizons of the B.

The clay band horizon nearly meets the minimum clay increase (3%) required for argillic horizons below eluvial horizons of this texture (Chapter 3). This pedon is downslope from Pedon 3a; clay bands are more numerous than they are upslope, and some of the bands are thicker than they are upslope. This suggests that some clay moved downslope in laterally moving water. Another factor is the discontinuity to the buried soil of Longview I (fig. 33). Discontinuities would tend to retard the vertical downward movement of soil water and its suspended clay. The discontinuity at Pedon 3b occurs at shallower depth than it does upslope and clay in the soil water would tend to be concentrated in a thinner zone. Still further downslope, the clay band horizon gradually nears the surface and eventually disappears altogether, where it has been removed by erosion of Muleshoe time as discussed later. The soil in Longview I is not much older than Longview II, judging from its weak B horizon, which has a few very thin clay bands. There is evidence of clay stripping in the B1tb3&A2 horizon (for an illustration and discussion of clay stripping, see Gile, 1981, p. 27, 28 and Stops 6 and 7).

Descent of clay bands into unstratified materials

Along much of the exposure at Site 3 there is a prominent contact of stratified Longview II sediments, in which clay bands have formed, on the unstratified Ab horizon of Longview I. The stratified Longview II sediments thin downslope, and as this happens the clay bands thicken and are concentrated in a thinner zone due to increasing shallowness of the buried soil. Lateral movement of soil moisture along the clay bands is important in thickening of the bands as discussed later (see also Site 32). These effects become apparent in the vicinity of Pedon 3b, where clay bands occur discontinuously on the contact between Longview I and II sediments, and dip below it only in scattered spots. But northward the whole zone of clay bands descends into the unstratified sediments of Longview I. Effects of

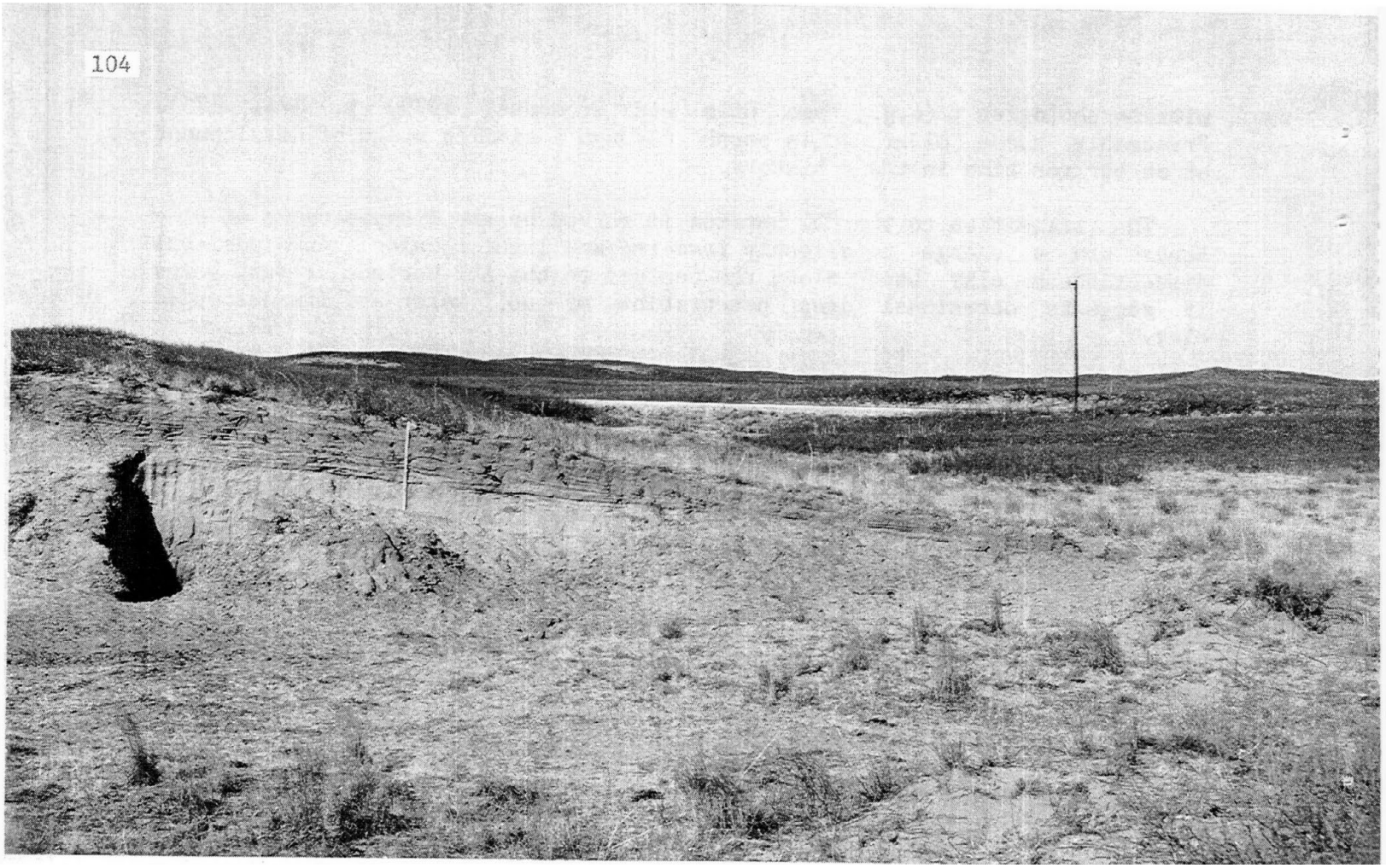


Figure 35. Photograph of the dune side at Site 3. Pedon 3b is in the trench at left. The tape at right of trench locates Figure 23, which shows the descent of clay bands from stratified to unstratified materials. Oak-covered ridges are in the background. Farm Road 1731 is at right. The view is west. Photographed April 1976.

lateral moisture movement and decreasing depth to the buried soil are well shown in the downslope part of the trench at Pedon 3b (fig. 35), where thickness of the uppermost band increases to 1 cm.

Figure 36 (at right of tape) shows the lower part of the main zone of clay bands as they descend from stratified Longview II sediments into unstratified materials. The descent of the clay bands into unstratified materials is abrupt, and occurs where the contact to stratified materials reaches a critical distance (about 75 cm) from the buried Longview II surface. Abruptness of the descent indicates that concentration of moisture at this depth along the contact is the controlling factor in descent of the bands below the contact.

Small bands, about 1 mm thick, are the first to descend below the contact. Then larger ones, 2-4 mm thick, also descend. The bands are much more irregular and wavy in the unstratified materials (fig. 36). Since the

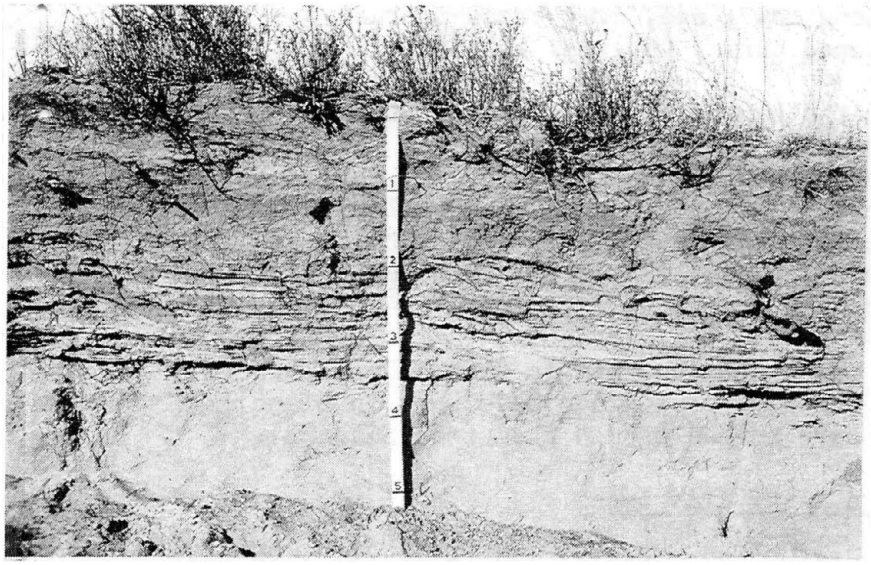
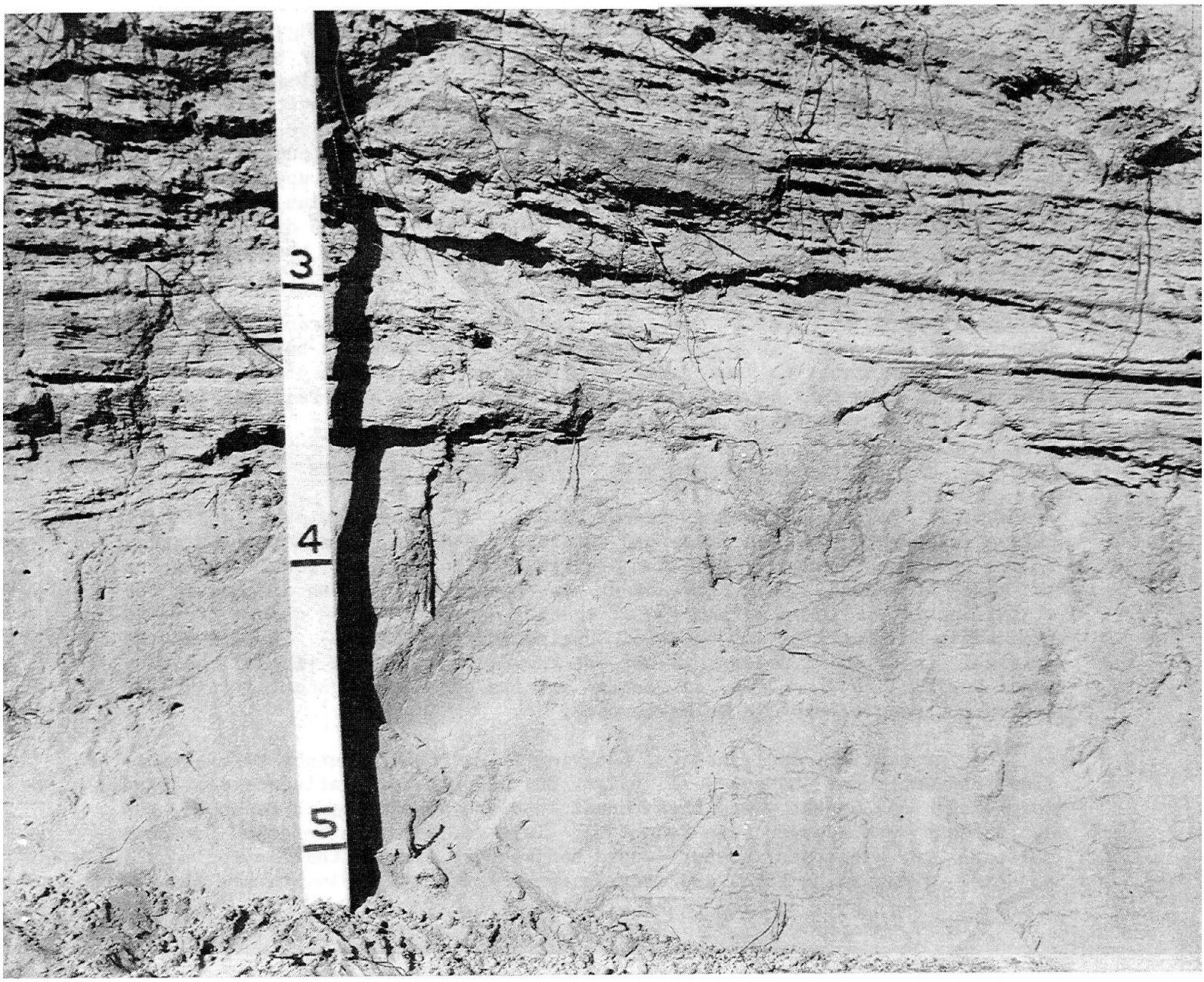


Figure 36. At left. Profile illustrating the descent of clay bands from stratified into unstratified materials.

Below. Closer view of band descent. At left of tape, the unstratified materials have only an occasional clay band. At right of tape, the unstratified materials have many clay bands. The clay bands in unstratified materials have more undulations than they do in stratified materials, but still roughly parallel the land surface. Scale is in feet.



bands cross the contact between the land-surface soil of Longview II age and the underlying buried soil of Longview I age, clay bands in the upper part of the latter soil must have developed during Longview II time.

Although the lower part of the banded zone has crossed the contact to unstratified materials, most of the clay bands still in Longview II sediments are thicker than upslope and the total thickness of soil occupied by bands is greater. The thicker clay bands occupy the following depths: 49-50 cm (in places is absent, or is segmented and appears to be breaking up); 57-58 cm; 65-65½ cm (discontinuous); 72-73 cm; 79-80 cm; 86-86½ cm (smaller-bifurcates); 99-100 cm (ranges from ½ to 1 cm thick).

Note the crotovina at the right of the tape in figure 36. This is a very young feature of this soil, but some crotovinas have been in place long enough for distinct clay bands to have formed around them (see Site 32).

Site 3c, shallow clay bands

Downslope towards Pedon 3c (fig. 37, table 13) both the clay band horizon in Longview II and the underlying sediments of Longview I gradually come closer to the surface. The shallow contact between Longview II and I sediments tends to compress the upper part of the zone of clay accumulation; Bt material occurs continuously in the B horizon, which contains enough clay to qualify as an argillic horizon and the pedon is a Psammentic Haplustalf. The upper part of the clay band horizon is so near the surface that the A1b horizon has formed in the upper part of the banded zone; reddish Bt parts are intricately mixed with darker A1 horizon material. The uppermost bands are only faintly visible and appear to be breaking up due to increased biotic mixing and wetting near the surface. Beneath the base of Longview II sediments, some clay bands of Longview II age have formed in the Ab2 horizon of Longview I age.

Shallowness of the Bt material indicates erosion because it is much deeper in the soil at stable sites. The erosion occurred before Fairview time and since Longview time, thus is of Muleshoe age. Some of the deposits wind-eroded from this general position on the dune may have been emplaced to the east in the vicinity of Site 2.

Site 3d, disappearance of Longview II sediments

Further downslope toward Pedon 3d (fig. 37) the Longview II sediments become even thinner, then disappear completely and the sediments of Longview I are at the surface. Since the argillic horizon in Longview II sediments is also truncated, the clay bands in Longview I become diagnostic for classification. These morphological changes cause an abrupt change from the Psammentic Haplustalfs to the Alfic Ustipsamments (fig. 33). Extent of the original Longview II deposit is not not known. But gradual rise of the clay band horizon in Longview sediments and its eventual truncation (fig. 37) indicate strong erosion in Muleshoe time.

The stratified sediments of Longview II and their contact to unstratified sediments of Longview I (figs. 36, 37) strongly influence clay band morphology and depth; where these conditions are absent, as in Pedon 3d, the clay bands are deeper (see Pedon 3c). This reflects the tendency for soil moisture to penetrate deeper where sedimentary strata (that approximately parallel the soil surface) and underlying unstratified sediments are absent,

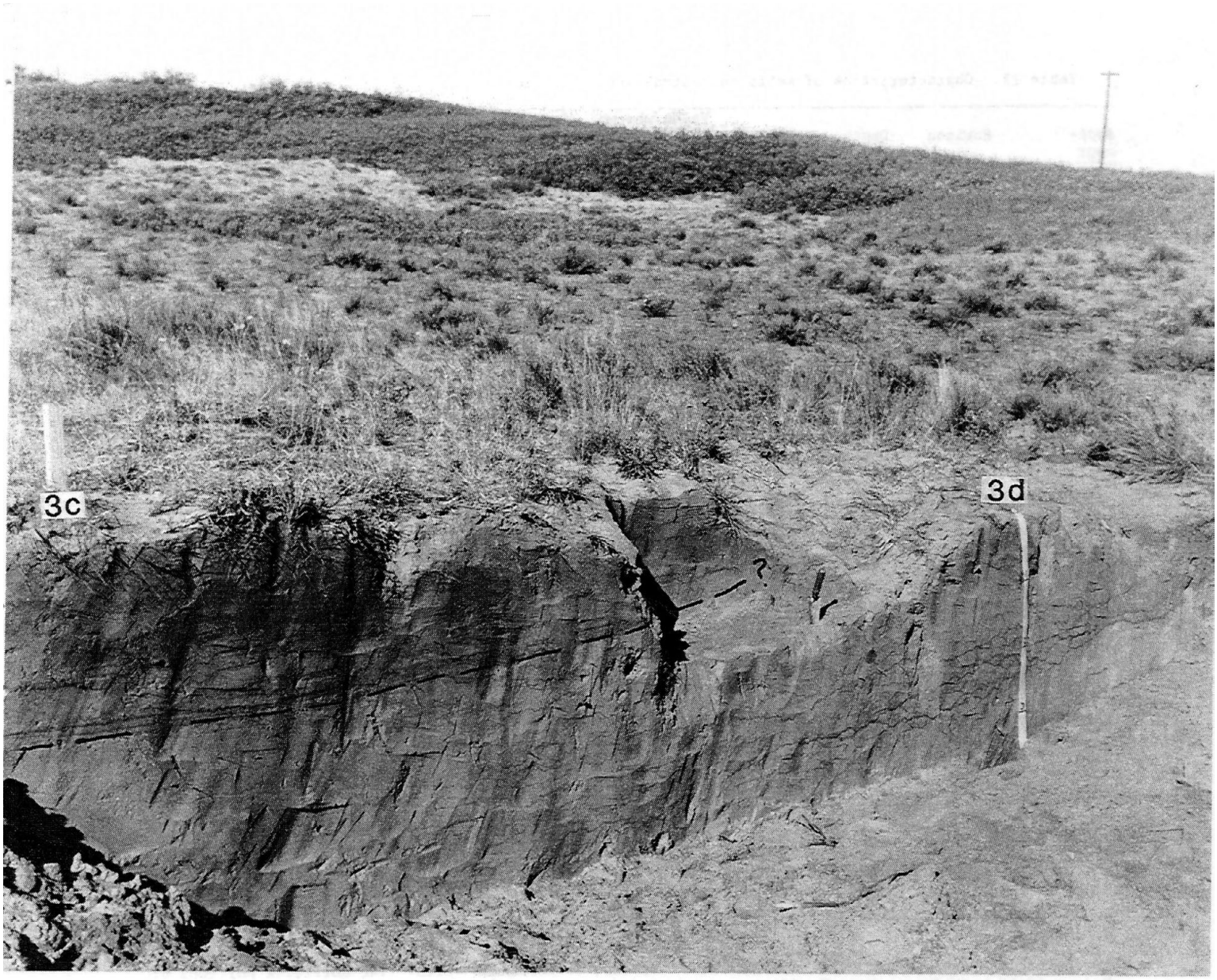


Figure 37. The study trench at Sites 3c and 3d. The dashed line locates the contact between stratified Birdwell II sediments, which grade out between 3c and 3d, and the underlying unstratified Birdwell I sediments. Note that the clay bands become more prominent at the tape, where the stratified sediments of Birdwell II are not present (see text discussion). The prominent morphological change between Pedons 3c and 3d causes a change in classification, from a Psammentic Haplustalf (left) to an Alfic Ustipsamment (right). Scale is in feet. The view is northwest. Photographed November 1976.

Table 13. Characteristics of soils on central and lower side of dune and in trough at Site 3[1/]

Sediment	Horizon	Depth, cm	Hue	Value/chroma Dry	Value/chroma Moist	Textural class	Structure	Dry consistence	pH	Lower boundary
Psammentic Haplustalf, Texico: Pedon 3c[2/]										
F	C	0-10	6YR	6/4	4/4	fs	m	s	7.0	aw
L-II	A1b	10-24	5YR	5/4	3.5/4	fs	m	sh,s	7.2	as
	B21tb	24-35	5YR	5.5/5	4/5	s	m	sh,h	7.2	as
	B22tb	35-48	5YR	6/5	5/5	s	m	sh	7.2	as
L-I	B21b2&Bt	48-66	5YR	6.5/4	5/4	fs	m	s	7.2	cw
	B22b2&Bt	66-103	5YR	6.5/4	5/4	fs	m	s	7.2	
Alfic Ustipsamment, Circleback: Pedon 3d[3/]										
L-I	A1	0-22	7.5YR	6/3	4/3	s	m	s	6.8	cw
	B1	22-48	6YR	6/4	4.5/4	fs	m	s	6.8	as
	B2&Bt	48-71	5YR	6/4	4.5/4	s	m	s,sh	6.8	as
B-II (?)	A2b	71-112	7.5YR	6.5/3	5/3	fs	m	s	6.8	as
	B2tb	112-135	5YR	6/4	4.5/4	fs	lcsbk	vh	6.6	cs
B-I	A2b2	135-145	10YR	8/3	7/4	fs	m	s,sh	6.4	
Psammentic Haplustalf, Texico: Pedon 3e										
L-I	A1	0-21	9YR	6/4	4/3	fs	m	s	6.8	cw
B-II	Bb	21-47	7.5YR	6.5/3	5/3	fs	m	s	7.0	as
	B2tb	47-77	6YR	5/4	4/4	lfs	lcsbk	vh	6.8	cw
B-I	A2b2	77-99	10YR	7/4	6/4	lfs	lcsbk	h,vh	6.8	
Psammentic Haplustalf, Texico: Pedon 3f[4/]										
M	A1	0-9	10YR	6/4	4.5/4	fs	m	s	7.4	as
B-II	B21tb	9-21	7.5YR	5/3	4/3	lfs	lcpr-lcsbk	h	7.0	as
	B22tb	21-36	7.5YR	5/3	4/3	lfs	lcpr-lcsbk	vh	7.4	as
B-I	A2b2	36-52	10YR	7/3	6/3	fs	m	sh	7.2	aw
	B1tb2	52-67	7.5YR	5/4	4/4	lfs	lcsbk	vh	7.2	cw
	B2tb2	67-80	5YR	6/4	5/4	ls	lcsbk	vh	7.2	
Aridic Argiustoll, Newell, sandy variant: Pedon 3g[5/]										
M	A11	0-8	7.5YR	5/2	3/2	fsl	m,cr	s	6.4	as
	A12	8-32	7.5YR	5/3	3/3	fs	m	s	6.8	cw
B-I	B11b	32-57	7.5YR	6/5	4.5/5	s	m	sh	6.8	cw
	B12tb	57-75	5YR	5/6	4/6	ls	m	sh	6.8	cw
	B2tb	75-90	5YR	5/6	4/6	ls	m	h	7.0	

1/ Subordinate colors and other comments are footnoted to pertinent soils. The surficial horizons of Pedons 3d through 3g may have a thin (several cm) deposit of Fairview sediments, not shown. Sediments are identified as: F = Fairview, M = Muleshoe, L-II = Longview II, L-I = Longview I, B-II = Birdwell II, B-I = Birdwell I.

2/ A1b: parts 7.5YR 4/3, dry. B21tb and B22tb: clay bands are 5YR 5/4, dry. B21b2&Bt and B22b2&Bt: clay bands are 5YR 5.5/4, dry.

3/ A2b: parts 5YR 5/4, dry. B2tb: parts 5YR 5/4, dry, in intricate pattern of clay-enriched zones that line pores and discontinuously coat faces of some peds.

4/ B21tb: parts 7.5YR 3.5/2, dry. B22tb: parts 5YR 5/4, dry, in intricate pattern. A2b2: parts 7.5YR 6/4, dry, that line some pores. B1tb2: parts 7.5YR 7/3, and parts 7.5YR 6/6, in intricate pattern of pore linings and discontinuous coatings on peds. B22tb2: parts 5YR 6/6, dry, coating some ped faces and lining some pores; parts 10YR 7/3, dry, occur in some pores.

5/ B11b: parts 6YR 6/5, dry. B2tb: parts 5YR 5/4, dry.

as is conclusively shown by coincidence of the morphological change with the disappearance of Longview sediments (fig. 37).

Buried horizons of Birdwell age occur beneath Longview I sediments. The thin B2tb horizon is thought to have formed partly in Birdwell colluvium, as is the situation in land-surface soils on lower sides of many Birdwell ridges to the south (see Sites 33-35 and 39). But the boundary between the two sediments is not certain because of mixing effects of pedogenesis and because of lateral moisture movement and leaching on sides of dunes. Lateral leaching can perpetuate already-existing buried A2 horizons, and can also move clay from buried B or C horizons, thus complicating pedogenic horizons and geologic contacts (see also Site 18).

Site 3e, disappearance of clay bands

Toward Pedon 3e (fig. 38) the clay band horizon gradually disappears as it nears the soil surface, with the upper bands disappearing first. The lower two bands are prominent, but they too are obliterated (about midway between Pedons 3d and 3e, fig. 38) as they approach the surface. Thus the upper of the two bands is well expressed at 56 cm depth but as it nears the surface downslope it gradually becomes less distinct and fades out at 35 cm depth. The lower of the two clay bands also disappears a few cm downslope. Obliteration of increasingly shallow bands by soil moisture and by soil biota is the usual situation in eroding landscapes as discussed earlier. Absence of bands downslope reflects the boundary to Birdwell sediments as they near the surface. A change in classification, from Alfic Ustipsamments to Psammentic Haplustalfs, is associated with the morphological change from the clay band horizon in Longview I sediments to the argillic horizon in Birdwell II sediments (fig. 33). The Bt horizon in Birdwell sediments is finer in Pedon 3e than in Pedon 3d (table 13). This is typical in soils of Birdwell age that occur on the lower sides of dunes; the finer textures occur on lower slopes (see also Sites 33-35 and 39).

Disappearance of the clay bands has affected the A2b2 horizon. Beneath the bands the A2b2 horizon has a mixed brownish-whitish appearance; where the bands are absent, it is mostly whitish. This suggests that, where the clay bands are absent, the soil solution strips clay from the brownish zones and then deposits it on the buried Bt horizon beneath. In addition the lateral analogue of illuvial clay deposited in bands must also have accumulated in the buried Bt horizon where the bands are absent.

Site 3f, disappearance of Birdwell II sediments

Towards Pedon 3f, the Bt horizon in Birdwell II sediments gradually rises in the soil, so that at Pedon 3f its top is only 9 cm from the surface (fig. 38, table 13). The Bt horizon in Birdwell II also contains more clay than it does in Pedon 3e. This clay increase is attributed to decreased slope of the buried surface, and to a colluvial origin of some of the clay.

Site 3g, trough

About 1 m north of Pedon 3f, the Bt horizon rises to the land surface and disappears. Slope of the Bt horizon (fig. 38) indicates that it once extended northward to a higher trough than now exists. Birdwell sediments must have been eroded during Longview and/or Muleshoe time.

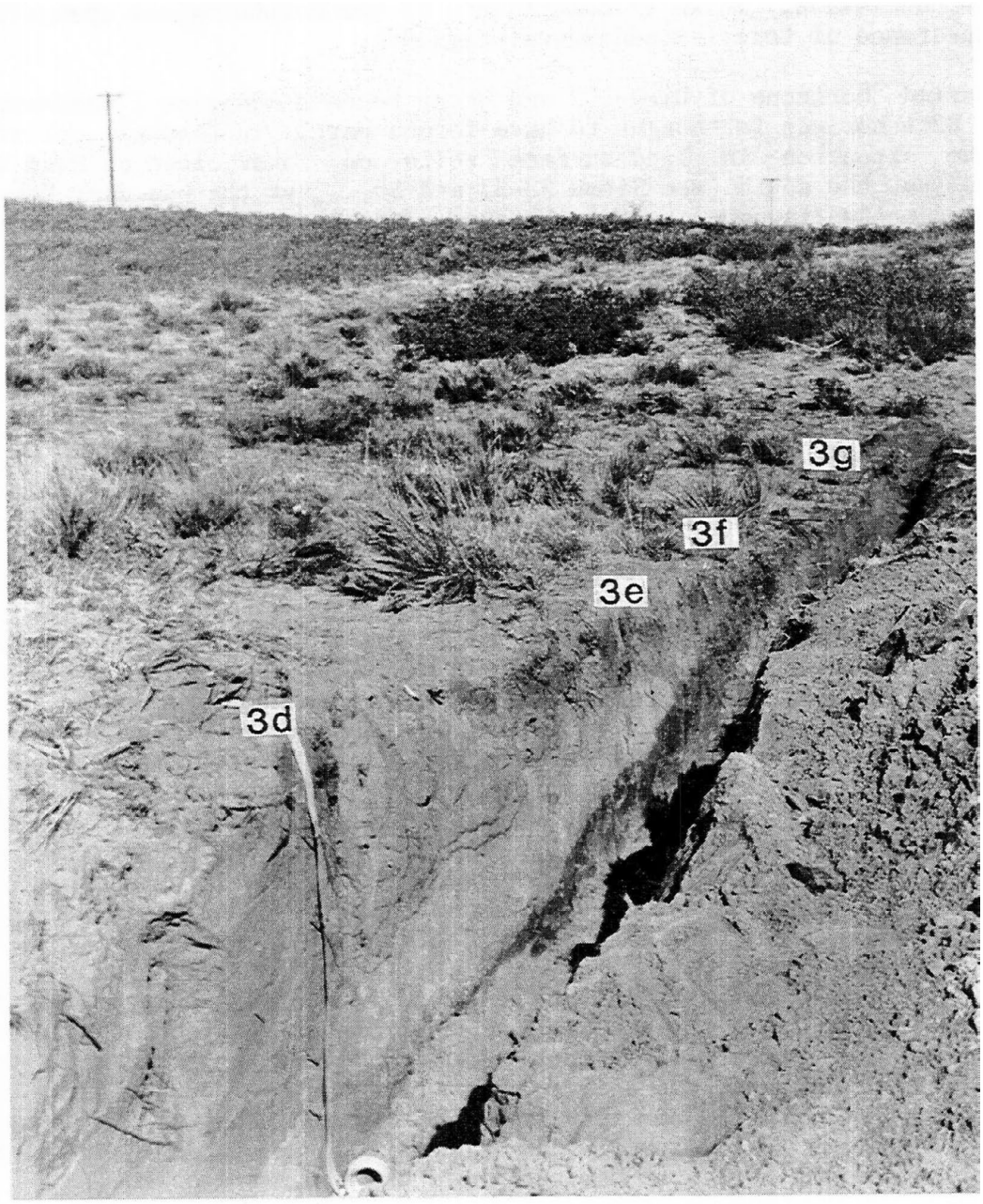


Figure 38. Sites 3d through 3g, in the study trench at Site 3. Note that clay bands between 3d and 3e disappear as they approach the surface downslope (see text discussion). Downslope the Birdwell II sediments (dark horizon near base of trench in foreground) rise toward the surface and their slope indicates that they once graded to a trough higher than the present one. Such a former trough must have been removed by erosion in Longview and/or Muleshoe time. Scale is in feet.

Muleshoe sediments thicken downslope (fig. 33) and extend as a continuous deposit into the trough, where Pedon 3g (fig. 39, tables 13, 13a) occurs. Texture becomes finer in the upper few cm, and is finest in the trough; the A11 horizon is fine sandy loam in contrast to fine sand in the A1 horizon at Pedon 3f (tables 13, 13a). Usually the finest texture in the trough is in the upper 1 or 2 cm. In blowouts and troughs the extra silt and clay are thought to have been derived partly from adjacent slopes and partly from dustfall.

Table 13a. Particle size distribution for Pedon 3g

Sediment	Horizon	Depth cm	Sand 2.0-0.05 mm	Silt 0.05-0.002 mm	Clay < 0.002 mm	Textural class
Muleshoe	A11	0-8	67.3	16.9	15.8	fsl
	A12	8-32	90.1	4.7	5.3	fs
Birdwell	B1b	32-57	93.0	0.8	6.2	s
	B21b	57-75	88.4	0.3	11.3	ls
	B22b	75-90	88.8	1.5	9.7	ls

Classification of Pedon 3g as a Mollisol is tentative. The A11 and A12 horizons contain 1.32 percent and 0.41 percent organic carbon respectively. The mollic epipedon must be at least 26 cm thick in this pedon. The sampled horizon was too thick (8-32 cm) to show the relationships. Nearby pedons would definitely qualify as Mollisols because their horizons below the A1 have finer texture than in Pedon 31, and would contain more organic carbon.

Auger samples taken below the bottom of the trench show that the soil of Birdwell I age is underlain by a thick soil of Hale age at a depth of 112 cm. This soil has a fine sand A2 horizon dominated by 10YR hue and a Bt horizon that gradually reddens to 2.5YR, as is typical for soils of Hale age. Texture of the Bt horizon gradually becomes finer with depth and the clay maximum is a sandy clay loam. Clay content then decreases in the B3t horizon. A buried soil of early Hale age (fig. 2) was encountered below a depth of 5 m. At a depth of slightly less than 6 m, clay increased to sandy clay loam, then decreased to loamy fine sand at slightly less than 7 m depth, the bottom of the core. The boundary between the two soils was a very gradual one. No C horizon material was found between them, and its absence is to be expected where a deposit is thin enough that it is totally encompassed by pedogenic processes -- in this case, the illuviation of silicate clay.

MODEL FOR DEVELOPMENT OF CLAY BANDS

The development of clay bands is one of the most prominent features of Holocene pedogenesis in the study area. Clay bands in soils have been widely reported and reviews of literature on them have been presented by Dijkerman et al. (1967) and Gray et al. (1976). Mechanisms for band

Figure 39. Upper. Landscape view of trough in Birdwell I and overlying Muleshoe sediments. Shrubs in the foreground are sand sagebrush. On the skyline are oak-covered dunes of Longview age, where Alfic Ustipsamments occur.
Lower. The Aridic Argiustoll Newell, sandy variant. Scale is in feet.

formation suggested by various authors include clay illuviation, clay formation in situ, flocculation by iron oxide, frost action, and geologic deposition.

The following evidence indicates that most or all of the clay in bands of the studied soils accumulated by illuviation.

(1) In thick deposits the clay bands are in a zone approximately parallel to the land surface, occur only in upper part of the deposits, and are underlain by C horizons. These are positional attributes of pedogenic horizons.

(2) In thick deposits and at uneroded sites, the clay bands typically occur as part of a soil horizon sequence of A-B1-B2-B3-C, in which maximum expression of the bands is in B2 position. Strata of depositional origin do not occur in a fashion that fits the arrangement and morphology of these pedogenic horizons.

(3) At uneroded sites, the clay band horizon underlies an eluvial horizon with less clay; A2 horizons are distinct under oak vegetation.

(4) Progressive development of clay bands takes place in a chronological setting (fig. 2) that can only be explained by pedogenic origin of the bands. The clay bands do not occur at all in the youngest soils (Fairview); are either absent, or are thin and discontinuous in the next older soils (Muleshoe); are thicker and continuous in the next older soils (Longview); and some are partially obscured by clay accumulation between bands in the next older soils (Birdwell). Thus, development of the bands is related to the soil-forming factor of age.

(5) If the deposit lacks strata, or if they are present but are level, the clay bands approximately parallel the land surface. If the strata change from level to steep, clay extends downward along some of the bands, and also extends deeper than it does in the level strata. Since steep strata would expedite downward movement of the wetting front, such deeper occurrence of the clay would be expected for clay of illuvial origin.

(6) An additional factor concerns a dustfall origin for some of the clay as proposed earlier. Such clay would be illuvial since it would have moved from the surface downward.

Soil morphology and the factors above suggest a model for development of clay bands in the study area. The clay would move downward in suspension, as indicated by the studies of Thorp et al. (1957, 1959), and the clay bands would form in the lower part of a zone frequently wetted by the soil solution. Water penetrates dry sandy soil uniformly in all directions until it encounters a change in texture or structure, or openings such as wormholes or root channels (Taylor, 1957). As the evenly-penetrating wetting front slows its downward movement, suspended clay may be deposited in a zone roughly parallel to the soil surface. Strata that differ in grain size retard downward movement of the wetting front (Taylor, 1957; Miller and Gardner, 1962). For example, in sediments with a layer coarser than overlying materials, water accumulates along the contact to the coarser materials until tension is low enough for water to move into the coarser layer. As downward movement of water is slowed, clay in suspension may be deposited horizontally along the contact to coarser materials. After

initial accumulation of clay along the top of coarser material, this zone should be preferred for subsequent clay accumulation since the initial emplacement of clay would tend to accentuate the original difference in grain size. Clay bands tend to be best expressed in well-stratified sediments. This is supporting evidence of changes in particle size as a significant cause of clay accumulation in banded form.

The wetting front may also be slowed by a decrease in water supplied to it. Precipitation in the study area commonly occurs as isolated events between which the soil dries, or partially dries; thus penetration of the wetting front may differ considerably from one storm to the next. The initial accumulation of clay from a wetting front that is slowed in this way could be a preferred site for subsequent accumulation. This factor may be important in determining loci of clay accumulation in unstratified or poorly stratified sands, and in sands having a high degree of uniformity in grain size.

Clay accumulation due to lateral movement of soil water is also important because in some soils clay bands thicken downslope (Sites 3, 32). Lateral movement may also be involved in initial development of some bands; if a change in grain size inhibits downward movement of water, it would tend to move laterally as shown by Miller (1963). Such lateral movement of water could be a major factor in lateral spread of developing clay bands.

Texture of the clay bands ranges from fine sand to fine sandy loam. Their thickness ranges from about 1/2 mm to 4 cm; the thicker ones tend to contain more clay. Since the bands are thin and do not contain much clay they are quite pervious. Thus, some clay probably moves through upper bands at times of deeply penetrating moisture and then accumulates primarily in bands beneath. During most of the development of the banded zone, the clay bands would continue to be preferred sites for clay accumulation for reasons discussed above. This explains the occurrence of more clay in the bands than between them, as is the case in soils of Muleshoe and Longview age. The B2 position, in which the clay bands are thickest, would represent a zone of frequent slowing of the wetting front. In contrast, the A horizon would represent a zone frequently wetted and subject to rapid water movement and clay eluviation.

The development and thickening of the clay bands with increasing age (fig. 2) gradually decrease soil permeability. Downward movement of moisture would tend to be slowed, and clay would begin to accumulate between bands as well as in them. In the soils next older than Longview (fig. 2), enough clay has accumulated between some bands that they are partially obscured. Because of erosion, in many of the latter soils the zone of clay bands is very near the surface, and parts of some bands in the upper part of the banded zone have been obliterated by soil biota and by percolating soil water.