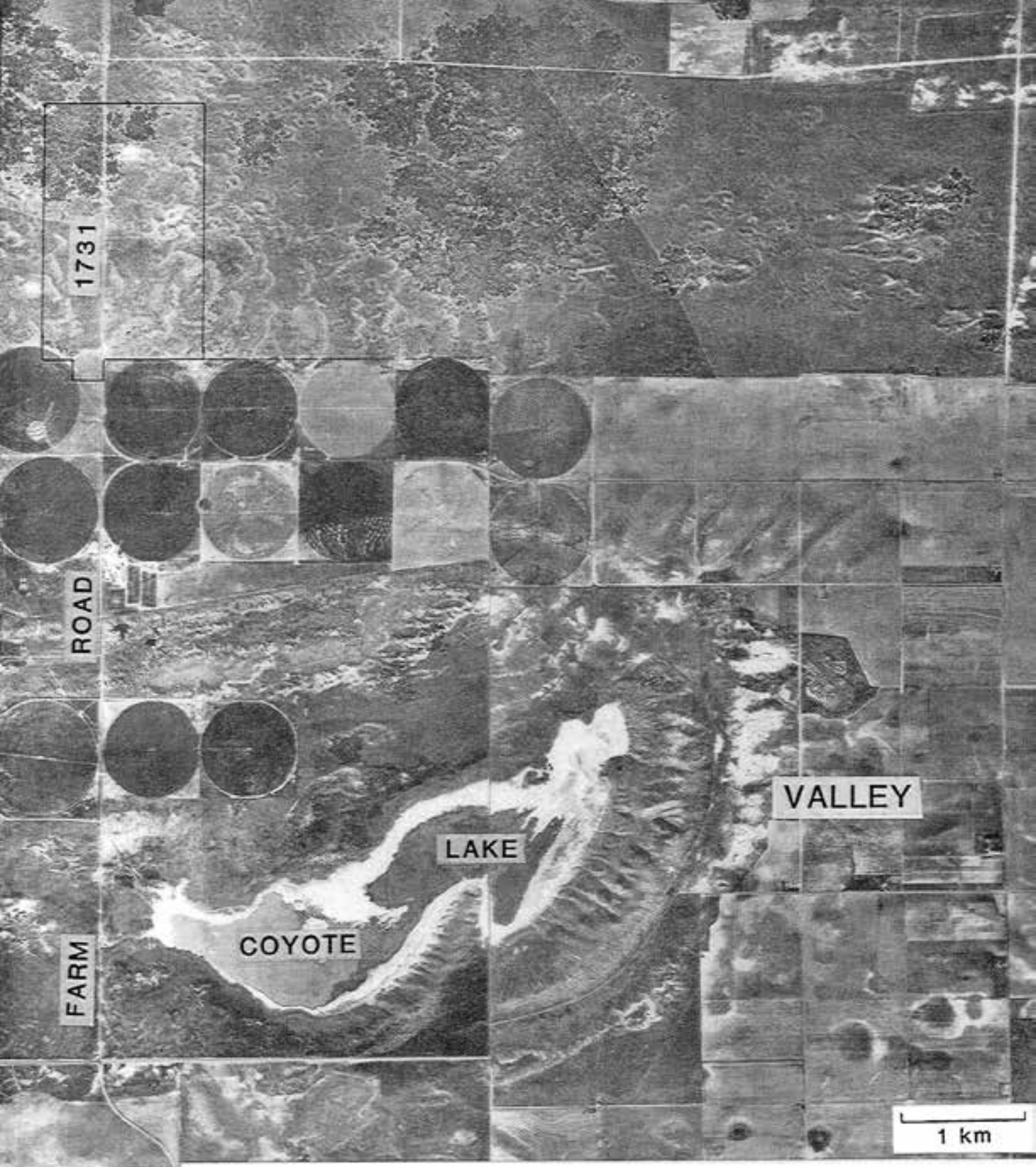
THE SANDHILLS PROJECT SOIL MONOGRAPH

Leland H. Gile

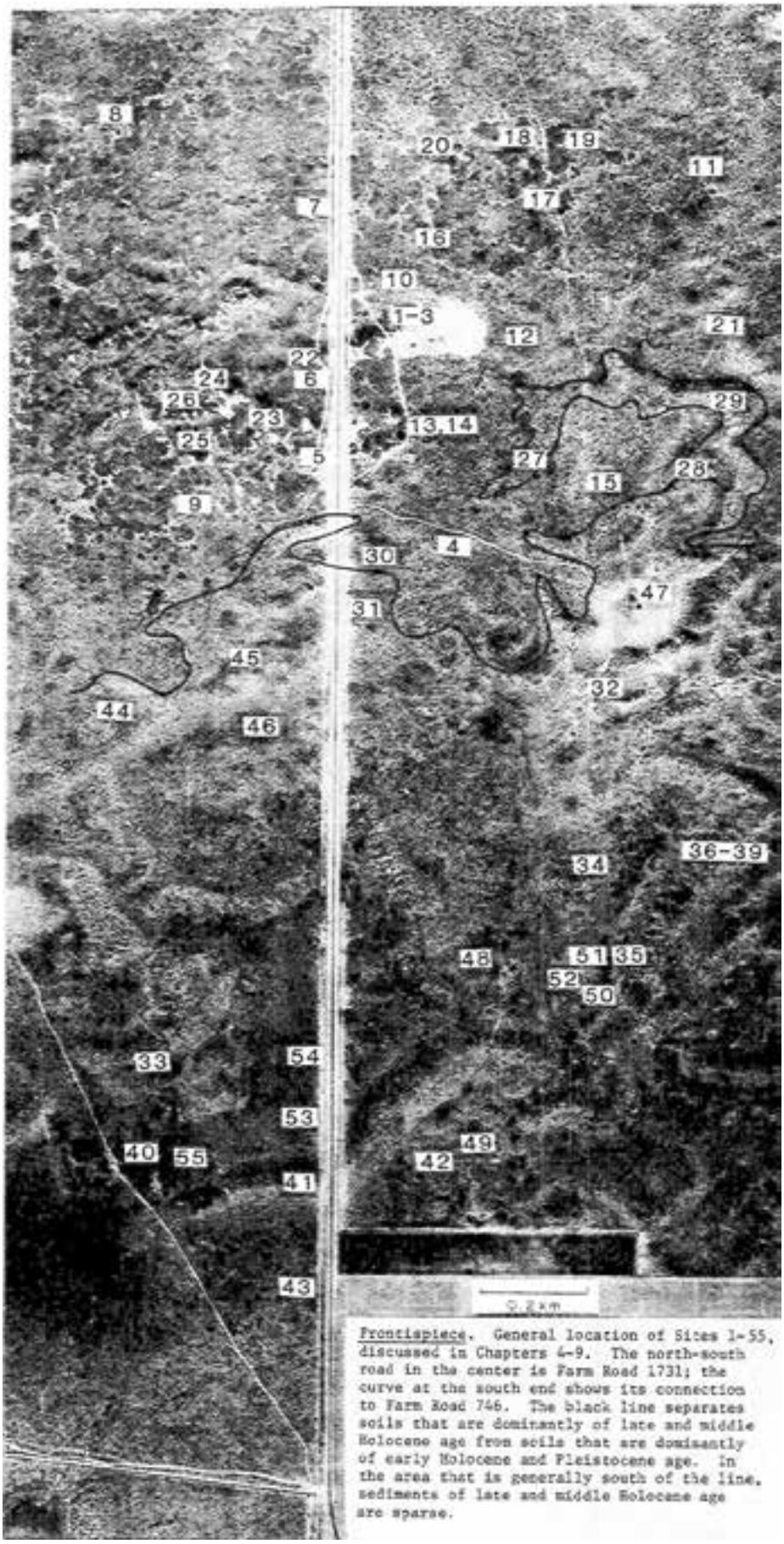
Natural Resources Conservation Service
U.S. Department of Agriculture
National Soil Survey Center, Lincoln, NE

in cooperation with
Rio Grande Historical Collections
New Mexico State University

INNER
PORTALES



Airphoto mosaic of the area in which this study is located (outlined in black, astride Farm Road 1731 and northwest of Coyote Lake). The sandhills are north of and in part of the inner Portales Valley. The large circles are irrigation sprinklers. The irregular dark patches north of the circles are shinnery oak. At upper left is a prominent east-west lobe of middle and late Holocene sediments. Photographed November 26, 1981 (ASCS). See back flyleaves for a topographic map of most of this area.



Frontispiece. General location of Sites 1-55, discussed in Chapters 4-9. The north-south road in the center is Farm Road 1731; the curve at the south end shows its connection to Farm Road 746. The black line separates soils that are dominantly of late and middle Holocene age from soils that are dominantly of early Holocene and Pleistocene age. In the area that is generally south of the line, sediments of late and middle Holocene age are sparse.

THE SANDHILLS PROJECT SOIL MONOGRAPH

A study of soils and landscapes on the Southern High Plains

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1997

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The cover photograph is a landscape view of the active blowout and dune east of Farm Road 1731 in the area of this study (flyleaf). Older sediments of the Fairview surface (post - 1880 A.D.) are in the high dune on the skyline. Fairview sediments extend to the dark horizon about midway down the tape at left (see also Fairview surface, Chapters 2 and 4), and were deposited during initial development of the blowout. These older Fairview sediments are now being removed as the blowout is enlarging by current erosion. Younger Fairview sediments are accumulating to the right of the high dune and beyond. The tape at left is about 2.4 m long. The view is east, the same direction as the dominant sand-moving winds. Photographed October, 1974.

To

Mr. J. E. Birdwell,

whose thoughtful cooperation and understanding

made this work possible

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1/ Underlined parts are soil mapping units (see fig. 27, and tables 6 and 7).

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PREFACE AND ACKNOWLEDGMENTS

The sandhills of Bailey County, Texas, and similar areas present some of the most complex soil patterns to be found anywhere on earth. An opportunity to study these distinctive soils arose at a meeting with Mr. J. E. Birdwell on September 25, 1972. At this meeting Mr. Birdwell gave me permission to study the soils and landscapes in sandhills of the Birdwell Ranch in Bailey County. Reconnaissance work began in the fall of 1972; detailed studies were started later and were carried out at various times between 1973 and 1983. Although work on the study has been unavoidably sporadic, throughout this time Mr. Birdwell maintained his strong interest in the work and his support of it has been steadfast from the beginning. It is a great pleasure to dedicate this volume to him.

At the beginning of the study I was a soil scientist in Soil Survey Investigations, Soil Conservation Service, USDA. In 1976 I retired from SCS and since that time have received financial support for this work from Texas Tech University. I thank them for this support.

Grateful acknowledgment is made to Mr. Birdwell and to Mr. and Mrs. W.E. Keeney for their permission to conduct these investigations. Detailed study of the older part of the stratigraphy, as illustrated by roadcuts along Farm Road 1731 and reported in an earlier volume, was made possible by cooperation and assistance of the Texas Department of Highways and Public Transportation. I thank B. L. Allen, Harold Dregne and John Hawley for reviewing the manuscript. I am indebted to Jerome Thompson, Vance Holliday, Boone Kaufman, George Threlkeld, B. L. Allen, Russell Pettit, and Dan Blackstock for assistance in soil sampling, and to Russell Pettit for plant identification. I thank Chalmer Davis for expediting access to various parts of the research area. The diagrams were prepared by Sam Horn, Tom McClue and Arnold Puentes.

Laboratory analyses at Sites 3b, 4-7, 18c-4, 21, 22, 41, 43, and 53 were made by the National Soil Survey Laboratory (NSSL), Lincoln, Nebraska. Particle-size determinations for other pedons were made by John Jacob, Paul Finnell and Stanley Ware, under the supervision of B. L. Allen at Texas Tech University, and by the Soil and Water Testing Laboratory, New Mexico State University. Organic carbon determinations at Sites 3g, 12a, 14, 15, and 50 were made by the Soil and Water Testing Laboratory, New Mexico State University. I thank Warren Lynn for work on the sand and clay mineralogy, and Hsin-yuan Tu for grain counts of very fine sands in eight pedons studied by the NSSL. Soil moisture determinations at Sites 4-7, 41, 43 and 53 were made under supervision of Russell Pettit, and may be obtained from him at the Department of Range and Wildlife Management, Texas Tech University. Special acknowledgment is made to my wife, Dora, for typing drafts of the manuscript.

Las Cruces, New Mexico
February 1985

Leland H. Gile

LOCATION OF INFORMATION

The table of contents is presented in some detail to assist in locating information. Additional items are located as follows.

SUMMARY

The summary contains a number of illustrative pedons that are identified by pedon and site number (e.g., Pedon 3b). Information about their morphology, laboratory data, soil occurrence, landscape position and other details is in the text (e.g., see Site 3b in the table of contents for Pedon 3b).

STUDY SITES

General location of the study sites is given in the frontispiece. Precise location is given on large-scale (1" - 330') aerial photographs as follows.

Page no.	Site no.	Page no.	Site no.
89	1-3	215	33, 40, 41, 53-55
120	4, 10-21, 27-31	224	34-39, 42, 48-52
122	5-9, 22-26	263	43
200	32, 47	271	44-46

SOIL MAPPING UNITS

Table 6 and 7 summarize composition of soil mapping units A-K, shown on the soil map (fig. 27). The composition of each mapping unit is also given in the introductory part of each mapping unit description, along with location of the unit, and its landscape, soil occurrence, vegetation, typical pedons and ranges in selected properties. Organization of the mapping unit descriptions is discussed on page 84. The table of contents locates mapping units A-K.

LATERAL MOVEMENT OF MOISTURE IN THE SOIL

There is evidence that lateral as well as vertical downward movement of soil moisture is an important factor in the origin of certain pedogenic features. Such evidence was found at sites 1, 3, 18, 25, 32-36, and 39, located in the table of contents.

DATA AND PHOTOGRAPHS

Table 1 locates tabular data and photographs by soil classification. Complete data sheets and descriptions for pedons sampled by the NSSL are in the Appendix. Summary tables for these data are included in table 1. Summary tables for sand and clay mineralogy and for resistant minerals are on pages 118 and 259.

Table 1. Location of tabular data and photographs, by soil classification

Soil classification	Tabular data: Laboratory	Tabular data: Morphological	Photograph(s)
	Page	Page	Page
ENTISOLS			
Typic Ustipsamments			
Sandy			
Tivoli	117, 118	90, 102, 132, 135, 136-139, 189	51, 55, 91, 93, 96, 101, 121, 126, 130, 133, 134, 142
Tivoli, thin variant #1	143	143, 150, 155, 161	
Alfic Ustipsamments			
Sandy			
Circleback	26, 134, 117, 118, 143, 192, 204, 244, 274	90, 102, 108, 132, 155, 161, 165, 166, 170, 173, 178, 192, 193, 204, 244	58, 98, 105, 110, 131, 159, 164, 174, 179, 181, 203, 206, 242, 243
Typic Ustifluvents			
(Sandy, coarse-loamy)			
Tivoli, thin variant #2	143	143, 150, 239	144, 151, 241
ALFISOLS			
Psammentic Haplustalfs			
Sandy			
Texico	64, 118, 171, 178, 187, 189, 192, 196, 204, 217, 227, 233, 234, 248, 259, 274	102, 108, 150, 161, 168, 171, 178, 183, 187, 189, 192, 196, 204, 217, 227, 233, 234, 245, 248, 255, 256, 274	61, 152, 169, 172, 188, 195, 209, 236, 246, 249, 250, 254, 257
Aridic Haplustalfs			
Coarse-loamy			
Farwell	64, 261,	261	261
Farwell, thin variant	26, 259, 264		
Farwell, calcic variant	298	298	296, 297
Fine-loamy			
Extee	233, 259, 292, 293	233, 292	230, 288, 291
Keeney	217, 274, 267, 277, 281	217, 255, 267, 274, 277, 281	66, 278, 280
MOLLISOLS			
Aridic Argiustolls			
Fine-loamy			
Newell, calcic variant	283, 292,	283, 292	68, 291, 296, 297
Newell	217, 227	217, 227	221, 226
Sandy			
Newell, sandy variant	111	108	110, 112
INCEPTISOLS			
Aridic Ustochrepts			
Fine-loamy			
Veal	292	292	287, 291

LARGE-SCALE AERIAL PHOTOGRAPHS

Large-scale aerial photographs taken at different times are useful in studying recent landscape history and the development of such features as erosion, deposition, cattle trails, roads and other evidences of man's activities. In the study area, aerial photographs have been taken at various times since 1941. Table 1a locates large-scale (1" - 330') aerial photographs taken during the indicated years, and lists developmental features illustrated by the photographs.

Table 1a. Features illustrated by aerial photographs taken at different times

Year of photography and page	Feature illustrated
1941, 1953, 1962, 1970, 1981	Enlargement of blowout caused by XIT cattle trail that began between 1887 and 1912
	Development of Farm Road 1731 and later roads
	Obliteration of traces of XIT cattle trail and development of new trails
34-38	Enlargement of oak clumps
	Oak crossing sandy road
	Fills of some study trenches visible in 1981
1941, 1953 1962, 1970	Effect of waterhole on proliferation of cattle trails and development of gullies since 1941
199, 200	Erosion and deposition of Fairview sediments
	Rapid healing of abandoned road
1941, 1953, 1970, 1981	Dark colors, in lowest parts of depressions, caused by record 1941 rainfall
	Intricate pattern of light and dark colors reflect complex soil patterns in depressions
214, 215	Enlargement of oak clumps
	Development of road and cattle trails
	Fills of some study trenches visible in 1981
1941, 1953	Distinct traces of XIT trail still present on dune crests of 1981
1970, 1981	Dark colors, in lowest parts of depressions, caused by record 1941 rainfall
222-225	Intricate pattern of light and dark colors reflect complex soil patterns in depressions
	Development of gullies on west-facing side of dune since 1941
	Fills of some study trenches visible in 1981

CARBONATES, WHITISH LENSES, MOTTLES, CROTOVINAS

Some features, such as clay bands, are widespread in the study area, and many of them are located in the table of contents. Other features, although observed only in a few areas, are important in the history and general character of many of the soils. Table 1b locates information about carbonates, whitish lenses, mottles and crotovinas.

Table 1b. Location of information about carbonates, whitish lenses, mottles, and crotovinas

Feature	Text discussion	Photographs	Diagrams
	Page		
Carbonates	14, 17, 19, 21, 23, 25, 26, 60, 65, 67, 70, 72, 79, 80, 145, 220, 229, 234, 244, 252, 258, 263, 264, 266-270, 276, 282, 285, 286, 289, 290, 293-295, 299	68, 230, 287, 288, 291, 296, 297	7, 12, 20, 265, 267
Whitish lenses	92, 193, 210, 213, 234, 237, 245, 258	236, 246	
Mottles	128, 149, 154, 156, 160, 163		153, 160
Crotovinas	106, 119, 166, 170, 205, 208, 252, 279	105, 121, 169, 206, 207	

SUMMARY

Objectives. This report presents a study of soils and landscapes in the sandhills of semiarid Bailey County, northwest Texas. The sandhills constitute a unique, largely wind-formed terrain with a distinctive array of soils, most of which are not found in adjacent areas. Little information is available about these soils. This study was undertaken to learn about their morphology, genesis, occurrence and soil-geomorphic relations, and to assist in understanding soils and landscapes in similar areas elsewhere.

Landforms, parent materials, and erosion. An east-west belt of sand dunes extends from northwest Texas into eastern New Mexico (fig. 1). Blowouts and blowout dunes of various sizes and shapes are the dominant landforms. Most of the blowouts and dunes started their development in the Pleistocene, and attained their present form by modification in the Holocene. The eolian sediments were originally derived from deposits of the ancestral upper Pecos-Brazos River, which flowed eastward through the Portales Valley (fig. 1) across the High Plains prior to integration of the upper and lower Pecos Valleys to form the present southward-flowing Pecos. Eolian parent materials of a particular soil were derived from older soils and sediments to the windward.

Parent materials of the study area are very low in silt and clay in some areas, and texture is fine sand. In other places the sediments were derived primarily from thick Bt horizons, and parent material textures of loamy fine sand and fine sandy loam are not uncommon.

Because of the long-time abundance of sand in the sandhills area, it should have been particularly susceptible to episodes of erosion caused by times of low effective moisture and high winds at various times in the past. That such episodes of erosion did in fact occur is indicated by the presence of a number of deposits and their associated soils that range widely in age, from late Holocene to middle Pleistocene (fig. 2). Buried soils are common, and in many places the deposits are thick enough that C horizons occur between the sets of pedogenic horizons. These sandy C horizons not only demonstrate soil burial and the episodes of sedimentation, but also permit an assessment of pedogenesis in the various deposits.

The chronology outlined in figure 2 must be considered tentative because no materials for dating were found in the study area. Instead, ages of sediments (morphostratigraphic units of Hawley and Kottlowski, 1969) and soils of the Holocene and latest Pleistocene were assigned by relating them to the chronology established at the Blackwater Draw archaeological site near Portales, N.M. Older sediments and soils in the Pleistocene were assigned very broad ranges in age.

Blowouts and the windward sides of dunes are particularly susceptible to wind erosion during a period of climatic stress and resistant erosion. Other landscape positions favor deposition; these are the crests and lee side of dunes. At times of maximum erosion, strong winds penetrated through relatively fine-textured Bt horizons to erosion-resistant, high-carbonate horizons of ancient soils where they are near the surface. In the study area, little erosion occurred in such places in the middle and late Holocene. Substantial erosion and deposition during this time took place

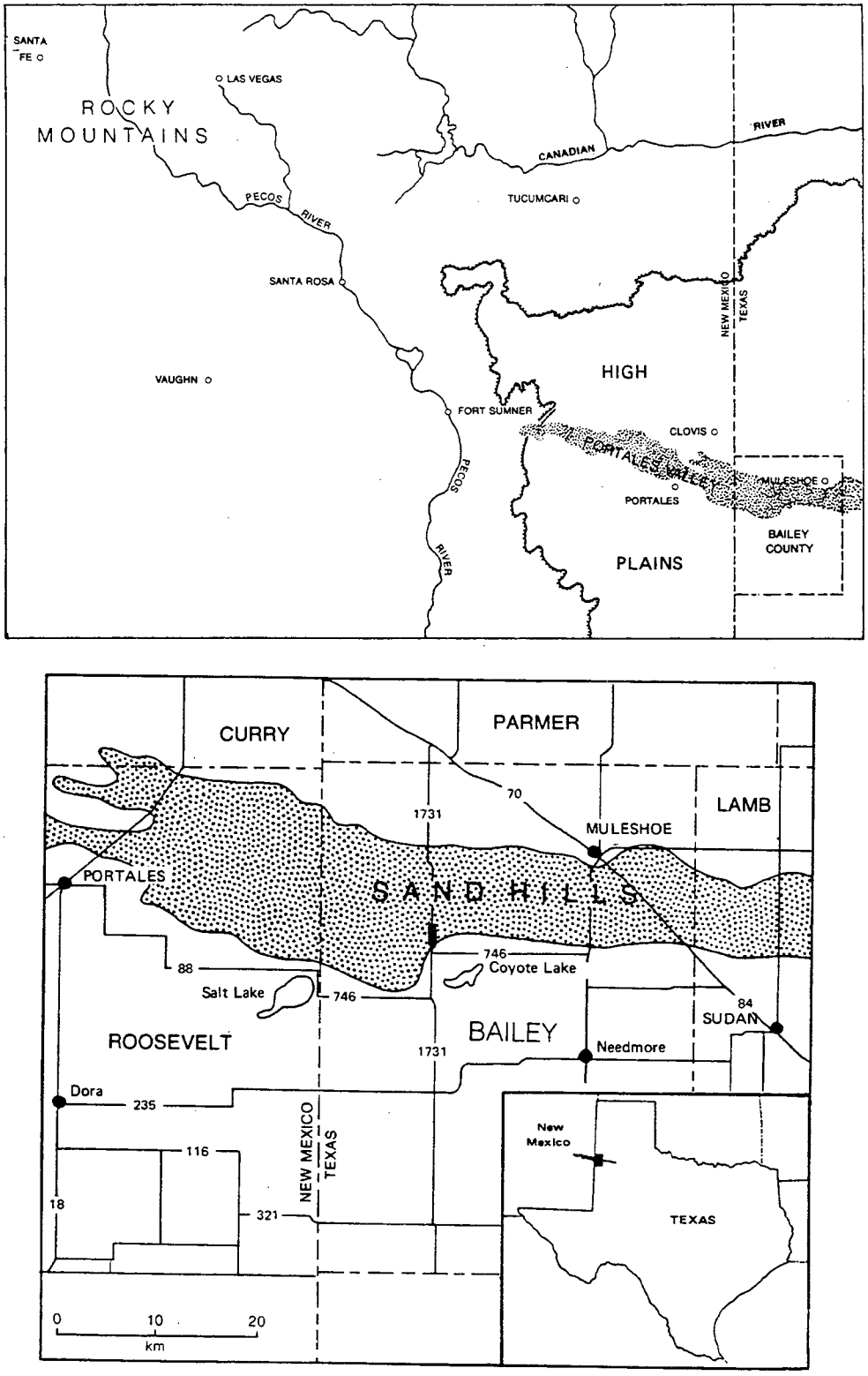


Figure 1. Upper. Location of the sandhills, Portales Valley and present course of the Pecos River. An ancestral upper Pecos-Brazos River once flowed eastward through the Portales Valley and across the High Plains. Deposits of the ancestral river are thought to have been the original source of eolian deposits in the sandhills. Hachures locate the High Plains scarp; the dotted pattern denotes the sandhills.

Lower. The Bailey County sandhills and location of the study area (black rectangle northwest of Coyote Lake, just north of the junction between Farm Roads 1731 and 746). The inset at right shows Bailey County and the sandhills in black.

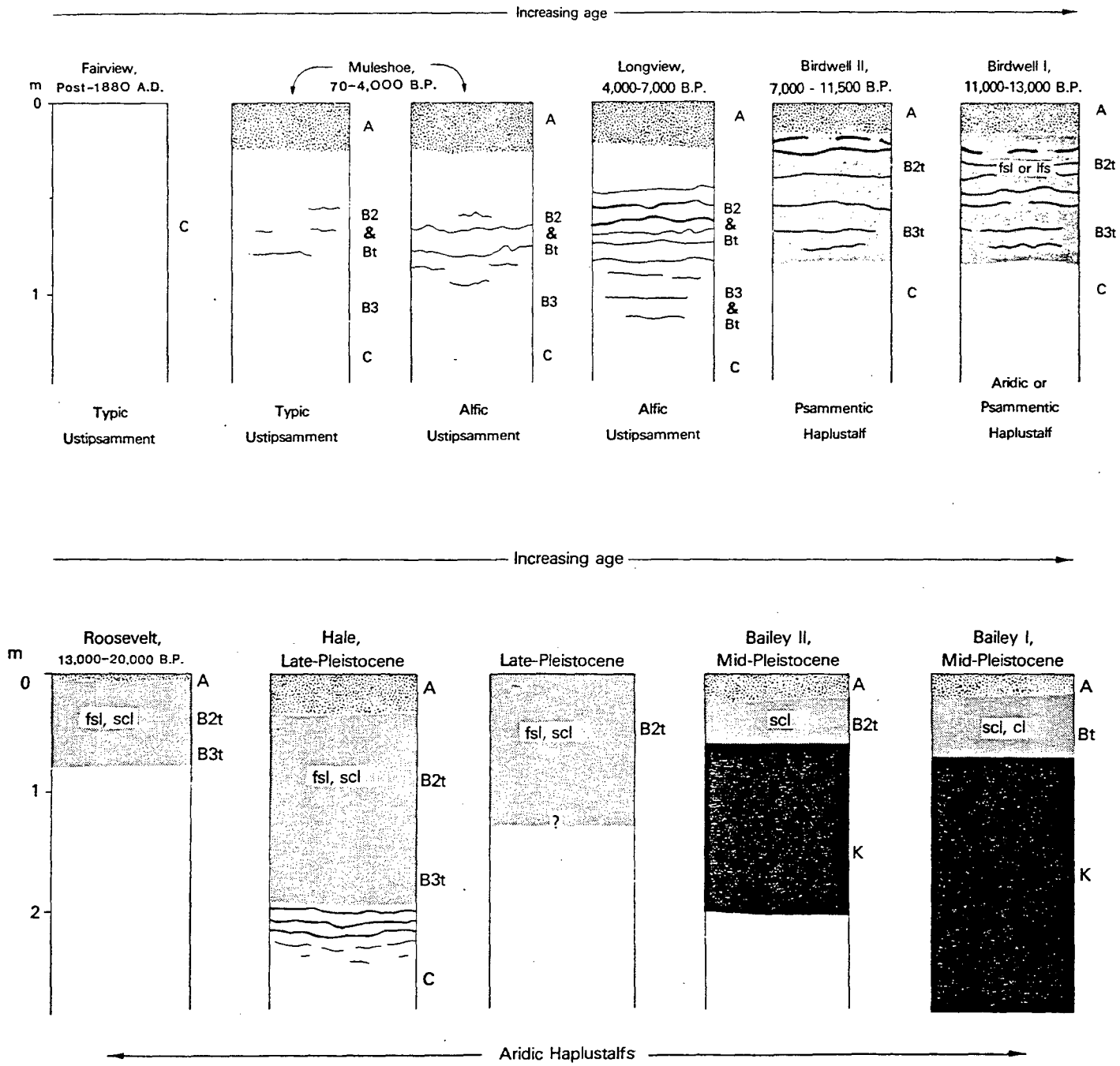


Figure 2. Diagram showing soil development with increasing age. The illustrative soils have formed in noncalcareous sandy sediments associated with geomorphic surfaces of indicated ages at the present land surface. Morphological variations from the indicated morphologies can be caused by erosion prior to burial; preservation by burial; and by presence of carbonates and/or more clayey sediments in the parent materials.

Upper. These soils formed in sediments deposited after the Tahoka pluvial ended about 13,000 years ago. Some soils of Muleshoe age have no clay bands, and weak Psammentic Haplustalfs occur in some deposits of Longview age. Longview I and II have been recognized in places (see Site 3).

Lower. These soils have formed in deposits emplaced during or before the Tahoka pluvial. The unnamed profile in the center was formerly designated Curry (Gile, 1981). This name has been dropped because the soil has been identified only in buried position; the associated surface and sediments are tentatively designated an early phase of Hale.

only where abundant sandy sediments were available for erosion. Water erosion has also occurred. Thin deposits of colluvium have accumulated on lower sides of some dunes and in margins of adjacent depressions.

Man's introduction of cattle and road-building has caused substantial erosion in places particularly susceptible; these are Holocene dunes without erosion-resistant soil horizons. Large blowouts have formed in some of these dunes where they are crossed by cattle trails. Sources of water tend to concentrate cattle movement. On slopes this can lead to the development of gullies, and associated emplacement of alluvium below the gullies. A few years after the gullies formed, vegetation became established in some of them and in the alluvium downslope. Thus the soils and landscape tend to "heal" to some degree in gullied terrain. Similarly, old roads (in areas that do not cross high dunes) heal rapidly in only a few years. This contrasts to earlier times of climatic stress, which resulted in large-scale erosion in areas unaffected by man's activities. But large-scale disturbance of the sandhills should be avoided, because it may result in severe wind erosion by just one dust storm.

Sand size. All five sizes of sands (Soil Survey Staff, 1951) occur in the sandhills. Fine sand (0.1-0.25 mm) is nearly always dominant, with medium sand (0.25-0.5 mm) next in order of abundance. The smaller sand grains tend to dominate the younger deposits (Fairview and Muleshoe) and the upper parts of pre-Muleshoe deposits. Fairview and Muleshoe sediments are young and were not deposited in a time of known major change in climate. The sediments generally contain enough fine sand, or suitable percentages of the other sand fractions (very coarse, 1-2 mm; coarse, 0.5-1 mm; and very fine, 0.05-0.1 mm) to qualify for the fine modifier (e.g., fine sand). Distinct strata of coarser sands can also occur in both Fairview and Muleshoe sediments, but the coarser sand sizes tend to occur mainly in the lower and middle parts of pre-Muleshoe deposits. The larger sand grains (dominantly medium sand, with a smaller amount of coarse sand, and almost no very coarse sand) are readily identified in many places because they occur in prominent strata.

Pedon 4 (fig. 3, upper), a Typic Ustipsamment, illustrates regular pattern of sand size with depth in Muleshoe sediments. All horizons are fine sand. Silt and clay percentages, not shown, are very low (less than 5 percent throughout, and commonly considerably less). The percentage of very coarse sand is even lower (0.3 percent or less).

Contrasting with the sand size uniformity of Pedon 4 are the sand sizes of Pedon 3b, an Alfic Ustipsamment of Longview age (fig. 3, lower). Pedon 3b has a thin surficial deposit of Fairview age and a discontinuity in the lower part of the Bb&Bt horizon. The maximum in fine sand is shown by the surficial Fairview deposits. Stratification is evident in the Bb&Bt horizon and becomes more prominent with depth. The percentage of fine sand decreases and that of medium sand increases with depth until in the B3b&Bt horizon they are the same (38 percent). The discontinuity between the Bb&Bt and Ab2 horizons is marked by a prominent increase in fine sand and decrease in medium sand (fig. 3, lower). The coarse and very coarse sands are low throughout. In Pedon 3b, only the upper two and the lowermost horizons qualify as fine sands; the remaining horizons contain too little fine sand (<50 percent) to qualify and are sands.

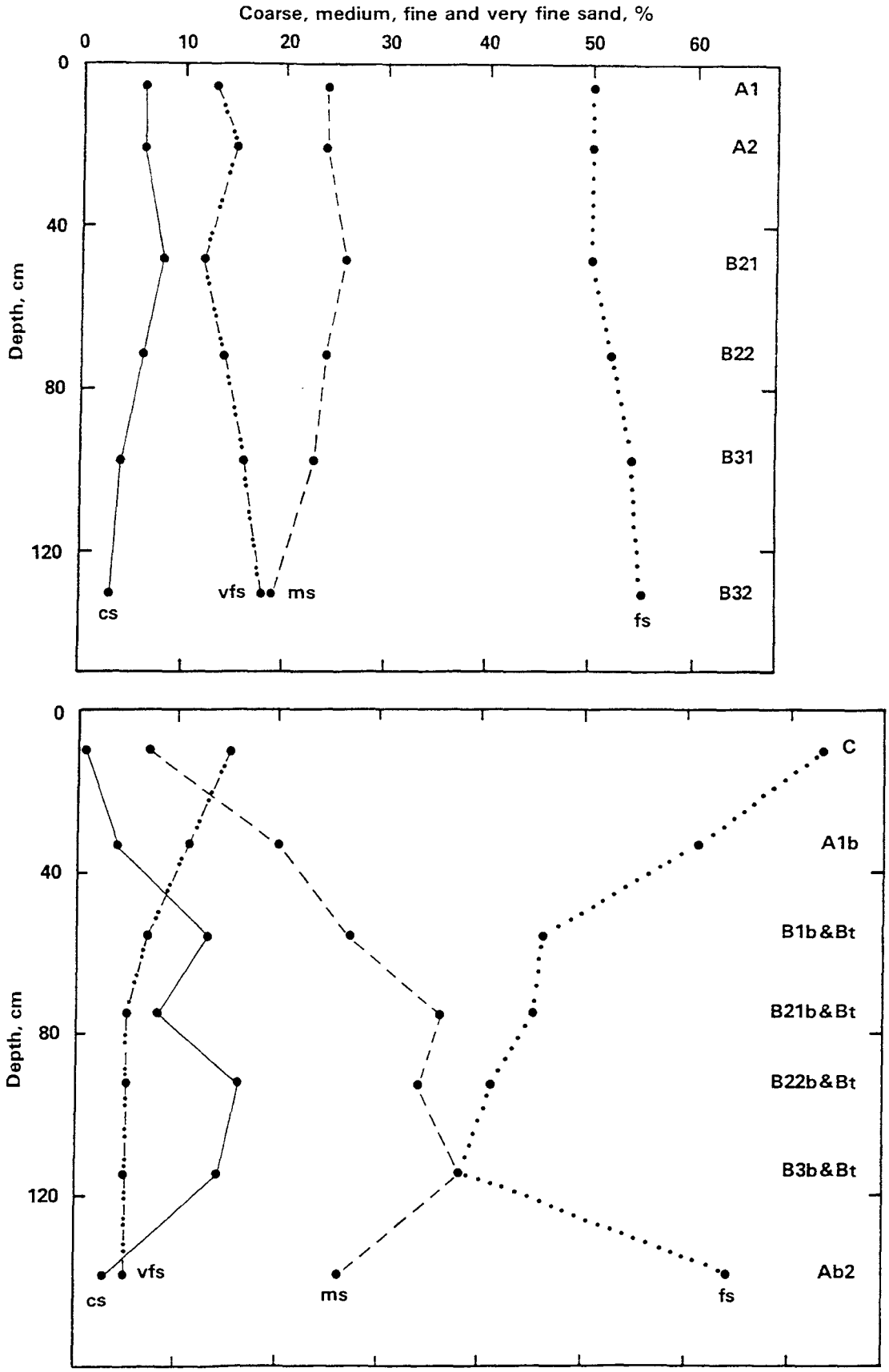


Figure 3. Percentages of four sand sizes in sediments of different ages. Horizon designations are at right.

Upper. Sand size of Muleshoe sediments in Pedon 4.

Lower. Sand size of Fairview (C horizon), Longview II (A1b through B3b&Bt horizons) and Longview I sediments (Ab2 horizon) in Pedon 3b.

Additions from dustfall. Much of the illuvial silicate clay is thought to have been derived from dustfall (dry dustfall and dust brought to earth by precipitation) after parent material deposition. This is indicated by the eolian character of the landscape, by dust storms at present and the likelihood of dust storms in the past, in many places by the low clay content of the parent materials, and by the high percentage of resistant minerals in the sands.

In some soils clay is accumulating in the surface horizon faster than it can move deeper into the soil, particularly under oak vegetation. This is illustrated by Pedon 22, a weak Psammentic Haplustalf of middle Holocene age (fig. 4). Silt and very fine sand have also accumulated in the surface horizon (fig. 4), but not below it because these coarser fractions do not move downward in the soil as readily as clay.

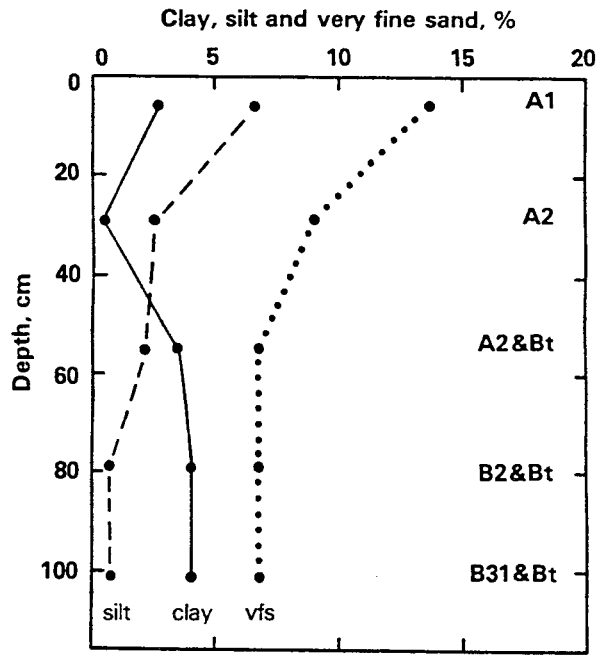


Figure 4. Percentages of clay, silt, and very fine sand in upper horizons of Pedon 22.

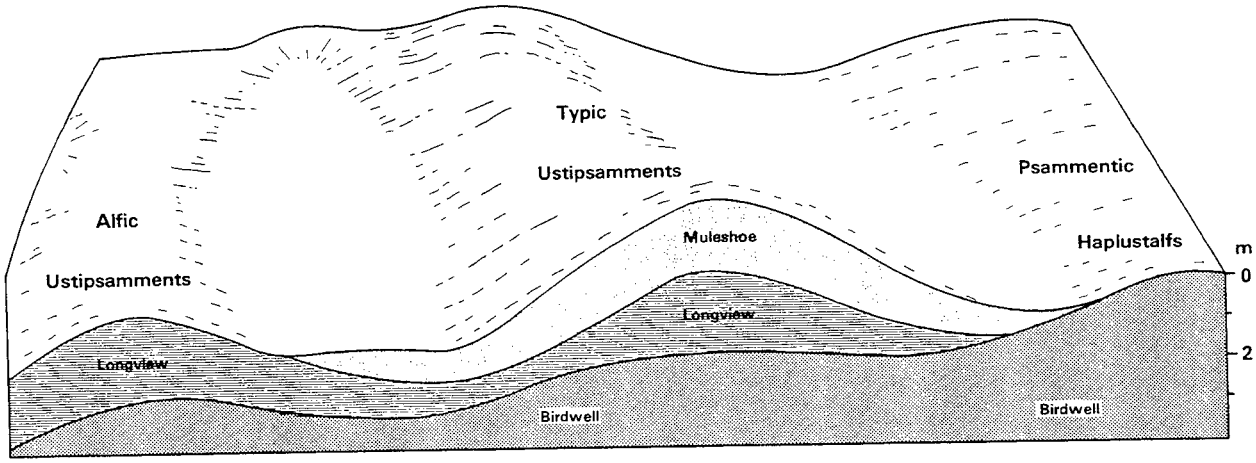
Although carbonate occurs in only a few soils, some of it has also been derived from dustfall as proposed earlier for many soils of arid regions (Gile and Grossman, 1979). This is discussed further in the carbonate section.

Soil occurrence and prediction. Table 1c presents soil orders, suborders, great groups and subgroups in the study area. Occurrence of soils is more complex in the sandhills than in terrains (such as terraces of differing levels) where soil morphology and relative ages of soils can be predicted. Soil prediction based solely on landscape position cannot be made in the sandhills, because soils of dune crests may be younger, older, or the same age as soils of dune sides and blowouts (fig. 5, upper). This is because eolian sediments may or may not be deposited on a given landscape position during a time of climatic stress and resultant erosion and deposition. Thus instead of a high surface being older as is the case in

Table 1c. Soil orders, suborders, great groups and subgroups in the study area

Order	Suborder	Great group	Subgroup
Entisols	Psamments	Ustipsamments	Typic Ustipsamments
			Alfic Ustipsamments
	Fluvents 1/	Ustifluvents	Typic Ustifluvents
Alfisols	Ustalfs	Haplustalfs	Psammentic Haplustalfs
			Aridic Haplustalfs
Inceptisols	Ochrepts	Ustochrepts	Aridic Ustochrepts
Mollisols	Ustolls	Argiustolls	Aridic Argiustolls
Vertisols			

1/ Fluvents may not have been previously recognized in sandhills. Fluvents must have texture of loamy very fine sand or finer in some subhorizon between 25 and 100 cm depth. In Fluvents of the study area, organic carbon decreases irregularly with depth, and a buried argillic horizon occurs between 50 and 100 cm depth. The Fluvents occur in two general ways. In one, the argillic horizon is buried by gully-derived alluvium and in the other, the argillic horizon is buried by eolian sediments of Muleshoe age (see fig. 2).



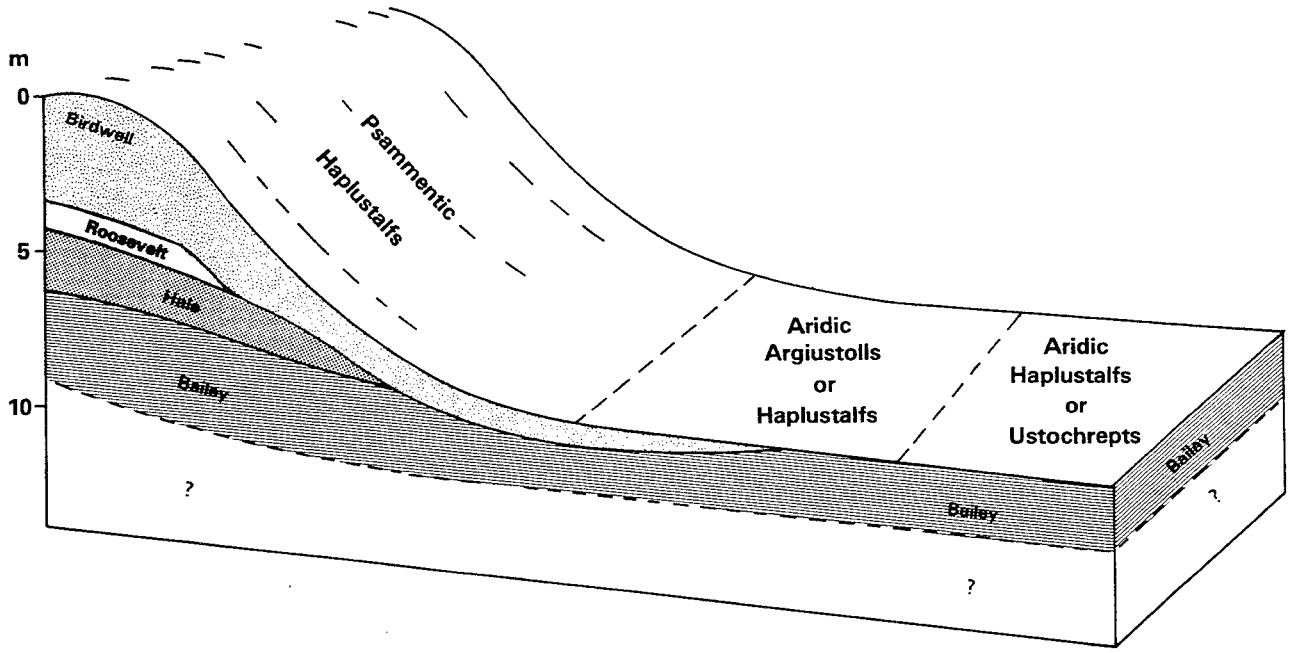


Figure 5. Generalized diagrams showing soils and sediments (morphostratigraphic units) in the sandhills.

Upper. Soils and morphostratigraphy of dunes and troughs in an area above the heavy line, frontispiece. Dunes are seldom of one age but instead usually consist of sediments of several ages, with the buried sediments having a soil characteristic of the sediment. Deposition of Birdwell sediments, followed by soil development and then by sporadic deposition of Longview and Muleshoe sediments, each with characteristic soils, has resulted in a complex pattern of Alfic Ustipsamments, Typic Ustipsamments and Psammentic Haplustalfs.

Lower. Soils and morphostratigraphy in an area below the heavy line, frontispiece. The area shown is dominated by high dunes and a large blowout. As in the younger dunes, Birdwell sediments also are underlain by buried sediments and soils. The oldest of these buried sediments (Bailey) is at the land surface in the blowout (right). In this ancient blowout, the erosion-resistant K horizon (fig. 2) is very near the surface.

many terraced terrains, in the sandhills a high surface may be very young because it is the site of youthful deposition that buries older soils. In addition, smooth slopes produced by wind and colluvium can mask important boundaries between soils that are markedly different.

However, several factors were found to be related to soil occurrence in a general way. Aerial photographs (frontispiece) are useful in assessing the general character of the dunes and their soils. The heavy black line in the frontispiece separates soils that are dominantly of middle and late Holocene age from soils that are dominantly of early Holocene and Pleistocene age. As can be seen in the frontispiece, dunes and blowouts north of the heavy black line are relatively minor land forms that are only faintly visible in airphotos, except for one small area west of Farm Road 1731. The more prominent dune forms in the latter area are thought to be inherited because these dunes have a core that is older than middle Holocene; Birdwell sediments are commonly within 3 or 4 m of the surface, and in places are at the surface.

If active blowouts and dunes are present, they show on airphotos as distinct whitish zones due to the sandy surface and scarcity of vegetation. These features suggest Entisols in the vicinity.

Entisols dominate sediments less than 7,000 years old (fig. 2) and do not occur in older sediments unless they have been strongly eroded. Soils of middle and late Holocene age are characterized by abundant sand and lack of erosion-resistant horizons. Figure 5 shows the stratigraphy of Muleshoe, Longview and Birdwell sediments, and its relation to the soil pattern in an area of complex occurrence of these sediments north of the heavy black line; Birdwell sediments are included because they do occur in places. Typic and Alfic Ustipsamments are most common. Typic Ustipsamments dominate Muleshoe sediments and either have no clay bands or have less than two continuous bands.

Clay bands occur continuously in soils of Longview age and most of these soils are Alfic Ustipsamments; a few have weak argillic horizons and are Psammentic Haplustalfs. A few Aridic Haplustalfs and Aridic Argiustolls occur in some of the small depressions, and a few Psammentic Haplustalfs occur on Birdwell dunes that were not covered by younger sediments (fig. 5).

Shinnery oak (*Quercus havardii*) is common on these soils of middle and late Holocene age (frontispiece) and because of its dark color on the aerial photograph is strongly suggestive of these soils. But the same kinds of soils also occur east of the oak (frontispiece), where common types of vegetation are sand sagebrush (Artemisia filifolia), sand dropseed (*Sporobolus cryptandrus*), three-awn (*Aristida sp.*), hairy grama (*Bouteloua hirsuta*), sumac (*Rhus aromatica*), and soapweed (*Yucca sp.*). In addition, shinnery oak can occur on older soils that have a thin cover of sand (see southern part of the area, frontispiece), but is less common.

South of the black line (frontispiece) the soils are dominantly of early Holocene or Pleistocene age (fig. 5, lower). The curving dunes south of the line are of Birdwell age and are much more prominent than the younger dunes to the north. The argillic horizon occurs almost continuously in soils of Birdwell age (fig. 2); most of these soils are Psammentic Haplustalfs. Textures are finer on lower slopes of most Birdwell dunes, and these soils are Aridic Haplustalfs.

Birdwell sediments dominate small blowouts and most of the soils are Psammentic or Aridic Haplustalfs. The large blowouts contain a high proportion of soils of Bailey age, which have argillic horizons and/or prominent calcic horizons. Most of these soils are Aridic Haplustalfs unless the argillic horizon has been eroded away by wind. If it has, the underlying calcic or petrocalcic horizon becomes diagnostic for classification and these soils are Inceptisols. Mollisols occur only in depressions, and primarily in parts of depressions that receive runoff from higher areas. High-chroma Bt horizons at shallow depths preclude the Mollisols in some soils with relatively high organic carbon.

The A horizon. A1 horizons and, in some cases, A2 horizons are well preserved in many soils of Muleshoe and Longview age. The A1 horizons contain more organic carbon and are darker than horizons below. Typically the A2 horizons are lighter-colored and contain less clay than adjacent horizons, and are not as red as the underlying B horizons. In the study area as a whole, A2 horizons are best developed and most common in soils of Muleshoe and Longview age with oak vegetation. But if the soils are in a position susceptible to wind or water erosion, then the A1 and A2 horizons have been truncated, wholly or in part. In active blowouts, the A horizons of Longview age commonly have been completely truncated; the more resistant clay band horizon may be at the surface, or may itself be strongly eroded.

In soils of Birdwell and pre-Birdwell age, the A horizons are commonly thin or absent, and the more erosion-resistant Bt horizons are at or near the surface. The presence of thicker A horizons in many younger soils is suggestive that older soils, which have Bt horizons with much more clay, also had thicker A horizons at one time. These older soils must have been strongly eroded, so that their A horizons are partly or wholly missing; the thicker A horizons occur only where they have been buried and preserved by younger deposits. In strongly eroded soils of Bailey age, high-carbonate horizons that were once beneath the Bt horizons are at or very near the surface. A scattering of carbonate-cemented fragments forms an erosion pavement on some of these surfaces, and constitutes the top of a thin A1 horizon.

Organic carbon accumulation. In most soils of the study area, the A1 horizon has the highest percentage of organic carbon, which drops markedly with depth below the A1. Percentage of organic carbon in the A1 horizons varies widely (fig. 6, right). Young sandy soils under nonoak vegetation have the lowest percentages as illustrated by Pedon 4, a Typic Ustipsamment (fig. 6). The highest values of organic carbon are found in finer-textured A1 horizons of soils in depressions that receive runoff from adjacent slopes. This is illustrated by Pedon 50, an Aridic Argiustoll in a depression near bordering slopes that furnish runoff. The A1 horizon of Pedon 50 has more than five times as much organic carbon as Pedon 4, and also has more clay (19 percent vs 4 percent in the A1 horizon of Pedon 4).

Pedon 4 is under nonoak (dominantly grass) vegetation. Organic carbon values tend to be higher under oak; A1 horizons of Pedons 5-7 and 22, which have about the same texture as Pedon 4 but occur under oak, have organic carbon percentages of 0.97, 0.66, 0.52, and 0.81 respectively. Thus the increased amount of organic carbon in A1 horizons under oak as compared to nonoak vegetation ranges from slight to more than double.

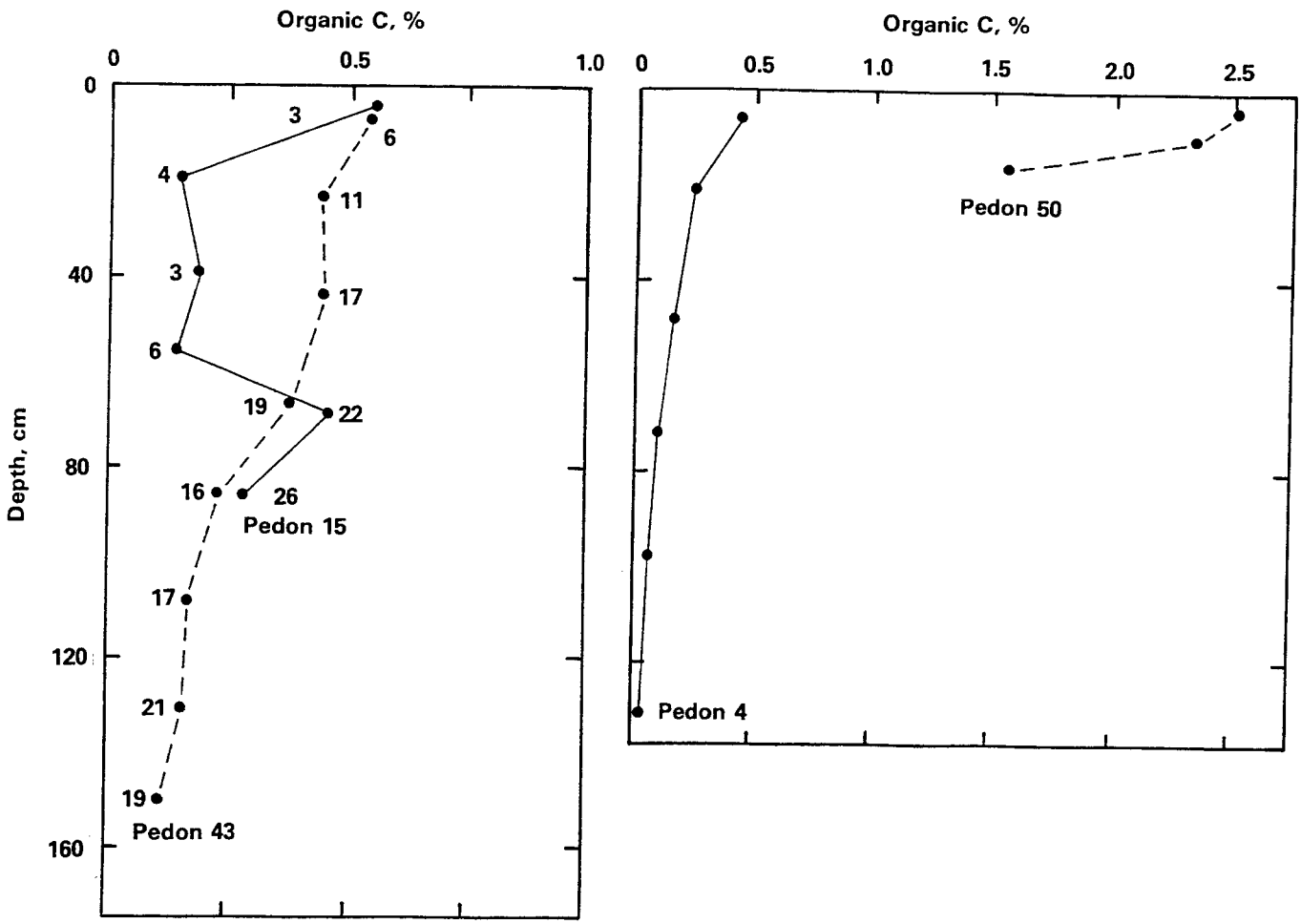


Figure 6. Left. The relation of organic carbon percentage to clay percentage and depth. Figures next to the plotted organic carbon values are clay percentages. Horizon designations for Pedon 15 are A1, B1, B21, B22, B21tb, B22tb; for Pedon 43 they are A1, B11t, B12t, B2t, B11tb, B12tb, B2tb, and B3tcab.

Right. Effect of landscape position and clay on content of organic carbon. Pedon 4, an Entisol, occurs on the side of a dune. Pedon 50, a Mollisol, occurs in a depression, and also has more clay. Horizon designations for Pedon 4 are A1, A2, B21, B22, B31, B32; for Pedon 50 they are A1, B21t, and B22tca.

In horizons that are relatively near the surface, organic carbon content is commonly related to clay content. This is illustrated by Pedons 15 and 43 (fig. 6, left). In Pedon 15, in which an argillic horizon of Hale age is buried by Muleshoe sediments, organic carbon increases markedly as clay increases from 6 percent in Muleshoe sediments to 22 percent in the buried Bt horizon. This irregular decrease in organic carbon with depth is characteristic of and diagnostic for Fluvents (table 1c). But with increasing depth, organic carbon gradually decreases despite increases in silicate clay (Pedon 43, fig. 6, left). Bt horizons that are deeply buried contain even less organic carbon as discussed later.

Silicate clay accumulation. In this semiarid study area, the horizon of silicate clay accumulation is the soil horizon that best accords with soil age. At stable sites, clay content of the Bt horizon increases with increasing age of soil (fig. 7).

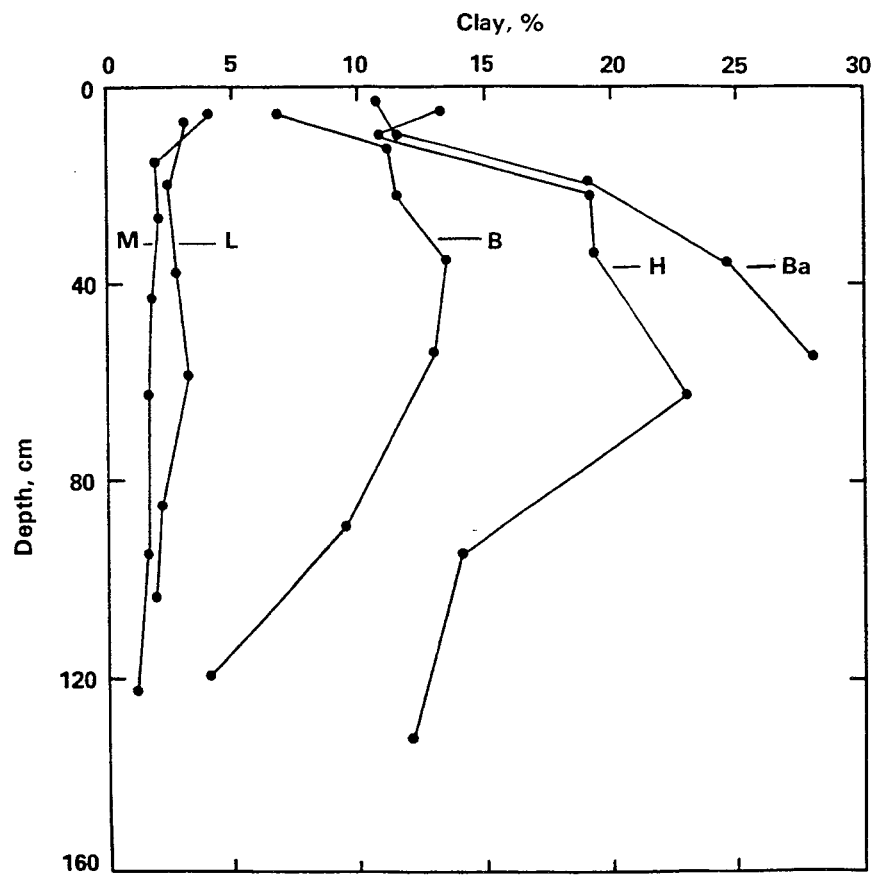


Figure 7. Increasing silicate clay with increasing soil age. M = Muleshoe (Pedon 5); L = Longview (Pedon 18c-4); B = Birdwell (Pedon 36a); H = Hale (Pedon 49); Ba = Bailey (Pedon 52a).

The first morphological evidence of clay accumulation consists of clay bands, some of which occur continuously in all soils of Longview age (fig. 2). Clay in the bands is primarily of illuvial origin and is thought to have been deposited from clay in suspension as the wetting front slows its downward movement. Some clay apparently moves through the upper bands at

times of deeply penetrating moisture and then accumulates in bands beneath as downward movement slows.

Horizons with clay bands in Alfic Ustipsamments of Longview age differ little in clay content from Typic Ustipsamments of Muleshoe age (fig. 7). Although most clay bands of Longview age are continuous, they are usually thin (commonly 2-3 mm). Thus the bands do not contribute greatly to the total clay content of the horizon as a whole, and are very sensitive morphological indicators of slight clay accumulation.

Morphology of the clay bands is closely related to soil age and landscape position. The clay bands do not occur at all in the youngest soils (Fairview); are not present, or are thin and discontinuous in the next older soils (Muleshoe); are thicker and continuous in the next older soils (Longview); and some bands are partly obscured by clay accumulation between them in the next older soils (Birdwell). The clay bands are only 1 or 2 mm thick in soils of Muleshoe age, but range up to 1 cm thick in soils of a few Longview and many Birdwell dune crests, and up to 4 cm thick on sides of some Birdwell dunes. Clay bands tend to thicken downslope, showing the effect of lateral movement of water on movement and subsequent deposition of clay.

In soils of Birdwell age, erosion has brought the clay band horizon closer to the soil surface; in many soils one or more of the upper bands is discontinuous and appears to be in the process of gradual obliteration. This is apparently caused by soil water, roots and soil fauna since the shallowness of upper bands should render them more susceptible to disruption by these agents.

The soils of Birdwell age and older, Bt material occurs throughout most or all of the B horizon instead of being concentrated only in bands (fig. 2). The Bt horizons are not thick in soils of Birdwell age because the parent materials were deposited and the soil formed after the Tahoka pluvial, which ended about 13,000 years B.P. Soils of Hale age are the first soils that have strong morphological evidence of pedogenesis in a Pleistocene pluvial. Soils of Hale age have thick, relatively fine-textured Bt horizons (fig. 2), even where buried by the sediments of Birdwell I. This is attributed to greater effective moisture of a pluvial and resultant deeper penetration of the wetting front.

The color of Bt horizons is also related to age, but is confounded in some of the younger soils by color of the parent materials. Thus Bt horizons of Birdwell age may have hue of 5YR or 2.5YR, or intermediate between 5YR and 2.5YR, but the redder part of the range is associated with redder colors of the parent materials. In contrast, if not underlain by buried high-carbonate horizons at shallow depth, Bt horizons of Hale age are always dominated by 2.5YR hues. Similarly, Bt horizons of Hale age are dominated by chromas of 6 but the younger Bt horizons are not; some of them have lower chromas.

Thin section studies of clay bands showed that nearly all of the clay occurred as oriented coatings on the sand grains (see Pedon 3a). Coatings of oriented clay on sand grains are typical of Bt horizons in arid regions, and also appear to be an important micromorphological feature of illuvial clay in semiarid areas.

Textural sequence in Birdwell dunes and adjacent depressions. A striking textural sequence occurs in soils of many Birdwell dunes and adjacent depressions (fig. 8). On dune crests, texture of the B2t horizon is dominantly loamy fine sand, with some fine sandy loam. Texture tends to be coarser (dominantly fine sand, with some loamy fine sand) on less stable parts of dunes (e.g., west-facing, upper and central sides of dunes, because of strong erosion by westerly winds). Clay in the B2t horizon increases downslope, to a fine sandy loam, then to a sandy clay loam on lower sides of dunes, and finally to a sandy clay in some of the adjacent depressions.

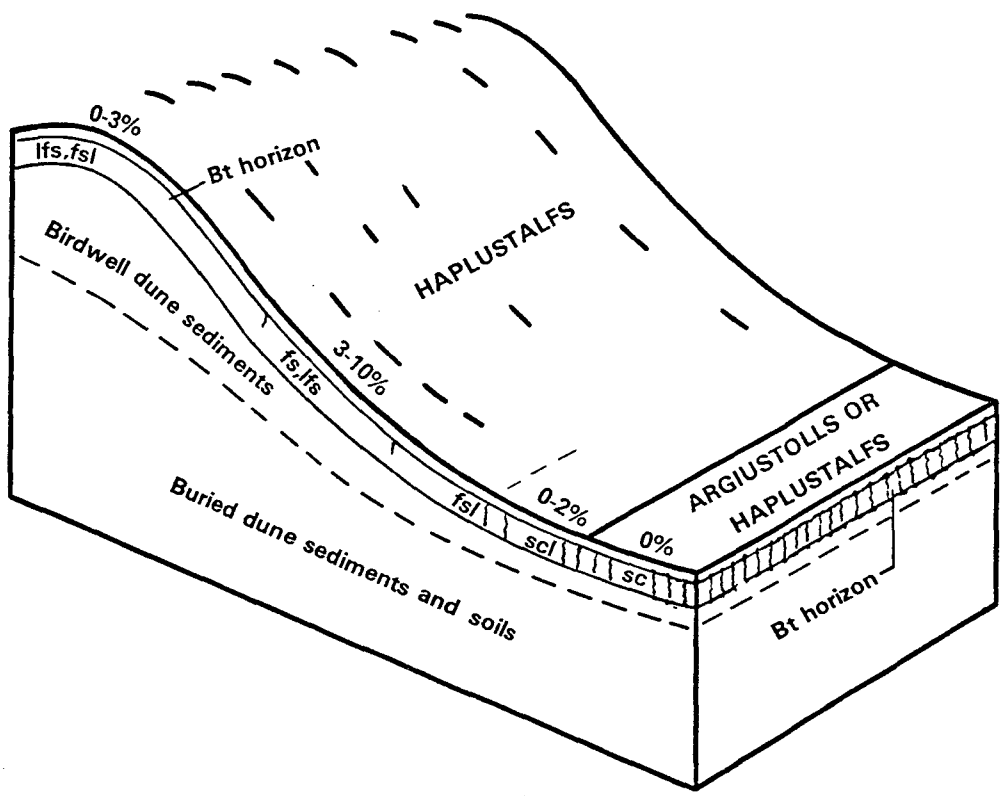


Figure 8. The relation of B2t horizon texture to landscape position on the crest and west-facing side of a Birdwell dune and adjacent depression.

The increase in clay downslope is attributed primarily to colluvium. The colluvium is commonly shallow, depth to its top ranging from about 10 to 50 cm. Its thickness ranges from about 5 to 45 cm. Because many dune sediments are strikingly low in silt and clay, abrupt changes in these components can be strong evidence of a discontinuity.

Figure 9 shows the contrast in clay and silt between the colluvium-containing and adjacent materials in Pedon 34c, an Aridic Argiustoll in a depression bordering a north-facing slope. Some of silt and clay in the surface horizon is attributed to colluviation during Muleshoe and Fairview time; as with Birdwell colluvium, the analogous horizons upslope contain less silt and clay. Thus the process of colluviation appears to be continuing at present. See Site 33 for a summary of evidence for colluviation, and Sites 33-35, 39, 44b, and 48 for further illustrations of colluvium.

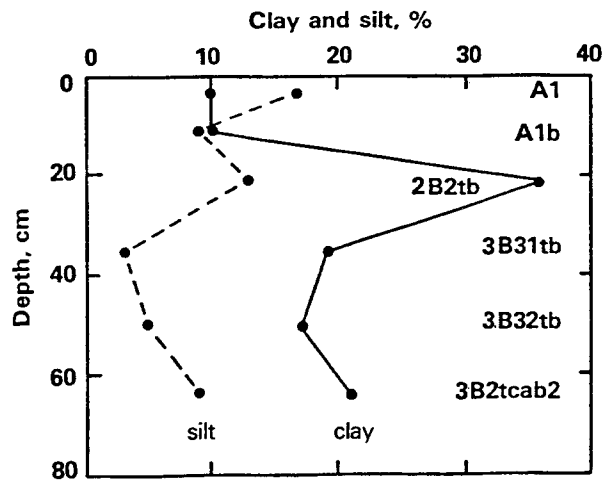


Figure 9. Percentages of silt and clay in Pedon 34c.

Carbonate accumulation. At stable sites and with increasing soil age and carbonate accumulation in well drained sediments, the carbonate horizon ultimately plugs with carbonate and a laminar horizon forms on top of the plugged horizon (fig. 10, upper); the more complex stages occur in soils shown to be older by geomorphic evidence. Development of the various stages is best expressed in arid regions because they have (and would have had during pluvials) less precipitation than in semiarid regions, and the accumulated carbonate is shallower in soils and sediments of a given age. Thus in many arid regions, the carbonate stages are diagnostic for a range in age of soils, and may be predicted once the soil-landscape relationships have been determined. Although this is true to some extent in semiarid regions, there the carbonate stages must be used with particular caution because precipitation is higher than in arid regions, and carbonate accumulates deeper in materials of similar texture. This is particularly the case in sandy, pervious sediments of sandhills.

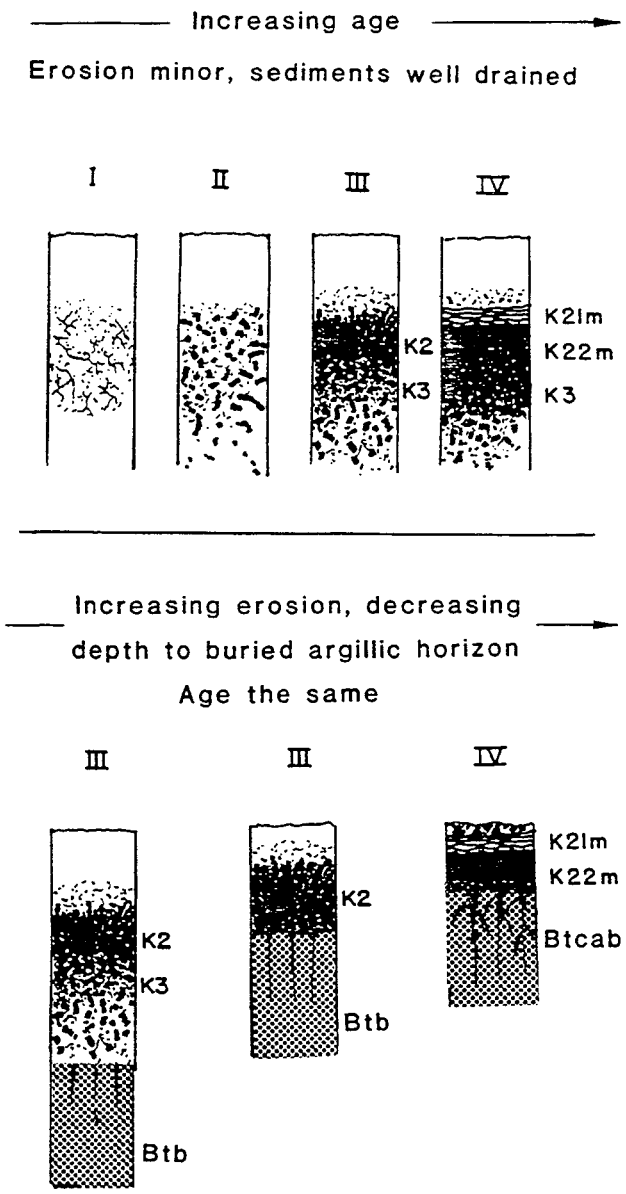


Figure 10. Upper. Schematic diagram of the diagnostic morphology for the stages of carbonate horizon formation in the nongravelly sequence. Carbonate accumulations are indicated in black for clarity. The morphology is summarized as follows (see Gile et al., 1966, for more detailed discussion): Stage I: carbonate filaments and coatings. Stage II: carbonate nodules separated by low-carbonate material. Stage III: carbonate occurs essentially throughout the horizon, which is plugged with carbonate in the last part of the stage. Stage IV: a laminar horizon has formed on top of the plugged horizon.

Lower. Development of the stage IV horizon by erosion and decreasing depth to a buried argillic horizon, which holds up the wetting front and speeds development of the plugged and laminar horizon. Black lines and tongues denote carbonate descending between and in prisms of the buried argillic horizon.

Modified from Gile et al., © 1966, the Williams & Wilkins Co., Baltimore.

The stage I carbonate horizon, a distinct feature in many soils of late and middle Holocene age in arid regions, does not occur at all in soils of this age (Muleshoe and Longview) in the study area (fig. 2). The stage I horizon has rarely been observed in numerous exposures of the still older Birdwell sediments. The pH data and character of the stage I horizon where it does occur in Birdwell sediments and in adjacent older sediments suggest possible positions for accumulation of dust-derived carbonate associated with pedogenesis in Birdwell sediments. Figure 11 gives pH and clay for three pedons that illustrate effect of parent material carbonate and of landscape position of development of the stage I horizon in sediments of different ages and textures.

Pedon 41 occurs on the crest of a high Birdwell dune. In Pedon 41, stage I carbonate filaments in the Btca horizon descend from primary, sand-size carbonate grains in the parent materials. This stage I carbonate is a direct result of carbonate grains in the parent materials since it does not occur in Birdwell sediments unless such parent material carbonate is present. Because the sediments are pervious, the carbonate filaments are "in transit" to deeper horizons. The pH values are high in this horizon and below it because of the parent material carbonate. The amount of carbonate by analysis (trace) is very slight, however.

Pedon 42 occurs on the crest of a low, broad dune where Birdwell sediments are much thinner and are underlain by buried horizons of Roosevelt and Hale age. Because of the broad, level landscape position, substantial penetration of soil moisture would be expected. Primary carbonate grains in Pedon 41 were not found in Pedon 42, in which pH values do not rise above 7.0 to considerable depth despite higher clay content (fig. 11). No stage I carbonate was found in either Birdwell II or Roosevelt sediments. But stage I carbonate does occur (as scattered carbonate filaments) in the B22tcab2 horizon of Hale age, where pH increases to 8.2 (fig. 11). This stage I carbonate could represent the approximate depth for accumulation of dust-derived carbonate in Birdwell sediments. A detailed stratigraphic study, tracing the stage I carbonate and its relation to both the Birdwell and buried horizons, would be required to demonstrate this conclusively.

However, stage I carbonate does not occur in soils of Hale age that are deeply buried by Birdwell and Roosevelt sediments along Farm Road 1731, both where the Hale Bt horizons are underlain by C horizons and by buried Bt horizons. This suggests that stage I carbonate in Hale Bt horizons that are not deeply buried was probably emplaced in the Holocene.

The general absence of visible carbonate immediately beneath the distinct Bt horizons in Birdwell sediments suggests that dust-derived carbonate of Birdwell age is emplaced well below the silicate clay accumulation of the same age. This contrasts with the carbonate accumulations in arid regions, where the carbonate accumulations overlap or immediately underlie the silicate clay accumulations.

From the foregoing it is clear that the stage I carbonate horizon is not readily related to a discrete deposit in the sandhills. It also appears that in some soils of semiarid regions, carbonate from dustfall may accumulate in sediments much older and deeper than overlying sediments through which the carbonate has passed.

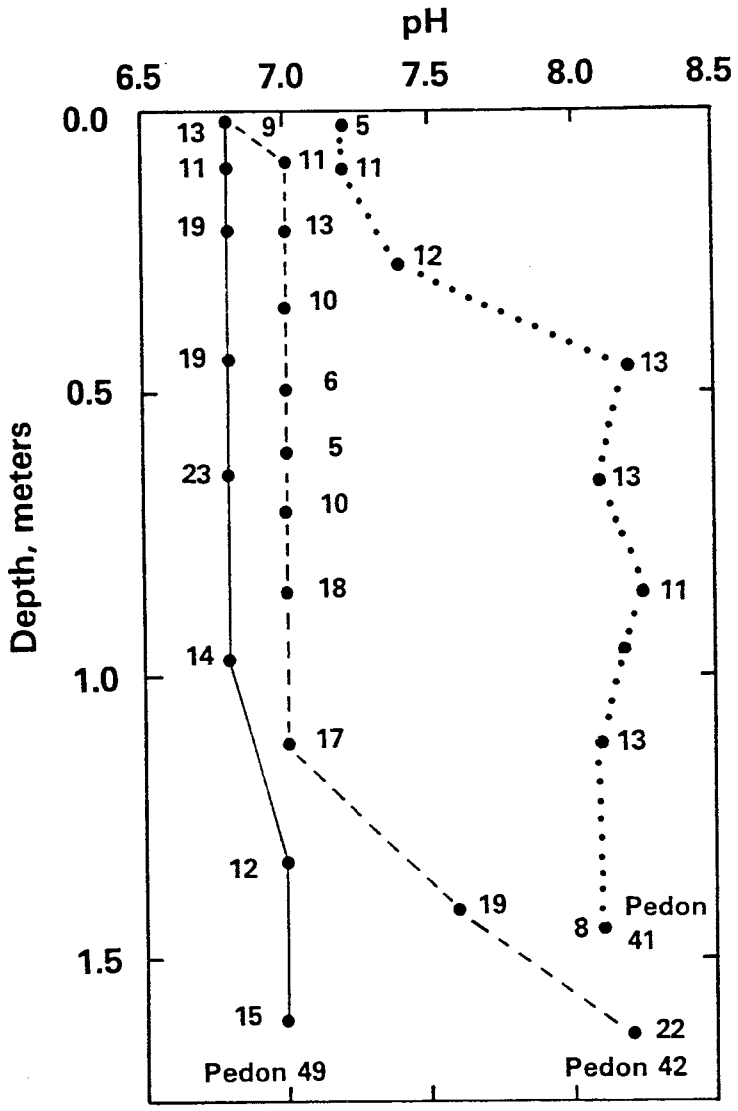


Figure 11. The pH and clay of Pedons 41, 42 and 49 (figures next to plotted pH values are clay percentages. Clay not available for the C1&B33t horizon). Horizon designations and sediments are given below. Sediments are designated as: M = Muleshoe, L = Longview, B = Birdwell, R = Roosevelt, H = Hale (see fig. 2).

Pedon 49		Pedon 42		Pedon 41	
M, L	A1	B	A1	B	A1
H	Ab		B1t		B1t
	B21tb		B21t		B21t
	B22tb		B22t		B22tca
	B23tb		B3t		B31tca
	B31tb		C		B32tca
	B32tb	R	B1tb		C1&B33t
	Btb2		B21tb		C2
			B22tb		C3
		H	B21tb2		
			B22tcab2		

Pedon 49 occurs in a small depression near Pedon 42. Pedon 49 is dominated by Hale sediments, lacks Birdwell and Roosevelt sediments present in Pedon 42, and has a buried Bt horizon in the lower part. Pedon 49 is noncalcareous to 170 cm depth, and pH is only 7.0 at that depth despite higher clay content than Pedon 42, and presence of a buried Bt horizon. Lack of the stage I carbonate in Pedon 49 is attributed to its position in a small depression; extra water from run-in should move illuvial carbonate to greater depths than in Pedon 42 on the nearby dune crest.

The stage II carbonate horizon, a characteristic feature of soils of specific ages in arid regions, was not found in a discrete deposit in this study area. The stage III carbonate horizon is common and occurs in soils of Bailey age (fig. 2). The stage IV carbonate horizon has not yet formed in stablest sites of the oldest surface (Bailey, fig. 2). The stage IV horizon has formed in a few places affected by both erosion and shallow depth to a buried argillic horizon (fig. 10). Buried argillic horizons are effective in slowing penetration of the wetting front (fig. 10); carbonate tends to accumulate along the top of the buried horizon, generally penetrating it only at sites of less restricted hydraulic conductivity such as cracks between prisms. Thus the buried argillic horizon tends to confine carbonate accumulation to a narrow zone, which effectively speeds the process of carbonate-plugging and laminar horizon formation that is diagnostic of stage IV. Erosion can also speed development of the plugged and laminar horizons because it brings the carbonate horizon nearer the surface (see Site 54).

pH. Deep sandy soils tend to have quite similar pH curves to a depth of about 1 or 1½ m. Commonly, pH tends to increase slightly with depth (e.g., from pH 6.8 in upper horizons to 7.2 in lower horizons) or to remain about the same (e.g., 6.8, 7.0, or 7.2). If buried soils are not present, pH often increases slightly with depth and then decreases slightly.

Oak tends to lower pH as compared to other types of vegetation. Under oak, soils with prominent A2 horizons occur in some soils of Muleshoe and Longview age, especially Longview. Figure 12 (left) shows the pH of two pedons of Longview age and an underlying buried soil. Textures are sand or fine sand in horizons of Longview age; in the buried Birdwell horizons, textures are sandy except for the B1tb horizon, a fine sandy loam. Under oak, pH first decreases from the A1 to the A2 horizon, then increases in the underlying B&Bt horizon. In less prominent A2 horizons, pH is similar to that of the A1 horizon, or the decrease in pH from A1 to A2 is less marked. In a soil of the same age but under nonoak (dominantly grass) vegetation, the pH of upper horizons drops slightly with depth, but does not increase in the B&Bt horizon as it does in the soil under oak (fig. 12, left).

The pH values developed during the late and middle Holocene tend to be higher than those of early Holocene or of Late Pleistocene, intervals that contained episodes with greater precipitation than now. Thus many buried soils show a characteristic pH trend with depth (fig. 12, left), in which pH decreases in the upper part of the underlying buried soil, then increases. The pH of such buried horizons has clearly increased during the present moisture regime, as indicated by pH curves that descend from overlying horizons and overlap upper horizons of the buried soil. Further evidence is provided by land-surface analogues (of the buried soils), which have pH curves essentially the same as those of late Holocene soils.

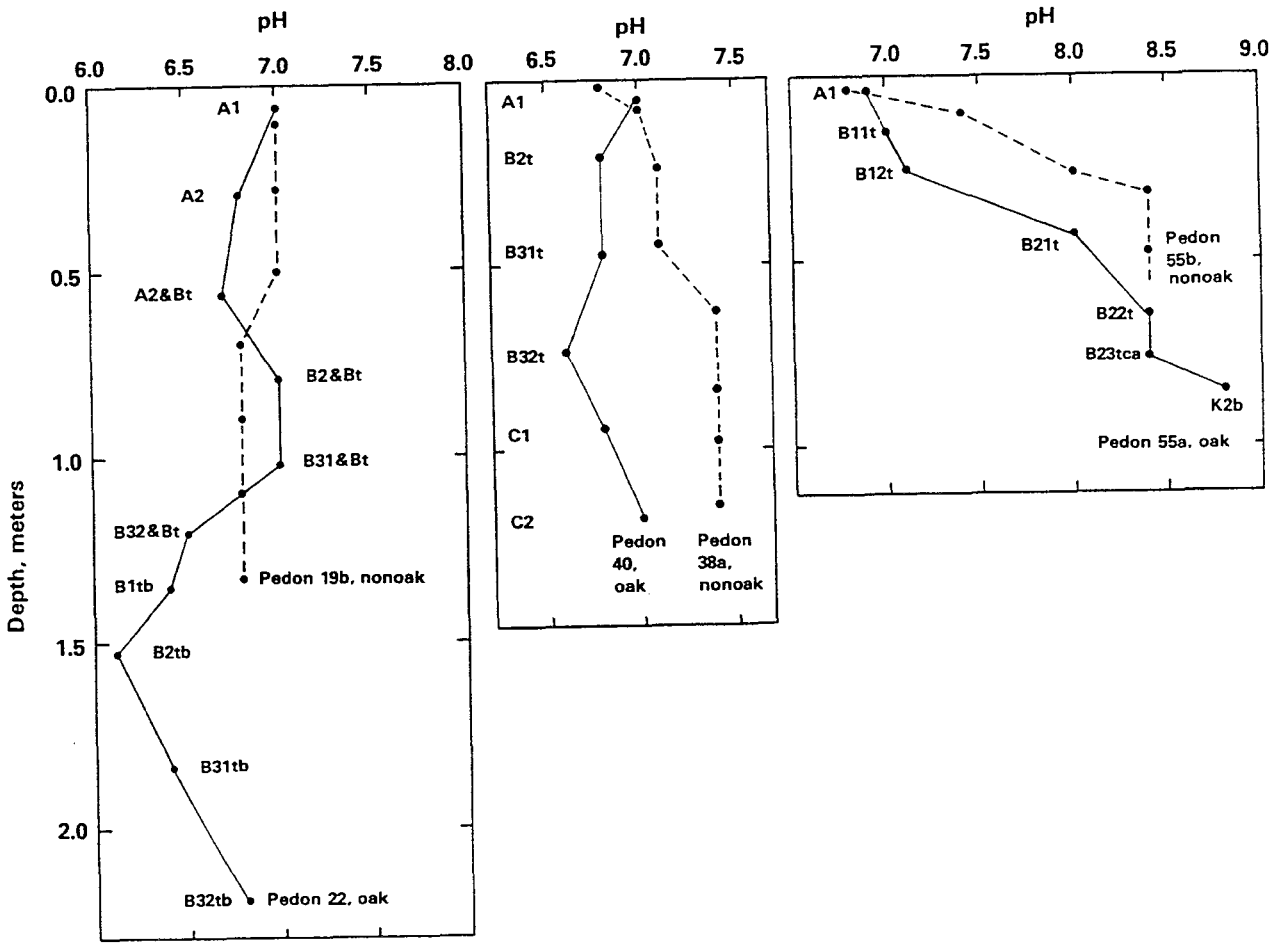


Figure 12. The pH of pedons under oak and nonoak vegetation under different conditions.

Left. The pH of two pedons of Longview age and in Pedon 22, buried horizons of Birdwell age. Horizon designations are for Pedon 22; those for Pedon 19b are A1, A2, A2&Bt, B21&Bt, B2&Bt, B3&Bt, and C.

Center. The pH of two pedons of Birdwell age. Horizon designations are for Pedon 40; those for Pedon 38a are A1, B21t, B22t, B23t, B24t, C1 and C2.

Right. The pH of two pedons of Hale age and for a buried horizon of Bailey age. Horizon designations are for Pedon 55a; those for Pedon 55b are A11, A12, B1t, B21t, and B22tca. pH for the lower two horizons (B23tca and K2b), not shown, is the same as for Pedon 55a.

Although oak is most common in soils of Muleshoe and Longview age, it does occur on some of the other soils. Figure 12, center, gives pH for two pedons of Birdwell age, one under oak and one under nonoak vegetation. Both pedons are Psammentic Haplustalfs and occur on crests of dunes. Pedon 40, under oak, has a Bt horizon of sand; pH decreases with depth (the only one of numerous Birdwell pedons to do so), then increases. In Pedon 38a, pH increases with depth, as is typical of soils of Birdwell age. The Bt horizon of Pedon 38a is dominated by texture of loamy fine sand or loamy sand, with several subhorizons of fine sandy loam.

Figure 12, right, shows pH of still older pedons, one under oak and one under nonoak vegetation. The soils are Aridic Haplustalfs and are of Hale age except for a buried K horizon of Bailey age. Even in these finer-textured soils, which contain high-carbonate horizons at relatively shallow depth, the effect of oak in lowering pH of upper horizons is still apparent.

Bulk density and extractable iron. Table 1d gives bulk density, extractable iron, clay and organic carbon data for two pedons that show major trends with depth and that illustrate differences in soils. Upper horizons could not be sampled for bulk density because of low coherence. Commonly there is a general trend for bulk density to increase with depth. Buried B2t horizons tend to have the highest bulk densities. This is illustrated by the B2tb horizon in Pedon 6, which has a bulk density of 1.84, 10.7 percent clay and 0.07 percent organic carbon. The Btb2 horizon of Pedon 7 (for which data are not given in table 1d), at 191-122 cm depth, has bulk density of 1.92, 15.7 percent clay and 0.01 percent organic carbon. Such bulk densities are higher than is generally the case for Bt horizons that are not buried, and are attributed to deep burial and resultant lessening of biotic activity.

The two extremes in bulk density for Pedon 6 and 7 are associated with the maximum values for moist consistence (very firm) in both pedons (see descriptions, Appendix). The low percentages of organic carbon at depth are typical and illustrate a common feature in many soils of arid and semiarid regions: Bt horizons that must once have contained moderate amounts of organic carbon (judging from numerous analyses of land-surface soils) and that are now deeply buried contain almost none. This is attributed to oxidation since burial. Deep burial and consequent isolation from the zone of major biotic activity precludes additions since burial.

Extractable iron, although quite low in all soils of the study area, does vary 6-fold among horizons (table 1d). Iron content is commonly dependent upon silicate clay content. Parent materials and soil age affect clay content and can therefore affect extractable iron. In Pedon 6, horizons of Muleshoe age are the youngest, have the least clay and also the lowest extractable iron, 0.2 percent or less throughout. Extractable iron rises to 0.4 percent in the lowest horizon of Pedon 6, where a buried B2t horizon of Birdwell age occurs, and silicate clay increases from 4.1 percent to 10.7 percent (table 1d).

Pedon 43 contains soils of three ages (table 1d). Horizons of Birdwell age are similar in clay and iron content to underlying horizons of Hale age. The value of 0.6 percent represents the highest percentage of extractable iron found in the analyzed soils. Iron drops markedly in the underlying Kb2 horizon of Bailey age (table 1d). Although the K21b2 horizon contains 23.5

Table 1d. Bulk density, extractable iron, clay and organic carbon for a Haplustalf and an Ustipsamment

Pedon, subgroup and NSSL no.	Sediment1/	Horizon	Depth cm	Bulk density g/cc	Extractable Fe %	Clay %	Organic C %
Pedon 6	M	A1	0-13		0.2	3.2	0.66
Alfic		A2	13-39		0.1	1.1	0.13
Ustipsamment		B21&Bt	39-56		0.1	1.9	0.08
S75TX-17-5		B22&Bt	56-82	1.63	0.2	2.5	0.07
		B31	82-109	1.68	0.2	2.9	0.09
		B32&Bt	109-139	1.68	0.2	3.4	0.06
		C	139-181	1.69	0.2	3.9	0.06
	B	B11tb	181-208	1.71	0.2	4.3	0.14
		B12tb	208-226	1.73	0.2	4.1	0.03
		B2tb	226-247	1.84	0.4	10.7	0.07
Pedon 43	B	A1	0-15		0.3	6.1	0.54
Aridic		B11t	15-32	1.57	0.4	10.6	0.44
Haplustalf		B12t	32-57	1.56	0.6	17.0	0.45
S75TX-17-2		B2t	57-76	1.65	0.6	19.0	0.38
	H	B11tb	76-96	1.70	0.5	16.3	0.23
		B12tb	96-120	1.70	0.5	16.9	0.17
		B2tb	120-142	1.70	0.6	20.7	0.16
		B3tcab	142-159	1.71	0.6	18.9	0.14
	Ba	K21b2	159-187		0.1	23.5	0.15
		K22b2	187-238		0.1	27.4	0.11
		K3b2	238-265		0.2	23.7	0.08

1/ M = Muleshoe, B = Birdwell, H = Hale, Ba = Bailey (see fig. 2)

percent clay by analysis, much of this clay is carbonate clay because the horizon contains 67 percent carbonate. The abundant carbonate thus confounds the quantitative relation between silicate clay and extractable iron.

Mineralogy. The sands of most soils contain very high percentages of minerals resistant to weathering, mostly quartz. Although further study is needed, it appears that all of the Entisols and many of the Psammentic Haplustalfs, coarse-loamy Aridic Haplustalfs and sandy Argiustolls have siliceous mineralogy (that is, have more than 90 percent resistant minerals). The fine-loamy Haplustalfs and Argiustolls probably have mixed mineralogy. The Ustochrepts have carbonatic mineralogy.

For the clay mineralogy, nearly all soils contain moderate amounts of mica and small amounts of montmorillonite-mica. Most soils contain small

amounts of kaolinite. Montmorillonite was found only in some carbonate horizons and in some buried Bt horizons. Usually the amount was moderate but abundant montmorillonite was found in a prominent buried Bt horizon.

Extrapolation of results, and additional work. Observations in nearby sandhills of Texas and New Mexico indicate that deposits and soils very similar to those reported in this study occur extensively in other sandhill terrains. Conclusions of this study should apply to other sandhill terrains with similar climates and parent materials.

Chronological studies are needed to determine absolute ages of the various sediments and soils in the sandhills. Such studies should center on areas having potential for dating, such as the Blackwater Draw archaeological site near Portales, N.M. The latter area has excellent potential for such studies because of work that has already been done. Extension of the chronology, sediments and soils from Blackwater Draw into the nearby sandhills proper would be critically important. Similarly, areas having potential in the Texas portion of the sandhills should be studied.

Intermittent streams, such as Blackwater Draw, extend through the sandhills along their margins. The character of the transition between soils and sediments of the sandhills and soils and sediments associated with these streams should be determined.

A soil chronology for the High Plains outside the sandhills is needed, because very little information is available about this important aspect of High Plains pedology. Soils and sediments of the sandhills should be related to soils and sediments of the region. How does soil and geomorphic evolution of the sandhills fit with evolution of the Portales Valley and its soils to the south? In turn, how do these events relate to older soils of the High Plains region?

More work is needed on the stratigraphy. The sparcity of late and middle Holocene sediments south of the black line (frontispiece) is a strong indication that deposits reflecting times of less severe climatic stress would be found primarily in areas that lack erosion-resistant horizons, particularly high-carbonate horizons. This would be an important factor to consider in an attempt to assemble a complete stratigraphic record in the sandhills. In a detailed study of the stratigraphy, places like the area north of the black line (frontispiece) should clearly be included. Another factor involves strong erosion in large blowouts. Some dunes, particularly high ones, could hold much of the stratigraphically demonstrable sedimentary and pedogenic evidence of some erosive episodes, because some deposits may be preserved only by burial in large dunes. Although buried soils and sediments were studied in a few dunes in this study, many were not. A detailed study of the stratigraphy should include representative examples of all types of dunes. More work is especially needed on the stratigraphy of sediments and soils of pre-Birdwell age, because most of these are buried in this study area. Since deep excavation of dunes would be required for these stratigraphic studies, proper safeguards should be taken to prevent erosion.

Sandhills in adjacent climatic zones should be studied to determine effects of changes in climate. What are the analogues of soils and sediments of this study in drier areas to the south and wetter areas to the north?

More work is needed to determine the range of airphoto and landscape expression of dunes of various ages and morphologies. For example, the expression of dunes and blowouts of Muleshoe and Longview age (fig. 2) differs from one place to another in the sandhills. In the study area, blowouts and dunes of these ages occur primarily as relatively minor land forms that generally are only faintly expressed on airphotos (fig. 5). But dunes of these ages also can have a general dune form that is inherited from older dunes (fig. 5). West of the study area (see back of front cover) blowouts and dunes of the same middle and late Holocene age have still another expression: prominent elongate-blowout dunes (Melton, 1940, fig. 18). A detailed cataloguing of the range of landscape and airphoto expression of dunes of various ages would greatly assist in predicting soil morphology and age of the various dunes, and improve airphoto interpretation in general.

The study indicates that some soil surveys of sandhills should be re-examined, particularly if they were made before the new U.S. system of soil classification was adopted. The soil map of this study was compared with a map of the same area in the Bailey County Soil Survey. The comparison indicates that more soils should be added to descriptions of some of the mapping units of the County survey. This is illustrated by the Tivoli fine sand mapping unit. Although no inclusions were listed for this unit in the County survey, the area of Tivoli fine sand that crosses the area of this study actually contains a wide variety of soils.

CHAPTER 1. SETTING

A linear, east-west belt of sand dunes, commonly designated "the sandhills", extends from the western part of Hale County, Texas, westward through Lamb and Bailey Counties into Roosevelt County, New Mexico (fig. 1). The dunes are on the Southern High Plains, or Llano Estacado of western Texas and eastern New Mexico, in the High Plains section of the Great Plains Physiographic Province (Fenneman, 1931). The area of this study is in the ancient Portales Valley of Hawley et al. (1976), astride Farm Road 1731 and northwest of Coyote Lake (front flyleaf; fig. 1). Coyote Lake is in an east-west low that may represent a later phase of the Portales Valley, and that for convenience here is termed the inner Portales Valley.

PHYSIOGRAPHY AND PARENT MATERIALS

Melton (1940) classified dunes of the High Plains, and some of the kinds of dunes described in his report occur in the study area (fig. 1). The most common types are blowout, elongate-blowout and windrift dunes (Melton, 1940, p. 126-130). All three are the same general type, differing only in the progressively greater degree to which the sand is carried to the leeward. Thus, orientation of the dunes indicates the dominant direction of winds that moved the sand. In places the directions of sand-moving winds are complicated by the emplacement of younger dunes on older ones. In some cases this can be overcome by finding an isolated area in which direction is expressed without complication of a younger dune.

Figure 12a, a topographic map of the study area, shows numerous topographic lows and adjacent ridges. The ridges are blowout and elongate blowout dunes (Melton, 1940). Both the blowouts and the associated dunes range widely in size. The smallest blowouts, which are mainly in the northern part of the study area, are level for only about 1 or 2 m or less, then slope to the bordering dune. The largest blowouts are in the southern part of the study area; one of these, on the east side of Farm Road 1731, is about 1/2 km long. The associated dune is even longer, and also is substantially higher than dunes associated with the smaller blowouts. Some dunes are separated by troughs.

The Portales Valley (fig. 1; Hawley et al., 1976) is thought to represent a course of the ancestral upper Pecos-Brazos River, which once flowed eastward across the High Plains prior to integration of the present southward-flowing Pecos (Baker, 1915; Meinzer, 1923; Fiedler and Nye, 1933; Galloway, 1956; Reeves, 1972; Thomas, 1972). A gravelly layer was found in a number of irrigation wells drilled on the Birdwell Ranch. The gravel occurred at depths ranging from 140 to 200 feet (Mr. J. E. Birdwell, personal communication); shallowest depths were in the Portales Valley. The gravelly layer may represent deposits of the ancestral Pecos River.

Presence of the valley has caused lower water tables in sediments adjacent to the valley than in sediments farther away. In addition, water tables have been lowered by decades of pumping for irrigation and municipal use (Cronin, 1969). Studies by Cronin (1969) show a 20-foot drop in the water table from 1937 to 1967, near the northern part of the study area.

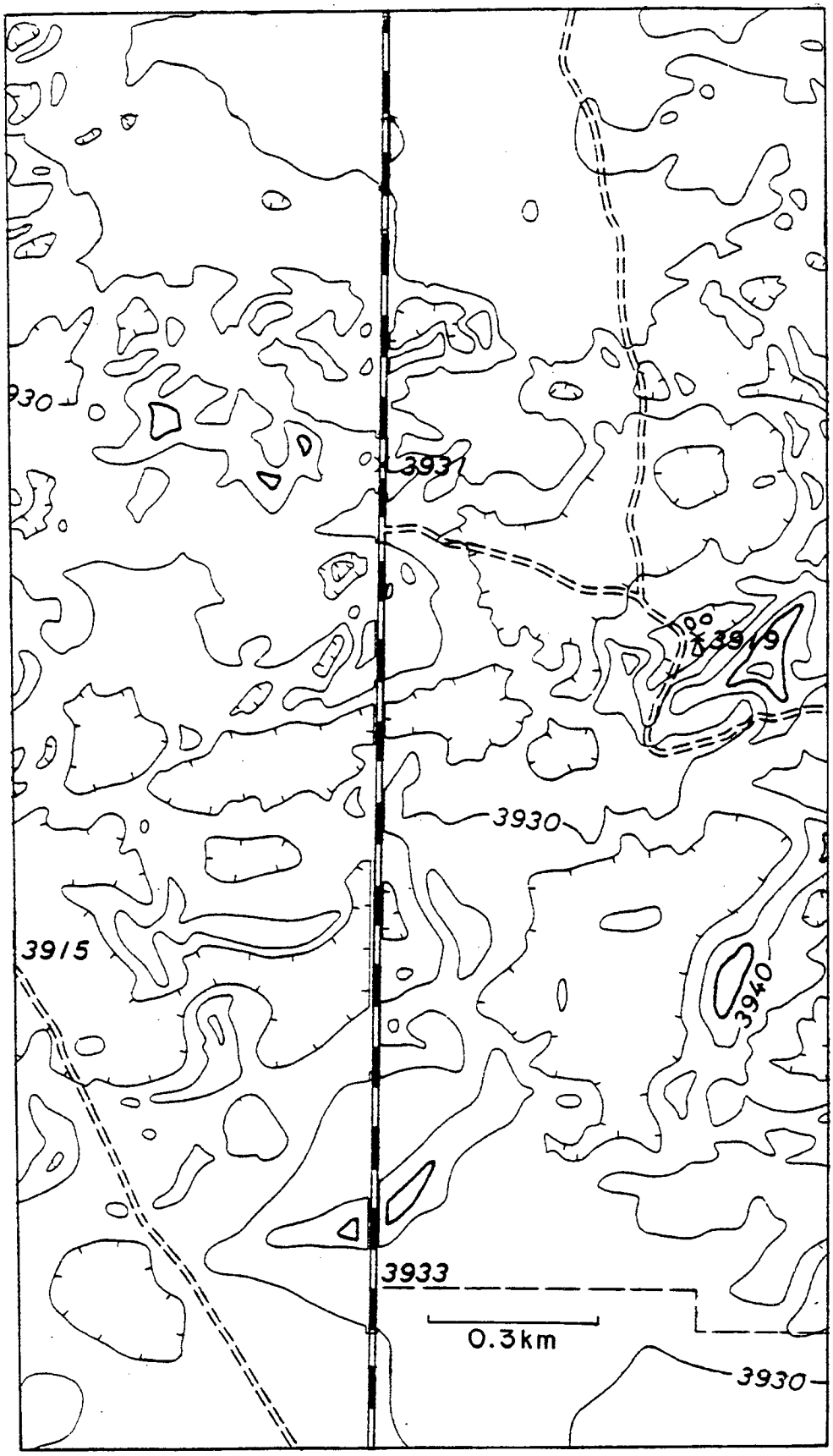


Figure 12a. Topographic map of the same area shown in the frontispiece. Hachures indicate blowouts; ridged areas are dunes.

The water table has probably dropped further since 1967 due to continued and increased irrigation.

Most soils of the study area have formed in eolian sediments. The original source of the eolian sediments must have been alluvium deposited by the ancestral Pecos-Brazos River, as indicated by location of the sandhills in the Portales Valley. Since the ancestral river was flowing in the valley during Pliocene and early Pleistocene time, the first eolian sediments derived from the river deposits must have been very old. Eolian parent materials of a particular soil were derived from older soils and sediments to the windward. There are also small areas of alluvium below gullies, and colluvium deposited by unconcentrated runoff on the sides of dunes.

HISTORY

Haley (1977, p. 35) quotes Josiah Gregg as giving one of the most common explanations of the name, Llano Estacado (Staked Plains):

> I have been assured by Mexican hunters and Indians (he wrote) that, from Santa Fe southeastward, there is but one route upon which this plain can be safely traversed during the dry season; and even some of the watering-places on this are at intervals of fifty or eighty miles, and hard to find. Hence the Mexican traders and hunters, that they might not lose their way and perish from thirst, once staked out this route across the plain, it is said; whence it has received the name of El Llano Estacado.

Early man has occupied places in the vicinity of the study area at various times since about 11,000 years ago. This is indicated by archaeological studies at Blackwater Draw (Wendorf and Hester, 1975), only 37 km to the west, and the Lubbock Lake site (Holliday and Allen, in press) about 110 km to the southeast.

The XIT Ranch

Except for early man, discussed in the previous section, the study area was nearly free of man and cattle until the 1880's, when the huge XIT Ranch was established. Haley (1977, p. 3) stated:

> During the middle eighties the XIT Ranch was established. It was the largest ranch in the cow country of the Old West, and probably the largest fenced range in the world. Its barbed wire enclosed over 3,050,000 acres of land in the Panhandle of Texas, patented by the State to a Chicago firm in exchange for the capitol at Austin. From 100 to 150 cowboys, with combined remudas of more than 1,000 cow ponies, "rode herd" upon approximately 150,000 cattle that wore the XIT brand.

Haley (1977, p. 5) further stated:

> The Texas State House was built in exchange for three million acres of land set aside by an act of the Texas Legislature in 1879. The tract lay along the western border of the Panhandle. At that time

> scarce a score of people were upon it. Not a plowshare had broken the sod, and not a wire fence had enclosed an acre of its grass.

However, the Bailey County sandhills were not a part of the XIT Ranch, and were separated from it by fence (Dunn, section F, p. 2, 1963):

> Spring Lake Hotel was a central gathering place of ranch officials and visitors - one of the favorite side trips for the visitors were the sandhills of Bailey County. They always explain how that the ranch rejected that wasteland, little realizing that was the part of Bailey County with a wealth of underground water.
>
> Fencing this vast ranch was a big undertaking and took almost four years. There was 260 miles of four-strand wire, 150 miles without a curve or turn, and it cost $181,000.00. The wire was a special patented wire. As late as 1942 some could still be recognized along the edge of the Sandhills just south of Muleshoe.

Although the Bailey County sandhills were not a part of the XIT Ranch, fires associated with it may have affected the sandhills. To quote Dunn (section F, p. 2, 1963):

> What is now Bailey County was one of the hardest hit by the Big Burn which started in the late Fall of 1894, in eastern New Mexico and covered a strip of 70 to 100 miles wide all across Bailey County on across Lamb. . . . Rumors had it that the fire wasn't an accident, and rustlers began to hit, and fences were found cut.

Haley (1977, p. 175) mentions the same fire. There were a number of prairie fires on the XIT Ranch, and some of them were maliciously set (Haley, 1977, p. 171).

The study area (frontispiece) is on the old VVN Ranch, just south of the XIT Ranch. The Birdwell family now owns much of what was the VVN Ranch. In this connection the Bailey County Journal states (1963, section I, p. 1):

> The oldest document recorded in Bailey County deals with the land in the VVN Ranch. In October 1882 the State of Texas deeded to H. S. Melven and Sylvian Blum land in southern Bailey County. The land was given in consideration of their service to the State during the 1878-1881 survey which was one of the preliminary bases for the Capitol Syndicate Company's land grants to the land company from the State, in exchange for their building the State Capitol building in Austin.

After various land transactions involving parties other than the Blums:

> On March 13, 1885, Matlock and Meade sold their land, and the VVN, back to Leon Blum. The whole portion of the original VVN was returned to Blums ownership in 1890.

The Bailey County Journal (1963, section I, p. 1) then details a number of subsequent transactions dealing with the VVN Ranch up to 1948, when:

> John L. Birdwell and wife, Cordie Birdwell, bought all of the remaining VVN Ranch land on January 31, 1948 from the West Texas Mortgage Company.

Cattle trails and development of a blowout

Roads and cattle trails are important not only as cultural features but because their development can result in erosion and deposition of new soil parent materials. These features are clearly visible in large-scale aerial photographs. Taken at different times, such photographs can be important tools in deciphering the developmental history of roads, trails, new deposits, and vegetation.

Figures 13-17 are aerial photographs of part of the study area (see frontispiece), taken in 1941, 1953, 1962, 1970, and 1981. In the 1941 photograph, the blowout at right center is visible but Farm Road 1731 is not. Thus the blowout must have started before 1941 and its development cannot be due to construction of Farm Road 1731. The blowout coincides with an old trail used by cattle of the XIT Ranch to get water in the inner Portales Valley, just south of the study area (Mr. J. E. Birdwell, personal communication). The blowout is in a high dune that lacks erosion-resistant horizons; only very faint traces of the trail may be seen adjacent to the blowout because the terrain lacks such dunes.

Traces of the old trail are apparent where it crosses high dunes but in many places cannot be seen between them. Traces of the trail are distinct on high dunes in the southern part of the area (see Site 33). Although the trail crosses a number of dunes, a large blowout formed only on the dune of Fairview and Longview age. This suggests that large blowouts could be expected to develop primarily in dunes with deep sand and without erosion-resistant horizons. Similar blowouts caused by wind erosion along old roads occur to the west in the vicinity of Portales, N.M. (Fred Nials, personal communication).

First deliveries of cattle to the XIT Ranch (Haley, 1977) and sale of the XIT cattle suggest a time during which the old XIT trail might have started. At the XIT Ranch in 1885, contracts were made for 65,000 cattle; during 1885 and 1886, all cattle were delivered north of or just south of the Canadian River, an area considerably north of the Bailey County Sandhills. In 1887, however, large numbers of cattle were delivered to the XIT ranges from south Texas. Haley states (1977, p. 81):

> During the dry year of 1887, dust cloud after dust cloud rose above the horizon of the South Plains, heralds of north-bound herds bearing a hundred brands, all trailing to the ranges of the XIT. Many of the herds were delivered at Yellow Houses. During the thirty days following June 7, 1887, the tally at the Yellow House headquarters increased by 30,000 . . .

Haley (1977, p. 217) also stated that the remnant of the XIT herds was sold on November 1, 1912. Thus the XIT trail was probably started at some time between 1887 and 1912; wind erosion of the blowout would have begun after the trail started.

Photographs after 1941 (figs. 14-17) show the gradual disappearance of the old XIT trail. No trace of it can be seen in the 1970 photograph (except for the blowout itself), although traces are still visible to the south in the 1981 photograph (Site 33). The photographs also show the gradual eastward enlargement of the large blowout dune; slight enlargement of smaller blowouts; and times of road-building adjacent to Farm Road 1731.

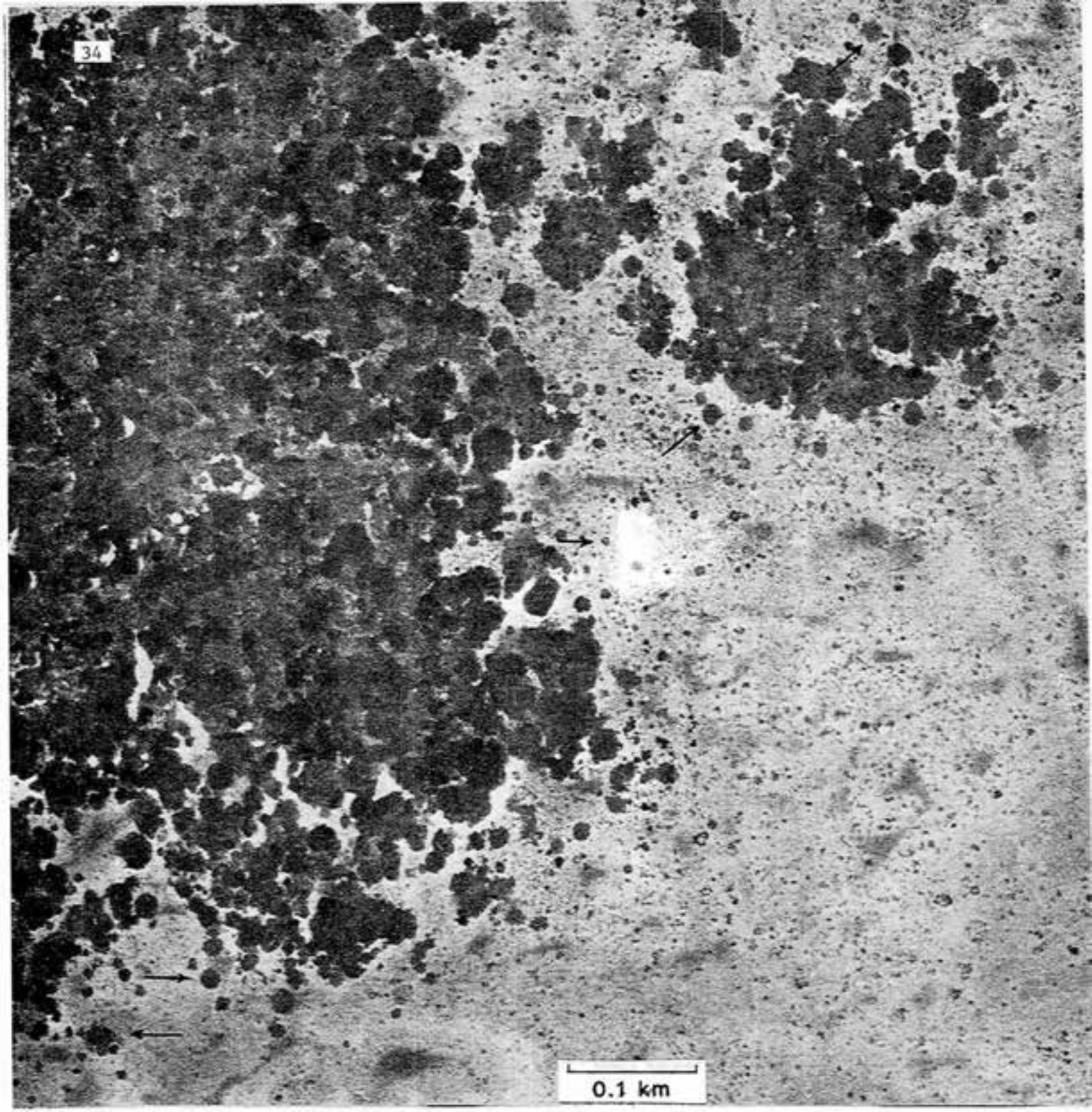


Figure 13. Aerial photograph taken August 3, 1941. Farm Road 1731 is not present and must have been built before 1953 (see fig. 14). The west face of the large active blowout at right center coincides with the old north-south XIT trail (see text discussion). Although traces of the old trail are still evident near the blowout, it has almost totally disappeared away from the blowout. The dark, roughly circular forms that dominate the left and upper right sides of the photograph are clumps of shinnery oak. Many isolated oak clumps have increased considerably in size between 1941 and 1981. Arrows locate illustrative clumps; note changes with passage of time through 1981 (figs. 14-17). Arrow near west edge of active blowout locates an illustrative clump that has also been photographed on the ground (see Site 3).

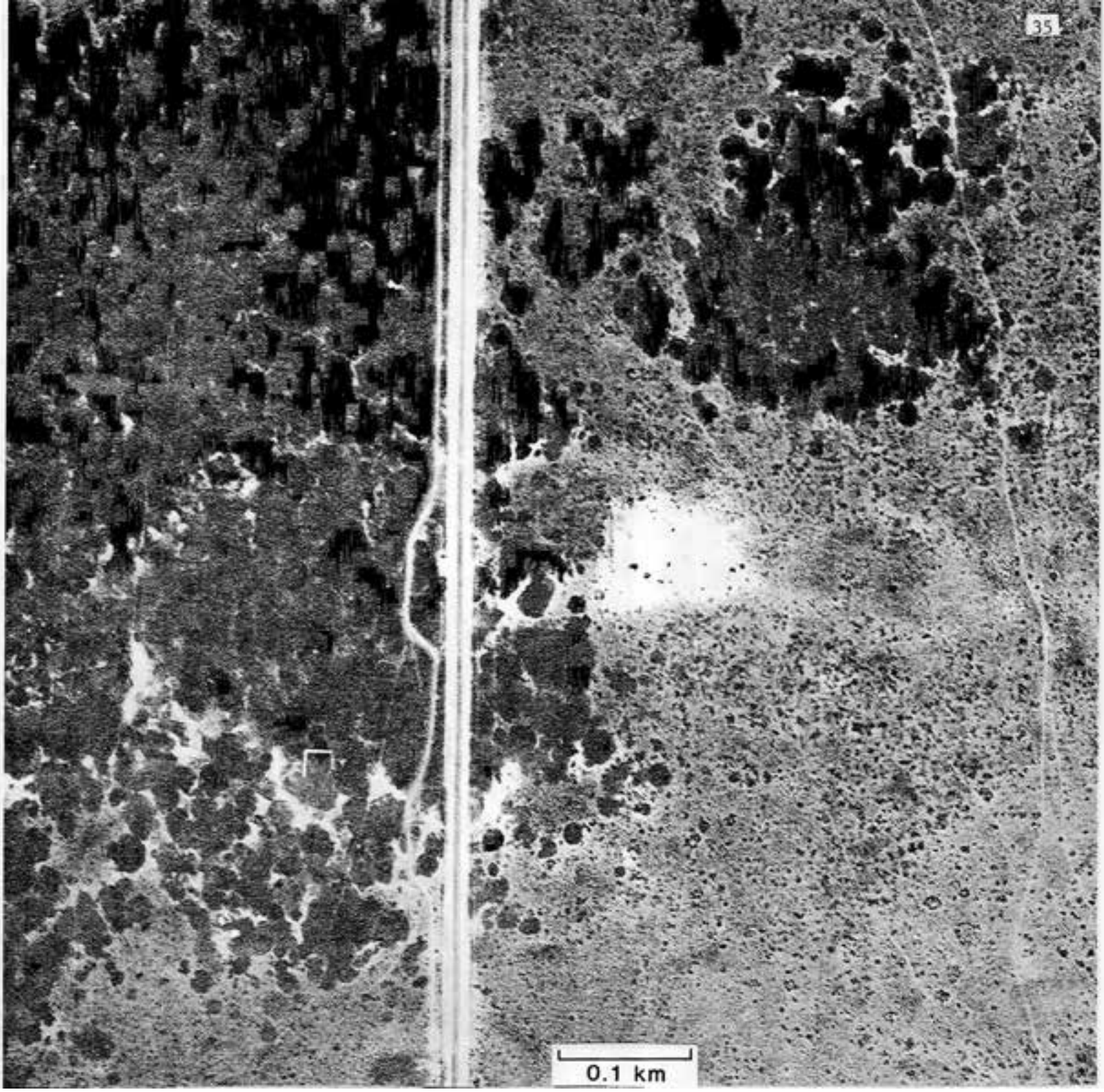


Figure 14. Aerial photograph taken February 25, 1953. Farm Road 1731 and a frontage road west of it have been constructed. The large active dune has moved a substantial distance to the east. The east face of the blowout is distinctly linear, and reflects erosion along a track on the east side of the old XIT trail. Several new cattle trails have appeared east of the active blowout; they reflect introduction of more cattle into that area, and expanded use of a water source (see Site 32).

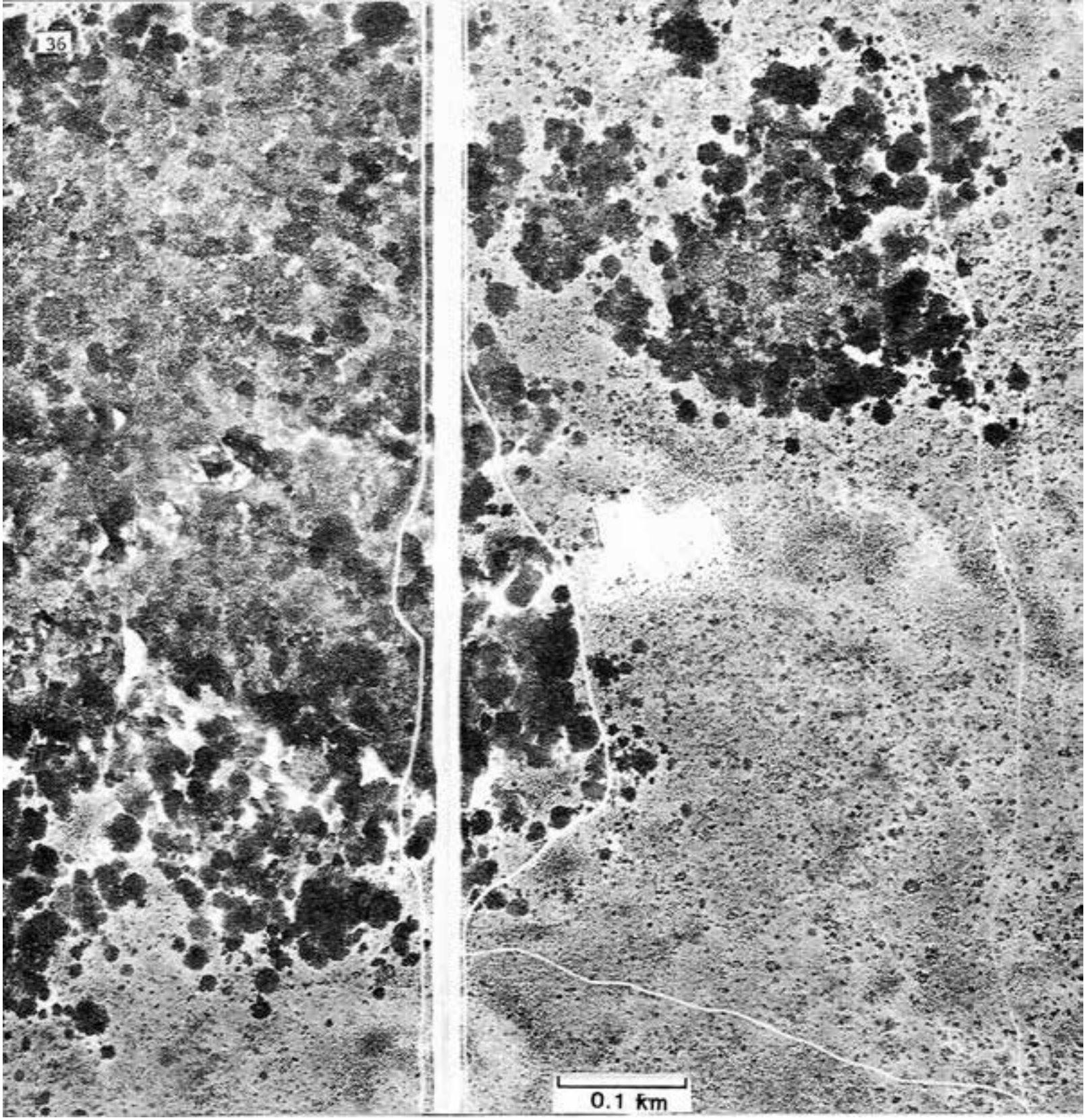


Figure 15. Aerial photograph taken October 31, 1962. Additional roads have been built, and connect to Farm Road 1731. On the east side of the blowout, parts of the dune still visible in the 1953 photograph have been breached and are furnishing sand for the dune to the east. Some of the blowouts between oak clumps have enlarged; arrows locate illustrative blowouts (compare with fig. 13). The western margin of the largest one, at left, accords with a cattle trail.

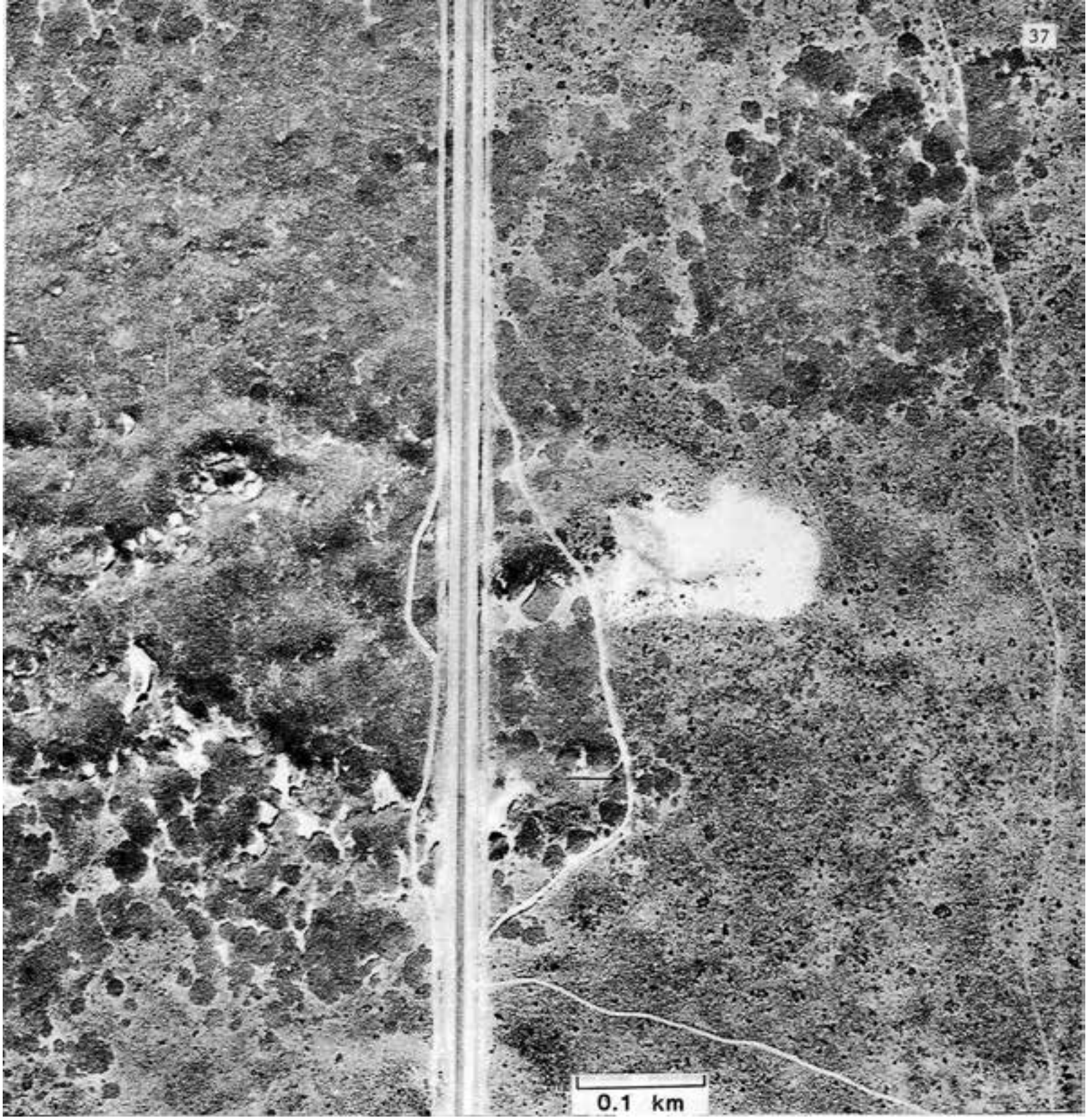


Figure 16. Aerial photograph taken December 13, 1970. Both the active blowout and its dune have enlarged considerably. The west face of the blowout is migrating westward due to slumping, observed on the ground at various times after 1972. Oak has impinged on or crossed the sandy frontage roads in places (arrow locates site of crossing).

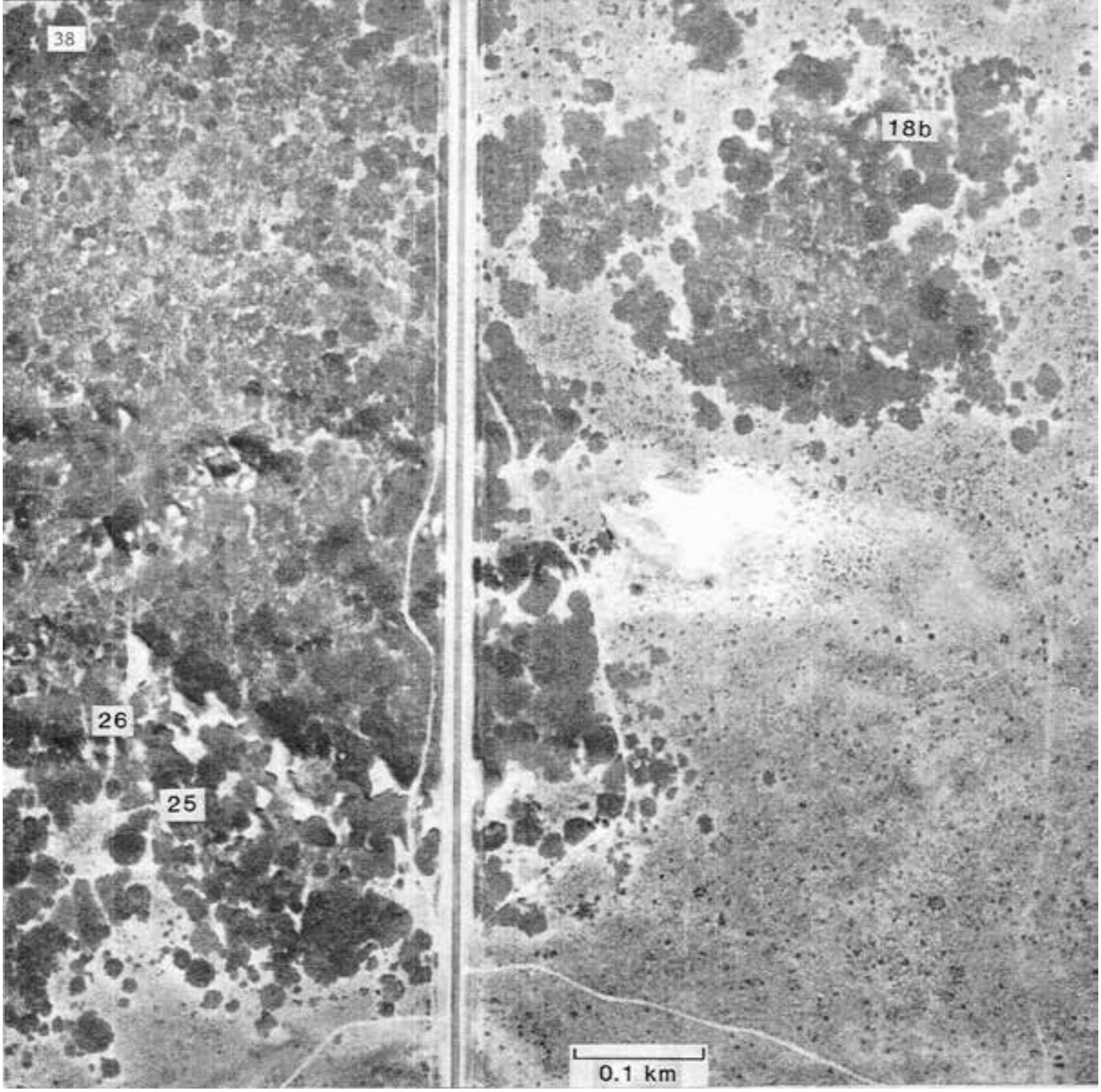


Figure 17. Aerial photograph taken November 26, 1981. The large active dune has continued to enlarge. Isolated oak clumps have continued to grow, and in places have merged with adjacent clumps to form larger ones. A new road has been started west of Farm Road 1731. Note trench locations at Sites 18b, 25, and 26, visible from the air in 1981 (compare with fig. 16, taken before the trenches were dug). The 1981 photography is at smaller scale (1:40,000) than earlier photography and detail is not as sharp.

Other trails in the study area are related to cattle movement within the VVN Ranch and not to XIT cattle crossing it for water. Referring partly to the VVN Ranch, the Bailey County Journal (1963, section I, p. 1) stated that "the Blums leased their land to various persons and parties for grazing purposes after 1980". Thus grazing may have started on the VVN Ranch at least as early as the 1890's, and some of the trails may date from that time. One such trail may have caused, or amplified development of the small blowout at Site 24. In the southern part of the 1962 photograph, a southeastward-trending road east of Farm Road 1731 leads to a windmill and water tanks (see Site 32). Other trails of the study area are illustrated and discussed at Sites 32, 33 and 37.

CLIMATE

The present climate is semiarid. Precipitation at Muleshoe (fig. 1, table 2) is 43 cm annually and most of it falls during the months of May through September. Snowfall is generally light and melts within a few days. Strong winds and occasional dust storms occur in February, March and April; during these months, winds are mostly from the west and southwest. The average annual air temperature is 14 C.

Although the present climate is semiarid, there are occasional times of very heavy rainfall. The Bailey County Journal (1963, section I, p. 3) details one of these times:

> Water everywhere -- the area in and around Muleshoe looked much like the Mississippi River June 4-6, 1941. . . . For two days, Muleshoe was almost isolated because of heavy floods that swept through the country causing much damage to the business houses, farm houses and farm lands. . . . Flood waters from the north part of the country tumbled in on fields washing out crops, drowning livestock, and damaging farm buildings. Ditches were not sufficient to carry the water, which overflowed fields and pastures. In several instances, farmers herded cattle and hogs on haystacks to save them . . . .

Total precipitation in 1941 was a record 43.52 inches (table 2). In contrast, precipitation was only 7.75 inches in 1954, the driest year. A series of dry years occurred from 1952 through 1956; during this period, precipitation averaged only 10.75 inches. These climatic extremes were not local phenomena but instead were typical in the southwestern U. S. For example, Las Cruces, New Mexico, also had a record precipitation in 1941, and a record drought from 1951 through 1956 (Malm and Houghton, 1977).

Climates of the past have also significantly affected the soils and landscapes. A change from a pluvial climate to an arid one is important in evolution of the sandhills because such changes initiate episodes of major erosion. During these times, sediments are removed from some landscape positions (e.g., blowouts) and deposited in others (e.g., blowout dunes). Climatically caused episodes of erosion in eolian sediments have been documented at Blackwater Draw archaeological site (Haynes, 1975), about 37 km to the west (fig. 1). Greater effective moisture of pluvials is important to soils because it tends to move clay and carbonate to greater depths, other factors being equal.

Table 2. Precipitation (in inches) at Muleshoe, Texas, for the years 1931 - 1982. Compiled from records furnished by the National Climatic Center, Asheville, N.C.

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual
1931	1.11	1.32	.45	3.46	2.41	.68	2.88	4.63	.52	.72	1.41	1.46	21.05
1932	.51	.52	.05	1.05	.85	4.25	.30	2.70	4.58	.63	--	1.89	17.33
1933	.48	.52	.69	.20	1.41	.69	.95	6.27	.91	.57	.86	--	13.55
1934	.12	.14	1.96	1.31	1.64	2.39	1.28	1.34	1.77	.98	2.14	.14	15.21
1935	.35	.28	.95	.07	1.85	4.48	2.96	1.04	.89	.11	1.70	.22	14.90
1936	1.82	.14	.12	.19	5.66	1.36	1.80	.41	2.55	.88	.12	.67	15.72
1937	.08	.18	1.66	.95	5.66	2.56	1.24	.60	4.71	1.28	--	.56	19.48
1938	.64	1.24	1.45	.73	1.63	7.74	1.78	.54	1.39	2.93	.34	.08	20.49
1939	1.96	.06	.40	.57	2.06	1.82	.94	3.42	.05	1.28	.18	1.34	14.08
1940	.27	.65	--	1.53	2.63	1.89	.33	3.97	.37	.22	2.04	.07	13.97
1941	.24	.38	3.14	1.99	11.86	5.77	6.92	2.09	3.46	6.37	.47	.83	43.52
1942	.02	--	1.15	2.96	.60	2.21	.98	4.50	2.29	4.94	--	1.45	21.10
1943	--	.50	--	.28	1.67	1.74	3.13	.21	1.12	1.06	1.10	3.45	14.26
1944	.57	.78	.01	1.14	2.07	4.00	2.21	3.44	4.77	.12	.47	.93	20.51
1945	.57	.13	.17	.35	.64	--	1.68	2.50	3.79	1.17	--	.21	11.21
1946	1.18	.05	.19	.14	.80	2.82	1.00	2.20	4.21	5.48	.64	1.17	19.88
1947	.58	.20	.67	1.36	4.32	.35	2.50	.33	.22	.22	.76	.58	12.09
1948	.53	1.62	.70	.31	1.09	1.90	2.02	1.79	.86	.23	.39	.31	11.75
1949	2.34	.84	.18	1.96	7.26	4.73	3.40	.26	1.81	1.23	.19	.29	24.49
1950	.15	--	--	.12	.45	1.24	7.78	4.55	4.88	.07	--	.03	19.27
1951	.62	1.16	.21	.11	6.86	5.34	3.48	1.34	.06	1.51	.28	.36	21.33
1952	.80	.09	.26	1.74	.47	1.59	1.64	1.60	.87	--	1.09	.29	10.44
1953	.81	.07	.81	.82	1.90	.82	3.70	1.61	--	2.18	.36	.21	13.29
1954	.01	.48	--	.32	1.51	.45	.06	2.82	.31	1.76	--	.03	7.75
1955	.72	--	.01	.41	3.77	.35	3.33	.67	3.37	.99	.12	--	13.74
1956	.11	1.13	--	.02	1.52	3.06	.75	.57	.48	.89	--	--	8.53
1957	.22	.67	1.18	2.43	3.88	1.80	1.12	3.68	3.34	3.12	.99	.08	22.51
1958	1.60	.36	1.75	1.46	2.86	1.73	2.07	1.51	3.48	.33	.75	.07	17.97
1959	.02	.15	.08	2.33	3.63	2.73	2.81	1.97	.78	2.47	.06	1.53	18.56
1960	1.15	.74	.25	.25	1.13	3.94	6.08	3.62	1.72	4.90	--	1.32	25.10
1961	.58	.32	1.67	.19	1.26	2.69	1.87	1.78	.80	.13	1.70	.39	13.38
1962	.71	.44	.50	.81	.43	1.48	8.73	1.58	2.45	2.47	.72	.52	20.84
1963	.01	.75	--	1.24	2.94	7.15	4.00	1.33	.43	.29	.77	.05	18.96
1964	.05	.70	.12	--	.95	3.10	.73	2.23	1.68	.05	2.98	.37	12.96
1965	.15	.57	.27	.94	1.22	5.38	2.61	1.88	1.76	1.67	.20	.42	17.07
	21.08	17.18	21.05	33.74	90.89	94.23	89.06	74.98	66.78	53.25	22.83	21.32	606.39

Table 2 continued

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual
1966	.95	.25	--	1.24	1.03	4.39	.82	7.90	3.02	.13	.27	.18	20.18
1967	--	.10	.23	.45	.36	4.03	5.76	.69	1.81	.08	.07	.62	14.20
1968	1.94	.67	1.25	.13	2.31	.31	1.95	1.75	1.52	.84	.81	.26	13.74
1969	T	.60	.48	1.98	3.33	2.28	2.20	.98	1.95	4.72	.40	.43	19.35
1970	T	.26	.71	.44	.34	1.99	1.82	1.52	2.55	.67	T	--	10.30
1971	.02	.40	.05	1.35	.64	1.43	2.08	6.01	2.96	1.24	1.06	1.09	18.33
1972	.05	.14	.09	--	3.16	1.78	2.40	2.80	2.88	1.61	1.35	.44	16.70
1973	.83	.92	2.72	1.86	.93	2.35	2.46	.15	1.02	1.43	.01	.01	14.69
1974	.70	.02	.60	.60	.39	.70	.68	7.21	3.36	4.81	.13	.70	19.90
1975	.41	1.48	.49	1.15	1.29	1.47	6.41	.84	1.15	.19	.50	.11	15.49
1976	.10	.22	.26	.77	.40	2.57	2.36	2.81	3.02	.76	.70	--	13.97
1977	.40	.72	.66	2.10	1.40	1.51	.43	5.20	.09	1.32	.15	.06	14.04
1978	.67	1.77	.48	.12	3.11	3.27	1.22	1.99	1.89	.58	2.09	.55	17.74
1979	.96	.27	.80	1.78	1.77	3.37	2.56	3.03	1.43	.69	.34	.57	17.57
1980	.29	.59	.48	.72	3.08	.15	.89	1.61	3.06	1.03	1.70	.16	13.76
1981	.37	.35	.99	.85	1.82	.47	2.04	6.12	4.60	2.96	.61	.04	21.22
1982	T	.40	.36	.89	3.13	3.72	4.18	.48	.14	.82	1.57	1.43	17.12
	7.69	9.16	10.65	16.43	28.49	35.79	40.26	51.09	36.35	23.88	11.76	6.65	278.20
Grand Total	28.77	26.34	31.70	50.17	119.38	130.02	129.32	126.07	103.13	77.13	34.59	27.97	884.59
Average	.55	.51	.61	.96	2.30	2.50	2.49	2.42	1.98	1.48	.67	.54	17.01

The most prominent of these climatic changes involves the Tahoka pluvial (Wendorf, 1961, p. 130). This pluvial represents a major climatic interval, substantially wetter than the present time, since the landscape was characterized by numerous small lakes, ponds and perennial streams (Haynes, 1975, p. 83). The Tahoka pluvial was originally thought to extend from 15,000 to 22,000 B.P. (Wendorf, 1961, p. 130). In a later publication (Wendorf and Hester, 1975) the Tahoka pluvial was confirmed but a different time was given for its occurrence (e.g., from 13,000 to some time prior to 20,000 years ago, Haynes, 1975, p. 83).

After the Tahoka pluvial came a dry interval, termed the Monahans Interval, from 11,000 to 13,000 years ago. During this time streams became ephemeral and many ponds dried up (Haynes, 1975, p. 83). Several minor pluvials, separated by drier times, were indicated by Haynes as extending from about 11,500 to 7,000 years B.P.

Antevs (1955) postulated the "Altithermal", or Long Drought, for the western U.S. from 7,500 to 4,000 years B.P., and considered it a time both warmer and drier than the present. A period of widespread drought and erosion occurred on the Llano Estacado from 7,000 to 5,000 years B.P. as indicated by extensive deflation, missing sediments and lowered water tables (Haynes, 1975, p. 83). Benedict (1979) proposed a "two-drought" Altithermal, with two short, severe droughts, from 7,000 to 6,500 years B.P. and from 6,000 to 5,500 years B.P. Holliday (1982) also found evidence of two phases of the Altithermal, from 6,500 to 6,000 years B.P. and from 5,500 to 4,500 years B.P. Recent correction curves for C-14 dates indicate that ages for these two phases should be about 500 years older, i.e., 7,000-6,000 years B.P. and 6,000-5,000 years B.P., respectively (Holliday, personal communication). These corrections have not been made for other C-14 ages in this report.

Climatic shifts having magnitude of the foregoing do not seem to have taken place in the last 4,000 years. However, Hall (1982) working with fauna and pollen, concluded that the period from 2,000 to 1,000 years B.P. was moister than today, and that at about 1,000 years B.P. the climate became drier. He also concluded that these drier conditions persist to the present day.

Several factors indicate that the present is not a time of such climatic stress as to cause strong erosion in the sandhills if the soils and vegetation are not disturbed.

(1) Vegetation is virtually continuous except for active blowouts due to man's activities. Vegetation must have been sparse during long, severe droughts and probably became sparser with continued erosion and deposition of sand.

(2) The surface of former trails heals quite rapidly except where they cross high dunes without erosion-resistant horizons.

(3) Although gullies have formed in cattle trails on dunes, the gullies eventually become vegetated if erosion-resistant horizons are present in the dunes.

(4) Most trenches dug for this study healed rapidly. Trenches dug in oak were slowest to fill in with vegetation (fig. 17), although even these are now difficult to locate on the ground.

(5) Even the most violent dust storms have little apparent effect on the sandhills where the vegetation and soils have not been disturbed. This is indicated by effects of a particularly violent dust storm that struck the High Plains in February 1977. A substantial amount of wind erosion was observed in cultivated lands in the Clovis-Portales area just west of this study but not in undisturbed rangeland (McCauley et al., 1981). Similarly, comparison of 1970 and 1981 aerial photographs in the area of this study indicate that the storm had little effect and that the effect was confined to areas already disturbed. Some of the expansion of the large active blowout evident in the 1970-1981 period (fig. 17) might be due to the storm of February 1977. West of the study area, a fresh-appearing, linear blowout may be seen on the south side of the Holocene eolian lobe (front flyleaf). Examination of the 1970 photographs showed that the blowout was present in 1970 and that it had changed little by 1981. But the considerable damage

done by a single storm in cultivated areas underlines the need for a continuous vegetative cover on the sandhills, and is a strong argument against plowing and other earth-moving operations in the sandhills.

Another factor favoring maintenance of natural vegetation and present conditions in the sandhills is the steady decline in water tables that eventually will severely limit irrigation (Cronin, 1969). Erosion in sandhills that were leveled might be slowed by irrigation and keeping the soil moist, but if sandhills are leveled and irrigation is later found not to be feasible, they would be particularly susceptible to severe erosion.

VEGETATION

Vegetation for Bailey County as a whole has been discussed (Girdner et al., 1963, p. 39-42). A large area of almost continuous shinnery oak (*Quercus havardii*) shows as dark rounded patches of different sizes in the northwestern part of the study area (frontispiece); a few also occur in the southwestern part. Aerial photographs taken at different times in the period 1941-1981 (figs. 13-17) show that many oak clumps are growing larger. Oak spreads rapidly where fresh sand is deposited near existing clumps. Oak plants have crossed sandy roads in a period of only several years (compare photographs of 1962 and 1970).

Some of the more common types of vegetation in the nonoak areas include snakeweed (*Xanthocephalum sarothrae*), blue grama (*Bouteloua gracilis*), hairy grama (*Bouteloua hirsuta*), catclaw mimosa (*Mimosa biuncifera*), sand sagebrush (*Artemisia filifolia*), sand dropseed (*Sporobolus cryptandrus*), purple three-awn (*Aristida purpurea*), prickly pear (*Opuntia sp.*), little bluestem (*Schizachyrium scoparium*), sideoats grama (*Bouteloua curtipendula*), soapweed (*Yucca sp.*), buffalo grass (*Buchloe dactyloides*), wolftail (*Lycurus phleoides*), wooly gaura (*Gaura villosa*), zinnia (*Zinnia grandiflora*), sand bluestem (*Andropogon Hallii*), queen's delight (*Stillingia sylvatica*), and sumac (*Rhus aromatica*). Vegetation observed in mapping units (see soil map, Chapter 3) is listed for each unit in the text. The intent is not to list all of the vegetative types in the units, but only some of the more common kinds.

CHAPTER 2. A CHRONOLOGY OF SURFACES, SEDIMENTS AND SOILS

INTRODUCTION

The High Plains region contains soils of many different ages, and some of the oldest soils to be found in the United States. Quaternary stratigraphy of the Southern High Plains has been reviewed by Frye and Leonard (1965, 1972), Reeves (1972, 1976), Leonard and Frye (1975) and Hawley et al. (1976). Figure 18 summarizes the general stratigraphic relationships of the major units in the uplands, and shows their relation to deposits of the study area.

In the Holocene, deposits of comparable ages have been found at the Lubbock Lake Site, Blackwater Draw and the Bailey County sandhills. Pre-Holocene Peoria (?) Loess of Reeves (1976) has been traced into the Southern High Plains but more work is needed on its character and transition into the sandhills. The loess overlies "cover sands" thought to be of Illinoian age (Frye and Leonard, 1957). Lenses of type O Pearlette ash, 0.62 m.y. old (Lava Creek B ash of Izett and Wilcox, 1982) have been found in the Tule Formation (Schultz, 1984). Thus the overlying "cover sands" must be less than 0.62 m.y. old. Reeves (1976) proposed that the "cover sands" be named the Blackwater Draw Formation. A small area of that formation has been mapped in the southern part of the study area (Eifler, 1977), but exactly what is included in that formation is not clear. Further work is needed on the relations between it and deposits of the study area.

A number of reports concern dunes in sandhills of Bailey County and adjacent counties, but the soils and their chronological relation to the dunes were not examined in detail. Tanner (1939) proposed four ages of dunes -- young, mature, old and very old. Hefley and Sidwell (1945) stated that the dunes represent at least two stages with respect to time of formation. Sanders (1951) indicated three ages of sand in the Bailey County dunes -- old, intermediate and young. Green (1951) identified four phases of sand dune activity in Lamb and Hale Counties. Jones (1959) studied two types of dunes, stable and active, in Lamb and Bailey Counties.

Nine geomorphic surfaces and associated sediments have been named in this study (figs. 2, 19). Only six surfaces are shown on the geomorphic map, but illustrations of all are given elsewhere as discussed later in this section. Longview I and II; Birdwell I and II; and Bailey I and II surfaces could not be readily distinguished and mapped without a substantial amount of detailed stratigraphic work, so they have been grouped together into Longview, Birdwell and Bailey, respectively. The mapping unit names (fig. 19) indicate the dominant surfaces present in each unit; inclusions are given in parentheses in the legend.

The sediments associated with a geomorphic surface -- that is, the sediments in which the soils have formed -- are designated by the geomorphic surface name (e.g., Muleshoe sediments; Hawley and Kottlowski, 1969). Figure 2 shows the relation of the surfaces to soil age, general morphological features and soil classification. The chronology must be considered tentative because additional sediments and soils, not yet found, may be buried in the dunes. This is particularly the case for the pre-Birdwell Pleistocene stratigraphy. Work on these sediments has been

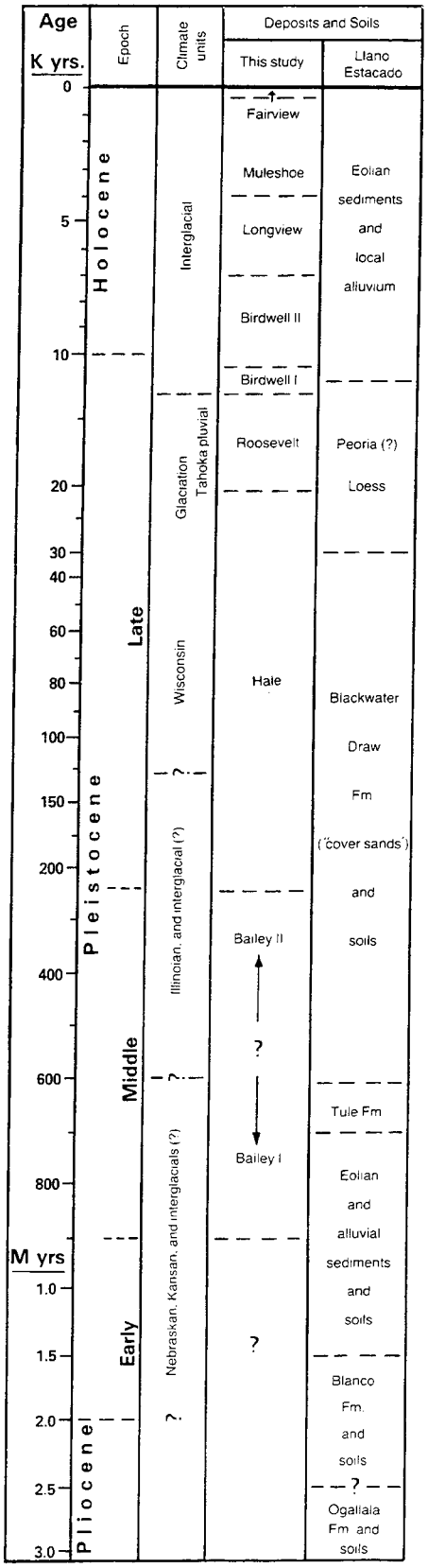


Figure 18. Diagram summarizing the chronology of upland deposits and soils of the Llano Estacado and the study area in Bailey County. Events in the Llano Estacado generalized after Hawley et al. (1976) and Reeves (1976).

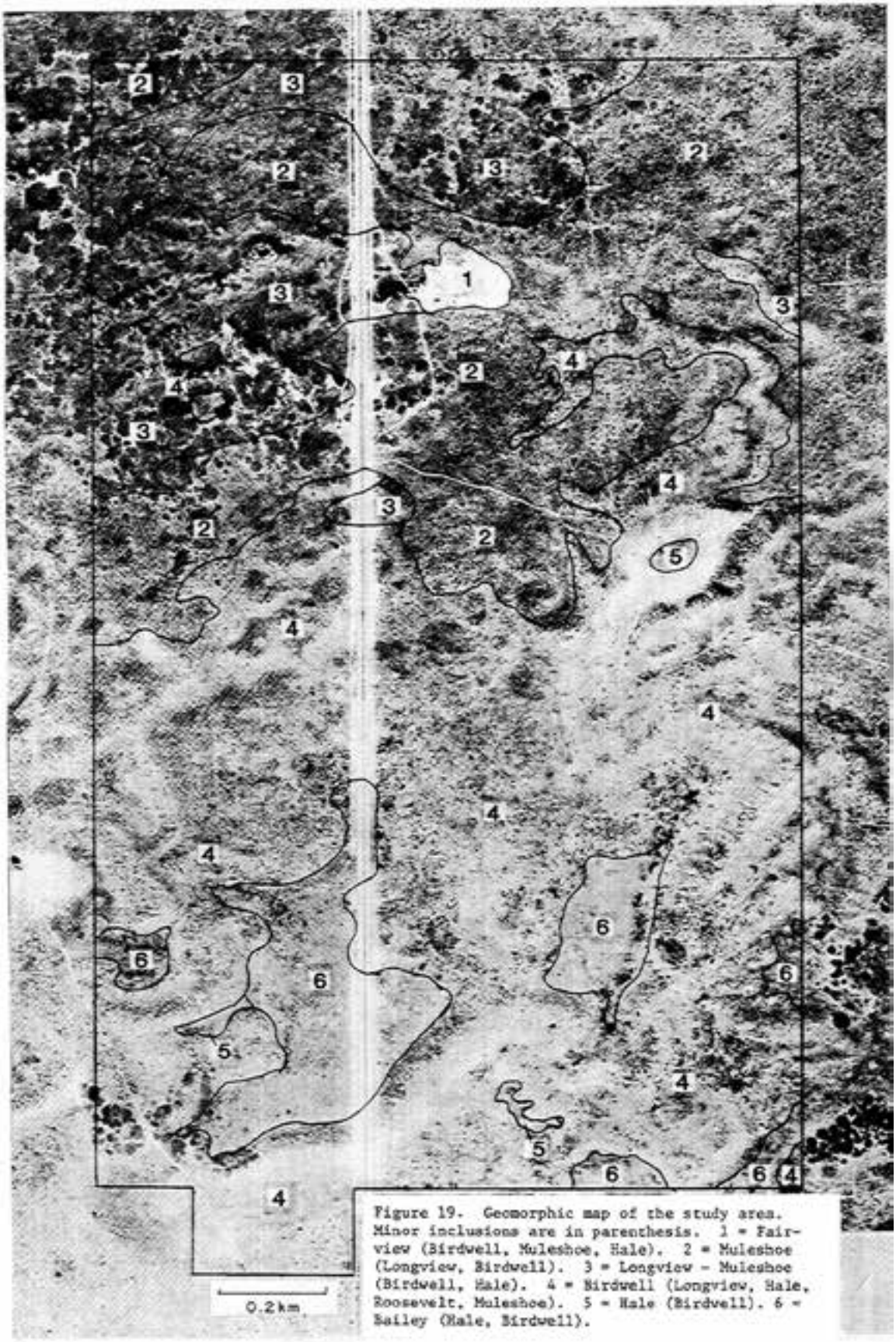


Figure 19. Geomorphic map of the study area. Minor inclusions are in parenthesis. 1 = Fairview (Birdwell, Muleshoe, Hale). 2 = Muleshoe (Longview, Birdwell). 3 = Longview - Muleshoe (Birdwell, Hale). 4 = Birdwell (Longview, Hale, Roosevelt, Muleshoe). 5 = Hale (Birdwell). 6 = Bailey (Hale, Birdwell).

difficult because they are buried in most places, and some of them are very deeply buried. In addition, still older soils are thought to be buried between the oldest soils of this study (Bailey) and deposits of the ancestral Pecos-Brazos River discussed earlier.

Because of erosion and deposition in the sandhills at various intervals over a long period of time, the amounts of erosion and deposition are an important factor to consider in mapping the geomorphic surfaces. The following were used as guides for surface identification in mapping.

Concerning erosion, winds of an erosive episode can remove upper horizons or all horizons of a soil associated with an original surface. If some pedogenic evidence of the original surface remains, the surface is still identified by the same name that it has where well preserved, and erosional modification is indicated in the text. The Bailey surface, discussed later, illustrates. Where not strongly eroded, soils of the Bailey surface have argillic and thick calcic horizons. In large blowouts the argillic horizon has been swept away by wind erosion in many places. But the prominent calcic horizon remains as evidence of the ancient surface, which is therefore still identified as Bailey.

For deposition, a deposit 1 cm thick or even a few centimeters thick might be too little for practical purposes, although a deposit of any thickness may be considered significant from the standpoint of distribution and genesis of a given sediment and its effect on soil morphology. Some limit is needed because thin, discontinuous deposits of Fairview, Muleshoe and/or Longview sediments occur in important areas of pre-Longview surfaces that are so near the land surface that they should be recognized. Up to 30 cm of these younger sediments are allowed on the pre-Longview surfaces. If the deposit is more than 30 cm thick it is formally designated as the younger surface. This thickness was chosen because many Birdwell dunes have deposits up to about that thickness on their lower sides.

EPISODIC EROSION AND SURFACE STABILITY

Evidence of erosion due to man's activities is considered elsewhere in this book. But there is strong evidence of episodic erosion long before man arrived at the scene. In discussing the origin of blowout dunes Melton (1940, p. 126, 127) stated:

> If the cover of vegetation is locally killed, say at a watering place, a trail, or a farmstead, the persistent wind may scour away the underlying sand, thus exposing and killing the root systems of the anchoring grasses . . . if the climate is becoming progressively more arid, or if the groundwater surface is being lowered by other means, the vegetative cover may find itself unable to grow as rapidly as its roots are being uncovered. . . . A continuation of this process will leave a recognizable basin in the sand surface. Since the coarser sand fractions usually do not travel far, some of this sand will accumulate near the margin of the excavation on the leeward side . . . Many factors may be responsible for the development of blowout dunes in restricted localities, but in the main climatic factors seem to control the time of their development. . . . This process appears to have been cyclic, though the interval of time periods between periods of dune formation was undoubtedly irregular.

Results of this study strongly support Melton's conclusions. A substantial amount of work in various disciplines now suggests time for some of these episodes of erosion (see Climate) although the times become much less certain with increasing age. A change in climate, to a time of less effective moisture, is also thought to have been a major factor in initiating erosion and sedimentation in the southwestern United States (Haynes, 1968), and in the development of geomorphic surfaces in southern New Mexico (Hawley et al., 1976; Gile et al., 1981).

The interpretation that severe droughts caused episodes of strong erosion explains the presence of various eolian deposits in the sandhills. They should have been particularly susceptible to erosion because of abundant sand. Sandy C horizons between sets of genetic horizons demonstrate both the episodes of sedimentation and soil burial. Morphological features of the soils help to distinguish the various sediments, assist in learning details of how and where the process of erosion and deposition operated, and show how the process affected the soils.

Erosion at a particular place may continue until the climate becomes wetter, or until a resistant layer is encountered in the soil (fig. 19a). The finer-textured argillic horizons are relatively resistant to erosion, but even these can be eroded as discussed later (see also Sites 51 and 52). Prominent carbonate horizons are most resistant to erosion in the study area.

After erosion during severe drought has penetrated to or into a resistant horizon, such as an argillic horizon, sand continues to move across its top during windstorms as long as there is a source of sand (fig. 19a). When the dry climate ends, sand movement virtually ceases and thus a younger deposit comes to rest on the erosion-resistant horizon beneath (or on underlying materials if the horizon has been completely removed). If a source of sand was available throughout the history of a particular soil with an erosion-resistant horizon, a number of such episodes of erosion and burial may have occurred. But if the source area was scoured clean of sand by the end of the latest erosive episode, then the resistant horizon is not overlain by younger sediments but instead is at the land surface (see Sites 51 and 52).

Identification of buried soils in an arid region has been discussed (Gile and Hawley, 1966), and similar procedures are followed in this semiarid region. The significance of C horizons between sets of genetic horizons was noted earlier in this report; the C horizon is at the land surface in areas affected by the latest erosive episode. The underlying horizon is commonly a buried A horizon, B&Bt horizon, Bt horizon or K horizon. The contact between the C horizon and the buried horizon is commonly distinct but is less evident in some instances. If the overlying deposit is thin and is old enough to have a Bt horizon, there is no C horizon between the sets of genetic horizons; the Bt horizon of the overlying deposit rests directly on the buried horizon (see Site 43). In other cases, sediments of similar texture have been subjected to the mixing and masking processes of pedogenesis -- that is, biotic activity and movement of soil moisture (see Sites 3 and 18). The likely position of the contact, however, may be determined by lateral tracing of the overlying deposit to an area where it is thicker.

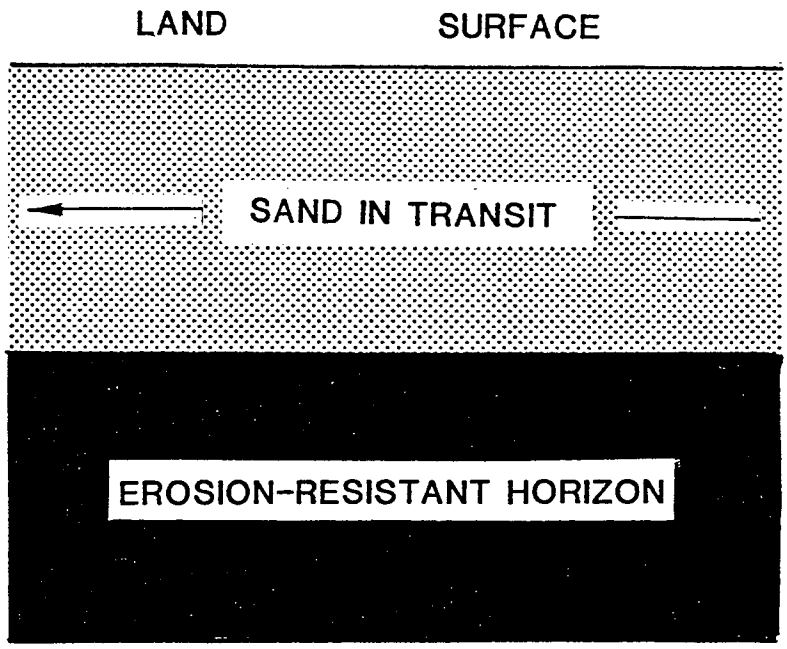


Figure 19a. Diagram showing relation between fresh sandy sediments and underlying erosion-resistant horizon. During times of severe drought, sand continues to move across the erosion-resistant horizon during windstorms as long as there is a source of sand. When the severe drought ends, sand movement stops and thus young sandy sediments come to rest on the older horizon beneath.

In some areas the sedimentary contact is illustrated in dramatic fashion. The power of sand-moving winds is suggested by the high dunes, but additional evidence is concealed beneath the deceptively smooth topography of the sandhills. Figure 17 in Gile (1981) shows sediments of Birdwell age resting abruptly on sediments of Hale age along the margine of a deep eolian groove cut in Hale sediments by strong winds in Birdwell time. Filling of such grooves may be associated with the end of the drought period and beginning of a wetter climate, when vegetation should start to grow in places that were formerly barren. The combination of more moisture and more vegetation should combine to slow erosion and deposition, and one of the effects could be the filling of eolian grooves that were cut during the period of maximum drought and erosion.

The concept of a stable surface is important in soil-geomorphic studies because surface stability controls both the character of infiltration into the soil and penetration of the wetting front. In turn, penetration of the wetting front controls the distribution of organic carbon, silicate clay and carbonate, all important components of various soils in the sandhills. The significance of surface stability has been discussed for terrains dominated by alluvial fans and fan-piedmonts (Gile et al., 1981). In these terrains,

such features as landscape dissection, drainageways, slopes, and parent materials are useful in assessing landscape stability and in predicting soil occurrence. But the situation is different in the sandhills, because the process that shaped the landscape is dominantly eolian instead of alluvial, and erosive episodes of various ages have resulted in smooth slopes that do not suggest or reflect the complex soil patterns. Thus it is possible to assess surface stability and to predict soil occurrence only in very general ways. More detailed studies are required to determine the location of stable surfaces of various ages than are required in terraced terrains.

The two most important horizons in assessing surface stability in the sandhills are horizons of silicate clay and carbonate accumulation. Most of the A horizons are and were very sandy and easily removed; A horizons are missing from most land-surface soils that are older than middle Holocene. Illustrations of stable surfaces of various ages are given later in this chapter.

At stable sites, soil development is closely related to age of soil and geomorphic surface (fig. 2). After a climatically-induced time of erosion and deposition, soil development began in the newly-deposited sediments, and for this reason the age of a geomorphic surface and its soil is considered to be the same.

When the morphological range of soils on a geomorphic surface has been determined, the soils themselves can be used to identify the geomorphic surface. More time is required to determine the morphological range in the sandhills than in alluvial or glaciated terrains, because of the highly complex soil patterns in the sandhills as discussed earlier.

In many areas of the Southwest, a large number of soils can occur on a given geomorphic surface because of substantial differences in such characteristics as mineralogy and particle size (Gile and Grossman, 1979). In this study area, however, these characteristics are similar for most soils, and for this reason a relatively small number of soils occur on each geomorphic surface. On the other hand, occurrence of the surfaces, sediments and soils of the sandhills is more complex than in many terrains where soil morphology and relative age can be predicted. Thus in the stepped sequences of geomorphic surfaces in stream valleys of the Southwest, specific soils occur on specific surfaces, and the soils on progressively higher surfaces are progressively older and more complex (Gile et al., 1981). But prediction of soil occurrence based solely on landscape position cannot be made in the sandhills; soils of topographic highs may be younger, older or the same age as soils of topographic lows. This is because eolian sediments can be deposited on none, part, or all of a given locality in the sandhills during a time of climatic stress and resultant erosion and deposition. Also, smooth slopes produced by wind and colluvium can mask important boundaries between soils that differ greatly in morphology. Features useful in predicting soil occurrence in the sandhills are discussed in Chapters 5-9.

FAIRVIEW SURFACE, 1880 A.D. TO PRESENT

Sediments associated with the Fairview surface (cover, fig. 20) postdate the large-scale introduction of cattle in the middle 1880's. Fairview sediments are usually only a few centimeters thick in the study area. However, in and near the large blowout (fig. 19) they range up to about 1.5 m

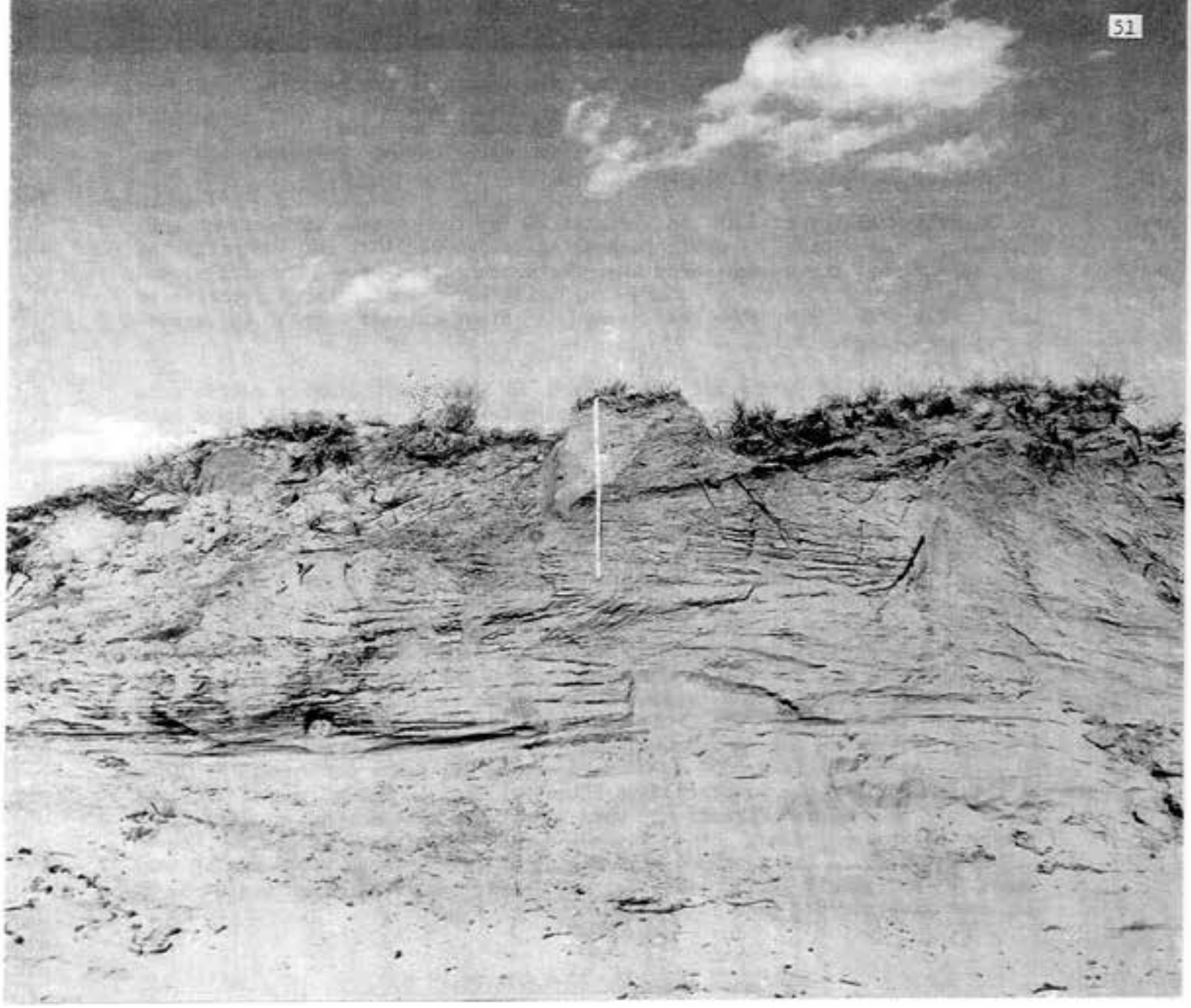


Figure 20. A closer view of the blowout exposure shown on the cover. A Typic Ustipsamment is in Fairview sediments on the dune crest, and is underlain by a buried Alfic Ustipsamment of Longview age. Fairview sediments have been eroded to the left and right of the area by the tape, furnishing sediments for younger Fairview sediments beyond. At the tape, Fairview sediments extend to a depth of about 4½ feet (1.4 m), where the dark A horizon marks the upper part of Longview sediments. See Site 1 for detail. The view is east. Scale is in feet. Photographed October 1974.

thick because a source of abundant sand was available for erosion. Fairview eolian sediments occur east of roads, fences, and active blowouts, where they are slowly accumulating at present during dry times with high winds (mostly in the spring). Gully-derived alluvium of Fairview age has accumulated at the foot of slopes (Site 37).

Fairview sediments can be identified by the absence of distinct soil horizons; in thick, freshly deposited sediments by the scarcity of vegetation; by their occurrence near features created by man or cattle; and in many places, by their sandy surficial appearance. Large deposits of later Fairview age show as prominent light-colored areas in aerial photographs (figs. 13-17).

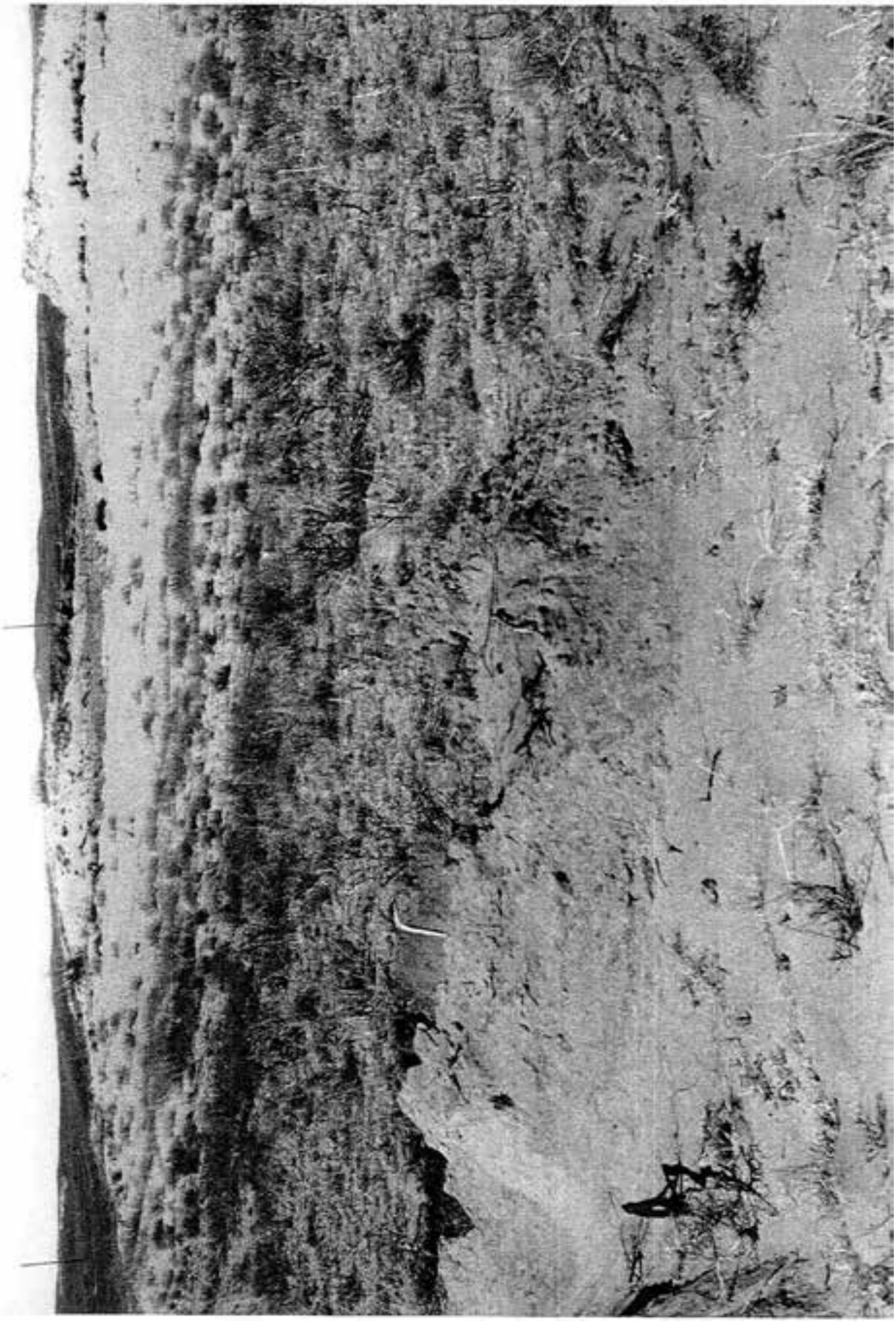
The degree of pedogenic alteration of Fairview sediments ranges from undisturbed strata of freshly deposited materials to strata that have been partly mixed by soil fauna or roots. The sediments are so young that they do not have A horizons that are darkened throughout by organic matter, although scattered particles of organic matter are present in some cases.

In the study area there is direct evidence that the major direction of sand-moving winds has been dominantly due east for at least a few decades. Figures 13-17 are aerial photographs of the large active blowout taken during the period 1941-1981. In all 5 photographs the dominant direction of sand-moving winds, as indicated by the accumulated sand, is approximately due east. Freshly deposited sediments also occur due east of Coyote Lake, just south of the study area (back of cover and flyleaf). Elsewhere in the Southern High Plains there is some variation in the direction of sand-moving winds at the present time. Melton (1940, p. 138, 141) indicated that the dominant direction of present-day active sand movement was toward N. 40° - 50° E. and locally N. 60° - 70° E. near Clovis, N.M.; and toward N. 20° - 25° E. in most of the Southern High Plains of Texas. Melton postulated that winds of the above directions were about the same during the last 5,000 years; he termed dunes that formed during this time, Series I. Reeves (1965) working in the southern High Plains of Texas, found winds during that time to be mainly N. 5° - 35° E., with an average wind direction of N. 20° E., approximately the same as Melton.

MULESHOE SURFACE, 70-4,000 YEARS B.P.

Sediments of the Muleshoe surface (fig. 21) occur on some of the high Longview dunes, in troughs between the dunes, in scattered small blowouts, and in blowout dunes. The thick deposits of Muleshoe sediments occur only in the northern part of the study area (fig. 19).

Although Muleshoe sediments are not extensive in the study area, they are pedogenically significant because they show an intermediate stage in soil development between the youthful C horizon material of the Fairview surface and distinct profiles of the Longview surface (fig. 21). Thickness of the deposits ranges from a few cm to about 3 m. Muleshoe sediments are commonly underlain by clay band horizons of Longview age, less commonly by pre-Longview argillic horizons. The following geomorphic and pedologic evidence indicates that Muleshoe sediments are in fact a deposit younger than these underlying horizons and not genetically related to them.



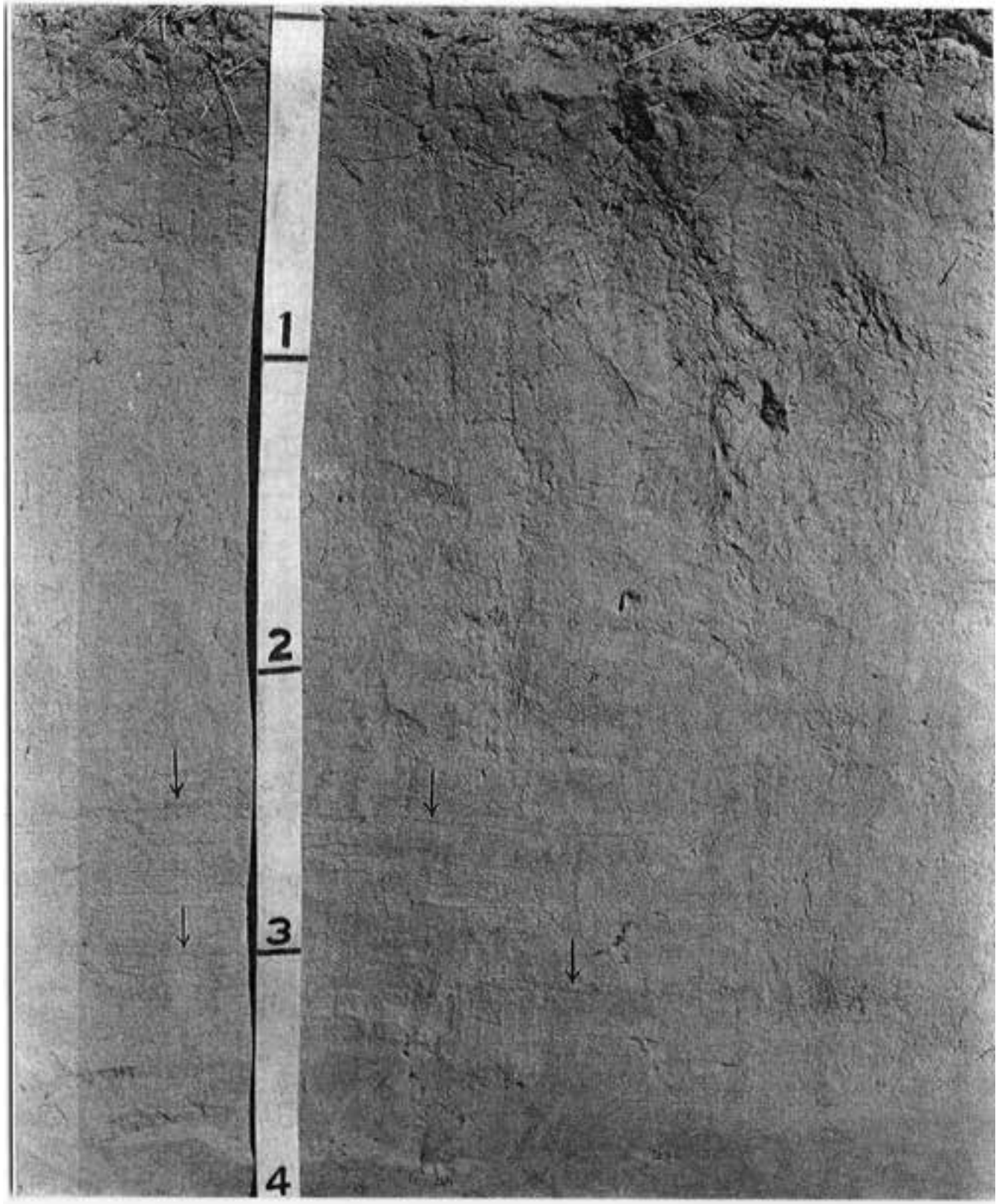


Figure 21. Upper. The Muleshoe surface and sediments are in the vicinity of the trench in the foreground. The light-colored sediments beyond are of Fairview age and were derived from the active blowout discussed earlier. On the skyline beyond the blowout are oak-covered ridges of the Muleshoe and Longview surfaces. The view is west. Photographed March 1977.

At left. The Typic Ustipsamment, Tivoli. Arrows locate occasional thin, discontinuous clay bands, which occur in some soils of Muleshoe age. Other soils of Muleshoe age have no clay bands. See Site 12 for details. Scale is in feet.

(1) Muleshoe sediments do not have the morphology of thick A1 or A2 horizons that formed at the same time as the argillic or clay band horizons beneath. Only thin A1 horizons and (in some pedons) thin A2 horizons have formed; and these horizons occur only in the upper part of the Muleshoe deposits. The A horizons are usually underlain by weak B horizons that are often slightly redder than adjacent horizons, and that in many instances show evidence of slight accumulation of silicate clay.

(2) The B horizons of Muleshoe and progressively older sediments increase in clay content with increasing age, thus are genetically related to the soil-forming factor of age and not to the horizons beneath, which must be buried.

(3) Sandy Muleshoe sediments, with the same youthful-appearing morphology described above, range widely in thickness and overlie B horizons that range widely in age (from Longview to Hale) indicating a discontinuity.

(4) In thick deposits the B horizon of Muleshoe age is underlain by C horizon material. This is conclusive evidence that the underlying argillic or clay band horizon is buried.

(5) The Muleshoe sediments are thickest near a source of relatively thick sand: the sandy A, B and C horizons of soils of Longview age. These horizons contain very little clay and silt, and should have been susceptible to erosion during severe droughts. Thus, the occurrence of Muleshoe sediments is dependent upon a source of sand for erosion, and not on the underlying horizons.

(6) Studies at Blackwater Draw (Haynes, 1975) indicate that deposits of the postulated range in age would be expected.

The likelihood that times of erosion and deposition have occurred since 4,000 B.P. in the High Plains area is indicated by Haynes (1975, p. 83):

> From 4,000 years ago to the present the stratigraphy of the Llano Estacado preserves a record of cycles of erosion, deflation and dune activity alternating with alluvial deposition and soil development, but amplitudes of the cycles did not approach those of the previous cycles, and the timing of events is obscure because of a lack of attention by geochronologists.

Although the precise age of Muleshoe sediments is not known, they are common in areas of Holocene sedimentation, and occur in the same stratigraphic position (below Fairview sediments and above Longview sediments) in both the study area and in the Coombs Ranch area near the Blackwater Draw Locality No. 1 archaeological site. At Coombs Ranch, Muleshoe sediments overlie Longview sediments that nearby have been dated with Archaic artifacts as discussed in the next section.

The contact between Muleshoe sediments and buried Longview sediments is typically characterized by the occurrence of a B or C horizon of Muleshoe age on a banded B horizon of Longview age, less commonly on an A horizon of Longview age.

Sediments of the Muleshoe surface represent the youngest of the major erosive episodes identified in the sandhills. That the episode is also the

weakest is suggested by thinness of the deposits and by their relative sparcity. The time from 70 to 4,000 years ago may in fact consist of more than one change to a drier climate and associated erosive episode. This is suggested by pedogenic evidence: some soils have only C horizons beneath A1 horizons; others have weak B horizons that show evidence of very slight accumulation of silicate clay in the form of very slight reddening and/or one or several, usually discontinuous clay bands. Since the presence of more than one deposit has not been demonstrated stratigraphically, however, the sediments older than Fairview and younger than Longview have been grouped together into a single deposit, Muleshoe.

Evidence for one such change to a drier climate in Muleshoe time has been presented for about 1,000 years B.P. by Hall (1982). The change to a drier climate could have started erosion in the sandhills at places most susceptible to erosion — the sandy A horizons of the next older soils (Longview). As more resistant horizons were encountered and/or vegetation gradually adjusted to the drier climate, wind erosion may have virtually ceased. Soils with an A1 horizon, but without clay bands, could have formed in a deposit emplaced earlier in the interval from 100-4,000 years B.P.

The southern boundary of Muleshoe sediments (fig. 19) is important because it also marks the boundary to older sediments dating from earliest Holocene or latest Pleistocene. South of this boundary, Muleshoe sediments occur only as thin, discontinuous deposits in scattered places such as the lee sides of ridges.

The direction of sand movement in Muleshoe time is not distinct on aerial photographs because the blowouts are small. However, the dominant direction appears to have been to the east, as indicated by field examination, because Muleshoe blowout dunes occur east of blowouts. The main body of Muleshoe sediments also extends in a general easterly direction (fig. 19). Direction of sand movement in Muleshoe time is also indicated by a broad lobe of these sediments west of the study area (front flyleaf). Both the broad lobe itself and the smaller dune forms within the lobe are headed approximately due east. A prominent belt of dune sediments also occurs due east of Coyote Lake (front flyleaf). Although these sediments were not examined, some of them may also be of Muleshoe age.

LONGVIEW SURFACE, 4,000-7,000 YEARS B.P.

Sediments of the Longview surface (fig. 22) occur in high dunes, in troughs between dunes, in blowouts and in blowout dunes. Thick deposits of Longview sediments occur only in the northern part of the study area (fig. 19). Where not eroded, soils of Longview age have A horizons and B horizons with continuous clay bands. The clay bands must have developed primarily in pre-Muleshoe time, because no difference in band morphology is apparent whether or not the soils of Longview age are buried by Muleshoe sediments. A2 horizons are distinct under oak vegetation, but are generally less prominent or absent under grass.

The soils of Longview age are very similar to dated soils with clay band horizons near Blackwater Draw Locality No. 1. At the Coombs Ranch site near Blackwater Draw, one complete Archaic point, half an Archaic point and a mano were found 10 to 15 cm below the surface of a soil with a clay band horizon (Fred Nials, personal communication). A period of widespread drought and erosion occurred on the Llano Estacado between 5,000 and 7,000

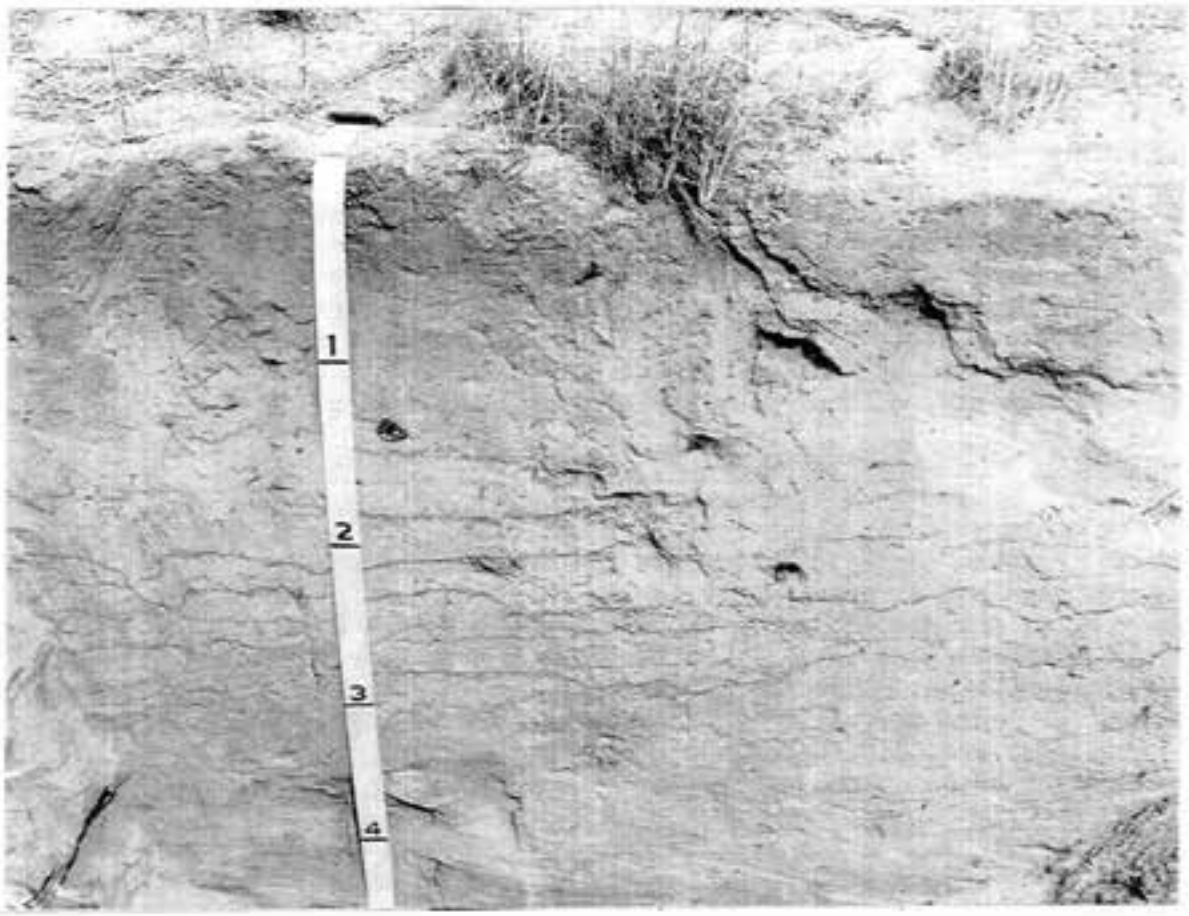


Figure 22. Upper. The foreground trench is in the Longview surface and sediments. Materials in the middle ground and on the skyline are outside the study area. The view is north. Photographed March 1976.

Lower. The Alfic Ustipsamment, Circleback, is typical of soils on the Longview surface. Clay bands are distinct and most are continuous, thus contrast with soils of the Muleshoe surface (fig. 21). See Site 19 for details. Scale is in feet.

years ago, as indicated by extensive deflation, missing sediments and lowered water tables (Haynes, 1975). Parent materials of the soil at the Coombs Ranch site were deposited during this time (Fred Nials, personal communication). Since the Archaic artifacts have an age range of 4,000 to 6,000 years B.P., the underlying clay band horizon must be at least 4,000 to 6,000 years old, but not older than about 7,000 years.

The Longview sediments range up to about 4 m in thickness, and overlie buried A horizons or buried Bt horizons. In many places Longview deposits are thick enough that the banded B horizon is underlain by C horizon material. This is conclusive evidence of a deposit younger than the underlying A or B horizons, which must be buried.

Two sediments, designated Longview I and Longview II, have been observed in thick deposits (Site 3). Longview I is buried beneath Longview II and its soil has weak A and B horizons. Longview I and II sediments may be correlative with strata 3 and 4 at the Lubbock Lake archaeological site (Holliday and Allen, in press; Holliday, 1982). Thus the Longview I sediments may have been deposited during the period from about 6,500 to 6,000 years B.P., and Longview II sediments during the period from about 5,000 to 4,500 years B.P. Holliday (1982) considers both of these periods to be times of severe drought, which reduced vegetative cover and started the erosion.

The contact between Longview I and II is distinct (Site 3), but both sediments are not always present. Formal names other than Longview I and II have not been used because identification is not always certain if both are not present. If there is no evidence indicating I or II, the soils and sediments are designated simply as Longview. Soils of Longview age that have the thickest bands are thought to represent a Longview I deposit not buried by Longview II, but this has not been demonstrated stratigraphically.

The south boundary of the main body of Longview sediments is similar to that of Muleshoe sediments (fig. 19). Only thin, isolated deposits of Longview age have been observed south of this boundary.

As in the case of the Muleshoe sediments, direction of sand-moving winds in Longview time is not distinct in aerial photographs because blowouts and blowout dunes are small. However, deposits of Longview age appear to be headed approximately due east as indicated by the position of Longview dunes, east of blowouts. Eastward-trending Longview sediments also occur in the large lobe of eolian sediments to the west as noted earlier (inside cover).

Regional significance of winds from both the west and northwest is shown by the occurrence of large eolian deposits to the east and southeast of numerous playas near the sandhills (Girdner et al., 1963). Although age of these deposits was not determined, their presence near playas over a wide area indicates significance of winds from the west and northwest.

Most of Longview time (4,000 - 7,000 years B.P.) falls within Series II time of Melton (1940) who shows Series II dunes in Bailey County as heading a few degrees north of due east (Melton, 1940, fig. 29). However, Melton (1940, p. 143) notes that "The date — 5,000 years in the past — which may divide Series II from Series I is of the most tentative nature." The change in direction from the sand-moving winds that formed analogues of Melton's

Series I dunes in the study area may actually have taken place earlier -- possibly in Birdwell time, discussed in the following section.

BIRDWELL SURFACE, 7,000-13,000 YEARS B.P

The Birdwell surface (figs. 19, 23), named in honor of Mr. J. E. Birdwell, is the most extensive surface, dominating the central and southern part of the study area. The Birdwell surface is also extensive as a buried surface in the northern part of the study area. Ubiquity of the deposits, except for blowouts of Hale and Bailey age that were swept clean by Birdwell winds, suggests the magnitude of the environmental change that took place at the end of the Tahoka pluvial.

Thickness of the deposits ranges from 1 m or less in low dunes and depressions to about 5 m in high dunes. The deposits are not as thick as might be suggested by height of some dunes because in many places the sediments were deposited on already-existing dunes. Birdwell ridges are higher in the southern part of the study area, which is near the inner Portales Valley, than they are in the northern part. The valley must have caused low water tables in pervious sediments nearby. This may have resulted in greater wind erosion and higher Birdwell dunes than in the northern part of the study area because surficial deposits in blowouts would tend to be drier if water tables were lower.

Soils of the Birdwell surface illustrate the next step in the development of clay bands and the argillic horizon (fig. 2). The Bt horizons in both Birdwell I and II sediments appear too thick and weak to have undergone deep leaching intervals such as the Tahoka pluvial. Some soils of Birdwell age also illustrate initial development of stage I carbonate in the sandhills. The carbonate horizons occur only where the Birdwell parent materials contain sand-size carbonate aggregates derived from older carbonate horizons to the windward (e.g., Site 41).

Another contrast between soils of Birdwell and pre-Birdwell age concerns the A horizon (which is still preserved in many soils of Longview and Muleshoe age) and depth to the clay band horizon. In soils of Birdwell and pre-Birdwell age, the A horizon is usually thin or absent due to strong erosion. Erosion has also brought the clay band horizon closer to the soil surface. As a result, one or more of the upper bands is commonly discontinuous and appears to be in the process of gradual disintegration by soil biota and percolating water.

The Birdwell I sediments are thought to have been deposited in the dry interval termed the Monahans Interval, from 11,000 to 13,000 years ago, at the end of the Tahoka pluvial (Haynes, 1975). The contact between Birdwell I and older sediments is the most prominent one observed in the study area and apparently reflects the magnitude of the environmental change associated with the end of the Tahoka pluvial at about 13,000 years B.P. The environmental change must have been profound indeed (Haynes, 1975, p. 83; Oldfield and Schoenwetter, 1975, p. 171). The contact is well shown at Stops 6, 7, 8, 9, and 13 along Farm Road 1731 (Gile, 1981).

The Birdwell II sediments are thought to have been deposited during an arid time in an interval designated by Haynes (1975) as extending from about 11,500 to 7,000 B.P. This may be equivalent to unit B2 in Haynes (1968) who notes (p. 607):

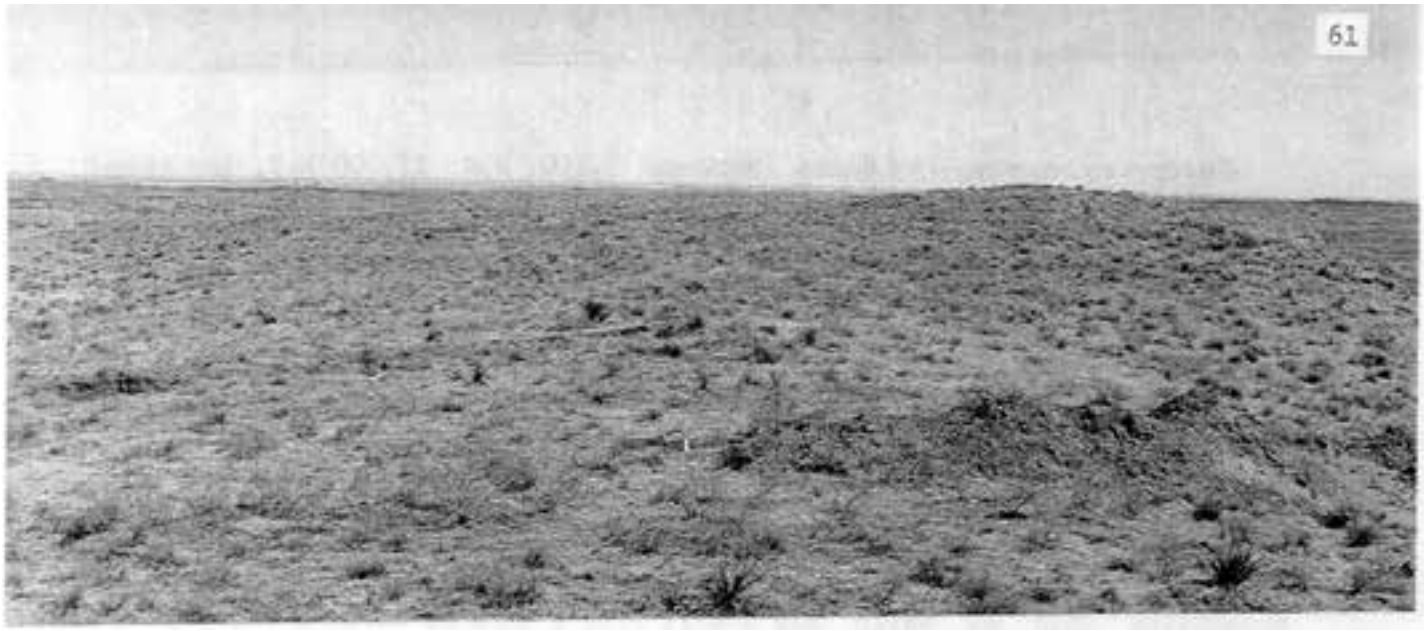
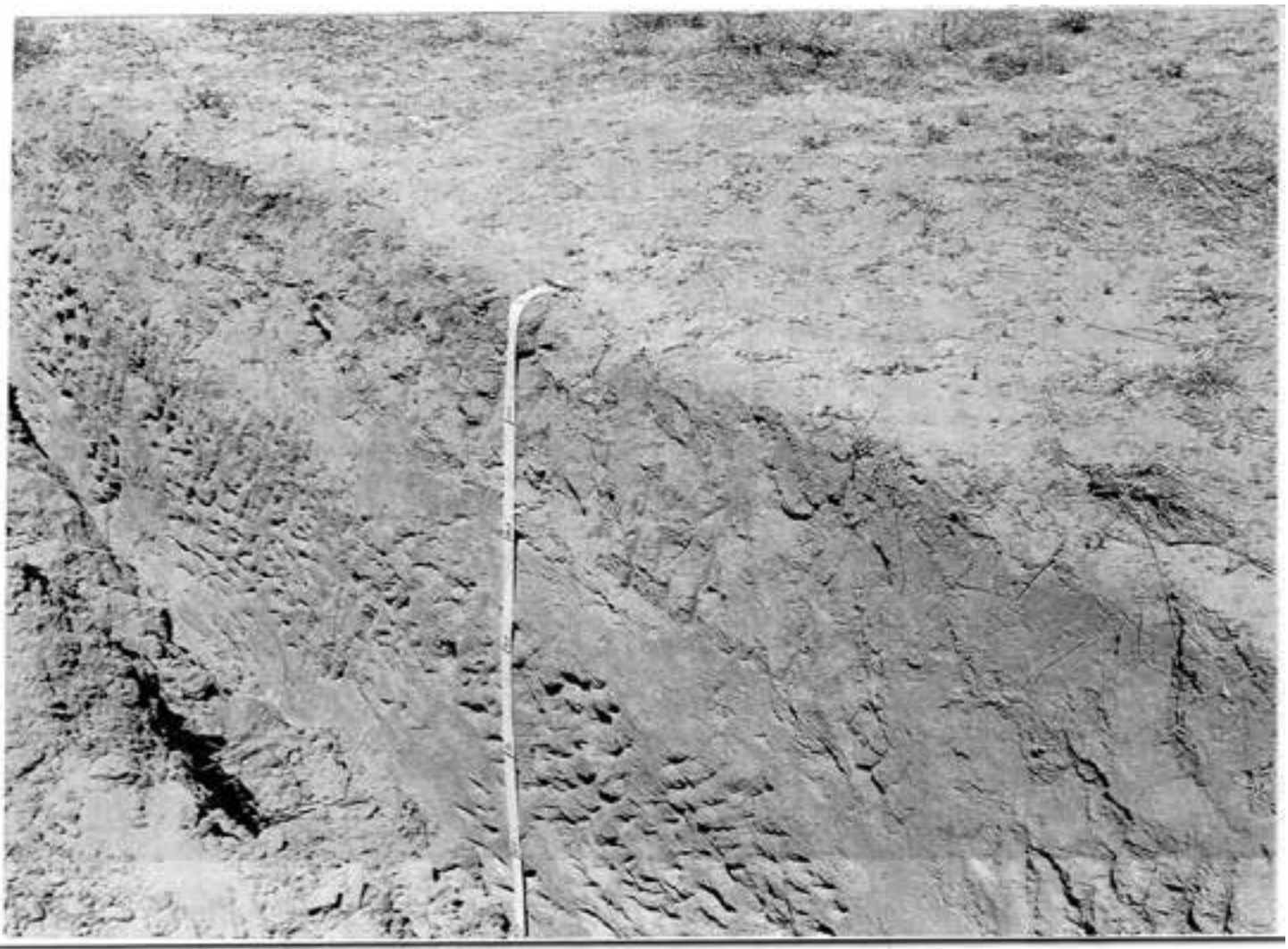


Figure 23. Above. The Birdwell surface and sediments occupy the ridge crest. The trench in the foreground locates the profile below, which occurs on the right, where the landscape changes from the level dune crest to the sloping ridge side. The view is north. Photographed March 1977.

Below. The Psammentic Haplustalf, Texico. This site illustrates a deposit of Birdwell II sediments that buries the sediments of Birdwell I. Birdwell II sediments occur to a depth of about 53 cm where they overlie the buried A horizon of Birdwell I. Sediments partly derived from the ridge side to the west have accumulated on the east-facing ridge side. See Site 38 for more detail.



> Forty-two carbon-14 dates between 7,100 and 11,000 B.P. for these cultural complexes are remarkably consistent over a wide geographic area. . . . In some dune-sand deposits of Colorado and Wyoming the occurrence of Cody artifacts . . . and Folsom artifacts . . . indicate that the deposits are eolian facies of unit B2.

The evidence suggests at least one time of erosion and sedimentation between 11,500 and 7,000 years B.P., and Birdwell II sediments may have been deposited during this interval.

As in Longview sediments, there is evidence of two different ages of materials in the span of time (post-Longview and pre-Roosevelt) occupied by Birdwell sediments; they are designated Birdwell I and II (fig. 2). The evidence consists of occasional bifurcation of Birdwell sediments into two sediments, each of which has a soil with a thin Bt horizon (Site 25); and deposition of Birdwell II sediments on lee sides of high Birdwell I dunes (Site 38, fig. 23). Two different surfaces have not been formally named because their identification as I or II is not always certain if both are not present. If there is no evidence indicating I or II, the soils and sediments are designated simply as Birdwell.

The first evidence of distinct difference from the present direction of sand-moving winds is found in dunes of Birdwell age. Pre-Birdwell dunes occur beneath Birdwell dunes, and this must be kept in mind in assessing wind direction by dune orientation. But the very size and extent of the Birdwell dunes suggests that their orientation may be a reliable indicator of wind direction. Most dunes of Birdwell age indicate directions of sand-moving winds ranging from about S. 35° E. to due east. However, linear trends in aerial photographs (fig. 19) and occasional blowouts both east and west of Farm Road 1731 suggest a time of winds from the southwest, heading in a direction of about N. 50° - 60° E. A small group of oak-covered ridges in the northwest part of the study area is heading in the same general direction; sediments of Birdwell age are known to be in at least some of these ridges, although they are buried in many places by discontinuous deposits of Longview and Muleshoe age. Reeves' (1965) wind directions for Series II dunes fall within this range of S. 35° E. to N. 50° E., and Melton's direction — a few degrees north of due east — for Series II dunes in the Bailey County sandhills (Melton, 1940, fig. 29) is about in the middle of the range.

Apparently, major changes in wind direction took place in Birdwell time — between about 7,000 and 13,000 years ago. Direction of the dune-forming winds may first have been to the southeast, then to the east and finally to the northeast. However, more work is needed on the chronology of change in wind direction.

ROOSEVELT SURFACE, 13,000 - 20,000 YEARS B.P.

A thin, but distinctive zone of materials, designated sediments of the Roosevelt surface, occurs between Birdwell and Hale sediments. Roosevelt sediments and their soils were found in a number of places by auger beneath Birdwell sediments in dunes (e.g., Sites 32 and 37), and in road cuts along Farm Road 1731 (Gile, 1981).

The Bt horizon in Roosevelt sediments is typically a fine sandy loam and grades downward into fine sand that overlies the thick Bt horizon of Hale age. It could be argued that the sand is C horizon material (of a post-Hale deposit) in which the Bt horizon formed. However, several factors suggest that the sand may represent the lower part of an A horizon on which a sandhills analogue of loess was deposited.

(1) Sedimentary strata have not been observed in the coarser material between the Roosevelt and Hale sediments. Lack of strata would agree with an A horizon interpretation since strata tend to be obliterated during pedogenesis.

(2) The coarser material overlies a thick Bt horizon of Hale age and could represent an A horizon associated with it.

(3) The Roosevelt sediments are remarkably uniform in thickness, more uniform than is generally the case for dune deposits in the sandhills.

(4) The bulk of the Roosevelt sediments contain more silt than the underlying coarser materials, and this would not conflict with an origin from a sandhills analogue of loess.

(5) Late Pleistocene loess has been extensively mapped north of the study area (Eifler, 1977). The irregular south boundary of the mapped loess is only about 25 to 30 km away.

Table 2a gives particle size data for two soils formed in Roosevelt sediments in roadcuts along Farm Road 1731, one at Stop 5 and one at Stop 7 (Gile, 1981). At stop 5, sighting from the dune west of the road indicates that Roosevelt sediments were about at the land surface on the side of the dune before Farm Road 1731 was built. Clay accumulation in a land-surface position would explain why upper horizons of Roosevelt age have more silicate clay than at stop 7 (table 2a) where Roosevelt sediments have been buried by Birdwell sediments for about 13,000 years (fig. 2). Note that all four subhorizons of the B horizon contain more silt than the A2b horizon. A sandhills analogue of loess could contain more silt than parent materials derived solely from a major erosive episode in the sandhills.

At Stop 7, sighting from the roadcut indicates that the sampled horizons at Stop 7 were overlain by about 1 m of Birdwell sediments before Farm Road 1731 was built. The upper two horizons contain less silt than the Bt subhorizons beneath. This may reflect a shift from regional deposition of a loess-analogue to local deposits derived from the sandhills.

Although Roosevelt sediments are common in dune crests beneath Birdwell sediments, they are sparse at the land surface in the study area. Apparently, as with sediments of the Hale surface to be discussed later, sediments of Roosevelt age were largely removed from interdune areas by strong erosion in Birdwell time.

The Roosevelt sediments are postulated to be correlative with Peoria (?) Loess of Frye and Leonard (1951, 1965) which they traced from Kansas into the Texas Panhandle. Peoria (?) Loess has been reported north of the area of this report (Reeves, 1972, 1976).

Age of the Roosevelt sediments may be indicated by the following. The

Table 2a. Particle size distribution for two Haplustalfs of Roosevelt age

Horizon	Depth, cm	Sand 2.0-0.05 mm	Silt 0.05-0.002 mm	Clay < 0.002 mm	Textural class
Aridic Haplustalf, Farwell[1/]					
B2t	0-18	64.8	16.4	18.8	fsl
B31t	18-29	74.3	11.7	14.0	fsl
B32t	29-52	81.2	8.8	10.0	lfs
B33t	52-75	84.9	8.2	6.9	lfs
A2b	75-97	89.0	5.0	6.0	fs
Psammentic Haplustalf, Texico[2/]					
A2b	0-20	94.3	2.1	3.6	fs
B1t	20-29	90.2	3.0	6.8	fs
B2tb	29-39	75.9	8.3	15.8	fsl
B31tb	39-56	82.8	7.3	9.9	lfs
B32tb	56-75	89.8	4.2	6.0	lfs
A2b2	75-86	89.9	5.1	5.0	fs

1/ Pedon at Stop 5 in Gile, 1981.

2/ Pedon at Stop 7 in Gile, 1981.

deposit would be older than about 13,000 years B.P. since it underlies the prominent contact at the base of Birdwell I sediments. In Illinois, Kleiss (1973) places the base of Peoria Loess at the Illinois River Valley bluff at 25,000 years B.P.; beyond 15 km from the valley, an age of 21,000 years B.P. was used for this base. Thus the age of basal Peoria Loess differs from one place to another. Deposition of Peoria Loess was thought to have ceased about 12,000 years ago. Kleiss (1973) also concluded that, because the latest increment of the loess is dominant, the major portion is relatively young where the loess is thin. From the above it is thought that (if the Roosevelt sediments are correlative with Peoria Loess) the bulk of the Roosevelt were emplaced within the period from about 13,000 to 20,000 years B.P. However, much more work is needed on the Peoria (?) Loess in areas adjacent to the sandhills, and the character of its transition into the sandhills.

If the Roosevelt sediments consist partly of late Pleistocene loess, it may have been deposited by northerly winds. Allen and Goss (1974), in discussing a late Pleistocene loess in the northern part of the southern High Plains, suggest that thinning of the loess southward was due to movement by northerly winds. If so, this would establish northerly winds during an interval just before erosion began in Birdwell time, discussed in the previous section. Thus some of the prominent Birdwell dunes, such as

the one associated with the blowout at Site 47 (frontispiece), could have been formed by winds from northwest at the beginning of Birdwell time.

HALE SURFACE, LATE PLEISTOCENE

Only small areas of the Hale surface and its soils have been found at the surface (figs. 19, 24), but they are buried in many places. Judging from their common occurrence in buried position, Hale sediments may once have formed a thick, essentially continuous blanket over the whole area. Large blowouts now occupied by the Bailey surface may once have been covered by Hale sediments that were later blown away in Birdwell time, to form the extensive dunes of Birdwell age. Hale sediments are thin -- about 1 m or less -- in the southern part of the area but thicken considerably to the north, where they are at least 7 m thick in places (e.g., Stop 5, Gile, 1981). The Hale sediments are thought to correlate with the upper part of the Blackwater Draw Formation of Reeves (1976).

Soils of Hale age have a Bt horizon that is substantially thicker and higher in clay than in soils of Holocene age (figs. 7, 24). This is thought to be due to greater age and to increased moisture of one or more pluvials. Soils of Hale age that are at or near the land surface commonly have a filamentary stage I carbonate horizon, or are noncalcareous throughout (see Sites 33, 37a, 42, 47, and 49). Where Hale sediments are thick and deeply buried by Birdwell and Roosevelt sediments along Farm Road 1731, the soils of Hale age are noncalcareous throughout, both where the Bt horizons are underlain by C horizons (e.g., Stop 5, 1981) and by buried Bt horizons (e.g., Stop 7, Gile, 1981). This suggests Holocene emplacement of the stage I carbonate in soils of Hale age at the land surface.

If the C horizon is present, a clay band horizon commonly occurs between the thick Bt horizon and the C. After the clay bands developed, they were apparently isolated and preserved because of clay accumulation higher in the profile. The latter may be due to gradually decreasing infiltration rates caused by continued clay accumulation in the Bt horizon.

Soils of Hale age are considered to be older than about 20,000 years and to be of late Pleistocene age, a general term for the period from about 10,000 to 250,000 years ago. Although usually buried in the sandhills, soils of Hale age appear to be extensive at the surface outside the sandhills, where they are similar to Brownfield soils of the Bailey County Soil Survey (Girdner et al., 1963, p. 13).

Direction of sand-moving winds in Hale time is not apparent in the study area because Hale sediments at the surface are scarce. Examination of the Hale sediments and soils outside the sandhills might reveal the dominant direction of winds during Hale time.

A buried soil of pre-Hale, post-Bailey age was found by auger at Site 3 and along Farm Road 1731 (Gile, 1981) beneath thick deposits of Hale age and above the ancient soils of Bailey age. Observed soils of this age have Bt horizons but little or no carbonate. These sediments are not known to be at the surface anywhere in the sandhills, and are tentatively designated an early phase of Hale. More work is needed on soils and sediments in this general stratigraphic position.

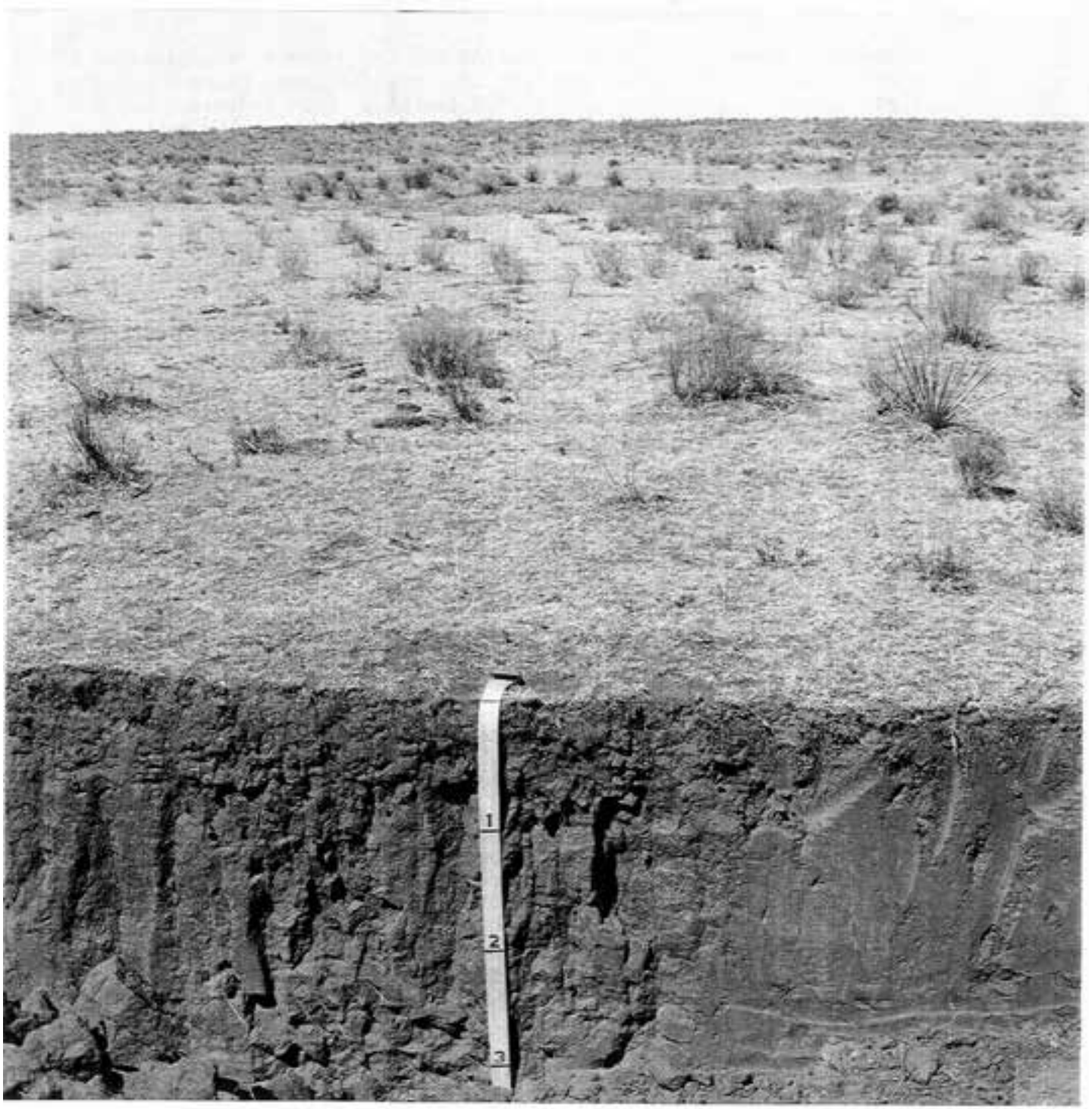


Figure 24. The Hale surface and soil are in the foreground. The soil is the Aridic Haplustalf Keeney. Note distinct prisms and the structural contrast to younger soils. See Site 49 for more detail. A Birdwell dune is on the skyline. The view is north. Scale is in feet. Photographed March 1977.

BAILEY SURFACE, MIDDLE PLEISTOCENE

The Bailey surface (figs. 2, 25) is of major extent in buried position; at the present land surface it is most extensive in depressions in the southern part of the study area (fig. 19). In the northern part, these ancient sediments and soils are deeply buried by Hale and post-Hale sediments except at Site 15.

Soils of the Bailey surface have a prominent calcic horizon, and in places an argillic horizon is also present. Few examples of well-preserved soils are known because of strong erosion at various times since the soils started to form. The thick calcic horizon is the best chronological marker because it is deeper in the soil and more resistant to erosion than the overlying argillic horizon. The calcic horizon is thicker and contains more carbonate in soils of Bailey I than in soils of Bailey II. Soils of Bailey II age have been identified in only one area, at Site 53 and vicinity. More work is needed on the relationships between Hale, Bailey II and Bailey I sediments. If there is no evidence indicating I or II, the soils and sediments are designated simply as Bailey.

The age of Bailey sediments is known only in a very general way. They are considered to be of middle Pleistocene age, and to have been emplaced between about 250,000 and 900,000 years ago. Even the older of the two sediments - Bailey I - may fall within the time span of the Blackwater Draw Formation (Reeves, 1976), and if so, Bailey sediments could be less than about 600,000 years old as discussed earlier. Until the stratigraphic relationships can be determined, however, the Bailey sediments as a whole are tentatively placed within the broader age bracket of the middle Pleistocene. Distinct dunes developed in Bailey time, as indicated by dune form of land-surface and buried sediments and soils of Bailey age (Gile, 1981, Stops 10-13).

The westernmost of the two areas of the Bailey surface (fig. 19) was mapped as the Ogallala Formation of Pliocene age by Eifler (1977). Since the sediments concerned are not Ogallala, the delineation may represent one of the inclusions of Pleistocene caliche mentioned in the legend (Eifler, 1977). But the bulk of Pleistocene time occurs between the Ogallala Formation and the Blackwater Draw Formation, which is the oldest Pleistocene unit mapped by Eifler (1977). Clearly, more work is needed on this aspect of the stratigraphy. More work is also needed to establish the relation of the Bailey sediments to the Blackwater Draw Formation.

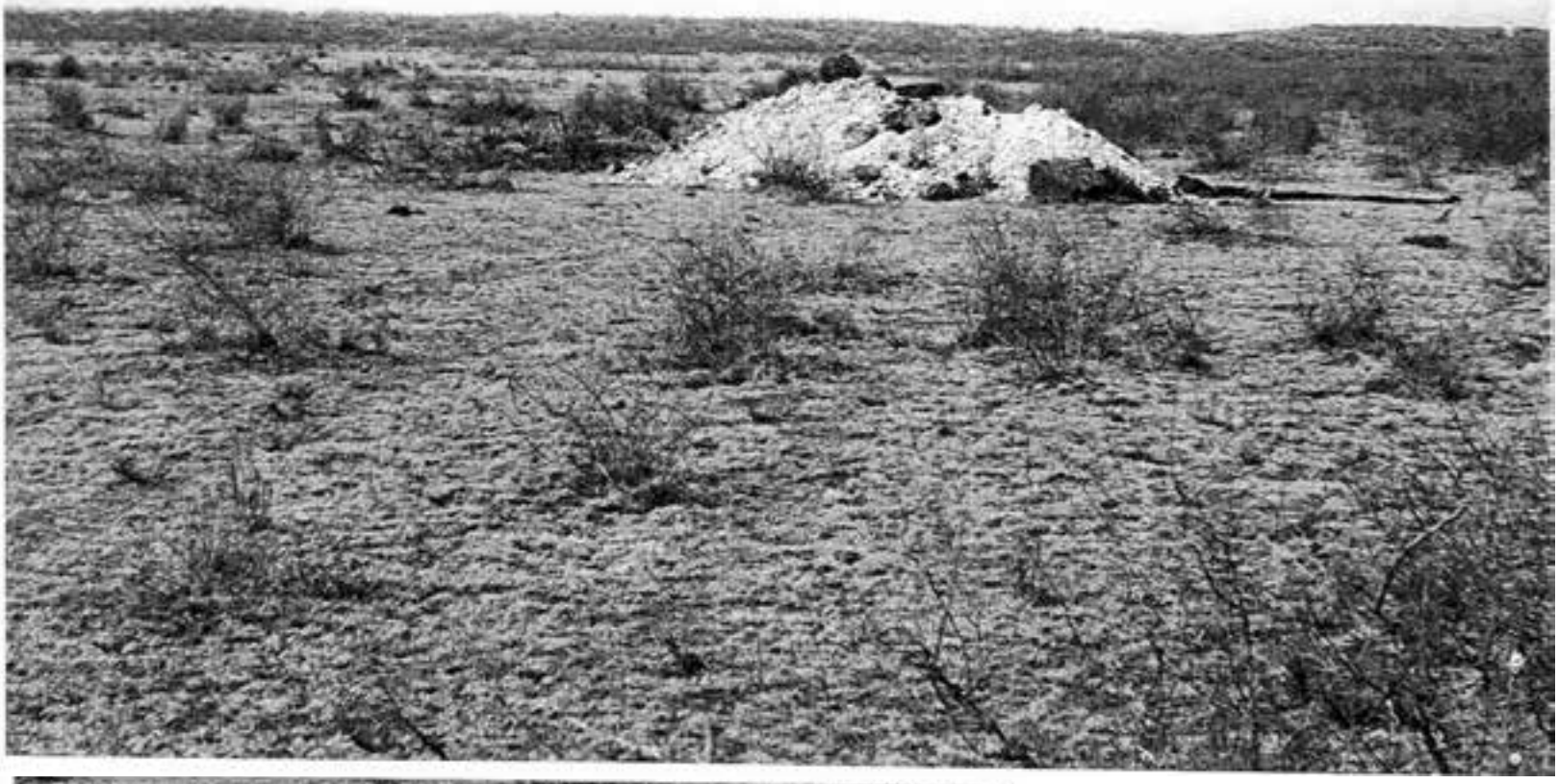


Figure 25. Upper. The trench is in the Bailey surface and sediments. A Birdwell ridge is on the skyline. The view is north. Photographed March, 1977.

At left. The Aridic Argiustoll Newell, calcic variant. The prominent carbonate horizon is typical in soils of Bailey age. See Site 50 for details. Scale is in feet.

CHAPTER 3. SOIL HORIZONS, TAXONOMY AND MAPPING

HORIZON NOMENCLATURE

Nomenclature for soil horizons may be considered as being of two general kinds. In one, master horizons and subhorizons are indicated by symbols, such as A1 and B2, that are used to describe soils in the field. The other kind consists of named horizons, such as mollic epipedon and argillic horizon, that are definitive for various taxa in the classification of soils. Subsequent sections present these two kinds of horizons.

Diagnostic horizons

Five diagnostic horizons are used to classify soils in the study area. Two of these (the mollic epipedon and the ochric epipedon) are surface horizons. The other three (the argillic, calcic and petrocalcic horizons) are subsurface horizons. Only summary statements concerning diagnostic horizons are presented here. Full definitions may be found in Soil Taxonomy (Soil Survey Staff, 1975).

The mollic epipedon has at least 0.6 percent organic carbon; values (moist) and chromas are 3 or less. The thickness is one of the following after mixing the upper 18 cm of soil:

(1) The epipedon must be more than 25 cm thick if its texture is finer than loamy fine sand and the upper boundary of pedogenic lime that is present as filaments, soft coatings or soft nodules is deeper than 75 cm, and the base of the argillic horizon is deeper than 75 cm.

(2) In other soils that have a loamy or clayey epipedon, the thickness of the epipedon must be 18 cm or more and it must be more than 1/3 of the depth from the top of the epipedon to the shallowest of one of the features listed in No. 1 if that depth is less than 75 cm.

(3) In other soils the epipedon must be more than 25 cm thick if texture of the epipedon is as coarse as or coarser than loamy fine sand throughout its thickness.

The ochric epipedon is too light-colored, too thin, and/or has too little organic carbon for a mollic epipedon.

The argillic horizon contains illuvial silicate clay. If the eluvial horizon has not been truncated, the increase in clay to the argillic horizon is as follows:

Clay content of eluvial horizon	Minimum clay increase required for an argillic horizon
pct	pct or ratio
15	3
15-40	ratio of 1.2 or more
40	8

Various kinds of evidences for clay illuviation are required in different situations. In this semiarid region, the pertinent evidence is at least 1% of oriented clay as viewed in thin section. Argillic horizons in this area meet this requirement.

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

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

Horizons designated by symbol

Horizon designations follow the 1962 Supplement to the Soil Survey Manual (Soil Survey Staff, 1962) except for the K horizon nomenclature (Gile et al., 1965). New designations for soil horizons in a revised Soil Survey Manual were recently announced (Guthrie and Witty, 1982). See table 3 for approximate equivalents of horizon designations in this book and in the revised Soil Survey Manual.

The A horizon

The A1 horizon is at the soil surface if it has not been buried. Mineral particles in the A1 horizon have coatings of organic material, or the soil mass is darkened by organic particles. The A1 horizon is as dark as, or darker than, the underlying horizon.

The A2 horizon underlies an A1 horizon. Clay has been moved from the A2 horizon to deeper horizons by descending soil water. The A2 horizon is usually lighter colored than adjacent horizons. The color is largely that of the sand particles, which have been leached virtually free of clay.

The A3 horizon is transitional to an underlying B horizon, but is more like A than B.

The A1, A2, and A3 horizons may be further subdivided (e.g., A11).

The B horizon

The B notation designates materials that have been altered by pedogenesis (e.g., the illuviation of silicate clay). An A1 horizon or an A2 horizon, or both, occurs above the B horizon if the soil has been little affected or unaffected by erosion. The B horizon may be subdivided as follows.

Table 3. Approximate equivalents of horizon designations in this book and in the revised Soil Survey Manual

Horizon designations, this text		Horizon designations, revised Soil Survey Manual 1/	
Without vertical subdivision	with vertical subdivision	Without vertical subdivision	With vertical subdivision
A1	A11 A12	A	A1 A2
A2	A21 A22	E	E1 E2
A3		AB or EB	
B1t	B11t B12t	BAt	BAt1 BAt2
B2t	B21t B22t	Bt	Bt1 Bt2
B3t	B31t B32t B32tca	BCt	BCt1 BCt2 BCtk
C	C1 C2	C	C1 C2
	If a K horizon is present		
K1	K11 K12	Bk	Bk1 Bk2
K2	K21 K22		Bk3 Bk4
K3	K31 K32		Bk5 Bk6
			Bk7

1/ Guthrie and Witty, 1982.

The B1 horizon is a transitional horizon between the A horizon and the B2 horizon, but is more like B than A.

The B2 horizon is the most strongly expressed part of the B horizon. If the horizon is a Bt horizon, the B2t is the subhorizon of maximum clay content as compared to B1 and B3.

The B3 horizon is a transitional horizon between the B2 horizon and a horizon beneath B3.

The B1, B2, and B3 horizons may be further subdivided (e.g., B11).

The K horizon

The K horizon is defined in terms of volumes of K-fabric, in which fine-grained authigenic carbonate occurs as an essential continuous medium (Gile et al., 1965). The carbonate coats and commonly separates and cements skeletal pebbles, sand, and silt grains. The horizons are usually prominent and light colored, and many are white throughout. Consistence ranges from soft to extremely hard, but most K horizons are cemented to a noticeable degree and many are indurated. Materials with K-fabric occur in a variety of forms, such as laminar, nodular, cylindroidal, massive, blocky and platy.

The K1 horizon is transitional to an A or B horizon from an underlying K2 or K2m horizon and contains 50 percent or more of K-fabric. The K1 horizon may be transitional because of less hardness, less continuous induration, or a lesser volume of K-fabric than in the K2 horizon. Some K1 horizons consist of discrete, somewhat loose nodules or plates overlying a continuously indurated K2m horizon.

The K2 horizon is the most prominent, hardest, and whitest part of the K horizon and generally contains most of the authigenic carbonate. The K2 contains 90 percent or more of K-fabric. The K2 can be massive, blocky, platy, nodular, or cylindroidal, and is commonly composed of two or more of these macroscopic forms. Indurated K2 horizons are designated K2m. A distinctive subhorizon, the laminar horizon, occurs at the top of most K2m horizons. The laminar horizon is composed primarily of laminar carbonate with a small amount of included sand, silt, clay and organic matter. In some K2m horizons, several laminar horizons occur and in places are separated by nonlaminar, carbonate-cemented material.

The K3 horizon is transitional from a K2 or K2m horizon to an underlying Cca horizon, C horizon, paleosol, or bedrock, and contains 50 percent or more of K-fabric. The K3 horizon contains less carbonate, a smaller volume of K-fabric, or is not as hard or as light colored as the overlying K2 horizon. The K3 horizon is not continuously indurated, but can contain indurated nodules or agglomerations of skeletal grains. In the K3 horizon, carbonate content and volume of K-fabric commonly decrease with increasing depth. K3 horizons occur in most soils with K2 horizons.

The C horizon

The C notation designates horizons or materials, other than bedrock, that have been little affected by pedogenic processes. The C horizon is subdivided by using Arabic numerals (e.g., C1, C2).

Suffixes

Suffixes of lower case letters are used to indicate certain kinds of master horizons, as follows:

b - buried horizon

ca - accumulation of pedogenic carbonate that does not qualify as K horizon, defined earlier.

t - accumulation of pedogenic clay, most commonly used with B (e.g., Bt). The horizon has evidence of illuvial clay, in the form of clay bands and/or of clay accumulation throughout the horizon. In thin section the clay occurs as oriented coatings on sand grains. The Bt designation is not restricted to the argillic horizon but is used to designate accumulations of silicate clay that do not qualify as argillic horizons — horizons with clay bands, for example. If both the clay bands and material between the bands qualify as Bt, the horizon concerned is designated Bt (e.g., B21t). If only the clay bands qualify as Bt and they occupy <50% of the horizon, it is indicated by a dual designation in which the dominant fabric is given first (e.g., B21t&Bt); the symbol Bt refers to the clay bands.

Prefixes

Most of the sediments are of eolian origin, but some are of colluvial origin and a few deposits are of alluvial origin. Arabic numberals have been used as prefixes to distinguish the distinct colluvium of Birdwell age from sediments of eolian origin. However, Arabic numerals were not used to distinguish sediments that contain only small amounts of colluvium, such as sediments of Muleshoe age. Arabic numerals were also used to distinguish eolian sediments from the alluvium below gullies.

Discontinuities

Arabic numerals have been used as prefixes to denote distinct differences in origin of parent materials. Although eolian sediments are dominant, areas of colluvium and alluvium do occur in places.

EFFECT OF BURIED SOILS ON CLASSIFICATION OF LAND-SURFACE SOILS

Table 4 presents soils of the study area and their classification according to Soil Taxonomy (Soil Survey Staff, 1975). Series names are not available for most soils and these are given informal names or are named as variants. Soils SND-1, Alfisols and Entisols undifferentiated, and SND-2, Vertisols undifferentiated (table 4) are very minor in extent and were not examined in enough detail to classify them below the level of soil order.

Buried soils are common in arid and semiarid regions, and are also important in the soil and landscape history of the sandhills. In parts of the sandhills, buried soils with diagnostic horizons are overlain by young deposits that lack diagnostic horizons and that range widely in thickness (Chapter 2). Such young deposits underlain by buried soils are not uncommon elsewhere in arid and semiarid regions. Since some of the buried soils

Table 4. Soil classification and diagnostic horizons and features of soils in the study area[1/]

Order	Suborder	Great group	Subgroup	Particle-size class[2/]	Series or variant
Entisols Lack diagnostic horizons unless they are buried	Psamments	Ustipsamments	Typic	Sandy	Tivoli. Lacks two or more continuous clay bands within 100 cm depth.
					Tivoli, thin variant #1. The same as Tivoli in upper part but has a buried argillic horizon with texture of loamy fine sand or coarser in some subhorizon between 50 and 100 cm depth.
			Alfic	Sandy	Circleback. Has two or more continuous clay bands within 100 cm depth and they are not those of a soil buried to depths greater than 50 cm.
	Fluvents	Ustifluvents	Typic	(Sandy, coarse-loamy)	Tivoli, thin variant #2. The same as Tivoli in upper part but has a buried argillic horizon with texture of loamy very fine sand or finer in some subhorizon between 50 and 100 cm depth.
Alfisols Argillic horizon	Ustalf	Haplustalfs	Psammentic	Sandy	Texico.
			Aridic	Coarse-loamy	Farwell.
					Farwell, thin variant. Like Farwell but there is no C horizon material between the argillic horizons of different ages; "PseudoPaleustalfs".
					Farwell, calcic variant. Has calcic horizon within 90 cm depth.
				Fine-loamy	Extee. Has calcic horizon within 90 cm depth.
					Keeney. Lacks calcic horizon within 90 cm depth.
(Alfisols and Entisols undifferentiated)					SND-1.
Mollisols Mollic epipedon	Ustolls	Argiustolls	Aridic	Fine-loamy	Newell, calcic variant. Has calcic horizon within 90 cm depth.
					Newell. Lacks calcic horizon within 90 cm depth.
				Sandy	Newell, sandy variant. Like Newell but is in a sandy family.
Inceptisols Ochric epipedon	Ochrepts	Ustochrepts Calcic or petrocalcic horizon	Aridic	Fine-loamy	Veal. Has calcic horizon within 90 cm depth.
				Sandy-skeletal	Veal, petrocalcic variant. Has petrocalcic horizon within 50 cm depth (is in shallow family).
(Vertisols undifferentiated)					SND-2.

1/ Diagnostic features listed are those important to the study area. See Soil Taxonomy (Soil Survey Staff, 1975) for a complete list. All soils are in the thermic temperature class. Mineralogical analyses indicate that some of the soils have siliceous mineralogy and that others have mixed mineralogy (see Sites 4-7, 22, 41, 43, and 53). Little data are available elsewhere for similar soils and eventually some of the series names may be changed, or mineralogy of some of the series may be changed (Earl Blakley, personal communication). Although further study is needed, it appears that all of the Entisols and many of the Psammentic Haplustalfs, coarse-loamy Aridic Haplustalfs and sandy Argiustolls have siliceous mineralogy. The fine-loamy Haplustalfs and Argiustolls probably have mixed mineralogy. The Ustochrepts have carbonatic mineralogy. Tivoli and Veal are established series. Circleback is a tentative series. Other names are informal.

2/ Particle-size class refers to the weighted average particle-size class of the control section, which refers to specific horizons and/or depths in the soil. For this area the control section for the Entisols extends from 25 to 100 cm depth; for the Alfisols and Mollisols, the control section is the upper 50 cm of the argillic horizon, or the whole argillic horizon if it is less than 50 cm thick; and for the Inceptisols, the control section is from 25 to 100 cm depth except for Veal, petrocalcic variant, in which the control section extends from the soil surface to the top of the petrocalcic horizon. As used in this report, Tivoli, thin variant #2 includes both the sandy and coarse-loamy particle-size classes.

are near the surface they must be considered in classification of land-surface soils, and for this reason Entisols may have buried diagnostic horizons (Soil Survey Staff, 1975, p. 179). Thickness limits for the young deposits are given in Soil Taxonomy (Soil Survey Staff, 1975, p. 2):

> A soil is considered to be a buried soil if there is a surface mantle of new material that is 50 cm or more thick or if there is a surface mantle between 30 and 50 cm thick and the thickness of the mantle is at least half that of the named diagnostic horizons that are preserved in the buried soil. A mantle that is <30 cm thick is not considered in the taxonomy but, if important to the use of the soil, is considered in establishing a phase. The soil that we classify in places where a mantle is present, therefore, has its upper boundary at the surface or <50 cm below the surface, depending on the thickness of its horizons.
>
> A surface mantle of new material as defined here is largely unaltered. It is usually finely stratified and overlies a horizon sequence that can be clearly identified as the solum of a buried soil in at least part of the pedon, as defined in the following chapter. The recognition of a surface mantle should not be based solely on studies of associated soils.

Thus, if the mantle of new material is more than 50 cm thick, or is 30 to 50 cm thick and is half or more the thickness of the buried diagnostic horizon, the upper boundary of the soil that we classify is at the land surface. In both cases the soils would be classified as Entisols because a surface mantle of new material, as defined, is excluded from the concept of diagnostic horizons.

Strata may or may not be present, in deposits of identical age; in practice, therefore, it is better and more consistent to simply use the absence of diagnostic horizons to identify the youthful mantle. Identification of its lower boundary was discussed in Chapter 2.

In the Grossarenic Paleustalfs, sandy epipedons >1 m thick overlie argillic horizons. Thus a basic decision in classification is whether thick sandy sediments constitute an epipedon that developed with the underlying argillic horizon, or are younger materials that have buried the argillic horizon. In the study area, sandy sediments of Muleshoe age have buried the argillic horizon as discussed in Chapter 2. But the provision for recognition of buried soils in Entisols is not always followed. In the vicinity of the study area, soils with 1 to 2 m of sandy sediments over buried argillic horizons have been classified as Grossarenic Paleustalfs (Earl Blakley, personal communication). Thus it should be recognized that some soils classified as Grossarenic Paleustalfs actually consist in part of buried soils. There is no doubt about the validity of thick A horizons and the Arenic and Grossarenic subgroups in some soils (e.g., North Carolina Paleudults, Gamble et al., 1970). But serious questions may be raised about the use of these subgroups in the Southern High Plains because the sandy sediments did not form with the underlying argillic horizon but instead are much younger sediments that bury it.

Another matter concerns suitability of the "Pale" great groups to classify thick, young sandy deposits underlain by buried argillic horizons. Much of the material and in some pedons the bulk of the material (the thick

sandy deposits) in such "Grossarenic Paleustalfs" is actually less than about 4,000 years old, and possibly much less (see Muleshoe surface, Chapter 2). This youthful material does not fit the concept of the Paleustalfs, which are stated to be ". . . the thick reddish or red Ustalfs that are on old surfaces" (Soil Survey Staff, 1975).

A similar question may be raised about the use of Arenic subgroups in the Southern High Plains. These soils, which also contain buried diagnostic horizons, have an epipedon that is between 50 and 100 cm thick and that has texture of loamy fine sand or coarser. In other places (e.g., the Western states where buried soils are common) the rules for classification of Entisols have been followed. In these states buried soils, where overlain by a young mantle of appropriate thickness, are noted in the series description instead of using them to classify at the great group level (e.g., Arenic Haplustalfs). Thus young mantles 50 to 100 cm thick over buried argillic horizons are routinely classified as Entisols. This is illustrated by the Arizona Fluvents Estrella, Trix and Valencia. Materials overlying the buried soils consist of alluvium instead of eolian sediments, but the principle is the same; the buried soils are overlain by youthful sediments that lack diagnostic horizons.

On the basis of the foregoing it is suggested that the Arenic and Grossarenic subgroups not be used in the Southern High Plains. Instead, it is suggested that the rules in Soil Taxonomy, and the lead of other states, be followed for handling buried soils in Entisols. Then there would be an expected and natural gradation from thick Entisols to thin ones as the youthful deposits become thinner in various places. This would also avoid the logically tortuous transition in classification, Entisols - Arenic Haplustalfs - Grossarenic Paleustalfs, for sandy sediments having identical ages and differing only in thickness. In addition, the unfortunate conflict with true Arenic and Grossarenic subgroups would be avoided.

ENTISOLS

Two suborders of Entisols are present, Psamments and Fluvents (table 5).

Table 5. Diagnostic features for suborders and great groups of Entisols in the study area.

Suborder	Great Group
Psamments Texture is loamy fine sand or coarser in subhorizons between 25 and 100 cm, except for clay bands too few or too thin to be an argillic horizon (Soil Survey Staff, 1975).	Ustipsamments Ustic moisture regime
Fluvents Texture is loamy very fine sand or finer in some subhorizon between 25 and 100 cm depth, and organic carbon decreases irregularly with depth and/or is more than 0.2% at 125 cm depth.	Ustifluvents Ustic moisture regime

The Fluvents occur in two general ways in the study area. In the first, youthful eolian deposits, primarily of Muleshoe age, overlie wind-eroded and buried argillic horizons at 50 to 100 cm depth. If a buried argillic horizon occurs between depths of 50 and 100 cm, organic carbon tends to be higher in it than in overlying coarser-textured materials because of the close relation of organic carbon to clay. Thus organic carbon decreases irregularly with depth and these soils are Fluvents if texture is loamy very fine sand or finer in some subhorizon between 25 and 100 cm depth. Some of the buried argillic horizons are thin but others are very thick, and both the 30 to 50, and $\geq$50 cm depths, cited in the previous section, would apply. For convenience in this work, only the $\geq$50 cm depth was used (consideration could well be given to dropping the 30 to 50 cm criterion).

Muleshoe sediments range widely in thickness; figure 26 summarizes changes in soil classification with progressive thinning of young sandy sediments that lack a diagnostic horizon and that are underlain by a buried argillic horizon. As the young sandy deposit thins to less than 100, and then to less than 50 cm thickness, the soil changes are, in order, Psamment - Fluvent - Ustalf.

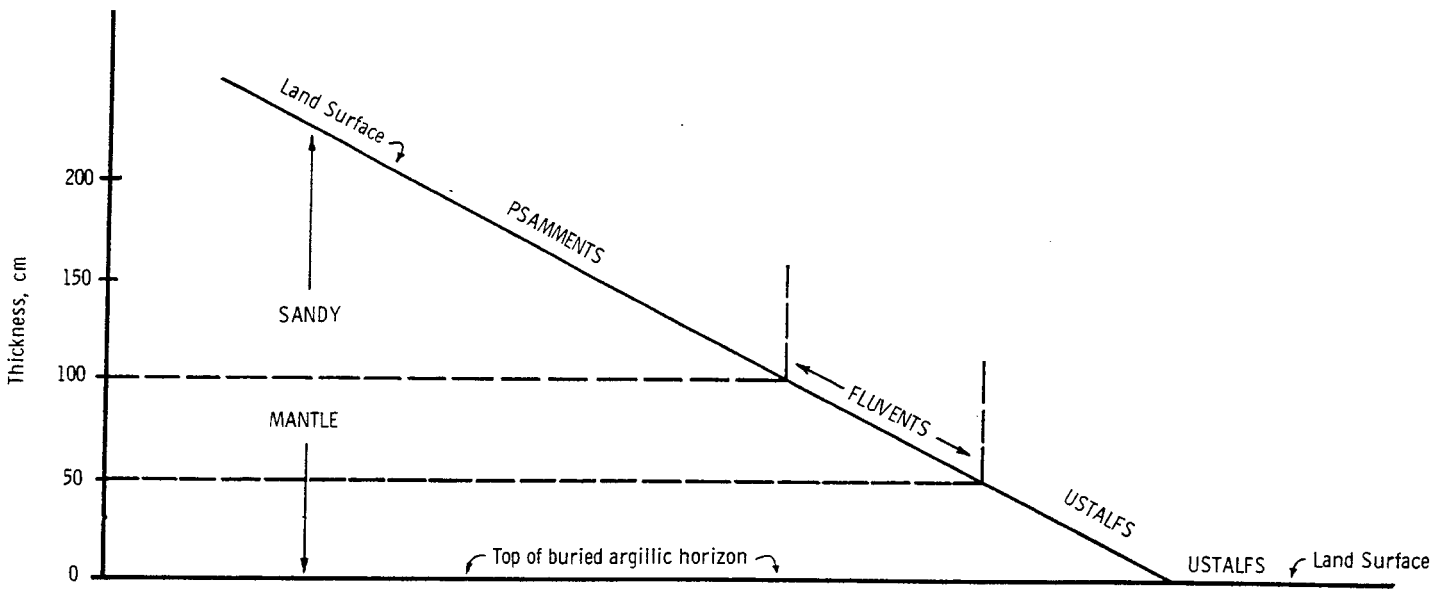


Figure 26. Diagram illustrating the suborder transition from Psamments to Ustalfs with the thinning of young sandy sediments that lack a diagnostic horizon.

The second way that Fluvents occur in the study area consists of deposits of gully-derived alluvium that overlie buried soils. Most of the alluvium is less than about four decades old; commonly the A horizons of the buried soils have been preserved (see Site 37). However, in most places the alluvium is less than 50 cm thick, in which case the buried soil is classified as the land-surface soil as discussed earlier (a phase could be used if desired, as cited in the previous section).

Typic Ustipsamments and Alfic Ustipsamments are the dominant Entisols in thick deposits. The Alfic Ustipsamments have clay bands, or lamellae, but they are too thin or too few to meet the requirements of the argillic horizon (Soil Survey Staff, 1975). Since the word lamellae is plural, the interpretation is that more than one is required for the Alfic Ustipsamments. In this study, therefore, soils designated Alfic Ustipsamments have two or more clay bands that are continuous enough to meet the requirements of the polypedon (>1 m^2; Soil Survey Staff, 1975). The clay bands are diagnostic for the Alfic Ustipsamments if they are within 1.5 m of the soil surface (Soil Survey Staff, 1975, p. 207). However, horizons with clay bands are not one of the formally defined diagnostic horizons (Soil Survey Staff, 1975, p. 14-47), and a mantle of new material above a soil with clay bands would not be distinguished for classification purposes in Soil Taxonomy. But in this study, horizons with clay bands are considered to be diagnostic for the purpose of recognizing buried soils with clay bands. Soil with clay bands are classified as Alfic Ustipsamments if the soils are at the land surface or if they are buried by a mantle of new material >50 cm thick.

ALFISOLS

Alfisols have argillic horizons (Soil Survey Staff, 1975). As discussed in Chapter 2, the transition between Entisols and Alfisols is marked, first, by the development of discontinuous clay bands, in Muleshoe sediments; second, by the formation of continuous bands and sporadic development of the argillic horizon and the Alfisols, in Longview sediments; and, third, by continuous occurrence of the argillic horizon and the Alfisols at stable sites in Birdwell sediments. All of the Alfisols, even the oldest ones, are Haplustalfs because the argillic horizons do not meet the requirements of Paleustalfs as discussed later.

The Ustalfs are the mostly reddish Alfisols of warm subhumid to semiarid regions (Soil Survey Staff, 1975). In the study area, the Ustalfs are in a semiarid region that borders and is transitional to Aridisols in drier areas to the west. Thus, the Ustalfs are in Aridic subgroups (Soil Survey Staff, 1975) except for soils that have argillic horizons with sandy control sections; these are the Psammentic Haplustalfs (table 1).

Paleustalfs are the thick reddish or red Ustalfs of old surfaces (Soil Survey Staff, 1975). Soils of this area that would qualify as Paleustalfs must have both of these characteristics (Soil Survey Staff, 1975):

> (1) a clay distribution such that the percentage of clay does not decrease from its maximum amount by as much as 20 percent of that maximum throughout a depth of 1.5 m from the soil surface . . . and
>
> (2) one of more of the following in the argillic horizon:
>
> > (a) a hue redder than 10YR and chroma that is more than 4 in the matrix of at least the lower part;
> > (b) a hue that is 7.5YR or redder and a value, moist, that is less than 4 and a value, dry, that is less than 5 throughout the major part; or
> > (c) common coarse mottles that have a hue of 7.5YR or redder or chroma more than 5, or both . . .

Some Ustalfs of the study area meet color requirements of 2(a) but do not meet other requirements for the Paleustalfs. First, some soils have abundant carbonate at shallow depths; when carbonate clay is treated as silt, as it must be (Soil Survey Staff, 1975; Guy D. Smith, personal communication, January 1981), the clay decrease requirement is not met. Second, other soils have little or no carbonate but clay decreases too much with depth. Third, some Haplustalfs that at first glance might appear to qualify as Paleustalfs actually consist of buried soils that are overlain by much younger (Holocene) sediments in which an argillic horizon has formed. Such soils were not intended to be classified as Paleustalfs (Guy D. Smith, personal communication, January 1981). In this situation no C horizon material occurs between the argillic horizons of different ages (see Site 43).

MOLLISOLS

Mollisols do not occur on ridges because of runoff and because of low percentage of clay (and consequent relatively low organic carbon) in the soils. Mollisols occur only in depressions, primarily where the bordering ridges contribute runoff and thick sandy deposits are absent. These factors contribute to denser vegetation, high organic carbon and a mollic epipedon. Surficial horizons of other soils in the depressions are not quite dark enough and/or have chroma too high for a mollic epipedon. All of the Mollisols are Argiustolls. Texture of the Bt horizons is not suitable for the Paleustolls, which must have argillic horizons with one or more of the following (Soil Survey Staff, 1975):

1. A vertical clay distribution such that the clay content does not decrease by 20 percent of the maximum clay content within 1.5 m of the soil surface, and the argillic horizon has one or both of these:

    a. A hue redder than 10YR and chroma higher than 4 in the matrix; or
    b. Common coarse mottles that have a hue of 7.5YR or redder or chroma higher than 5; or

2. A particle-size class in the upper part that is clayey and an increase of at least 20 percent clay (absolute) within a vertical distance of 7.5 cm or of 15 percent clay (absolute) within 2.5 cm at the upper boundary.

In some soils of depressions, organic carbon, chroma and value requirements of the mollic epipedon are easily met (e.g., Pedons 33d, 50). But in other soils, although organic carbon is sufficient, the epipedon is barely mollic or is ochric, depending upon chroma, value and depth to carbonates (see Sites 34, 35, 48, and 49 for illustration). These factors can cause complex soil occurrence at the highest level of classification (soil order): Mollisols - Alfisols - Inceptisols.

INCEPTISOLS

Minor areas of Inceptisols occur in large blowouts in the southern part of the study area. Ustochrepts occur side by side with Haplustalfs, the only difference being that the argillic horizon has been wind-truncated in the Ustochrepts but not in the Haplustalfs (Sites 51, 52). The calcic or petrocalcic horizon remains, however, and in this area is diagnostic for the Ustochrepts. Consideration could well be given to adding two new subgroups to the Ustochrepts: Calcic Ustochrepts, which would have a calcic horizon, and Petrocalcic Ustochrepts, which would have a petrocalcic horizon.

SOIL MAP

Conventions and mapping units

The study area was first explored with a hydraulic power probe to a depth of about 1.25 m, and in places with a hand auger and extensions to depths up to 7 m. Sites were then selected for detailed study and trenching; some of the trenches were later expanded to obtain additional information.

The soil map (fig. 27, tables 6, 7) has eleven mapping units. The mapping units consist of (1) soils belonging to one or more dominant series or variants (termed "dominant soils"), which occupy more than 10 percent of the map unit and are capitalized in the table of mapping unit composition, and (2) lesser proportions of other soils (termed "inclusions"), each of which occupy 10 percent or less of the mapping unit. Percentages of dominant soils are estimated to be within $\pm$ 10 percent of the figure given. The designation "variant" and a modifier have been used as a handle to designate soils that differ in an indicated characteristic from a soil defined at the series level (e.g., Newell, calcic variant, has a calcic horizon within 90 cm depth).

The mapping units are designated as texture phases, as variants, and as soil complexes. Texture phases (e.g., Tivoli fine sand) indicate the average texture of the surface layer (as used here, the upper 15 cm). In soil complexes, the dominant soils occur in such intricate patterns that they cannot be mapped separately at a scale of 1:15,840. Soils are not considered complexes if the dominant soil occupies at least 50 percent of a mapping unit and no other component occupies more than 10 percent of the unit.

Figure 27. Soil map of the study area. A = Tivoli fine sand. B = Tivoli variants. C = Circleback complex. D = Texico - Circleback complex. E = Texico fine sand. F = Texico - Farwell complex. G = Farwell variant. H = Texico complex. I = Keeney complex. J = Newell - Extee complex. K = Extee - Veal complex.

Table 6. Composition of mapping units A - E 1/

Series or variant	Subgroup	Particle-size family	Percentage of mapping unit
Unit A, Tivoli fine sand			
TIVOLI	TYPIC USTIPSAMMENTS	SANDY	80
Circleback	Alfic Ustipsamments	Sandy	10
Texico	Psammentic Haplustalfs	Sandy	5
Other inclusions (Tivoli, thin variants #1 and 2, Farwell; Keeney)			5
Unit B, Tivoli variants			
TIVOLI, THIN VARIANT #2	TYPIC USTIFLUVENTS	(SANDY, COARSE-LOAMY)	45
TIVOLI, THIN VARIANT #1	TYPIC USTIPSAMMENTS	SANDY	30
Circleback	Alfic Ustipsamments	Sandy	10
Texico	Psammentic Haplustalfs	Sandy	10
Other inclusions (Farwell,Keeney)			5
Unit C, Circleback complex			
CIRCLEBACK	ALFIC USTIPSAMMENTS	SANDY	35
TIVOLI	TYPIC USTIPSAMMENTS	SANDY	30
TEXICO	PSAMMENTIC HAPLUSTALFS	SANDY	25
Newell, sandy variant	Aridic Argiustolls	Sandy	5
Other inclusions (Farwell, Keeney, Tivoli, thin variant #1)			5
Unit D, Texico - Circleback complex			
TEXICO	PSAMMENTIC HAPLUSTALFS	SANDY	45
CIRCLEBACK	ALFIC USTIPSAMMENTS	SANDY	40
Tivoli, thin variant #1	Typic Ustipsamments	Sandy	5
Tivoli	Typic Ustipsamments	Sandy	10
Unit E, Texico fine sand			
TEXICO	PSAMMENTIC HAPLUSTALFS	SANDY	75
Farwell	Aridic Haplustalfs	Coarse-loamy	10
Circleback	Alfic Ustipsamments	Sandy	10
Other inclusions (Keeney, SND-1)			5

1/ Tivoli is an established series. Circleback is a tentative series. Other names are informal.

Table 7. Composition of mapping units F - K[1/]

Series or variant	Subgroup	Particle-size family	Percentage of mapping unit
Unit F, Texico - Farwell complex			
TEXICO	PSAMMENTIC HAPLUSTALFS	SANDY	60
FARWELL	ARIDIC HAPLUSTALFS	COARSE-LOAMY	30
Other inclusions (Keeney, Tivoli, Circleback)			10
Unit G, Farwell variant			
FARWELL, THIN VARIANT	ARIDIC HAPLUSTALFS	COARSE-LOAMY	95
Farwell	Aridic Haplustalfs	Coarse-loamy	5
Unit H, Texico complex			
TEXICO	PSAMMENTIC HAPLUSTALFS	SANDY	60
KEENEY	ARIDIC HAPLUSTALFS	FINE-LOAMY	20
Newell	Aridic Argiustolls	Fine-loamy	10
Farwell	Aridic Haplustalfs	Coarse-loamy	10
Unit I, Keeney complex			
KEENEY	ARIDIC HAPLUSTALFS	FINE-LOAMY	65
NEWELL	ARIDIC ARGIUSTOLLS	FINE-LOAMY	25
Farwell	Aridic Haplustalfs	Coarse-loamy	10
Unit J, Newell - Extee complex			
NEWELL, CALCIC VARIANT	ARIDIC ARGIUSTOLLS	FINE-LOAMY	35
NEWELL	ARIDIC ARGIUSTOLLS	FINE-LOAMY	30
EXTEE	ARIDIC HAPLUSTALFS	FINE-LOAMY	30
Other inclusions (Farwell, SND-2)			5
Unit K, Extee - Veal complex			
EXTEE	ARIDIC HAPLUSTALFS	FINE-LOAMY	40
VEAL	ARIDIC USTOCHREPTS	FINE-LOAMY	35
Newell, calcic variant	Aridic Argiustolls	Fine-loamy	10
Other inclusions (Farwell, calcic variant, Keeney, Veal, petro-calcic variant			15

1/ Tivoli and Veal are established series. Circleback is a tentative series. Other names are informal.

Table 8 gives areas of soil mapping units and individual soils. The Psammentic Haplustalf, Texico, is the most extensive soil in the study area. Although some soils are only of minor extent, their repeated occurrence in specific landscape positions indicates that their total area in all similar sandhills would be considerably greater, and underlines the significance of even these soils of lesser extent as components of the sandhill terrain.

It is of interest to compare the soil map of this study with that of the Bailey County Soil Survey (Girdner et al., 1963, sheet 18). The survey was completed before the new soil classification system (Soil Survey Staff, 1975) was adopted, thus soil classification differs from the system presently in use. It should also be stressed that the survey was made on a much smaller scale and that the mapping units covered a much larger area than mapping units of this study. Nevertheless, the comparison does illustrate the kinds of soils found in a detailed examination of parts of some mapping units in the survey.

Table 9 presents a comparison of mapping units and dominant soils from the Bailey County survey and from this study. Six mapping units of the survey cross the study area. Although no mapping unit inclusions were listed for units Sh and Tv (Girdner et al., 1963), these units showed the greatest contrast between soils indicated to be present in the survey and soils actually found. The part of mapping unit Tv (Tivoli fine sand) that crosses the study area actually contains only about 30 percent of Tivoli soils. The comparison indicates that some mapping units in the Bailey County survey should be reexamined, and that more soils should be added to descriptions of some of the mapping units.

Organization of mapping unit descriptions

Information in the mapping units is arranged as outlined below.

Table of mapping unit composition. This table lists the soils present in the mapping units (see also tables 6, 7), and approximate percentages of the soils.

Location, landscape, soil occurrence, vegetation.

Typical pedon(s), properties and ranges. This section locates information on typical pedons, properties and ranges of characteristics of dominant soils.

Study site(s). This section presents information about study sites that occur in the mapping unit and in some instances in an adjacent unit if the study trench crosses a mapping unit boundary.

The individual study sites are designated in several ways, depending upon the number of studied areas at a given location. Each site is designated first of all by number (e.g., Site 8). Most sites consist of more than one part; the components are designated a, b, c, etc. In some instances a component part was further subdivided and designated by a dash and number following the letter (e.g., Site 8c-2). The pedon that was actually described and/or sampled is designated Pedon 8c-2, for the purpose of specific reference to the small volume of soil containing the horizons that were sampled (Glossary).

Table 8. Areas of mapping units and individual soils

Map symbol	Mapping unit name	Acres	Percent of total
A	Tivoli fine sand	109	15.5
B	Tivoli variants	104	14.8
C	Circleback complex	66	9.4
D	Texico-Circleback complex	52	7.5
E	Texico fine sand	159	22.7
F	Texico-Farwell complex	84	12.0
G	Farwell variant	8	1.1
H	Texico complex	36	5.2
I	Keeney complex	9	1.3
J	Newell - Extee complex	44	6.2
K	Extee - Veal complex	30	4.3
	Total	701	100%

Individual soil	Acres	Percent of total
Circleback	81	11.5
Extee	25	3.6
Farwell	46	6.6
Farwell, thin variant	8	1.1
Keeney	13	1.8
Newell	19	2.7
Newell, calcic variant	18	2.6
Newell, sandy variant	3	0.4
Texico	247	35.2
Tivoli	112	16.0
Tivoli, thin variant #1	47	6.7
Tivoli, thin variant #2	34	4.9
Veal	11	1.6
Other inclusions (Circleback; Farwell; Farwell, calcic variant; Keeney; SND-1; SND-2; Tivoli; Tivoli, thin variants #1 and 2; Veal, petrocalcic variant)	37	5.3
Total	701	100%

Table 9. Comparison of mapping units and dominant soils of the Bailey County Soil Survey[1/] and this study

Bailey County Soil Survey		This study[2/]	
Mapping unit symbol	Dominant soil	Mapping unit symbol	Dominant soil(s)
AfA	Amarillo	G	Farwell, thin variant
AfB	Amarillo	F	Farwell Texico
Br	Brownfield	A,B,C	Circleback Tivoli Tivoli, thin variants
MkB	Mansker	K	Extee Veal
Sh	Springer	Mostly E,F; also smaller areas of B,I,J, and H	Texico Farwell Keeney Tivoli, thin variants Newell Newell, calcic variant
Tv	Tivoli	Mostly A,B,C,D, and E; also smaller areas of F,H, and I	Tivoli Tivoli, thin variants Circleback Texico Farwell Keeney Newell

1/ Girdner et al. (1963)

2/ Dominant mapping unit(s) and soil(s) that occur in indicated mapping unit of the County survey, left column, as the unit crosses the area of this study.

Abbreviations in tables of soil characteristics follow the Soil Survey Staff (1951) except for terms indicating effervescence with HCl (e = slight effervescence, es = strong effervescence; nc = noncalcareous). Intermediate hue designations indicate the closest hue, e.g., 8YR indicates that the hue is between 7.5YR and 10YR, but closer to 7.5YR than 10YR.

In Chapters 5-9 the soils are presented by increasing age of a dominant geomorphic surface. All of the mapping units contain more than one surface and age of sediment, and this must be kept in mind in assessing the chronomorphologic relationships of soils in the units.

LABORATORY METHODS

Laboratory determinations at Sites 3b, 4-7, 18c-4, 21, 22, 41, 43, and 53 were made by the National Soil Survey Laboratory. The NSSL methods of analyses (referenced in the Appendix) have been presented (Soil Conservation Service, 1972). Organic carbon determinations by the Soil and Water Testing Laboratory, New Mexico State University, were made by the Walkley-Black method. Particle size analyses of Pedon 27a were made by the Soil and Water Testing Laboratory at New Mexico State University, using the pipette method. Samples for thin sections were impregnated according to the method described by Gile (1967); the thin sections were made commercially by the National Petrographic Service Co., Houston, Texas.

Laboratory investigations at the Texas Tech University Laboratory centered primarily on particle size analyses. The analyses were undertaken to document these aspects of the study: the initial development of the argillic horizon, because of its genetic significance and because its presence distinguishes soils of the study area at the highest level of soil classification (Entisols vs. Alfisols); the character of silicate clay distribution for the wide variety of morphological expression, landscape position, and degree of landscape stability in the study area; the striking textural sequence on sides of Birdwell dunes and in adjacent depressions; and the postulated additions of sediment from dustfall during times considered to be fairly stable (i.e., between major erosive episodes).

Table 10 summarizes methods of particle-size analysis used for the various pedons. Particle-size analyses at the Texas Tech Laboratory were made by hydrometer method as follows.1/ Because the Bouyoucos method (Bouyoucos, 1962) overestimates the clay fraction (Gee and Bauder, 1979), the Simplified Day procedure was used in the initial investigations (table 10). Later it was found that a modified Bouyoucos procedure, in which a 6-hour reading instead of a 2-hour reading was taken for clay, gave results very similar to the Simplified Day method. Since the 6-hour clay reading was considerably faster, it was used during the remainder of the particle-size investigations (table 10).

Particle-size determinations for Pedon 15; for selected horizons of Pedons 47 and 50; for the caliche pit exposure south of the sandhills; and for horizons in Roosevelt sediments (see Roosevelt sediments, Chapter 3) were made by the Soil and Water Testing Laboratory at New Mexico State University, also using Bouyoucos procedure with a 6-hour reading for clay.

1/ This section written by B. L. Allen, Texas Tech University.

Table 10. Methods used for particle-size analyses

Pipette procedure	Hydrometer procedure	
	Simplified Day method	Modified Bouyoucos method (6-hour reading for clay)
Pedon nos. 3b, 4-7, 18c-4, 21, 27a, 41, 43, 53	Pedon nos. 27b-1, 28, 29, 31b, 33a, 35b, 36a, 37b, 38a, 42, 44a, 45a, 46, 55b	Pedon nos. 3g, 15, 25b, 32b, 32c, 33b, 33c, 33d, 34a, 34c, 39b, 47-50, 51a, 51b, 52a, 52b, 55a; pedons in table 2a

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.

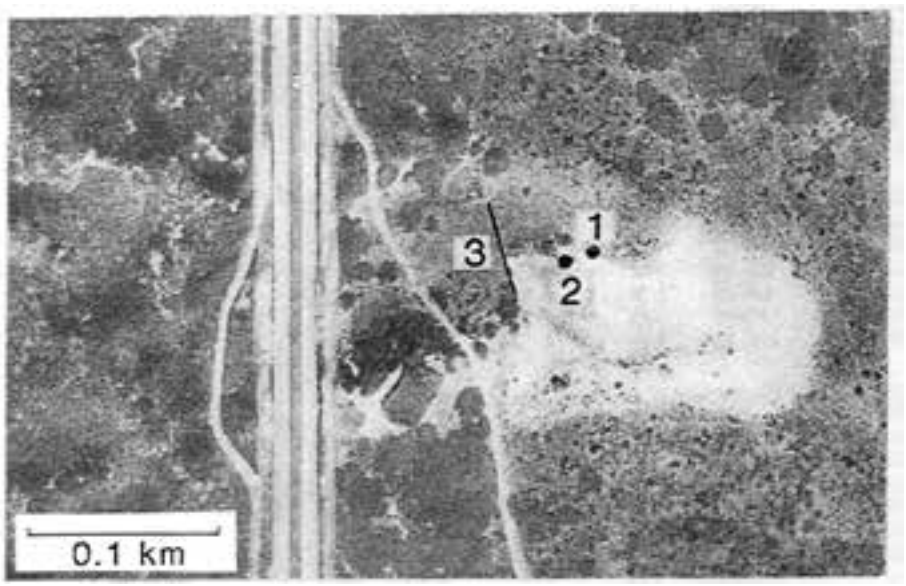


Figure 28. Location of Sites 1-3 in the active blowout (1970 photograph).

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	Texture	Structure	Dry consistence	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.

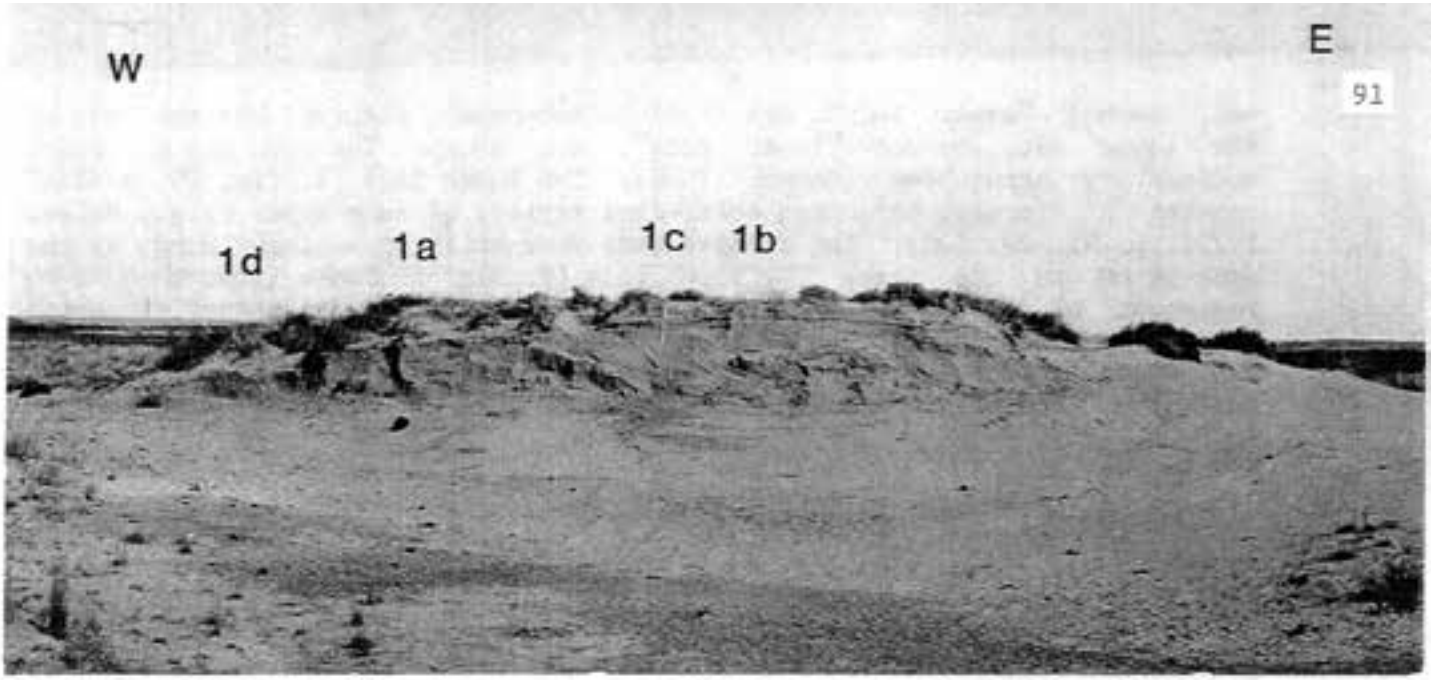
4/ A11: a few parts slightly darker. B12&Bt, B2&Bt: clay band and occasional bits of clay-enriched material colored 5YR 5/4, dry.

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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91
1d
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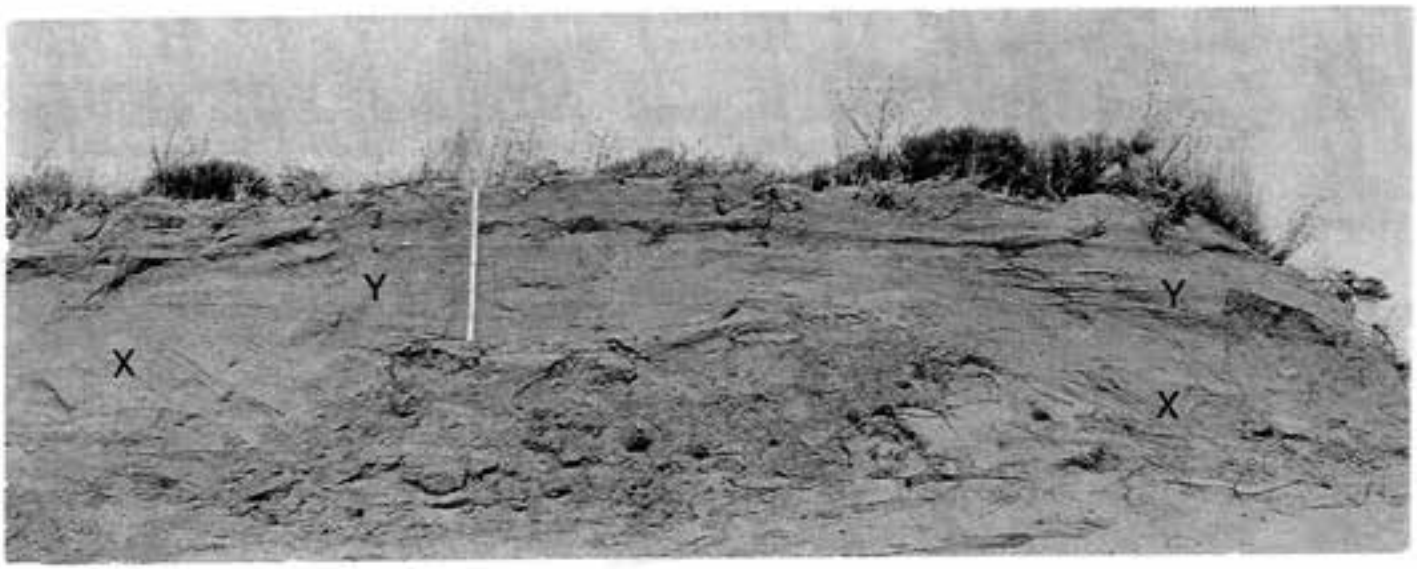

Y
X
Y
X

1

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

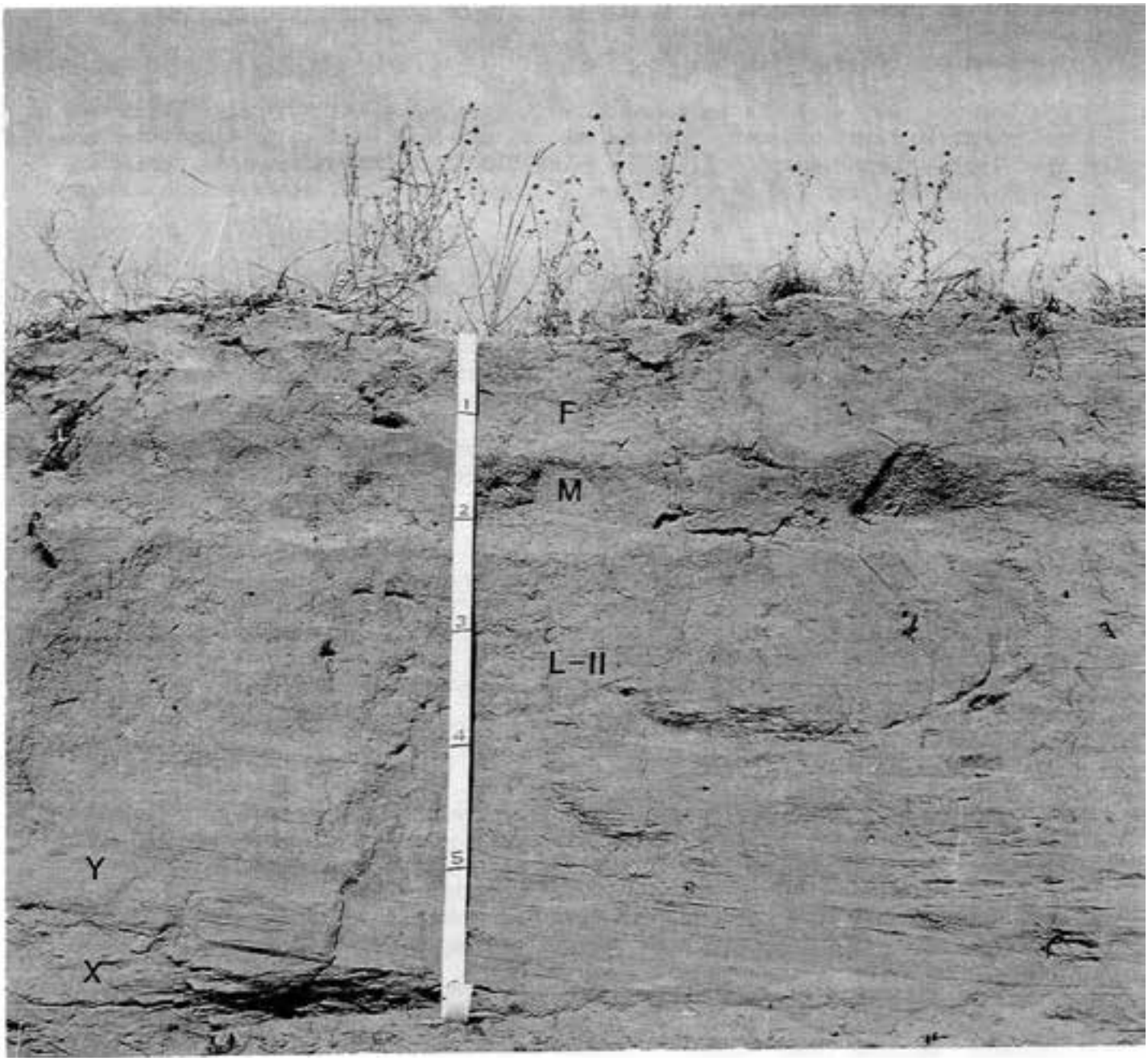


Figure 30. Closer view of Site 1b. Sediments identified as F = Fairview, M = Muleshoe, L-II = Longview II. The contact between the lower steep beds and the upper beds is at lower left. The upper beds (Y) are level or nearly level at right but increase in slope at left. Scale is in feet.

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.

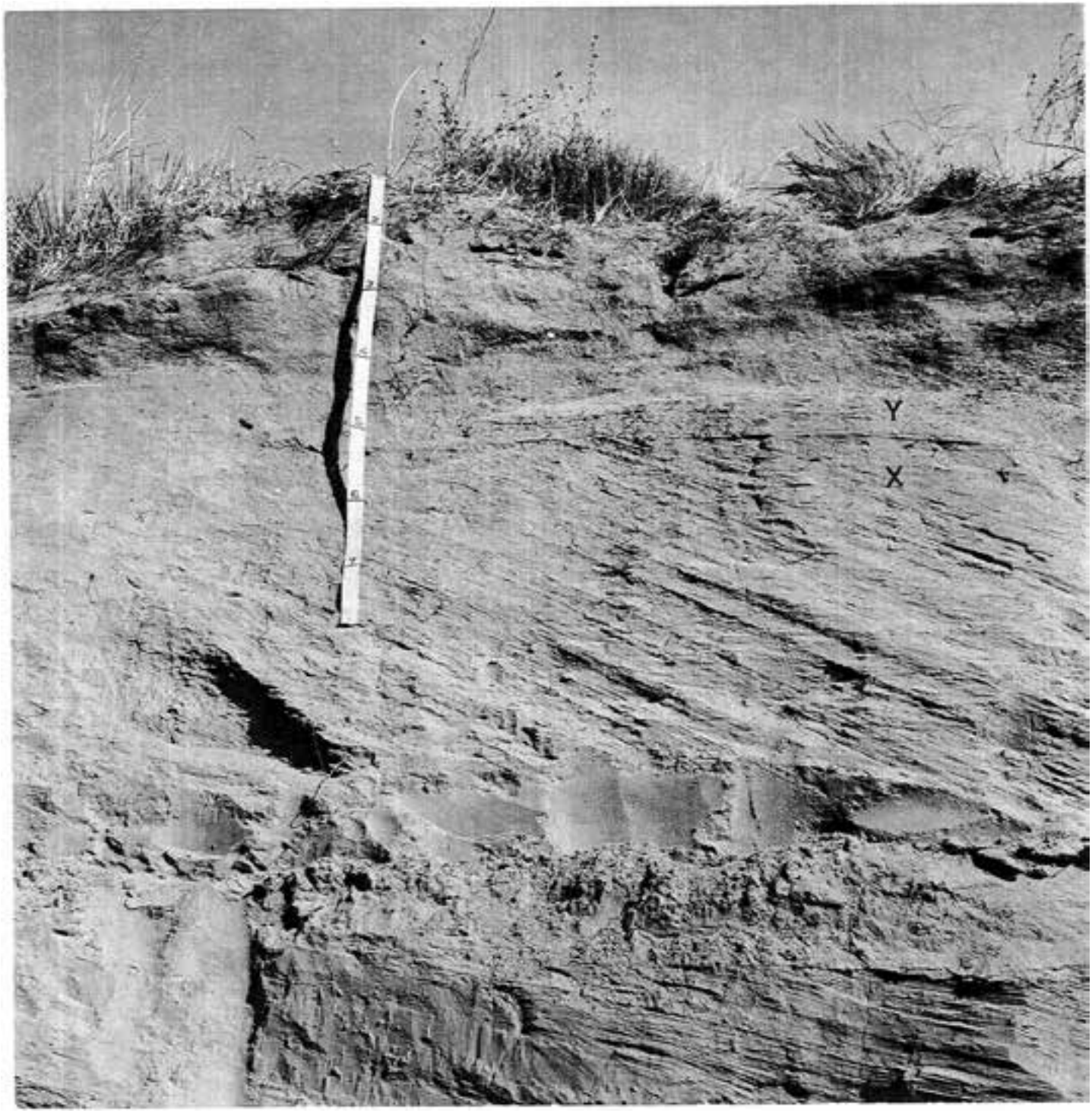


Figure 31. Site 1c. Here the land surface slopes to the west, beds slope to the east, and the contact between lower beds (X) and upper beds (Y) rises toward the surface. The clay band along the contact (just below the 5 ft mark at tape) is distinct at right of tape. But at left of tape the clay band 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.

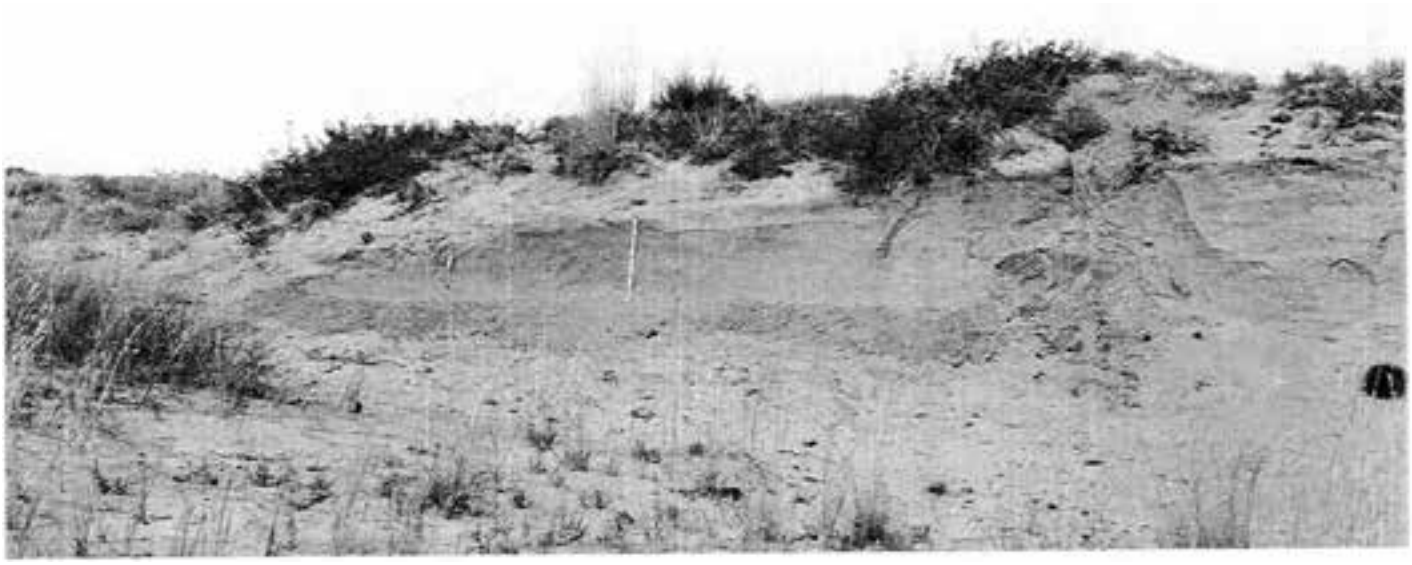
Site 1 and Site 3, to be discussed, well illustrate the effects of differing thickness of sediments and slope of sedimentary beds on clay illuviation. An important difference between Sites 1 and 3 is the much greater thickness of stratified Longview II sediments at Site 1. At Site 3, the stratified sediments 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



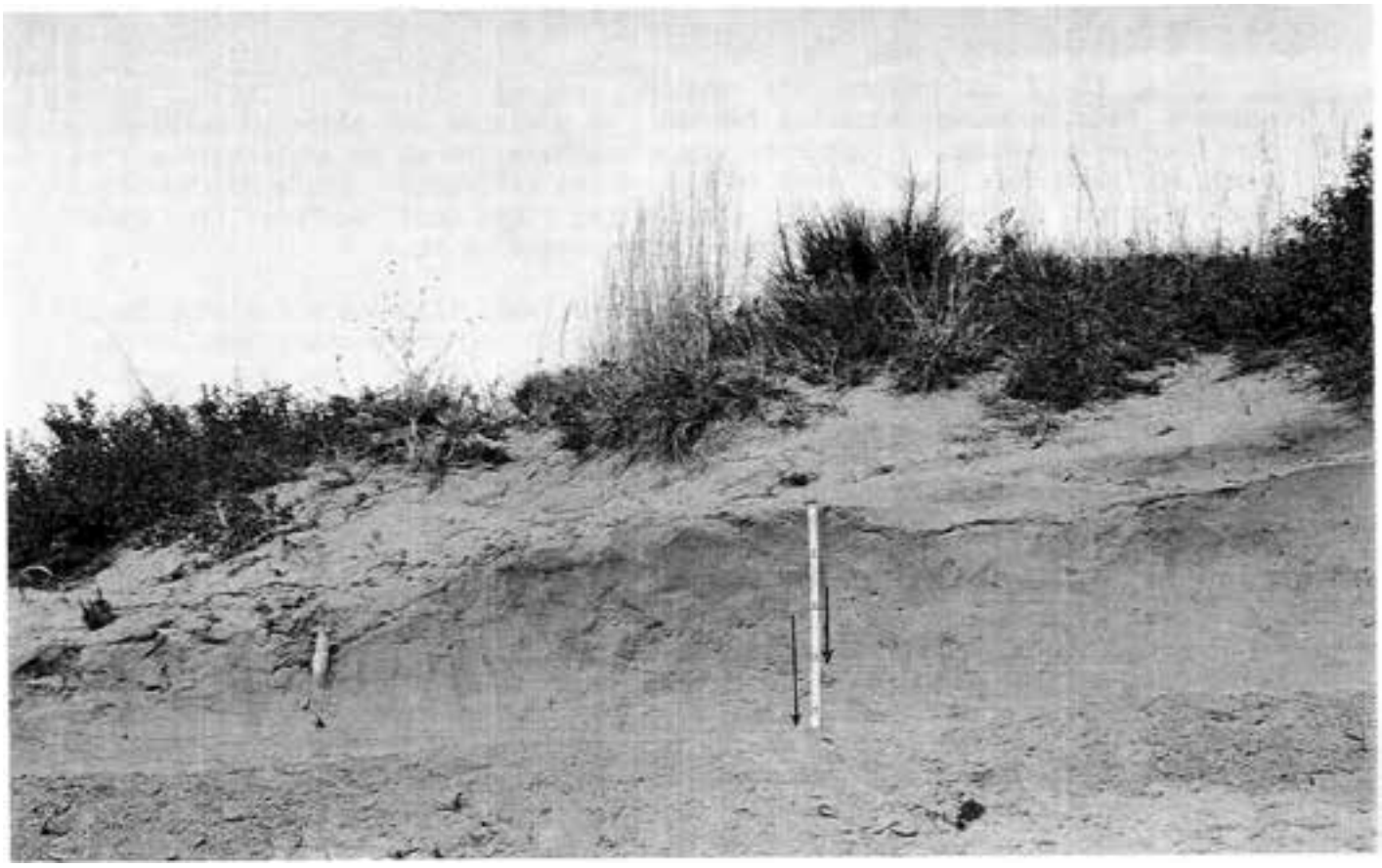


Figure 32. Upper. Landscape view of Site 1d. Fairview sediments are on the skyline except at far left. The once-buried soil of Longview II age is at the tape and crops out along the exposure, sloping downward from right to left.

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

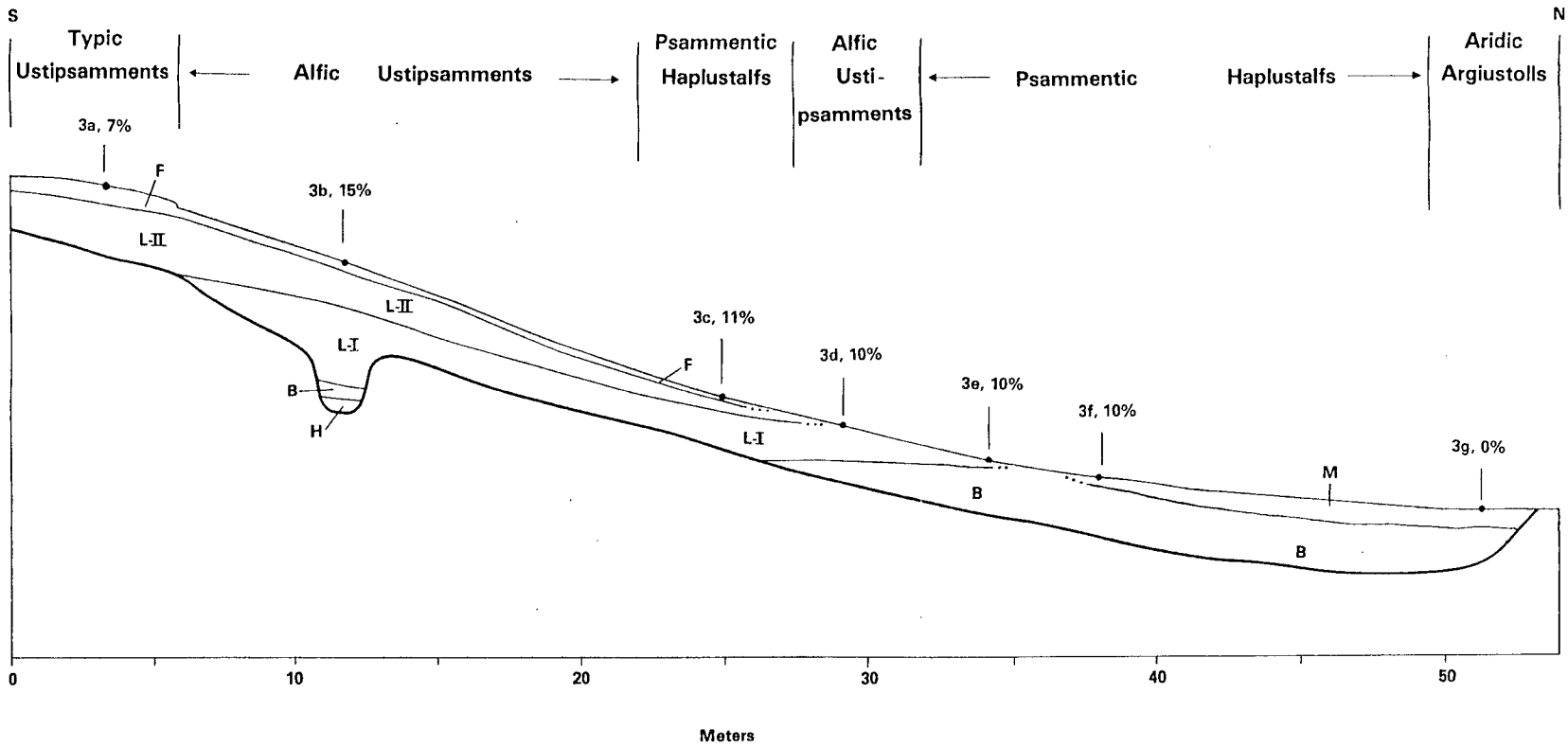
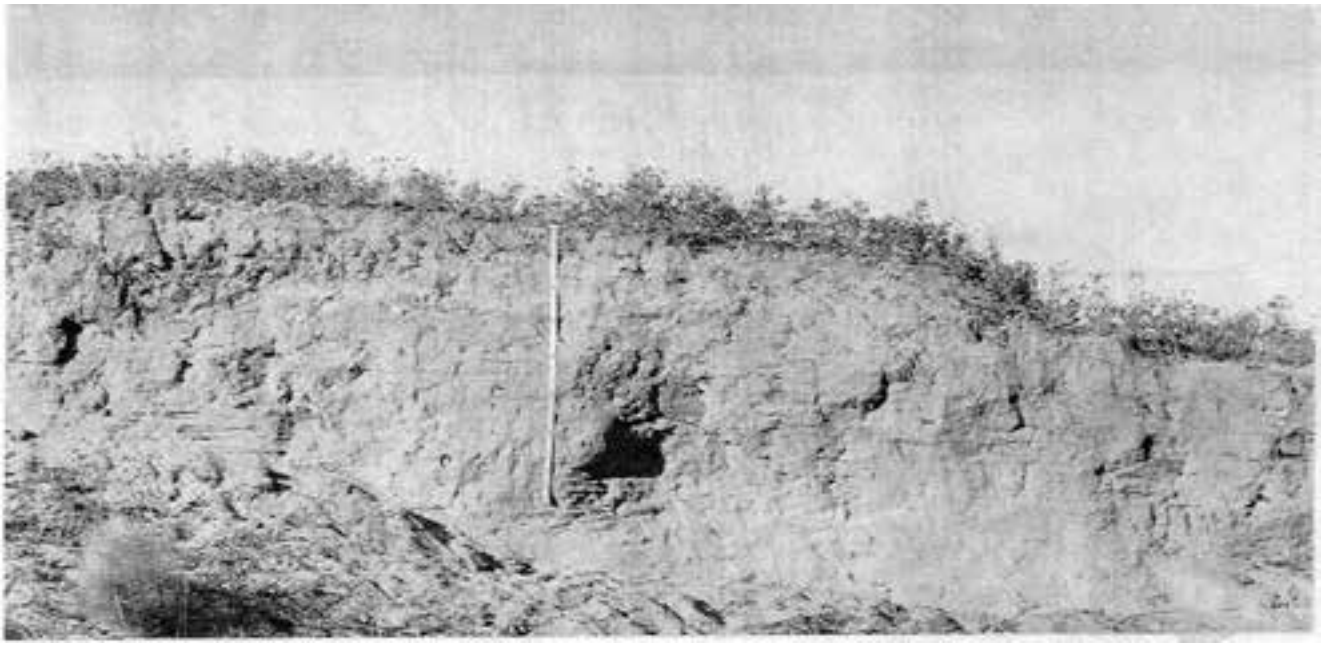


Figure 33. Diagram showing stratigraphy, soil occurrence, and the location and slope of the sampled pedons at Site 3. No vertical scale.



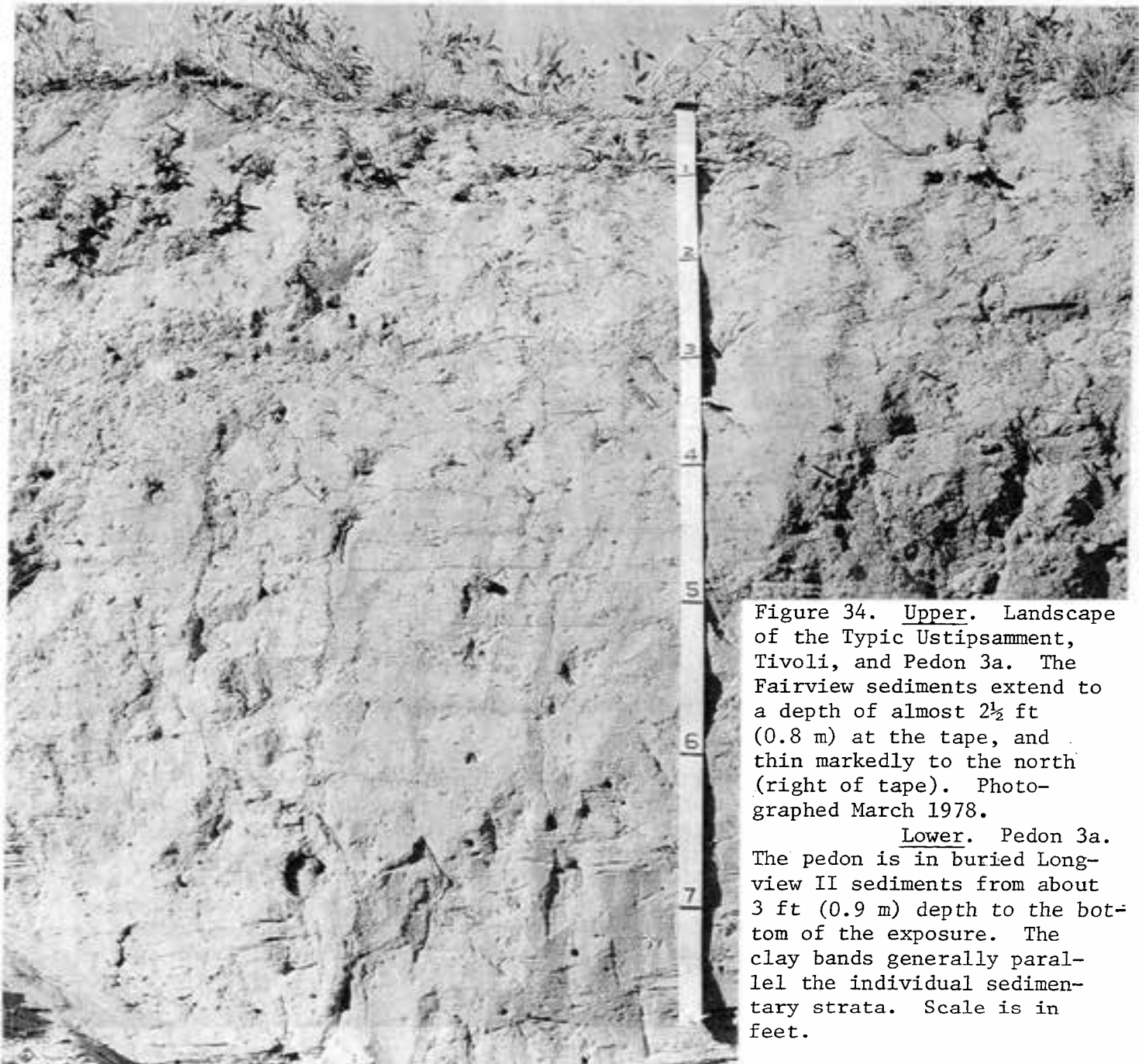


Figure 34. Upper. Landscape of the Typic Ustipsamment, Tivoli, and Pedon 3a. The Fairview sediments extend to a depth of almost 2½ ft (0.8 m) at the tape, and thin markedly to the north (right of tape). Photographed March 1978.

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/

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
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

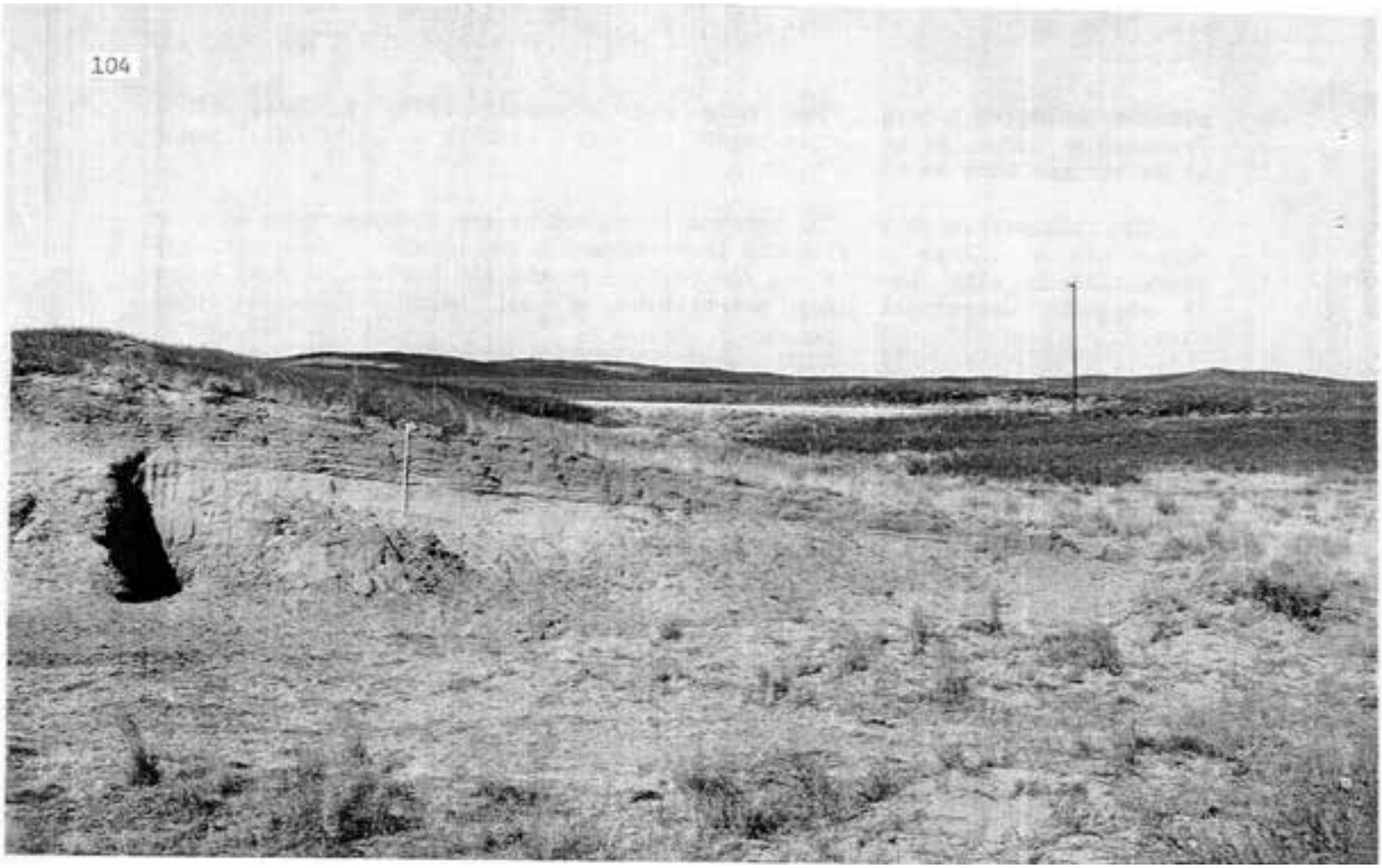


Figure 35. Photograph of the dune side at Site 3. Pedon 3b is in the trench at left. The tape at right of trench locates Figure 23, which shows the descent of clay bands from stratified to unstratified materials. Oak-covered ridges are in the background. Farm Road 1731 is at right. The view is west.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

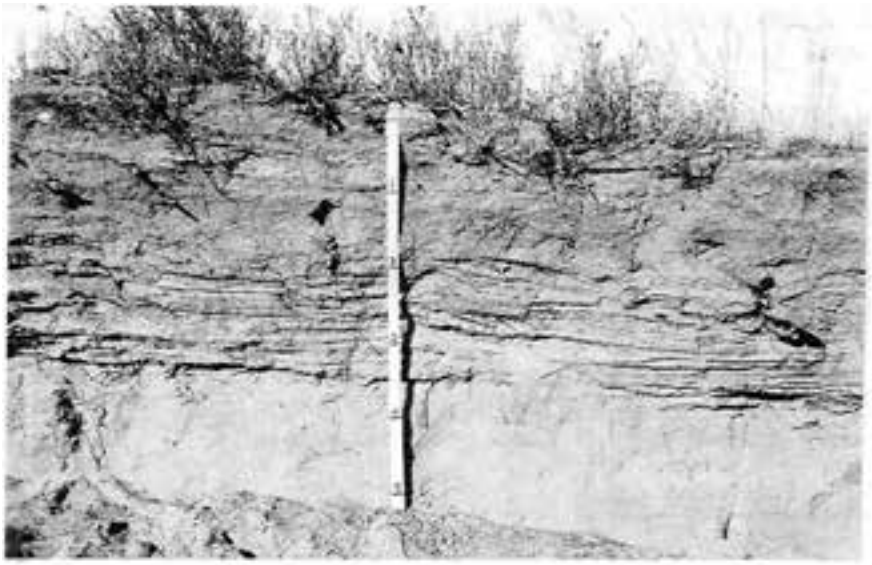
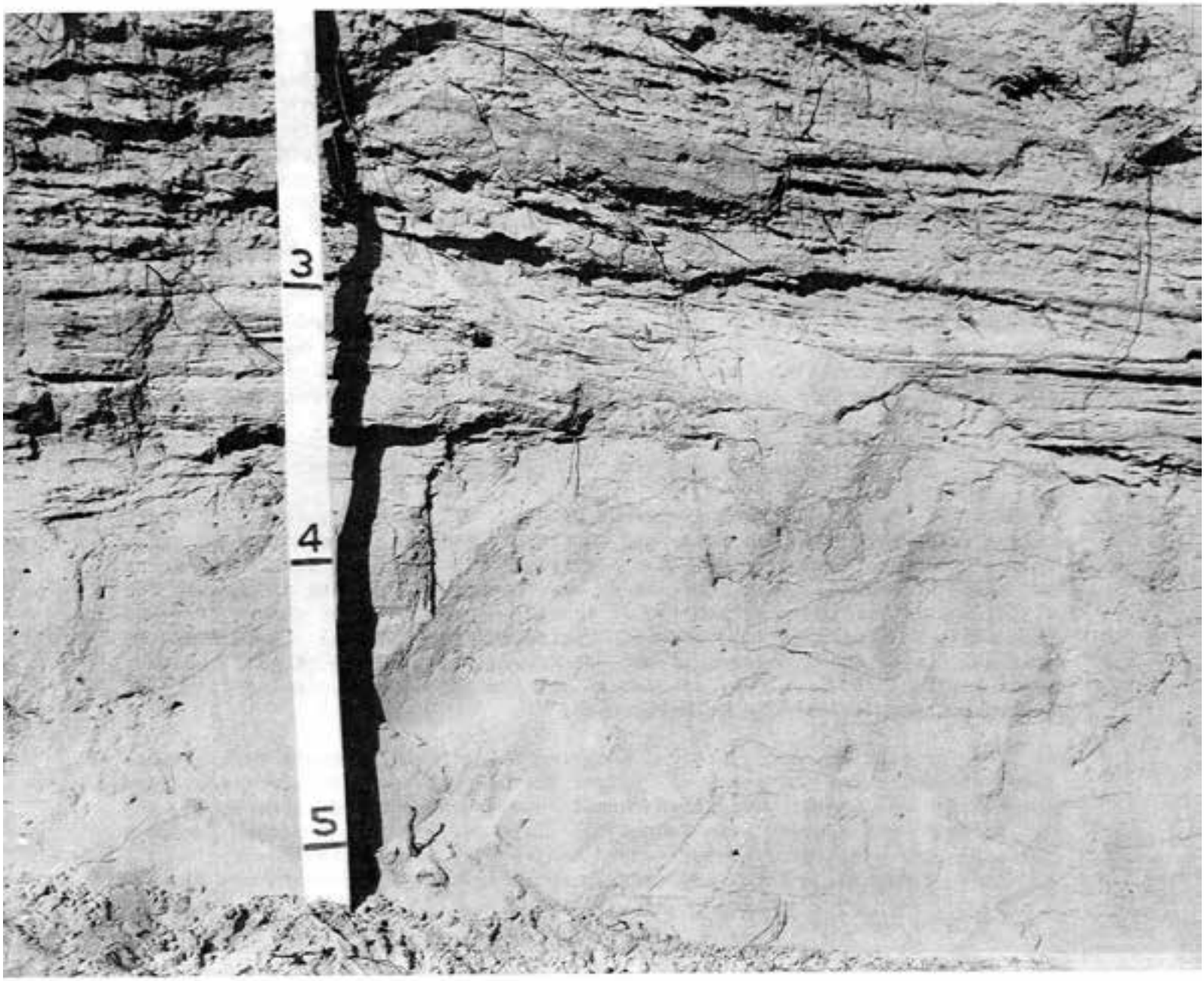


Figure 36. At left. Profile illustrating the descent of clay bands from stratified into unstratified materials.

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,

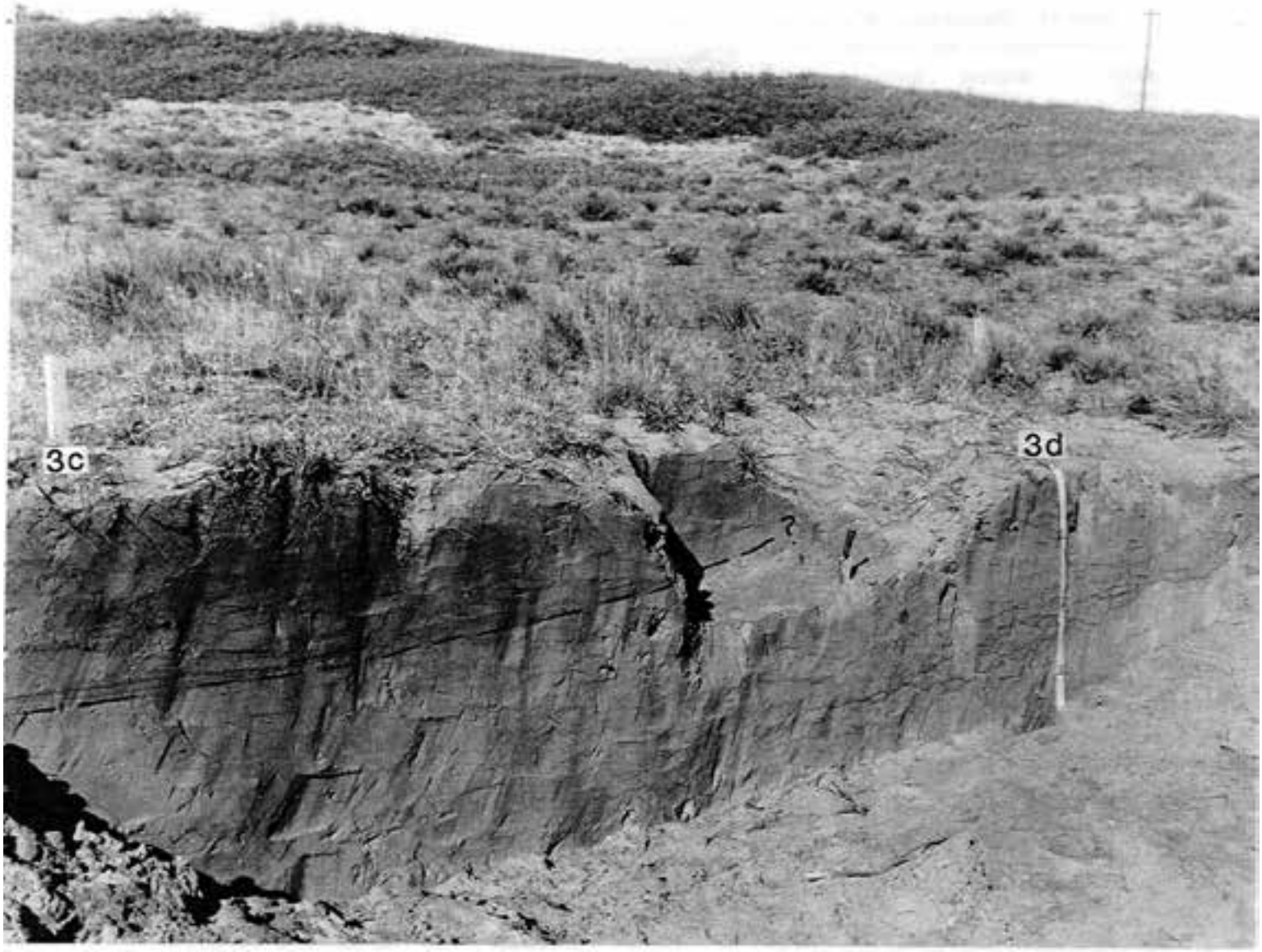


Figure 37. The study trench at Sites 3c and 3d. The dashed line locates the contact between stratified Birdwell II sediments, which grade out between 3c and 3d, and the underlying unstratified Birdwell I sediments. Note that the clay bands become more prominent at the tape, where the stratified sediments 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	1csbk	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	1fs	1csbk	vh	6.8	cw
B-I	A2b2	77-99	10YR	7/4	6/4	1fs	1csbk	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	1fs	1cpr-1csbk	h	7.0	as
	B22tb	21-36	7.5YR	5/3	4/3	1fs	1cpr-1csbk	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	1fs	1csbk	vh	7.2	cw
	B2tb2	67-80	5YR	6/4	5/4	1s	1csbk	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	1s	m	sh	6.8	cw
	B2tb	75-90	5YR	5/6	4/6	1s	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.

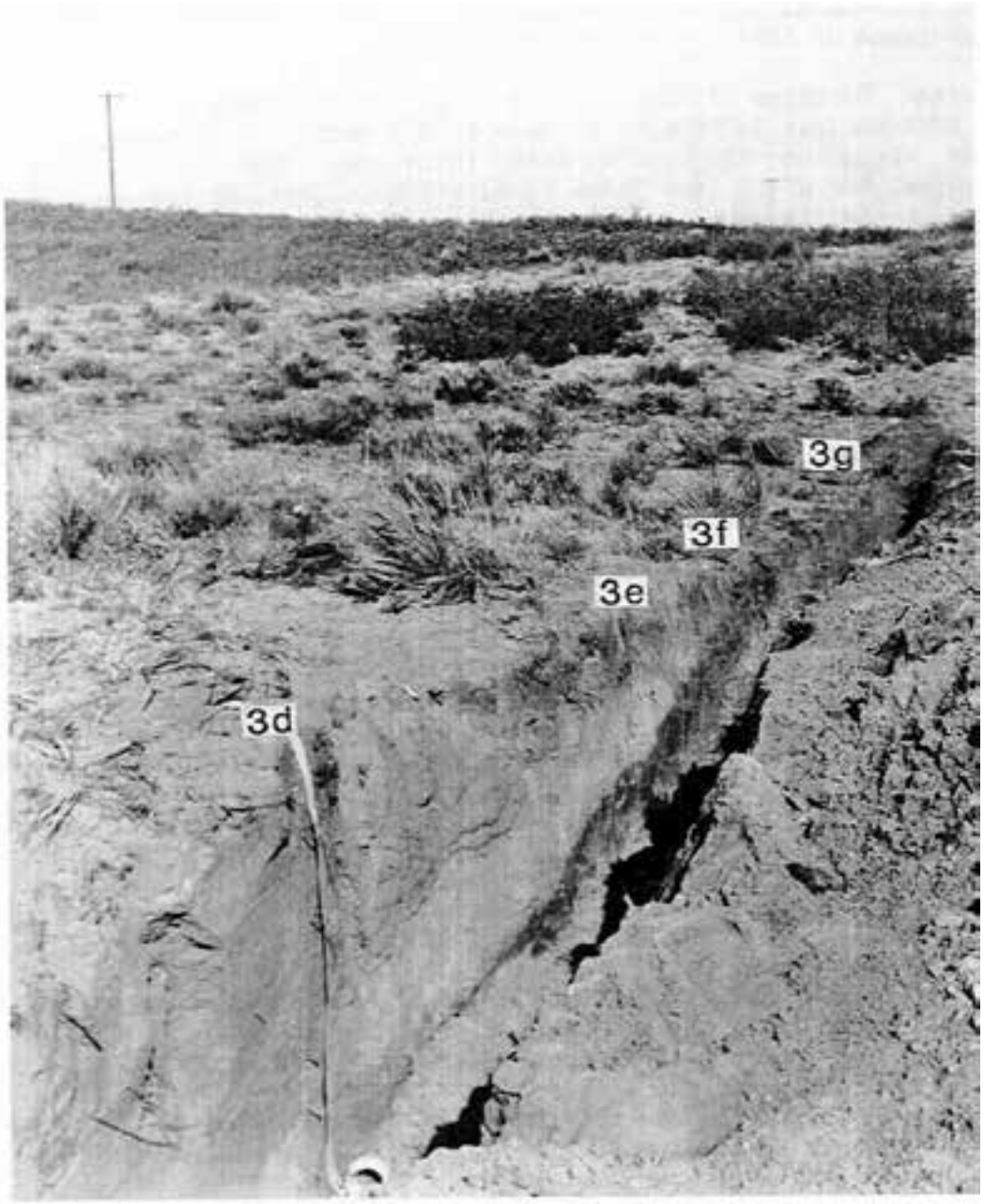


Figure 38. Sites 3d through 3g, in the study trench at Site 3. Note that clay bands between 3d and 3e disappear as they approach the surface downslope (see text discussion). Downslope the Birdwell II sediments (dark horizon near base of trench in foreground) rise toward the surface and their slope indicates 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.

CHAPTER 5. USTIPSAMMENTS AND USTIFLUVENTS OF THE MULESHOE SURFACE

The soils occur in mapping units A and B (fig. 27).

TYPIC USTIPSAMMENTS DOMINANT: MAPPING UNIT A, TIVOLI FINE SAND

MAPPING UNIT COMPOSITION

Series or variant	Subgroup	Particle-size family	Percentage of mapping unit
TIVOLI	TYPIC USTIPSAMMENTS	SANDY	80
Circleback	Alfic Ustipsamments	Sandy	10
Texico	Psammentic Haplustalfs	Sandy	5
Other inclusions (Tivoli, thin variants #1 and 2, Farwell; Keeney)			5

LOCATION, LANDSCAPE, SOIL OCCURRENCE, VEGETATION

Soils of unit A occur only in the northern part of the study area. The landscape is undulating, with common small blowouts and associated dunes. Minor areas of the unit are in troughs and on the sides of high dunes. Tivoli soils are dominant; all are of Muleshoe age. Circleback soils are in the few deposits of Longview age and also occur discontinuously in minor areas of Muleshoe sediments. Minor areas of Texico soils occur in the few deposits of Birdwell sediments. Very minor areas of Tivoli, thin variants #1 and #2; Farwell; and Keeney occur in depressions.

Vegetation observed in unit A consists of sumac, soapweed, dropseed, sand sagebrush, three-awn, prickly pear, hairy grama, little bluestem, sand bluestem, sandreed, queen's delight, and shinnery oak. The shinnery oak occurs in the western part of the unit; as noted in Chapter 1, in aerial photographs the oak appears as dark, roughly rounded areas. Sumac occurs primarily in the eastern part of the unit, and in aerial photographs shows as isolated dark spots that not only locate the sumac but that are useful for precise location in the field.

TYPICAL PEDON AND RANGES IN SELECTED PROPERTIES

Pedon 12b is a typical pedon for Tivoli, except that the A horizon is usually less red, and many pedons lack strata that occur in the lower part of the B horizon. See table 20 for characteristics of Pedon 12b. Ranges in color and texture follow; underlined entries are typical.

The A1 horizon has hue of 6YR through 10YR (7.5YR), value of 5 through 6 dry, 3 through 4.5 (4) moist, and chroma of 2 through 4 (3). It is a fine sand, except for thin (a few cm) surface horizons of loamy fine sand that occur in some depressions. If an A12 horizon is present, commonly it is 1/2 or 1 chip lighter in color than the A11. A2 horizons are present in some pedons.

The B2 horizon has hue of 5YR through 10YR, value of 5 through 7 (6) dry, 4 through 5 (4.5) moist, and chroma of 4 through 6. It is fine sand or sand.

The C horizon has hue of 5YR through 7.5YR, value of 6 through 7 (6.5) dry, 4 through 6 (5) moist, and chroma of 4 through 6. It is fine sand or sand.

These soils are always noncalcareous throughout. B horizons are weak or absent. C horizons are lacking in thin deposits with B horizons. Some pedons consist entirely of C horizon material (e.g., Site 1a).

STUDY SITES

Sites 4-7, summary

Soils of the Muleshoe surface occur in a wide variety of landscape positions as discussed in Chapter 2, but all have the youthful morphology typical of soils of Muleshoe age. All are Typic Ustipsamments except for a very few Alfic Ustipsamments (e.g., Site 6), in which there is sporadic development of enough clay bands to qualify as Alfic Ustipsamments.

The Ustipsamments at Sites 4-7 (table 14) were studied in trenches dug for sampling by the National Soil Survey Laboratory. All four pedons have a high percentage of fine sand and have A1 and A2 horizons. The A1 horizons contain more organic carbon and are darker than horizons below. The A1 horizons also contain slightly more clay than horizons of the same age beneath (table 14). This may be due to origin of the clay from dust storms, as postulated by Dan et al. (1969) for dunes in Israel. Thus some of the clay brought to earth in dry dustfall and in precipitation may be accumulating in A1 horizons faster than it can move into deeper horizons. All A1 horizons contain substantially more silt than the horizons beneath, and some of this silt may also have been derived from dustfall (Dan et al., 1969). The A1 horizons under oak also contain more very fine sand than horizons beneath, suggesting effectiveness of the mulch of oak leaves and twigs in trapping very fine sand in the dustfall.

The A2 horizons are typically lighter-colored and contain less clay than adjacent horizons, and are not as red as the underlying B horizons. The A2 horizons under oak have less clay than the A2 horizon under nonoak vegetation (table 14), suggesting that clay movement under oak may be greater than under nonoak vegetation. In the study area as a whole, A2 horizons are best developed and most common in Holocene soils that have oak vegetation. The pH values for most A2 horizons are lower than those of adjacent horizons. All four pedons have buried soils of Pleistocene age (table 14). The Bt horizons of these buried soils tend to have maximum values for bulk density and hardness (table 14). This is thought to be due to the scarcity of soil biota at the greater depths.

The pH tends to be higher in soils of middle and late Holocene age than in older soils (table 14). Apparently, leaching was more rigorous at times in the Pleistocene and in the early Holocene than at present (see also Sites 14-17). These times are thought to be associated with times of greater effective moisture than at present.

Table 15 summarizes sand and clay mineralogy for Sites 4-7 and 22. For sand mineralogy, the siliceous mineralogy class has in the 0.02 to 2 mm fraction, more than 90 percent by weight of silica minerals (quartz, chalcedony, or opal) and other extremely durable minerals that are resistant to weathering (Soil Survey Staff, 1975). All soils shown in table 15 are

Table 14. Characteristics of Ustipsamments at Sites 4-7[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 0.1-0.5	Silt 0.05-0.002	Clay < 0.002	Organic C	Ext. Fe	Bulk density	pH	Textural class	Dominant dry color
		cm	%									g/cc			
Typic Ustipsamment, Tivoli, S75TX-17-8, on side of dune: Pedon 4															
M	A1	0-12	0.3	5.9	23.6	49.6	12.5	3.9	4.2	0.44	0.2		7.1	fs	7.5YR 5/4
	A2	12-31	0.1	5.9	24.0	49.9	14.5	1.7	3.9	0.24	0.2		6.8	fs	7.5YR 6/4
	B21	31-61	tr	7.5	26.0	50.2	11.6	0.8	3.9	0.16	0.2		7.1	fs	5YR 5.5/6
	B22	61-84	tr	5.6	24.4	51.9	14.4	1.6	2.1	0.10	0.2		6.9	fs	5YR 6/6
	B31	84-112	tr	4.2	22.7	53.9	15.7	1.3	2.2	0.07	0.2		6.6	fs	6YR 6/6
	B32	112-151	tr	3.1	19.1	55.3	17.5	3.0	2.0	0.04	0.2		7.0	fs	6YR 6/6
B	B1b	151-168	tr	3.4	22.3	55.0	14.5	3.0	1.8	0.04	0.2		6.9	fs	5YR 6/4
	B21tb	168-182	0.0	2.6	14.4	46.6	16.7	5.9	13.8	0.13	0.4		6.9	fsl	5YR 5/4
	B22tb	182-206	tr	2.9	15.1	45.0	19.5	7.6	9.9	0.07	0.3		6.1	lfs	9YR 5/4
Typic Ustipsamment, Tivoli, S75TX-17-4, on side of dune: Pedon 5															
M	A1	0-11	tr	2.1	14.5	53.8	20.4	5.2	4.0	0.97	0.2		7.5	fs	10YR 4.5/2
	A2	11-20	tr	3.4	20.1	59.0	14.0	1.6	1.9	0.29	0.1		7.4	fs	9YR 5/4
	B1	20-33	tr	4.2	22.9	57.1	12.8	1.0	2.0	0.15	0.1		7.2	fs	7.5YR 6/4
	B21&Bt	33-52	0.0	2.9	23.6	59.3	11.4	1.0	1.8	0.10	0.1		6.9	fs	7.5YR 6/4
	B22&Bt	52-82	tr	3.0	22.6	59.1	12.8	0.9	1.6	0.06	0.1		7.2	fs	6YR 6/4
	B31	82-109	tr	4.8	24.2	56.1	12.0	1.2	1.7	0.08	0.1		7.1	fs	6YR 6/4
	B32	109-137	0.1	6.2	25.9	51.9	12.8	1.8	1.3	0.08	0.2		7.2	fs	6YR 6/4
L	B1b	137-165	0.0	6.2	26.7	53.1	10.1	1.4	2.5	0.07	0.2	1.69	7.3	fs	5YR 6/4
	B2b&Bt	165-198	0.1	4.9	22.7	55.4	11.1	2.3	3.5	0.06	0.2	1.71	7.5	fs	5YR 6/4
Alfic Ustipsamment, Circleback, S75TX-17-5, in trough: Pedon 6															
M	A1	0-13	0.1	7.1	20.3	46.2	16.9	6.2	3.2	0.66	0.2		7.0	s	10YR 5/3
	A2	13-39	0.1	8.4	24.1	50.5	13.3	2.5	1.1	0.13	0.1		6.9	fs	9YR 6.5/3
	B21&Bt	39-56	tr	7.0	22.6	50.9	15.0	2.6	1.9	0.08	0.1		7.3	fs	6YR 6/4
	B22&Bt	56-82	0.1	7.2	23.4	51.6	12.8	2.4	2.5	0.07	0.2	1.63	7.8	fs	6YR 6/4
	B31	82-109	0.1	5.8	20.4	50.2	17.0	3.6	2.9	0.09	0.2	1.68	7.8	fs	6YR 6/4
	B32&Bt	109-139	0.1	7.6	23.2	48.2	12.9	4.6	3.4	0.06	0.2	1.68	7.8	s	6YR 6/4
	C	139-181	tr	6.5	21.7	48.9	13.0	6.0	3.9	0.06	0.2	1.69	7.2	s	7.5YR 6/4
B	B11tb	181-208	0.1	6.3	22.7	48.8	10.7	7.1	4.3	0.14	0.2	1.71	7.3	s	10YR 6.5/3
	B12tb	208-226	0.1	5.3	22.0	45.3	10.7	8.5	4.1	0.03	0.2	1.73	7.0	s	10YR 6.5/3
	B2tb	226-247	0.2	5.7	20.4	43.6	8.9	10.7	10.7	0.07	0.4	1.84	7.2	fsl	5Y 6/1
Typic Ustipsamment, Tivoli, S75TX-17-7, on gently undulating plain: Pedon 7															
M	A1	0-11	0.2	8.1	23.5	49.2	11.9	3.8	3.3	0.52	0.2		7.0	s	10YR 5/2
	A2	11-34	0.3	9.9	25.9	50.1	11.1	1.0	1.7	0.51	0.1		7.2	fs	10YR 6.5/2
	B1	34-53	0.3	8.9	24.9	51.4	11.6	0.6	2.3	0.08	0.1		7.4	fs	10YR 7/4
	B21&Bt	53-81	0.4	8.9	25.0	50.8	10.9	1.7	2.3	0.06	0.1		7.4	fs	7.5YR 7/4
	B22	81-111	0.2	8.1	23.6	50.9	10.9	2.8	3.5	0.06	0.2		7.4	fs	7.5YR 6/4
L	B2b&Bt	111-143	0.3	10.5	27.4	49.8	7.6	1.2	3.2	0.05	0.1		7.1	s	9YR 7/4
	C1b&Bt	143-164	0.3	9.9	26.5	52.7	7.7	0.8	2.1	0.00	0.1		6.3	fs	10YR 7/3
	C2b	164-191	0.2	6.8	22.1	55.1	12.8	1.4	1.6	0.00	0.1		6.2	fs	10YR 8/3
B	Btb2	191-221	0.1	7.0	19.8	43.9	10.8	1.7	16.7	0.01	0.3	1.92	6.4	fsl	2.5Y 6/2

1/ Particle-size distribution is by method 3A1 (Soil Conservation Service, 1972); organic carbon, method 5A1a; extractable Fe, method 6C2b; bulk density, method 4A1h; pH, method 8C1a (1:1H_2O). M = Muleshoe, L = Longview, B = Birdwell.

Table 15. Sand and clay mineralogy, and resistant minerals of Pedons 4-7 and 22

	Sand[1/]				Percent resistant minerals[2/]	Clay[3/]
	Fine		Very fine			
	QZ	FD	QZ	FD		
Pedon 4 (S75TX-17-8)						
B21, 31-61 cm	94	6	85	11	93.2	MI 3, KK 2, MM 1
B21tb, 168-182 cm			83	14		MM 3, MI 3, KK 3
Pedon 5 (S75TX-17-4)						
B21&Bt, 33-52 cm	95	5	84	14	93.8	MI 3, MM 2, KK 2
B2b&Bt, 165-198 cm			90	7		MI 3, MM 2, KK 2
Pedon 6 (S75TX-17-5)						
B22&Bt, 56-82 cm	96	4	85	13	94.6	
B2tb, 226-247 cm			87	10		MM3, MI 3, KK 2, MC 1
Pedon 7 (S75TX-17-7)						
B22, 81-111 cm	93	7	85	12	92.3	MI 3, MM 2, KK 2
B2b&Bt, 111-143 cm			84	14		
Btb2, 191-221 cm			88	10		MI 3, MM 3, KK 2, MC 1
Pedon 22 (S75TX-17-6)						
B2&Bt, 66-92 cm	94	6	87	11	93.6	MI 3, MM 2, KK 2, MC 1
B32tb, 205-235			88	8		MI 3, MM 2, KK 2

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

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. Relative amounts are indicated as 3 = moderate, 2 = small, 1 = trace.

easily in the siliceous class. Some series used in this study are defined as having mixed mineralogy (table 4), but this will be corrected after enough data are obtained to be certain about occurrence of the mineralogy classes.

Clay mineralogy is very similar at Sites 4-7 and 22 (table 15). All soils have moderate or small amounts of montmorillonite-mica, mica, and kaolinite. A trace of montmorillonite-chlorite was found at Sites 6 and 7.

Site 4, east-facing side of dune

Figure 40 locates Sites 1-4, 10-21, and 27-31. The general area from the vicinity of Site 4 to the southern bounmdary of figure 40 represents a body of Muleshoe sediments derived from higher, pre-Muleshoe dunes just east of Farm Road 1731.

Site 4 (fig. 41) occurs on the side of a low dune just east of the high dune with Longview sediments at Site 30. The site occurs in the southernmost major body of Muleshoe deposits in the study area (fig. 19). The sampled pedon (S75TX-17-8), table 14) is in Soil Moisture Site 8 (Appendix).

Pedon 4 (fig. 41, table 14) illustrates one of the few A2 horizons found under nonoak vegetation. The A2 is only slightly lighter-colored than adjacent horizons. The pH is lower in the A2 than in adjacent horizons, as is typical of many A2 horizons in the study area.

The B horizon is slightly redder than adjacent horizons, and this is attributed to very slight accumulation of silicate clay. Although the color difference is small, it is genetically significant because it is a pedogenic feature related to soil age. The redder horizon is in the same general zone that, in some soils of Muleshoe age, is occupied by discontinuous clay bands. Distinct crotovinas are present at the right of the tape (fig. 41).

Although no clay bands were present in the sampled pedon, the sampling trench illustrates the sporadic development of clay bands that occurs in many soils of Muleshoe age. On the east end of the trench, discontinuous clay bands 1-2 mm thick occur at 41, 46, 51, and 53 cm depths; two thinner ones are at depths of 64 and 69 cm.

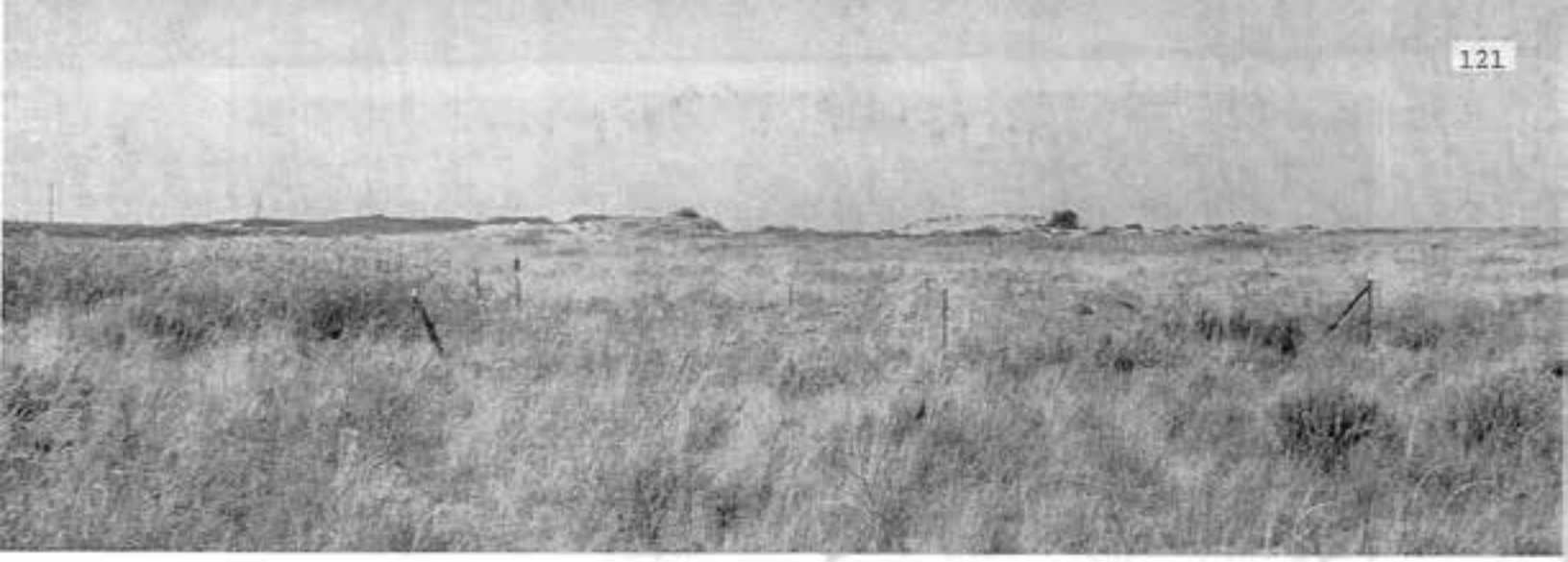
Site 5, north-facing side of dune

Site 5 (figs. 42, 43) is on the north-facing side of a high dune that, as shown in the roadcut just north, also contains sediments of Longview, Birdwell, and Hale age. The site occurs in a belt of Muleshoe sediments emplaced along the side (and discontinuously on the top) of the high dune complex just north. Slope at Site 5 is 3 percent to the south.

The sampled pedon (S75TX-17-4, table 14) is in a soil moisture exclosure at Soil Moisture Site 4 (Appendix). The B1 horizon has a mixed-appearing fabric, dominated by brownish material but also having lighter-colored crotovinas occurring as roughly circular to cylindrical shapes in cross section, and ranging from 2 to 10 cm in diameter. These are thought to represent former root channels, as discussed earlier at Site 1.

The B2&Bt horizon illustrates sporadic occurrence of discontinuous clay bands. The B21&Bt horizon has one discontinuous clay band, 5YR 6/6 dry,

Figure 40. Location of Sites 1-4, 10-21, and 27-31. Farm Road 1731 is at left. 1970 aerial photograph.



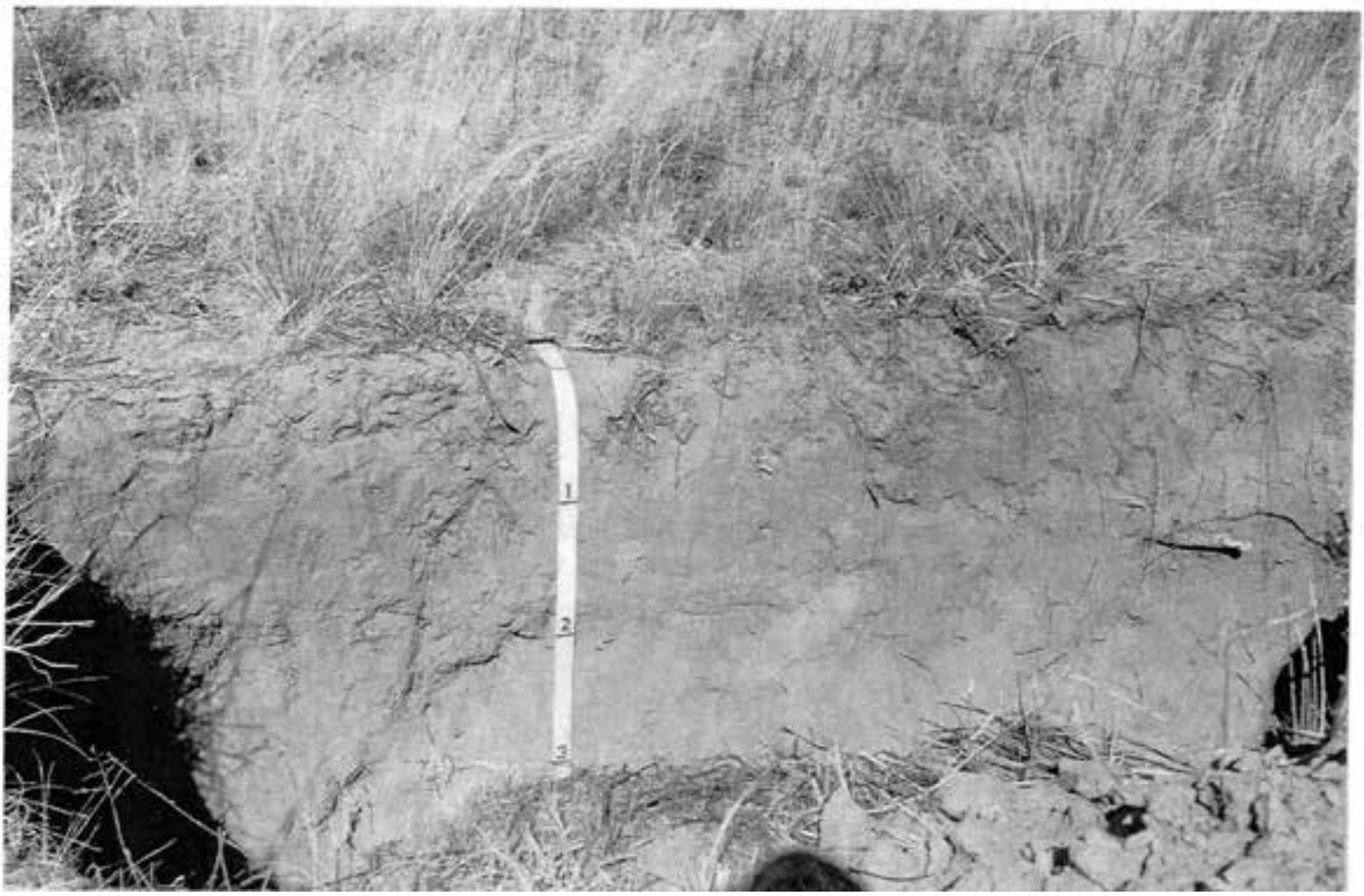


Figure 41. Upper. Landscape of the Muleshoe surface and Tivoli soils at Site 4. Farm Road 1731 is at left; the high dune at Site 1 is on the skyline at right center. The fenced exclosure for Soil Moisture Site 8 (Appendix) is in the foreground. The view is north. Photographed November 1975.

Lower. The Typic Ustipsamment, Tivoli, Pedon S75TX-17-8 (table 14; Appendix). Note crotovinas at right of tape. Scale is in feet.

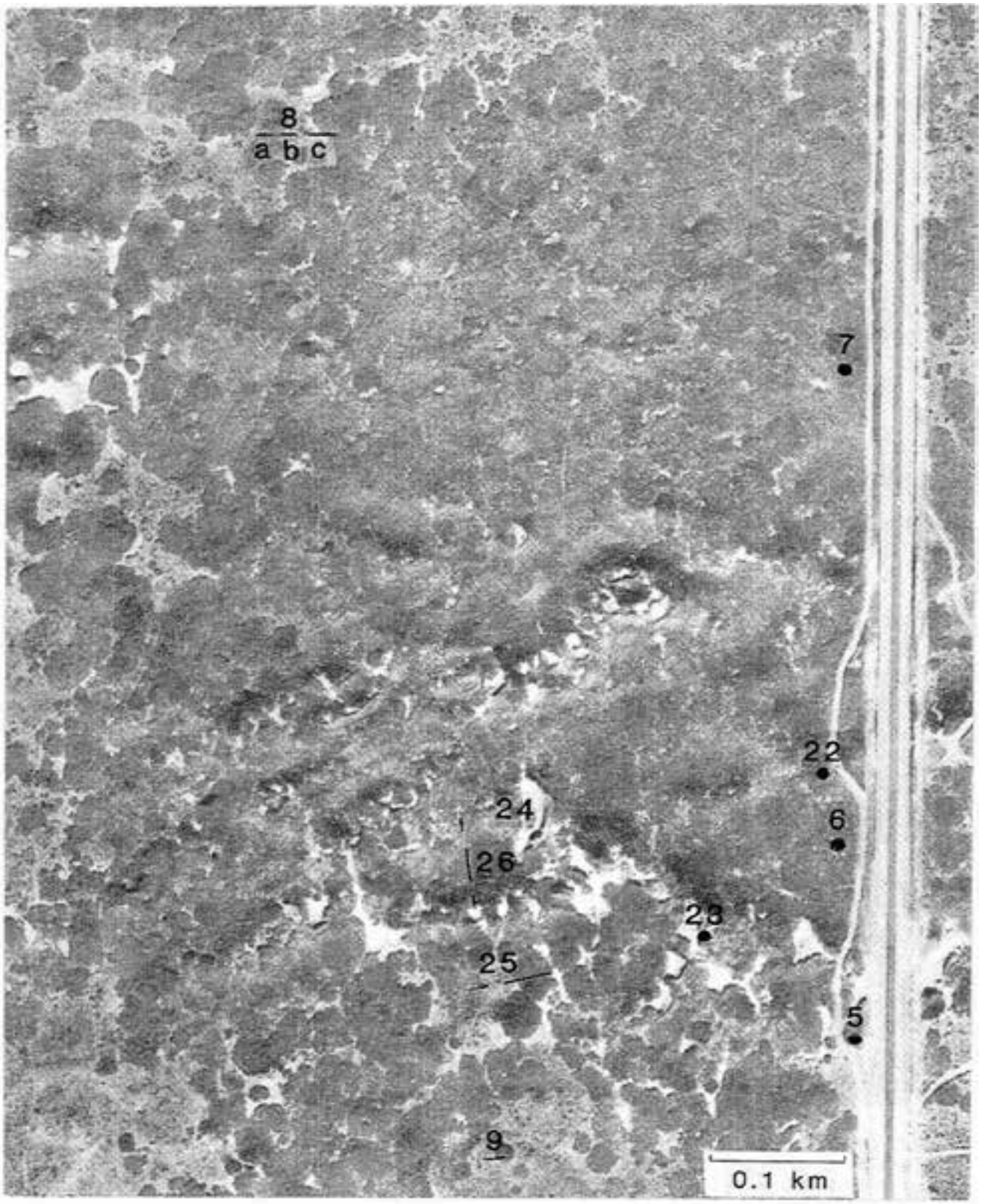


Figure 42. Location of Sites 5-9 and 22-26. Farm Road 1731 is at right. 1970 aerial photograph.

Figure 43. Landscape of the Muleshoe surface and Site 5. Arrow locates Site 5 and Soil Moisture Site 4 (Appendix). Farm Road 1731 is in the foreground. Photographed March 1981.

1 mm thick, that occurs for about 50 cm in the center of the horizon, then disappears. The B22&Bt horizon has two discontinuous clay bands about 1 mm thick and 3 to 4 mm apart. The B2b&Bt horizon, of Longview age, has six continuous clay bands, 5YR 5/6 dry, from 1 to 3 mm thick and 2 to 8 cm apart; the bands are thickest in the upper part of the horizon.

Beneath Muleshoe sediments, Pedon 5 has a buried soil of Longview age. A buried argillic horizon of Birdwell age was found with an auger at a depth of about 250 cm.

Site 6, trough

The soil and landscape at Site 6 has been illustrated (fig. 4 in Gile, 1979). Figure 44 shows the trough form of the linear depression in which Site 6 occurs.

The soil at Site 6 (table 14) has the same general stratigraphy as the soil at Site 5, but has enough continuous clay bands in Muleshoe sediments to qualify as an Alfic Ustipsamment. The B21&Bt horizon has two discontinuous and two continuous clay bands, 5YR 5/6 dry, 1 to 2 mm thick and 2 to 6 cm apart. The B22&Bt horizon has 4 to 6 clay bands, 5YR 5/6 dry, 1 to 3 mm thick and 2 to 4 cm apart.

The B32&Bt horizon has one discontinuous clay band, 5YR 5/6 dry, 1 mm thick. The individual clay bands have enough clay increase for an argillic horizon, but are too thin and too few (Soil Survey Staff, 1975) to qualify. The amount of clay for the B horizon as a whole is similar to that of the Typic Ustipsamments (table 14).

Figure 44. View of trough in which Site 6 is located. Site 6 occurs just to the left of, and beyond, the utility pole at left center. The view illustrates a typical trough between high dunes. The view is west. Photographed October 1974.

These marginal Alfic Ustipsamments in Muleshoe sediments occur in a complex pattern with the Typic Ustipsamments, with enough clay bands for qualification as Alfic in some spots but not in others. At Site 6, for example, clay bands were almost totally absent in the west end of the sampling trench. This contrasts with soils of Longview age, in which some clay bands are always continuous. Bulk density is highest in the buried soils of Pleistocene age, as is common in horizons of this texture that are largely below the zone of biotic mixing.

Site 7, gently undulating plain

The soil at Site 7 (figs. 42, 45; table 14) is on a gently undulating plain. Buried horizons of Longview and Birdwell age occur beneath Muleshoe sediments (table 14). Morphology of the soil of Muleshoe age is similar to the other soils of that age. The B21&Bt horizon in Muleshoe sediments has one discontinuous clay band, 5YR 5/4, dry, from 1/2 to 1 mm thick; it occurs as segments a few cm in length, separated by much wider zones in which the clay band is absent. The B2b&Bt horizon in Longview sediments usually has about 4 clay bands, 5YR 5/6, dry; most bands are continuous and from 2 to 3 mm thick, with one being about 1/2 cm thick. The bands are usually 5 to 6 cm apart, ranging from 4 to 12 cm apart. The C1b&Bt horizon has two continuous clay bands, 5YR 5/4, dry, about 1 mm thick and from 5 to 10 cm apart.

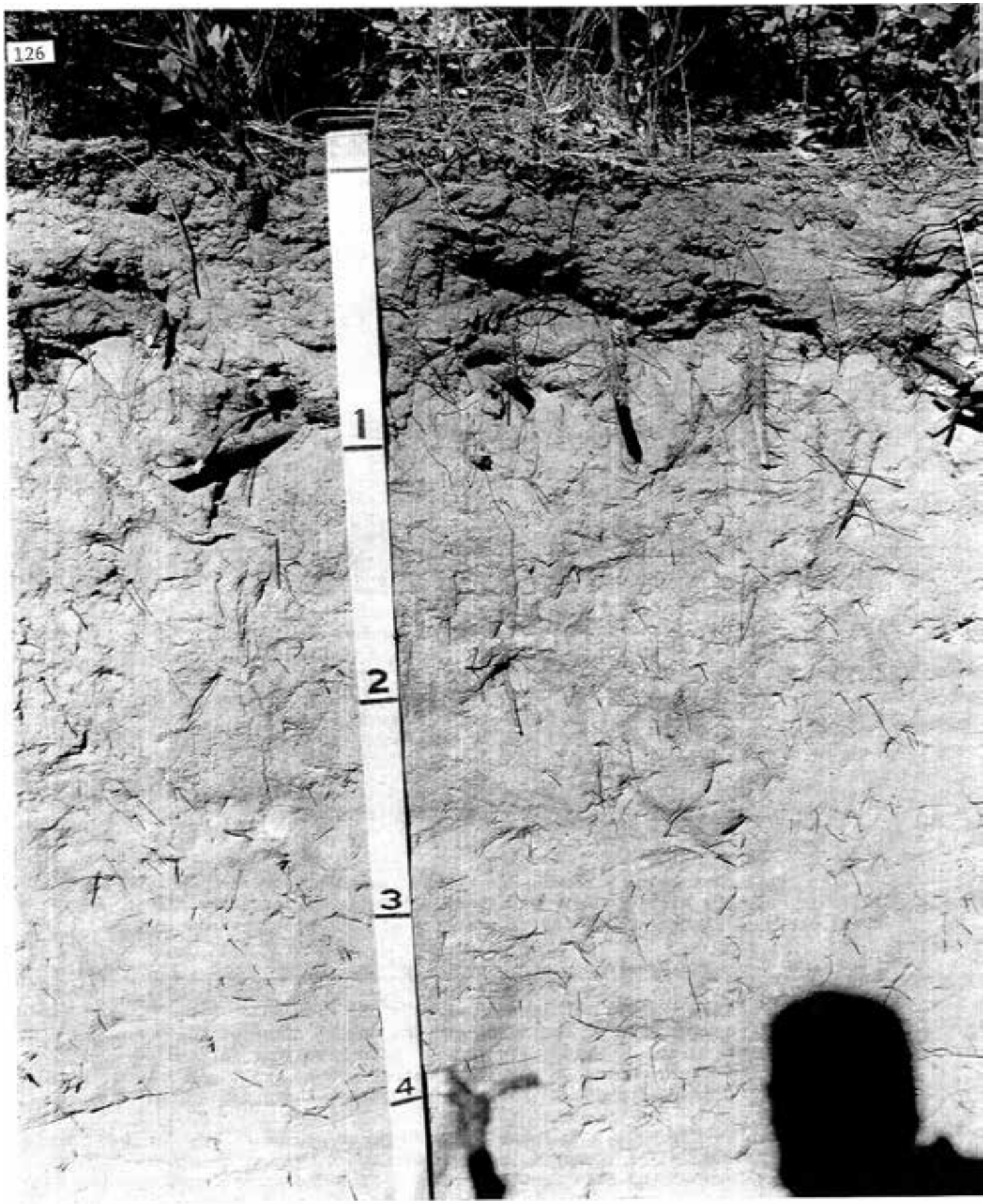
Figure 45. Above. Landscape of the Muleshoe surface and Tivoli soils at Site 7. The fenced exclosure for Soil Moisture Site 7 (Appendix) is in the foreground. The view is west. Photographed March 1981.
Overleaf. The Typic Ustipsamment, Tivoli, Pedon S75TX-17-7 (table 14; Appendix). The clay bands below a depth of 4 ft (1.2 m) are bands of a buried soil of Longview age, overlain by Muleshoe sediments and soil. Scale is in feet.

The Btb2 horizon of Birdwell age is the lowermost horizon sampled (table 14); it has the highest bulk density of all horizons measured. As at other sites, this is thought to be due to scarcity of soil biota at that depth.

Site 8, episodic development of blowout and dune; oak-nonoak transition

Site 8 (figs. 42, 46) consists of three study trenches: Site 8a, in the blowout; 8b, on the side of the dune; and 8c, on the crest of the dune. Site 8c is further divided into Site 8c-1, nonoak vegetation, and 8c-2, oak vegetation. Figure 46 shows the slope, stratigraphy, soil occurrence, and location of the sampled pedons. Table 16 gives soil characteristics.

As shown in figure 46, Muleshoe deposits occur sporadically, burying the Alfic Ustipsamments of Longview age in some areas but not in others. Thus the present form of the dune is the result of episodic sedimentation and not a single deposit. But the dune could have started to form before Longview time, as is the case at Site 18, discussed later. The sporadic burial resulted in an intricate pattern of Alfic and Typic Ustipsamments.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1
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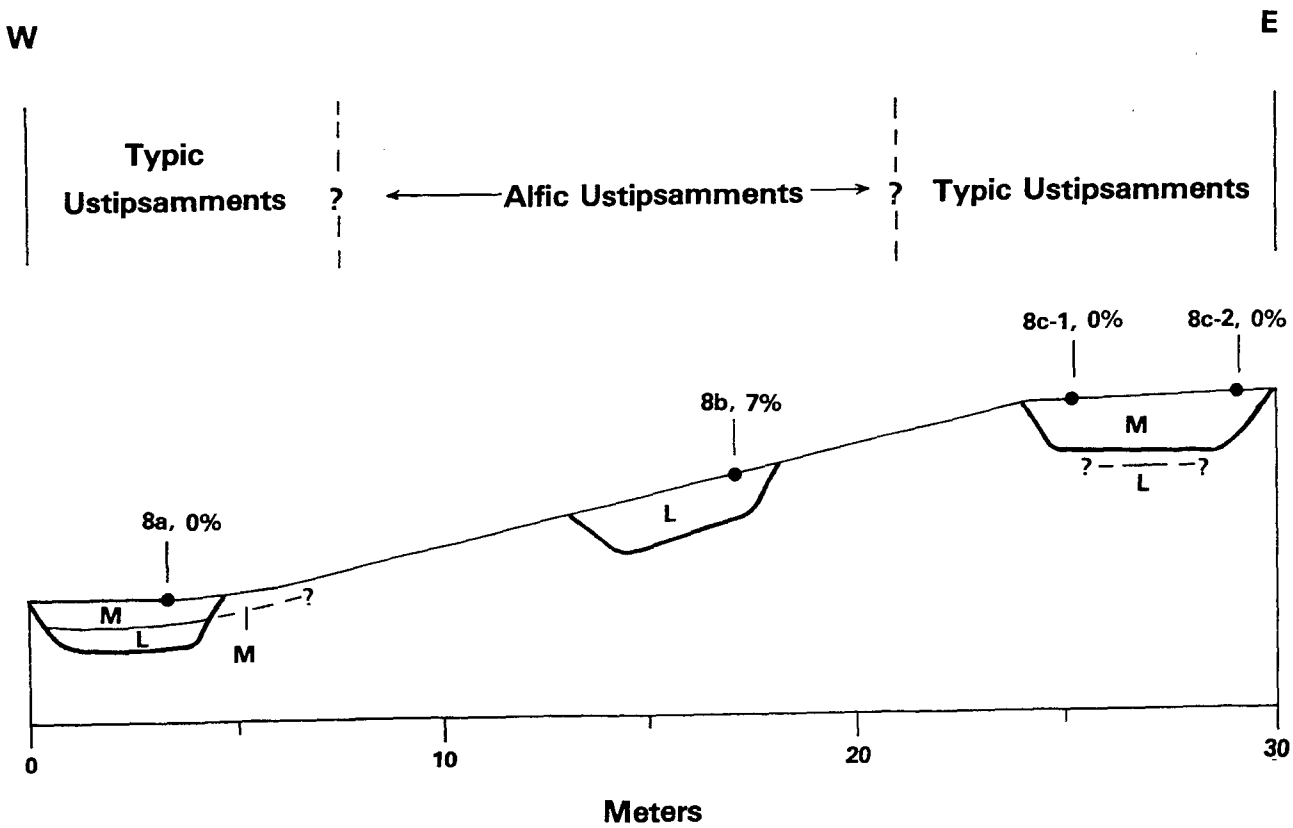
Figure 46. Above. Landscape view of the blowout and dune at Site 8, and from left to right, the three study trenches at Sites 8a, 8b and 8c. A grassy, non-oak area is in the foreground. Vegetation in the middle ground and background is dominantly oak.

Below. Diagram showing stratigraphy, soil occurrence, and the location and slope of sampled pedons at Site 8. M = Muleshoe sediments; L = Longview sediments. The heavy lower lines represent the bottom of the trenches. No vertical scale (see table 16 for thickness of sediments and soil horizons).



Site 8a, blowout

The center of the blowout (figs. 47, 48) is level, but only several meters away the land surface rises in all directions to the crest of the bordering dune. To 51 cm depth the horizons are weakly expressed and have the typical youthful appearance of Muleshoe sediments. Since the Muleshoe deposit lacks diagnostic horizons and is more than 50 cm thick, classification is based on it instead of the buried soil. Textures are coarse and diagnostic horizons are lacking to a depth of more than 1 m, and the soil is the Typic Ustipsamment, Tivoli. The A horizon is darker and thicker in the blowout than in the surrounding dune, reflecting run-in from adjacent slopes and resultant thicker vegetation. However, the epipedon is not mollic because color values are too high. Also, textures are quite coarse and analyses for similar materials elsewhere (see Site 12a) indicate that the epipedon would have too little organic carbon for mollic.

The thin surficial horizon is a loamy fine sand in contrast to fine sand beneath (table 16). Finer texture at the surface is common in Muleshoe blowouts. Silt and clay apparently have accumulated in the blowout as a result of run-in and additions from dustfall. The pH of the surface horizon is lowest of any horizons in the four soils studied. This also may be due to run-in; relatively low pH values were also found in the blowout at Site 18.

The top of the B21b&Bt horizon is a clay band that is 1 to 2 cm thick at the sample site. The band becomes diffuse and thins westward to only 1 to 2 mm thick in the west 1 m of the pit. The lower band in the B21b&Bt horizon also becomes more diffuse westward. The B22b&Bt horizon has occasional yellowish mottles and streaks and is yellower than in soils of Longview age on dunes. These colors are attributed to the high water table that existed prior to extensive pumping for irrigation (Cronin, 1969).

Site 8b, side of dune

Longview sediments, buried in the blowout, rise to the surface on the side of the dune (fig. 49). The distinct clay band horizon is typical of soils of Longview age (see Unit C), and the soil is an Alfic Ustipsamment. The soil lacks the loamy fine sand surficial horizon of the blowout (table 16).

The described pedon (fig. 49, table 16) is just left of the tape. A light-colored A2 horizon is just above the banded zone. The A2 horizon has no continuous clay bands but does contain scattered bits of material colored 5YR 5/5, dry. These are interpreted as remnants of former clay bands that were once continuous with bands to the right of the tape, where the uppermost clay band is 1-3 mm thick and is at 36 cm depth. The band is nearly continuous on the east end of the pit but only occasional segments occur on the west end; the band appears to be slowly disintegrating by biotic action and movement of soil water. The next band is at 44 cm depth and is less broken than the one above. But it also is generally not present on the west end of the pit.

The main zone of clay bands starts at 61 cm. Most of the bands range from 1/2 to 1 cm thick. There are eight well-defined bands on the east end of the pit and several less on the west end, where the upper bands are generally more discontinuous. There are no bands in the B3 horizon, but

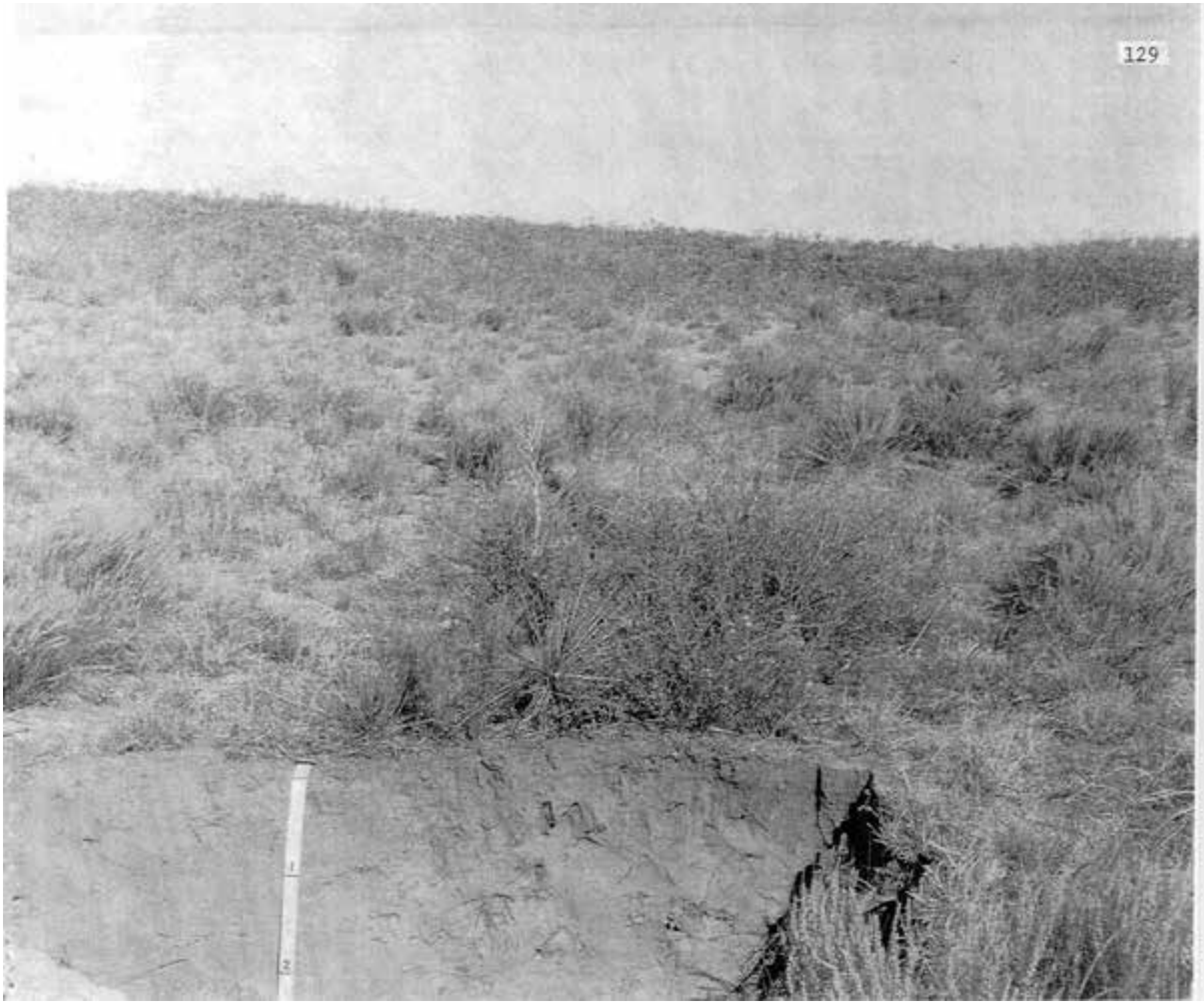


Figure 47. Above. Landscape view of Site 8a in the blowout and slopes leading to the rim on the skyline. The view is north. Scale is in feet. Photographed November 1976.

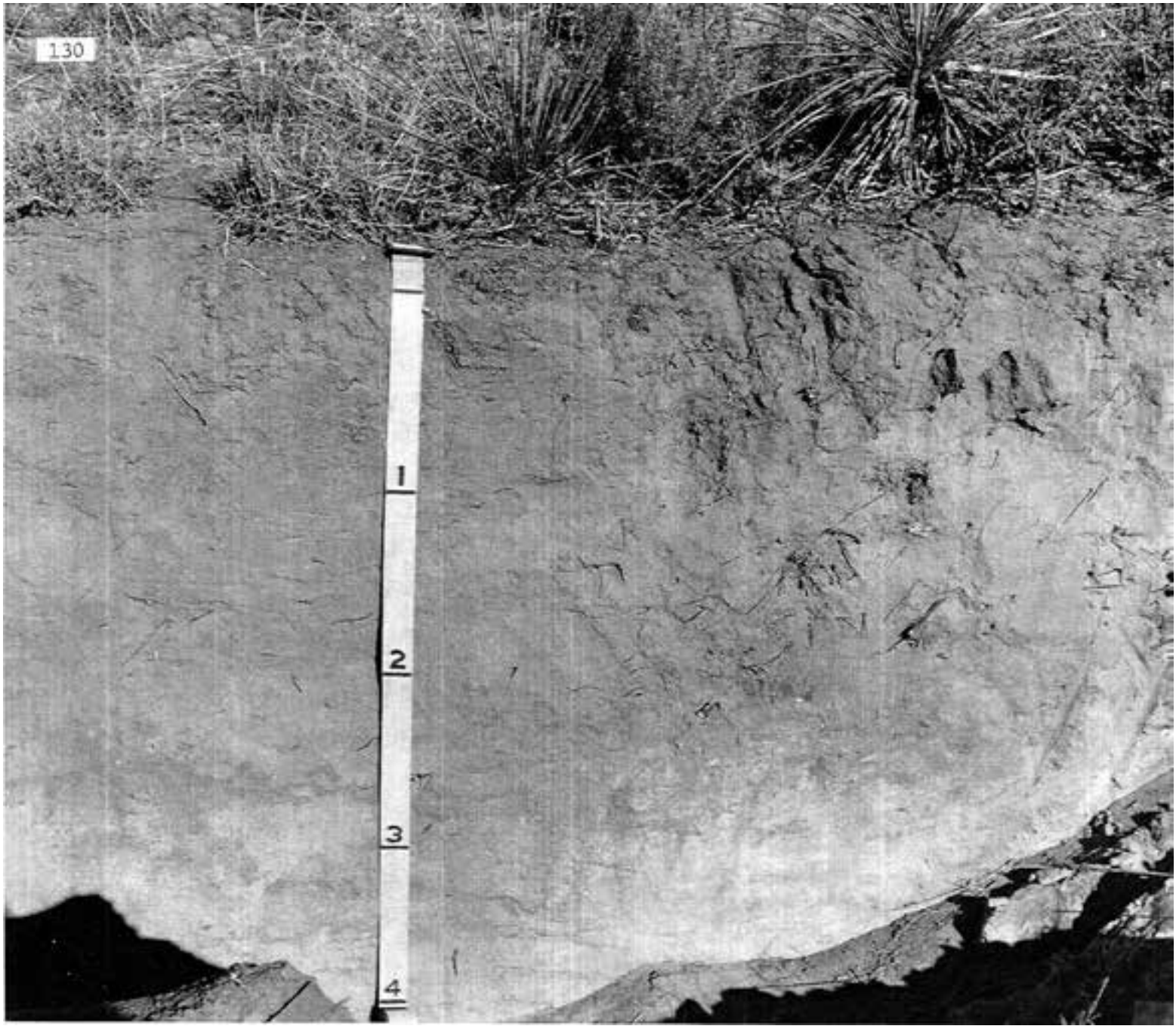


Figure 48. The Typic Ustipsamment, Tivoli, in the blowout. Muleshoe sediments extend to a depth of slightly less than 2 ft (0.6 m) and are underlain by Longview sediments with clay bands. Scale is in feet.

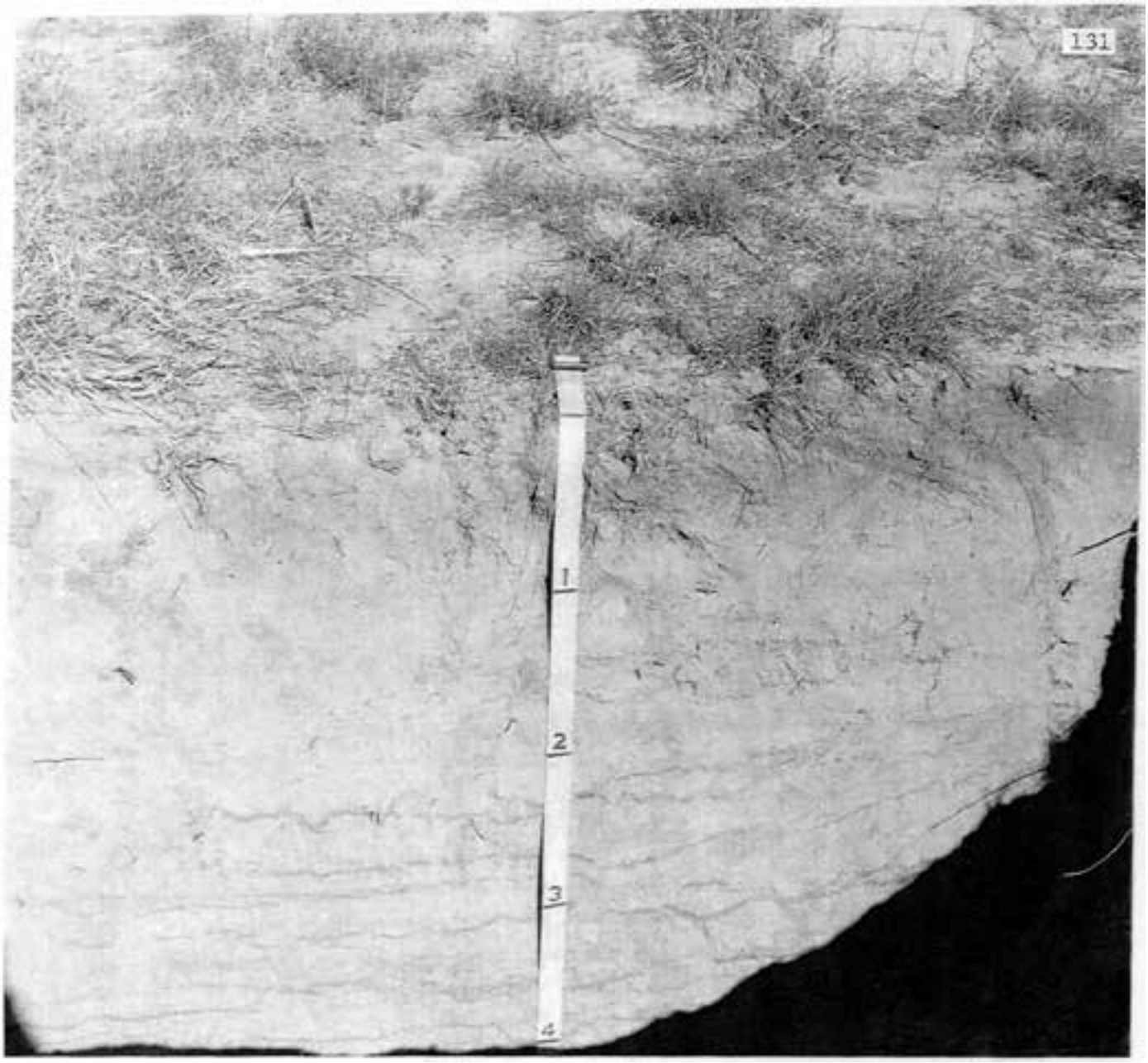


Figure 49. The Alfic Ustipsamment, Circleback. Sediments of Longview age, buried at Sites 8a and 8c, are at the surface here at Site 8b. Scale is in feet. Photographed November 1976.

Table 16. Characteristics of Ustipsamments at Site 8[1/]

Sediment	Horizon	Depth cm	Hue	Value/chroma Dry	Value/chroma Moist	Texture	Structure	Dry consistence	pH	Lower boundary
Typic Ustipsamment, Tivoli, in blowout; Pedon 8a[2/]										
Muleshoe	A11	0-5	10YR	5/2	3/2	lfs	m	s	6.2	as
	A12	5-16	10YR	5.5/2	3.5/2	fs	m	s	6.8	cw
	A13	16-39	9YR	6/4	4.5/4	fs	m	s	6.8	cw
	A14	39-59	9YR	6/3	4.5/3	fs	m	sh	6.8	cw
Longview	B1b	59-78	7.5YR	6/5	4.5/5	fs	m	sh	6.8	aw
	B21b&Bt	78-110	7.5YR	6/5	4.5/5	fs	m	sh	6.8	aw
	B22b&Bt	110-122	10YR	7/4	6/4	fs	m	h	6.8	
Alfic Ustipsamment, Circleback, on side of blowout dune; Pedon 8b[3/]										
Longview	A11	0-18	9YR	6/4	4/4	fs	m	s	6.8	cw
	A12	18-44	7.5YR	6/4	4.5/4	fs	m	sh	6.8	aw
	A2	44-61	7.5YR	7/4	5/4	fs	m	s	6.8	aw
	B21&Bt	61-88	7.5YR	6.5/4	4.5/4	s	m	sh	6.8	aw
	B22&Bt	88-118	7.5YR	6/4	4.5/4	s	m	sh	6.8	aw
	B3&Bt	118-130	7.5YR	7/4	6/4	s	m	sh,s	6.8	
Typic Ustipsamment, Tivoli, on crest of blowout dune: Pedon 8c-1 (nonoak)										
Muleshoe	A1	0-22	7.5YR	6/4	4.5/4	fs	m	s	6.8	cw
	B1	22-38	7.5YR	6/5	4.5/4	fs	m	sh	7.2	cw
	B21	38-63	7.5YR	6/5	4.5/5	fs	m	sh	6.8	cw
	B22	63-85	7.5YR	6/5	4.5/5	fs	m	sh	6.8	cw
	C	85-112	7.5YR	6.5/5	5/5	fs	m	s	6.8	cw
Typic Ustipsamment, Tivoli, on crest of blowout dune: Pedon 8c-2 (oak)										
Fairview	A1	0-11	9YR	6/4	4/4	fs	m	s	7.0	cw
Muleshoe	A1b	11-24	9YR	6/4	4.5/3	fs	m	s	6.6	cw
	A2b	24-40	8YR	6/4	4.5/4	fs	m	s	6.6	cw
	B1b	40-61	7.5YR	6/4	4.5/4	fs	m	s	6.8	cw
	B21b	61-89	7.5YR	6/5	4.5/5	fs	m	s	6.6	cw
	B22b	89-127	7.5YR	6/5	4.5/5	fs	m	sh	6.6	cw
	Cb	127-144	7.5YR	6.5/5	5/5	fs	m	sh	6.6	cw

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

2/ B21b&Bt: mottles and streaks of 7.5YR 5/4, 10YR 7/4 and 10YR 7/6, dry. B22b&Bt: mottles and streaks of 10YR 7/6, dry and clay bands 7.5YR 5/4, dry.

3/ B22&Bt: clay bands 5YR 5/4, dry. B3&Bt: also 9YR 8/2, dry.

only about 15 cm of this horizon was exposed above the bottom of the trench.

Site 8c, crest of dune

This site (fig. 50) is on the nearly level crest of the dune, where the Muleshoe sediments are thicker than in the blowout. The trench extends from a nonoak area into oak (fig. 50). All soils exposed in the trench are Typic Ustipsamments (Tivoli). The soils lack continuous clay bands and thus contrast with the Alfic Ustipsamment of Longview age only a short distance downslope (fig. 49). Augering below the trench bottom showed the Longview clay bands to be present at a depth of about 185 cm.

Pedon 8c-1 is under nonoak vegetation and has a weak B horizon, which is very slightly harder and darker than the C horizon. The B horizon also has zones that differ in color: scattered small volumes of material are slightly yellower and lighter-colored than the horizon as a whole, apparently due to faunal mixing. There is one discontinuous clay band.

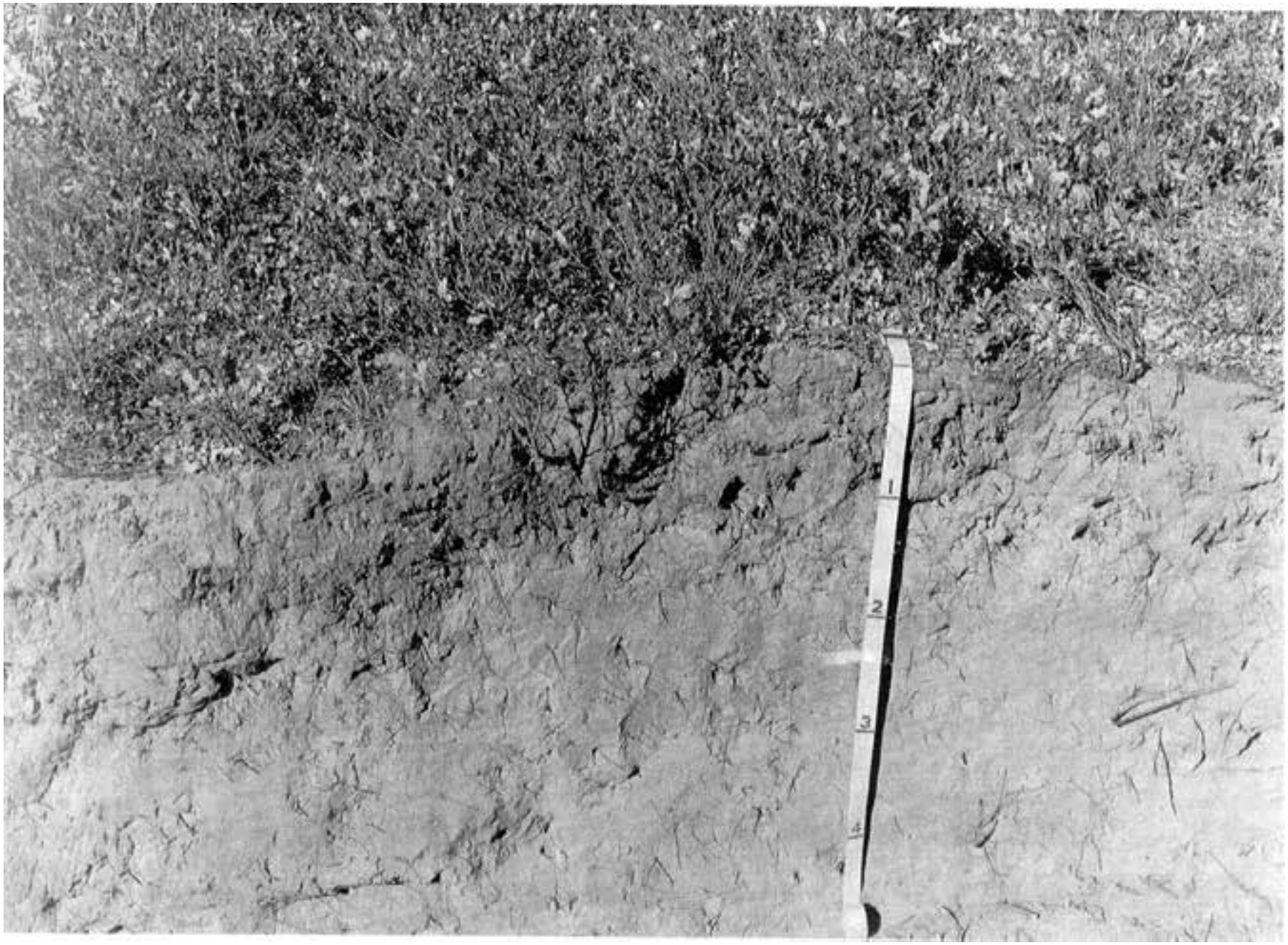
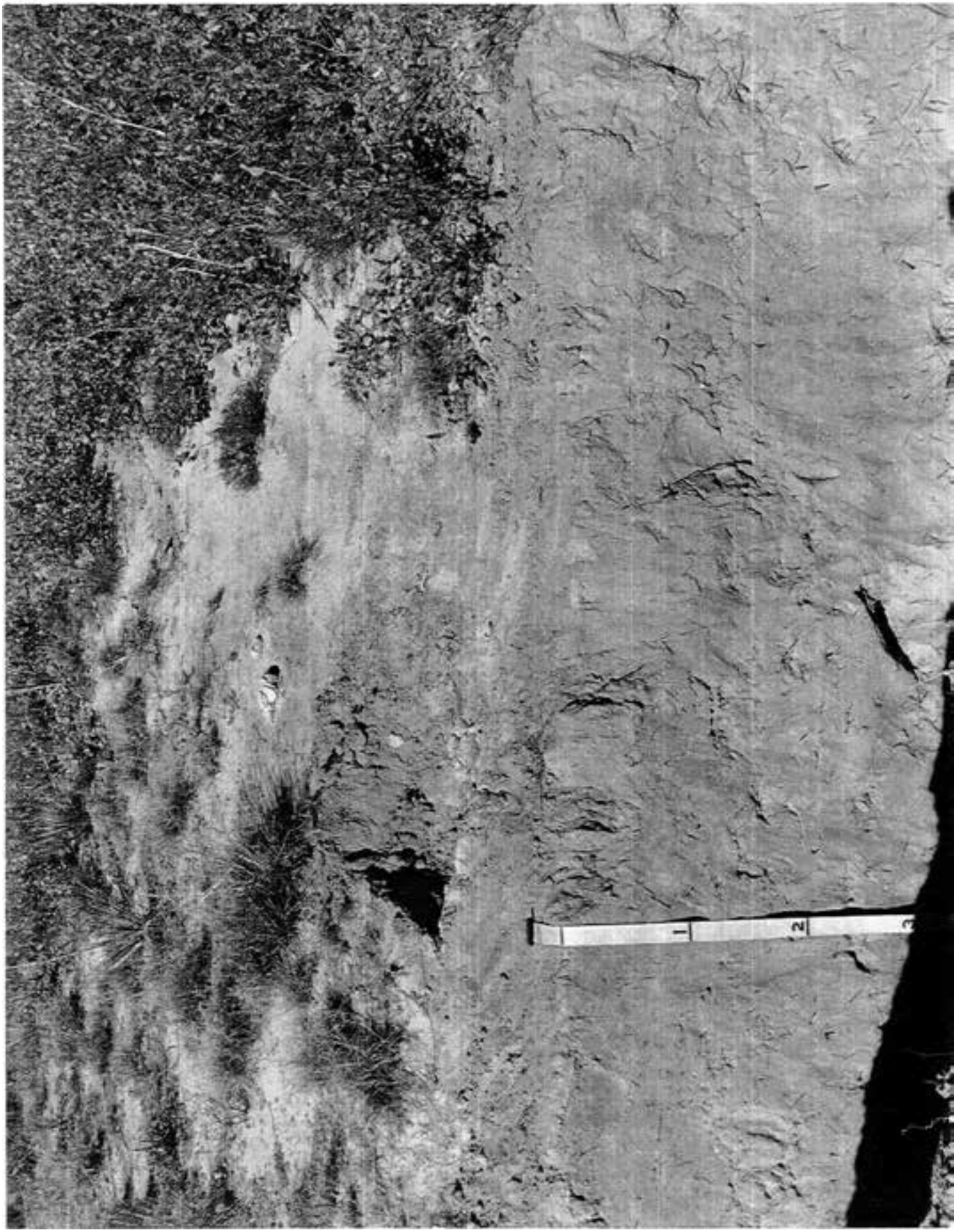


Figure 50. Above. The Typic Ustipsamment, Tivoli, at Site 8c-2. A thin deposit of Fairview age is indicated by burial of oak clumps at left of tape, but not at right of tape.

Overleaf. The Typic Ustipsamment, Tivoli, under nonoak vegetation at Site 8c-1, and the oak-nonoak contact. Scale is in feet. Photographed November 1976.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Pedon 8c-2 is under oak vegetation. Although Fairview sediments bury portions of oak trunks, unburied grass clumps are rooted in the deposits. This suggests stability for at least several years. Oaks appear to be advancing into the area once barren or occupied by grass, since a number of small oak plants, only a few cm high, mark the western edge of the oak patch. The nonoak area has common barren spots and would be more susceptible to erosion than the oak, which should resist erosion because of the mulch of oak leaves and twigs on the surface. Roots are larger and more prominent under the oak than under the adjacent nonoak vegetation.

Only slight differences are apparent in the soil under oak as compared to nonoak vegetation. Reaction values are slightly lower under oak. In places the A1 horizon in Fairview sediments has been slightly darkened by organic carbon. The A2b horizon has the lightest color and is beneath the former ground level, as indicated by the buried oak branches. The A2b horizon is very slightly lighter in color than adjacent horizons although not enough to show on the color chips.

The expression of pedogenesis in the Bb horizon is similar to that under nonoak vegetation except that the Bb horizon is not quite as hard and is easier to remove than the Cb horizon, possibly because of numerous oak roots. A discontinuous clay band, 1 mm thick, occurs in the lower part of the B21b horizon. Another discontinuous clay band, 1 mm thick, is at 107 cm depth. It occurs in segments 5 to 10 cm in length, separated by longer intervals in which the band is absent. The bands are indistinct and difficult to see in shadow, and could easily be missed in all but direct sunlight.

Site 9, crest of blowout dune; oak-nonoak transition

Site 9 (fig. 42, table 17) extends from an oak into a nonoak area on a dune crest that is west of a small blowout. Along the western margin of the oak patch, burial of oak trunks indicates that about 12 cm of Fairview sediments have been added since Muleshoe time. The sediments were apparently derived primarily from the nonoak area just west, which contains many barren spots.

Table 17. Characteristics of Typic Ustipsamments (Tivoli series) on dune crest at Site 9.

Sediment	Horizon	Depth cm	Hue	Value/chroma Dry	Value/chroma Moist	Texture	Structure	Dry consistence	pH	Lower boundary
Pedon 9a, nonoak										
Muleshoe	A11	0-10	7.5YR	5/4	3.5/4	fs	m	s	6.6	cw
	A12	10-37	7.5YR	6/4	4.5/4	fs	m	s	6.6	cw
	B21	37-71	5YR	6/6	4.5/6	fs	m	sh	7.0	cw
	B22	71-99	5YR	6/6	4/5/6	fs	m	sh	7.0	cw
Longview	Bb&Bt	99-110	5YR	6/6	4.5/6	s	m	sh	7.4	
Pedon 9b, oak										
Muleshoe	A11	0-16	8YR	6/3	4/3	fs	m	s	6.6	cw
	A12	16-35	7.5YR	5.5/4	4/6	fs	m	s	6.6	cw
	B21	35-55	5YR	6/6	4/6	fs	m	s	6.8	cw
	B22	55-92	5YR	6/6	4/6	fs	m	sh	6.8	cw
Longview	Bb&Bt	(similar to the Bb&Bt horizon of Pedon 9a)								

There is little difference between the soils under oak, vs. nonoak vegetation. Both appear slightly weaker than other soils of Muleshoe age. The pH is slightly lower under oak than under nonoak vegetation, as is common. The only clay band evident in Muleshoe sediments is in the west (nonoak) end of the trench. The band is at about 50 cm depth and extends for a lateral distance of about 1 m.

No evidence of a light-colored A2 horizon is apparent in the soil under oak. This contrasts with other soils under oak previously discussed, all of which had A2 horizons. Lack of an A2 horizon is attributed to youthfulness of the oak clump, which may only be a few decades old. The clump was smaller in 1941, as shown by comparison of 1941 and 1981 airphotos (figs. 13-17).

At about 1 m depth all along the exposure there is a buried B horizon of Longview age, with prominent clay bands. The contact between Muleshoe and Longview sediments is thought to occur at the top of the banded B horizon. This horizon is the most erosion-resistant horizon in soils of Longview age, and is currently at the surface in some of the small active blowouts in mapping unit C (fig. 27). Morphology of materials above the banded B horizon is typical of soils of Muleshoe age, and the area occurs in a belt of Muleshoe sediments (fig. 19).

Site 10, dune crest; oak-nonoak transition

Site 10 (fig. 40) is on the nearly level crest of an elongate blowout dune. Two pedons were sampled (table 18), one in the oak (west) part of the trench, and the other in the nonoak (east) part. The study trench illustrates sporadic development of clay bands that is typical of many soils of Muleshoe age. Most soils exposed in the trench are Typic Ustipsamments.

Table 18. Characteristics of Ustipsamments on dune crest at Site 10

Horizon	Depth, cm	Hue	Value/chroma Dry	Value/chroma Moist	Texture	Structure	Dry consistence	pH	Lower boundary
Typic Ustipsamment, Tivoli: Pedon 10a, oak									
A1	0-9	7.5YR	5/3	3/3	fs	m	s,l	7.0	aw
A2	9-25	7.5YR	6.5/3	5/3	fs	m	s,l	6.4	cw
B1	25-41	7.5YR	6.5/4	5/4	fs	m	s,sh	6.6	cw
B21	41-62	7.5YR	6.5/4	5/4	fs	m	sh	6.6	cw
B22	62-88	7.5YR	6.5/4	5/4	fs	m	sh	6.8	cw
B23&Bt	88-120	7.5YR	6.5/5	5/5	fs	m	sh	6.6	cw
B3	120-141	7.5YR	6.5/5	5/5	fs	m	sh	7.0	cw
C	141-148	7.5YR	6.5/5	5/5	fs	m	sh	7.0	
Alfic Ustipsamment, Circleback: Pedon 10b, nonoak									
A1	0-12	7.5YR	5/3	3.5/3	fs	m	s,l	7.0	cw
A2	12-25	7.5YR	6/4	4/4	fs	m	s	7.2	cw
B1	25-46	7.5YR	6/5	4/5	fs	m	s	7.2	cw
B21&Bt	46-71	7.5YR	6/5	4/5	fs	m	sh	7.0	as
B22&Bt	71-88	7.5YR	6/5	4/5	fs	m	sh	6.8	cw
B3	88-106	7.5YR	6.5/6	5/5	fs	m	s	6.8	cw
C	106-129	7.5YR	6.5/5	5/5	fs	m	s	6.8	

The soil under nonoak vegetation is an Alfic Ustipsamment, but only on the north side of the trench, where the pedon was sampled; less than two continuous clay bands are present on the south side. The B21&Bt horizon has one continuous and one discontinuous clay band, about 1 mm thick. The B22&Bt horizon has one continuous and one discontinuous band in the center of the horizon and also in the lower 5 cm.

A clay band at 71 cm depth extends continuously from the soil under nonoak vegetation into the soil under oak, where the band gradually deepens and is discontinuous. Several other discontinuous bands, about 1 mm thick, are also present. At the sample site in oak, the only clay band present is at about 92 cm depth. Except for the surface horizon, pH of upper horizons is lower under oak than under grass.

Site 11, blowout

Muleshoe deposits are usually quite thin in blowouts. Site 11 (fig. 40, table 19) illustrates a thicker deposit of Muleshoe sediments in a blowout. The A horizon has been darkened by organic carbon. No clay bands and no reddening occur in the B horizon. The A1 horizon, biotic mixing in the B horizon and slight increase of consistence with depth reflect slight pedogenic change from the parent materials. The abrupt smooth boundary at the base of the Muleshoe sediments appears to reflect an erosional contact to the older sediments beneath.

Table 19. Characteristics of the Typic Ustipsamment, Tivoli, in blowout at Site 11 1/

Horizon	Depth cm	Hue	Value/chroma Dry	Value/chroma Moist	Texture	Structure	Dry consistence	pH	Lower boundary
A11	0-9	7.5YR	5/3	3/3	fsl	m	h, sh	6.4	as
A12	9-26	9YR	5.5/3	3.5/3	fs	m	s	6.2	cw
B21	26-48	9YR	6/3	4/3	s	m	s	6.6	cw
B22	48-64	9YR	6.5/3	4.5/3	s	m	s, sh	6.8	cw
B23	64-104	9YR	6.5/3	4.5/3	s	m	sh	6.8	cw
B24	104-138	9YR	6.5/4	4.5/3	s	m	sh	6.8	as
Bb	138-143	10YR	7/3	6/3	s	m	h, vh	6.8	

1/ Bb: parts 10YR 6/2, dry. Muleshoe sediments occur from 0-138 cm. Sediments from 138-143 not identified.

Site 12, side and crest of blowout dune

Site 12 (figs. 21, 40) consists of a study trench in a blowout and one in the adjacent blowout dune. Site 12a illustrates a soil that occurs in some of the small blowouts. The epipedon does not quite qualify as mollic; upper horizons are not quite dark enough, and organic carbon is too low (table 20). Since the Muleshoe deposit is thinner than 50 cm and lacks diagnostic horizons, classification is based on the buried soil beneath, which is the Psammentic Haplustalf, Texico.

Table 20. Characteristics of an Ustipsamment and a Haplustalf at Site 12[1/]

Sediment	Horizon	Depth cm	Hue	Value/chroma Dry	Value/chroma Moist	Texture	Structure	Dry consistence	pH	Lower boundary	Organic C
Psammentic Haplustalf, Texico, on side of blowout dune, near bottom; Pedon 12a[2/]											
Muleshoe	A11	0-9	7.5YR	5/3	3/3	lfs		s	6.8	cs	1.35
	A12	9-28	7.5YR	5/3	3.5/3	fs	m	s	6.8	cw	0.34
	A13	28-44	7.5YR	5.5/3	4/3	fs	m	s	7.0	cw	0.32
Birdwell	B1tb	44-53	7.5YR	5/4	3/4	fs	m	h	7.0	cs	0.28
	B21tb	53-65	7.5YR	6/4	5/4	lfs	lmsbk	vh	7.0	cw	0.28
			5YR	5/4	4/4						
			7.5YR	5/4	3.5/4						
	B22tb	65-80	5YR	7/4	6/4	fs	lcsbk	vh	7.4		0.16
			5YR	6/4	5/4						
Typic Ustipsamment, Tivoli, on crest of blowout dune; Pedon 12b[3/]											
Muleshoe	A11	0-13	6YR	5/3	3.5/3	fs	m	s	6.8	cw	
	A12	13-26	5YR	5.5/4	4/4	fs	m	s	6.8	cw	
	B21	26-56	5YR	6.5/4	5/4	fs	m	s	7.0	cw	
	B22	56-73	5YR	6.5/4	5/4	fs	m	s,sh	7.0	as	
	B23&Bt	73-114	5YR	6.5/4	5/4	fs	m	sh	7.0	as	
	C	114-120	5YR	6.5/4	5/4	s	m	s,sh	7.0		

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

2/ B21tb: approximately equal amounts of given colors occur in irregular masses 1-10 cm diameter; also, about 5% of coarse mottles, 1-5 mm diameter, 5YR 6/6, dry, occur throughout. B22: 10% irregular zones of 10YR 8/3, dry, and 5% mottles, 5YR 6/8, dry, 1-3 mm diameter.

3/ B23&Bt: several discontinuous clay bands, about 1 mm thick.

Site 12b (fig. 21) is on the south rim of the dune and illustrates incipient clay band development in Muleshoe sediments. Sedimentary strata are well preserved in the lower part of the pedon (fig. 21). In most places, distinct strata are not apparent in Muleshoe sediments.

Site 13, blowout dune; oak-nonoak transition

At site 13 (figs. 40, 51) a trench was dug across an oak-nonoak boundary on the east-facing side of a blowout dune. Pedon 13a was sampled under oak, and Pedon 3b under nonoak vegetation (table 21). A weak A2 horizon occurs under oak but not under nonoak vegetation. A discontinuous clay band, about 1 mm thick, occurs in the B2 horizon of Pedon 13b. The band could be traced into the soil under oak, where it is also discontinuous. Over the exposure as a whole, the single clay band was similarly developed under both oak and nonoak vegetation.

Work with the auger and backhoe indicates a continuous Muleshoe deposit in the dune at Site 13 (fig. 51). An exploratory trench was also dug in the crest of the dune (fig. 51). A pit 130 cm deep and 3 m wide showed the soil of Muleshoe age to have a weak A1 horizon; no A2 horizon, despite being under oak; no clay bands; and only a very slight reddening in the B horizon.

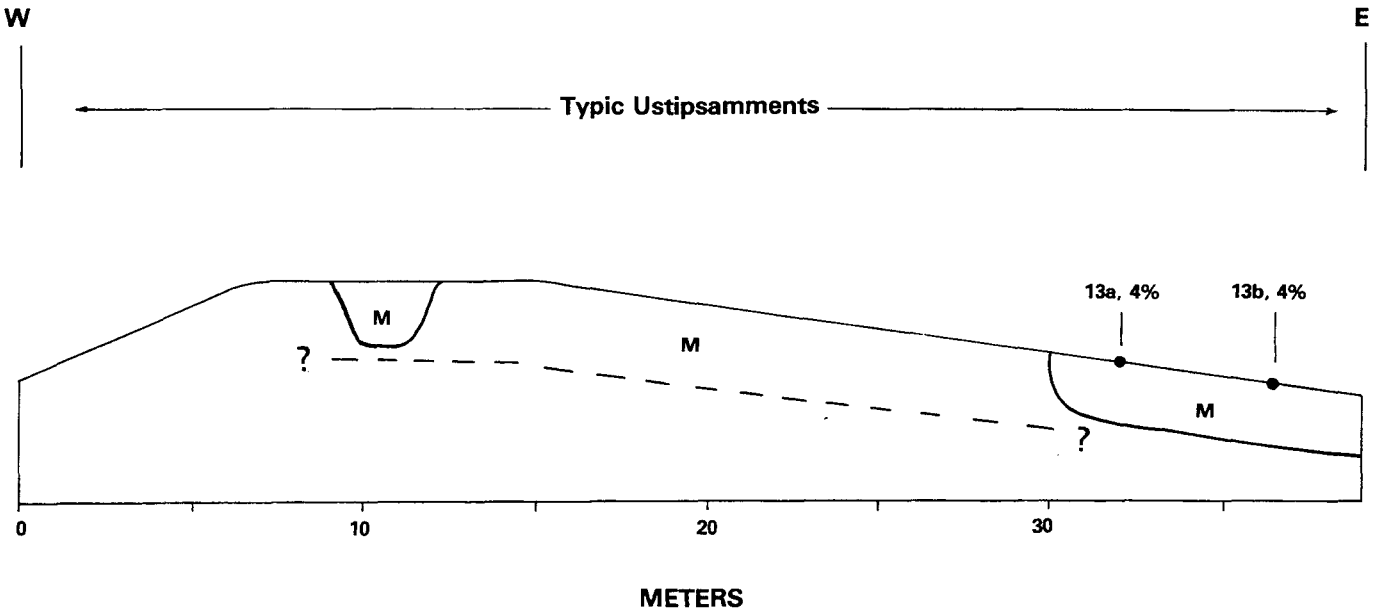


Figure 51. Diagram showing study trenches, stratigraphy, subgroups, and slope and location of sampled pedons at Site 13. M = Muleshoe sediments. No vertical scale (see table 21 for thickness of soil horizons). The heavy lower line represents the bottom of the trenches.

Table 21. Characteristics of Typic Ustipsamments, Tivoli, of the blowout dune at Site 13[1/]

Sediment	Horizon	Depth cm	Hue	Value/chroma Dry	Value/chroma Moist	Texture	Structure	Dry consistence	pH	Lower boundary
Pedon 13a, oak										
Muleshoe	A1	0-12	6YR	5/3	3.5/3	fs	m,sg, lfcr	s,l	6.8	cw
	A2	12-28	6YR	5.5/3	4/3	fs	m	s,sl	6.8	cw
	B1	28-43	5YR	5.5/4	4/4	fs	m	s,sh	7.0	cw
	B21	43-74	5YR	6/5	4.5/5	fs	m	sh	7.0	cw
	B22	74-119	5YR	6/5	4.5/5	fs	m	sh,s	7.0	
Pedon 13b, nonoak										
Muleshoe	A11	0-10	8YR	5.5/4	4/3	fs	m,sg, lfcr	s,l	7.0	cw
	A12	10-21	8YR	5.5/4	4/3	fs	m	s	7.0	cw
	B1	21-43	6YR	6/4	4.5/4	fs	m	s	7.0	cw
	B21	43-72	5YR	6/4	4/4	fs	m	sh	7.0	cw
	B22&Bt	72-92	5YR	6/4	4/4	fs	m	sh,s	7.0	as
	B3	92-117	5YR	6.5/4	4.5/4	fs	m	sh,s	7.0	aw
Longview?	Bb	117-134	5YR	6/4	4/4	fs	m	sh	7.0	

1/ One clay band occurs discontinuously in the lower part of the B22&Bt horizon of Pedon 13b.

The oak-nonoak contact at Site 13 showed no visible evidence suggesting oak advance or retreat. However, the sandy road west of the dune crest demonstrates the speed of oak movement into sandy sediments that lack vegetation. Aerial photographs (figs. 15, 16) show that road was present in 1962 but not in 1953. The road appears fresh in the 1962 photograph, with no evidence of oak. But the 1970 photograph shows darkening across the road west of the study trenches. The oak plants were seen on the ground by the author in 1974. The evidence suggests that much of the oak crossing of the sandy road could have been accomplished in a period of less than about 8 years.

TYPIC USTIFLUVENTS AND USTIPSAMMENTS DOMINANT:

MAPPING UNIT B, TIVOLI VARIANTS

MAPPING UNIT COMPOSITION

Series or variant	Subgroup	Particle-size family	Percentage of mapping unit
TIVOLI, THIN VARIANT #2	TYPIC USTIFLUVENTS	(SANDY, COARSE-LOAMY)	45
TIVOLI, THIN VARIANT #1	TYPIC USTIPSAMMENTS	SANDY	30
Circleback	Alfic Ustipsamments	Sandy	10
Texico	Psammentic Hapulstalfs	Sandy	10
Other inclusions	(Farwell, Keeney)		5

LOCATION, LANDSCAPE, SOIL OCCURRENCE, VEGETATION

Soils of unit B occur only in broad topographic lows in the northern part of the study area. There are slight undulations and, in places, blowouts 1 to 2 m deep. Muleshoe sediments are thinner in mapping unit B than in unit A, and buried argillic horizons occur between 50 and 100 cm depth. Organic carbon tends to be higher in the buried argillic horizons than in overlying coarser-textured materials because of the close relation of organic carbon to clay content. Thus organic carbon decreases irregularly with depth and if the argillic horizon is finer than loamy very fine sand, the soil is the Typic Ustifluvent Tivoli, thin variant #2. If some subhorizon of the argillic horizon is not finer than loamy very fine sand, the soil is the Typic Ustipsamment Tivoli, thin variant #1. Tivoli, thin variant #2 dominates the unit as a whole, being most extensive in lowest parts of the broad depression (see Site 15). Otherwise, occurrence of the two thin variants is difficult to predict, and depends on texture of the buried Bt horizon. Circleback soils occur in scattered places where Longview sediments are at the surface. Texico and Farwell soils occur in a few areas where soils of Birdwell age, usually buried in unit B, are at the surface.

Vegetation observed in mapping unit B consists of sumac, shinnery oak, soapweed, hairy grama, sideoats grama, sand sagebrush, three-awn, dropseed, little bluestem, prickly pear, lovegrass, and queen's delight.

TYPICAL PEDONS AND RANGES IN SELECTED PROPERTIES

Pedon 14, at Site 14, is a typical pedon for Tivoli, thin variant #1. See table 22 for characteristics of Pedon 14. Ranges in color and texture follow; underlined entries are typical. Two underlined entries indicate that it is typical for both entries to occur in the stated horizons.

The A1 horizon has hue of 7.5YR through 10YR, value of 5 through 6 dry, 3 through 4 moist, and chroma of 2 through 4 (3). It is fine sand, sand or loamy fine sand. If an A12 horizon is present it is commonly 1/2 or 1 chip lighter than the A11 horizon.

The B2 horizon has hue of 5YR, value of 5.5 through 6.5 (6) dry, 3.5 through 4.5 (4) most, and chroma of 4. It is fine sand or sand.

The B2tb horizon has hue of 2.5YR through 5YR (4YR), value of 5 through 6 dry, 4 through 5 moist, and chroma of 4 through 6. It is loamy fine sand or sand. The pH values tend to decrease slightly in lower horizons. Other soil properties also change as the buried soil is encountered; texture becomes finer and dry consistence becomes harder.

Pedon 15 may be considered a typical pedon of Tivoli, thin variant #2, except that texture of fine sandy loam may be more common than sandy clay loam in the buried Bt horizon, and both sandy and coarse-loamy pedons are included. See table 22 for characteristics of Pedon 15. 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, 3 through 4 moist, and chroma of 3 through 4. It is fine sand, sand, or loamy fine sand.

The B2 horizon has hue of 5YR, value of 5.5 through 6.5 (6) dry, 3.5 through 4.5 (4) moist, and chroma of 4. It is fine sand or sand.

The B2tb horizon has hue of 2.5YR through 10YR, value of 4 through 5 (4.5) dry, 3.5 through 4.5 (4) moist, and chroma of 2 through 6. It is fine sandy loam or sandy clay loam.

The B2 horizon is not present in pedons of Fairview age.

STUDY SITES

Sites 14-17, broad topographic low; the Ustipsamment-Ustifluvent transition

The Muleshoe deposits are thinner in mapping unit B than in unit A and as a result, buried argillic horizons are nearer the surface in most places. Since the mantle of younger deposits is more than 50 cm thick, classification is based on the mantle. In Tivoli, thin variants #1 and #2, a buried argillic horizon occurs from 50 to 100 cm depth. Table 22 gives soil characteristics.

Site 14 (fig. 52) illustrates the Typic Ustipsamment Tivoli, thin variant #1. The pedon is near the west edge of a broad, gently undulating depression. The Muleshoe sediments extend to 77 cm depth, where they overlie Birdwell sediments with a buried argillic horizon. Although organic carbon decreases irregularly with depth (table 22), texture between 25 and

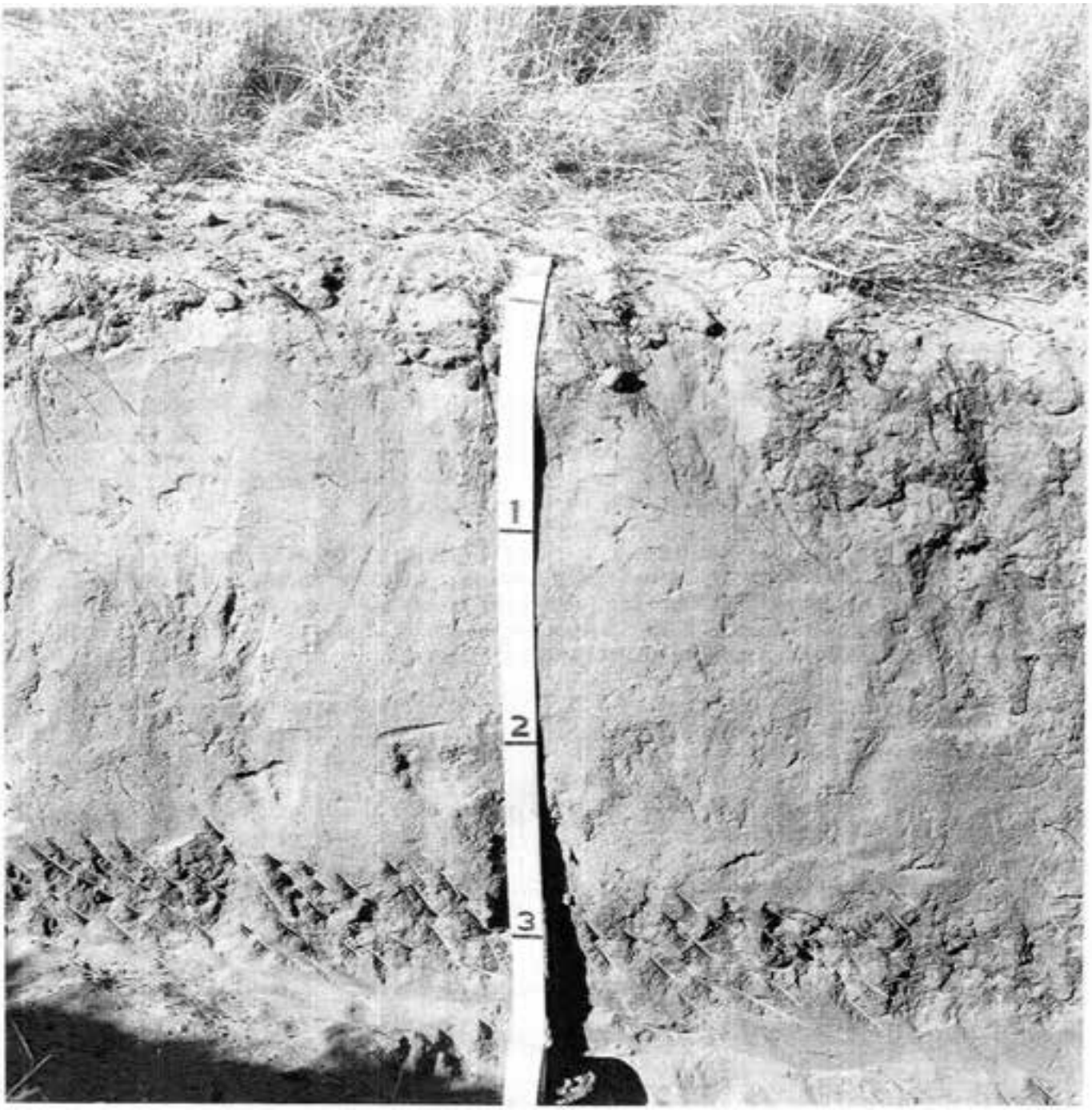


Figure 52. The Typic Torripsamment Tivoli, thin variant #1, at Site 14. The top of the buried argillic horizon of Birdwell age is at a depth of about 2½ ft (0.8 m). The overlying sediments are of Muleshoe age. Scale is in feet.

Table 22. Characteristics of Ustipsamments and an Ustifluvent at Sites 14-17[1/]

Sediment	Horizon	Depth, cm	Hue	Value/chroma Dry	Value/chroma Moist	Structure	Dry consistence	pH	Lower boundary	Organic C, %	Textural class	Sand 2.0 0.05 mm	Silt 0.05-0.002 mm	Clay < 0.002 mm
Typic Ustipsamment, Tivoli, thin variant #1, on eastern edge of broad topographic low; Pedon 14														
M	A11	0-9	7.5YR	5/3	3.5/3	m	s,l	7.0	cw	0.59	fs			
	A12	9-26	7.5YR	6/4	4/3	m	s	7.0	cw	0.29	fs			
	B21	26-51	7.5YR	6/4	4/4	m	sh	7.0	as	0.29	fs			
	B22	51-77	5YR	6/4	4.5/4	m	sh	7.0	as	0.23	fs			
B	B1tb	77-83	5YR	5/4	4/4	lmsbk	vh	7.2	as	0.38	lfs			
	B2tb	83-98	4YR	5/4	4/4	lmsbk	vh	6.8	cw	0.32	lfs			
	B3tb	98-115	4YR	6/5	5/5	m	h	7.0		0.36	fs			
Typic Ustifluvent, Tivoli, thin variant #2, in broad topographic low; Pedon 15														
M	A1	0-9	7.5YR	5/4	3/4	m	s,l	7.0	aw	0.56	fs	90.2	7.0	2.8
	B1	9-29	7.5YR	5.5/3.5	3.5/4	m	s	7.0	cw	0.15	fs	94.9	2.8	3.8
	B21	29-50	5YR	6/4	4/4	m	sh	7.0	cw	0.19	fs	94.3	2.9	2.8
	B22	50-63	5YR	6/4	4/4	lmsbk	h	7.0	as	0.13	fs	92.0	2.4	5.6
H	B21tb	63-74	4YR	4.5/5	4/5	lcsbk	eh	7.0	cw	0.46	scl	65.7	12.7	21.6
	B22tb	74-98	2.5YR	4.5/6	4/6	lcsbk	eh	6.6		0.28	scl	61.5	12.7	25.8
Typic Ustipsamment, Tivoli, thin variant #1, in broad topographic low; Pedon 16														
M	A11	0-12	10YR	5/3	3/3	m	s	7.6	cw		lfs			
	A12	12-28	7.5YR	6/3	4.5/3	m	s	7.6	cw		fs			
	B21	28-46	7.5YR	6/4	4.5/4	m	sh	7.6	cw		fs			
	B22	46-64	5YR	6/4	4.5/4	m	sh	7.6	as		fs			
B	B2tb	64-85	4YR	6/5	5/5	lcsbk	vh	6.0			lfs			
	B3tb	85-97	6YR	5/4	4/4	lcsbk	vh	6.2			fs			
Alfic Ustipsamment, Circleback, on slight dune in broad topographic low; Pedon 17[2/]														
L	A11	0-10	9YR	5/4	3/4	m	s	7.0	cw		fs			
	A12	10-28	9YR	6/4	4/4	m	s	7.2	cw		s			
	B1	28-42	7.5YR	6/4	4/4	m	sh	7.2	cs		s			
	B2&Bt	42-59	6YR	6/4	4/4	m	sh	7.0	as		s			
	B3	59-74	7.5YR	7/4	5/4	m	sh	6.8	cs		s			
	C	74-89	7.5YR	8/4	6/4	m	sh	6.8	as		s			
B	Btb	89-97	5YR	5.5/6	5/6		vh	6.8			ls			

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

2/ B2&Bt: one clay band is 1 cm thick and 5YR 5/4, dry. Four thinner bands are also present. Btb: also parts 7.5YR 7/4, dry, occurring as pore fillings and as irregularly shaped volumes ½ - 2 cm diameter.

100 cm depth is too coarse for the Fluvents and the pedon is a Psamment. The buried argillic horizon grades to sandy C horizon material beneath the bottom of the study trench.

The transition from Ustipsamments to Ustifluvents occurs where the buried argillic horizon has texture of loamy very fine sand or finer in some subhorizon between 50 to 100 cm depth. This happens further east in the broad depression in Hale sediments and in some sediments of Birdwell age. Pedon 15 (fig. 53) illustrates the Typic Ustifluvent Tivoli, thin variant #2. It has a buried argillic horizon of Hale age. The overlying Muleshoe sediments have the characteristic weak morphology. One clay band, 1 mm thick and 5 cm long, is at a depth of 40 cm in the center of the exposure. Another band of about the same size is in the east end. The buried Bt horizon, a sandy clay loam, is distinctly finer than the Bt horizon at Site 14 (table 22), and the pedon is coarse-loamy; Tivoli, thin variant #2

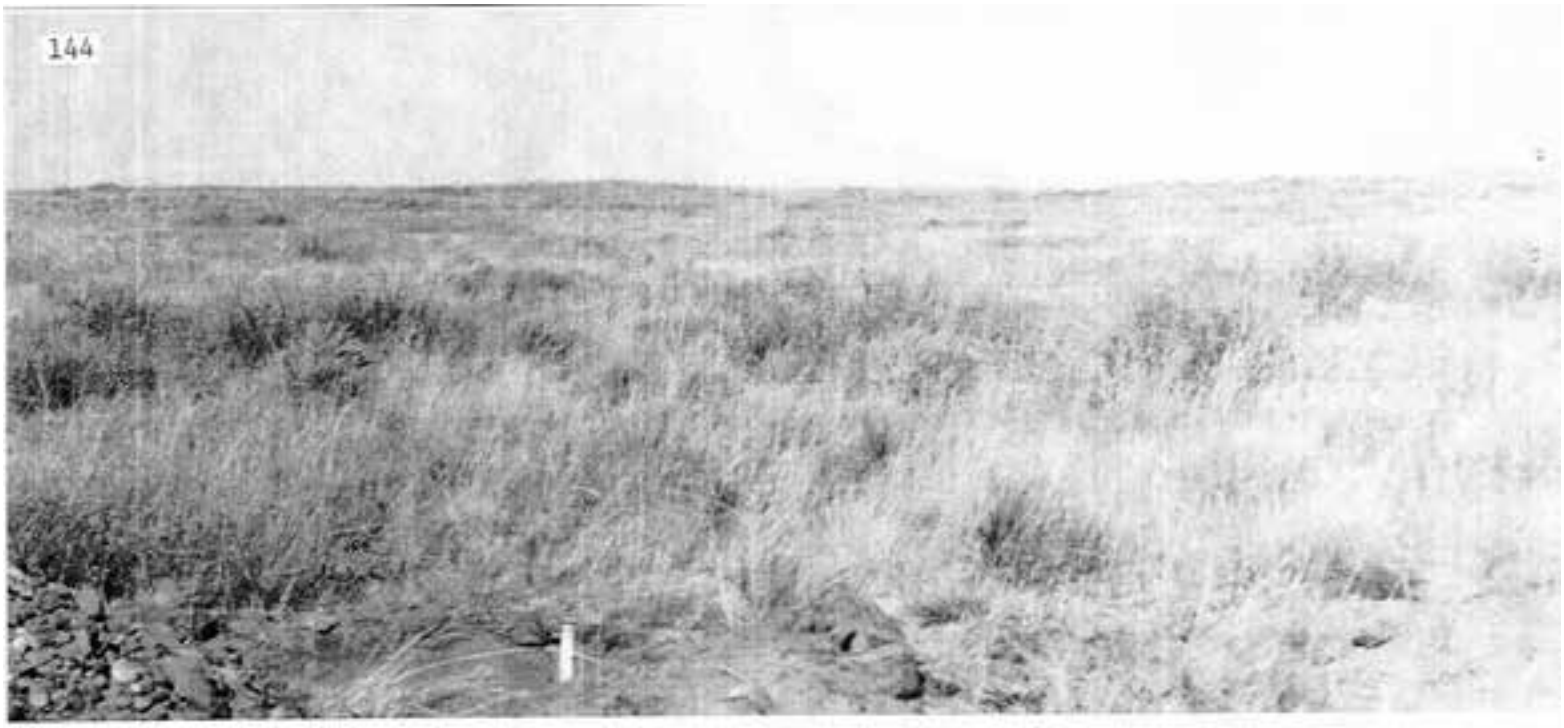
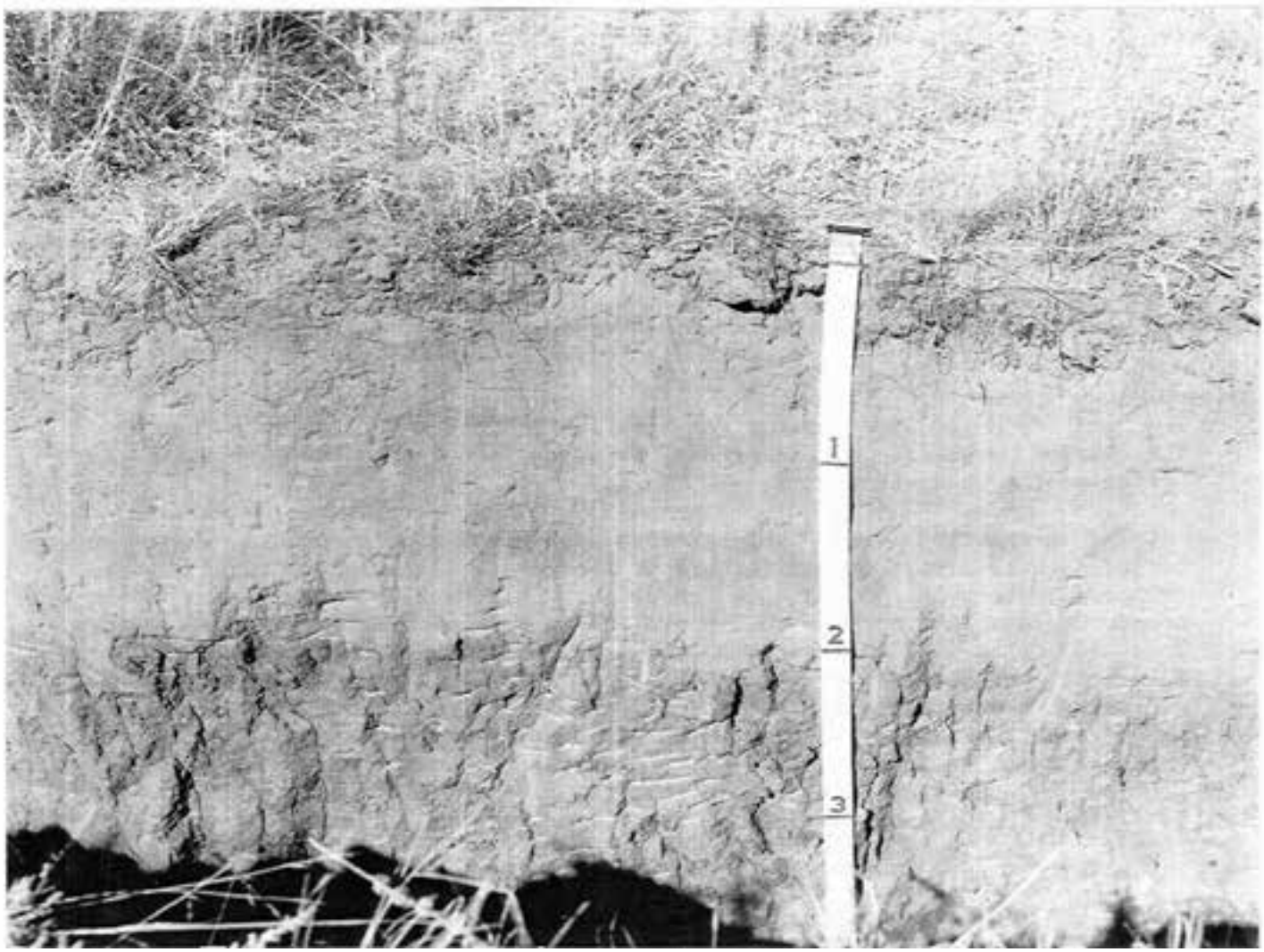


Figure 53. Above. Landscape of the Muleshoe surface at Site 15, in the topographic low in the foreground and middle ground. A Birdwell dune occupies most of the skyline. Photographed November 1975.

Below. The Typic Ustifluvent, Tivoli, thin variant #2. A buried argillic horizon of Hale age is at a depth of about 2 ft (0.6 m). The overlying sediments are of Muleshoe age. Scale is in feet.



includes both sandy and coarse-loamy pedons (table 4). Organic carbon decreases irregularly with depth (0.46 percent in the B21tb vs 0.13 percent in the overlying B22 horizon) and the pedon is a Fluvent.

Augering below the bottom of the trench showed that clay gradually decreases to a light sandy clay loam, then to a noncalcareous fine sandy loam. Clay then increases again to a sandy clay loam, and a K horizon of Bailey age occurs at about 205 cm depth. At about 235 cm depth the K horizon grades into a noncalcareous loamy sand. At 280 cm there is a fine sandy loam with scattered carbonate accumulations, and 305 cm depth there is a calcareous sandy clay loam with a minor amount of carbonate.

Auger samples nearby Site 15 showed nodular carbonate accumulations at depths less than 1 m. Their significance is not known, but they may represent soils of Bailey age that once occupied minor topographic highs in the depressions. More work is needed on such depressions because their present smooth topography may mask important evidence of a pedogenic and geomorphic history more complex than suggested by their appearance.

Site 16 (table 22) is on the edge of an oak patch. The pit is in a very slight ridge in the broad depression, a few cm higher than some of the adjacent highs, and level with others. Weak morphology and lack of clay bands above the Bt horizon (table 22) fits Muleshoe age. The thin B2tb horizon is characteristic ob Birdwell sediments.

Site 17 (table 22) is on a slight ridge that constitutes the back rim and western edge of a blowout. Pedon 17, an Alfic Ustipsamment, illustrates an inclusion of Longview age in a unit dominated by soils of Muleshoe age. A Btb horizon of Birdwell age is the lowermost horizon sampled (table 22).

CHAPTER 6. USTIPSAMMENTS AND HAPLUSTALFS OF THE MULESHOE, LONGVIEW AND BIRDWELL SURFACES

The soils occur in mapping units C and D (fig. 27).

ALFIC AND TYPIC USTIPSAMMENTS, AND PSAMMENTIC HAPLUSTALFS DOMINANT: MAPPING UNIT C, CIRCLEBACK COMPLEX

MAPPING UNIT COMPOSITION

Series or variant	Subgroup	Particle-size family	Percentage of mapping unit
CIRCLEBACK	ALFIC USTIPSAMMENTS	SANDY	35
TIVOLI	TYPIC USTIPSAMMENTS	SANDY	30
TEXICO	PSAMMENTIC HAPLUSTALFS	SANDY	25
Newell, sandy variant	Aridic Argiustolls	Sandy	5
Other inclusions	(Farwell, Keeney, Tivoli, thin variant #1)		5

LOCATION, LANDSCAPE, SOIL OCCURRENCE, VEGETATION

Soils of unit C occur only in the northern part of the study area. Dune height ranges from low to some of the highest in the study area. Where dunes are highest, the terrain consists of elongate dunes and intervening troughs. Small, isolated blowouts also occur. Circleback soils occur both in dunes and depressions, but in places are discontinuously buried by Muleshoe sediments and Tivoli soils. Texico and Farwell soils occur in scattered areas of Birdwell sediments on sides of dunes and in depressions. Tivoli, thin variant #1, Newell, sandy variant, and Keeney soils occur in some of the depressions.

Vegetation observed in mapping unit C consists of shinnery oak (which dominates in most places), sumac, little bluestem, sand bluestem, snakeweed, sideoats grama, sand dropseed, prickly pear, three-awn, sand sagebrush, soapweed; blue grama and hairy grama occur in some of the depressions.

TYPICAL PEDONS AND RANGES IN SELECTED PROPERTIES

A typical pedon of Tivoli was given in mapping unit A. Pedon 21, at Site 21, is a typical pedon of Circleback, except that its C horizon is darker than typical. See tables 26 and 29 for characteristics of Pedon 21. Ranges in color and texture follow; underlined entries are typical.

The A horizon has hue of 7.5YR through 10YR, value of 5 through 6 dry, 3.5 through 4.5 (4) moist, and chroma of 3 through 4. It is fine sand or sand.

The B2&Bt horizon has hue of 2.5YR through 10YR (5YR), value of 5.5 through 6.5 (6) dry, 4.5 through 5.5 (5) moist, and chroma of 4 through 6. It is fine sand or sand.

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

A2 horizons are present in some pedons and have slightly lighter color than adjacent horizons. Clay bands are commonly slightly darker than other parts of the horizon; 5YR 5/4, dry, is a typical color.

Pedon 33a, at Site 33, is a typical pedon of Texico; see table 40 for its characteristics. Ranges in color and texture follow; underlined entries are typical.

The A horizon has hue of 5YR through 10YR (6YR), value of 4.5 through 5.5 (5) dry, 3 through 4 (3.5) moist, and chroma of 3 through 4. It is fine sand, sand, or loamy fine sand.

The B2t horizon has hue of 9YR through 2.5YR (4YR), value of 4.5 through 5.5 (5) dry, 3.5 through 4.5 (4) moist, and chroma of 4 through 6. It is loamy fine sand, fine sandy loam, fine sand or sand.

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

Site 18, episodic development of blowout and dune; oak-nonoak transition

Initial investigations at Site 18 (figs. 40, 54) were made in a short trench in the blowout and in the east crest of the blowout dune. These and subsequent study trenches comprise Sites 18a, 18b, and 18c.

Site 18a, blowout and south side of dune

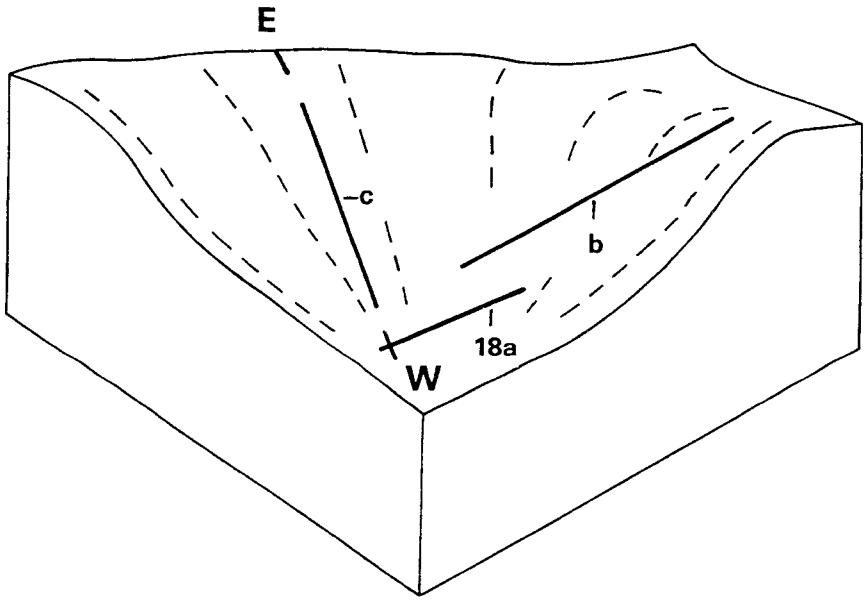
Site 18a consists of a small east-west trench in the blowout and a connecting, later north-south trench extending from the blowout into the south side of the dune. Figure 55 shows the stratigraphy, soil occurrence, and slope and location of the sampled pedons. Table 23 gives characteristics of the soils.

Muleshoe sediments are at the surface for the full length of the trench. The western margin of the blowout (fig. 54) has a low area with a barren, sandy surface that is a site of present movement of windblown sand. Muleshoe sediments apparently moved through this low area also, as well as discontinuously along the bordering rim.

Blowout. Figure 56 shows Pedon 18a-1, in the first trench dug in the blowout. The upper 12 cm is slightly finer than below and is thought to reflect additions of silt and clay from dustfall and run-in after deposition of Muleshoe sediments. The A horizon is darker and thicker in the blowout than in the bordering dune. Coarse texture indicates that organic carbon is too low for a mollic epipedon. Finer texture at depth (table 23) indicates that organic carbon decreases irregularly with depth and that the soil is a Fluvent.

Two buried soils occur in Pedon 18a-1 (fig. 56, table 23). The Btb horizon of Longview age is thin and contains much more clay than adjacent horizons; it is similar in these respects to the Bt horizon in Longview

Figure 54. Sites 18a, 18b and 18c viewed from the east (photograph, above) and from the west (diagram, below). The two trenches shown in the photograph locate the initial investigations -- one in the east rim (foreground) and one in the blowout. Pedons 18c-4 and 18c-5 are located in the foreground trench, which was cut across the oak - nonoak boundary. Most of the studied area lies within the dashed lines. The south rim is beyond the left edge of the photograph.



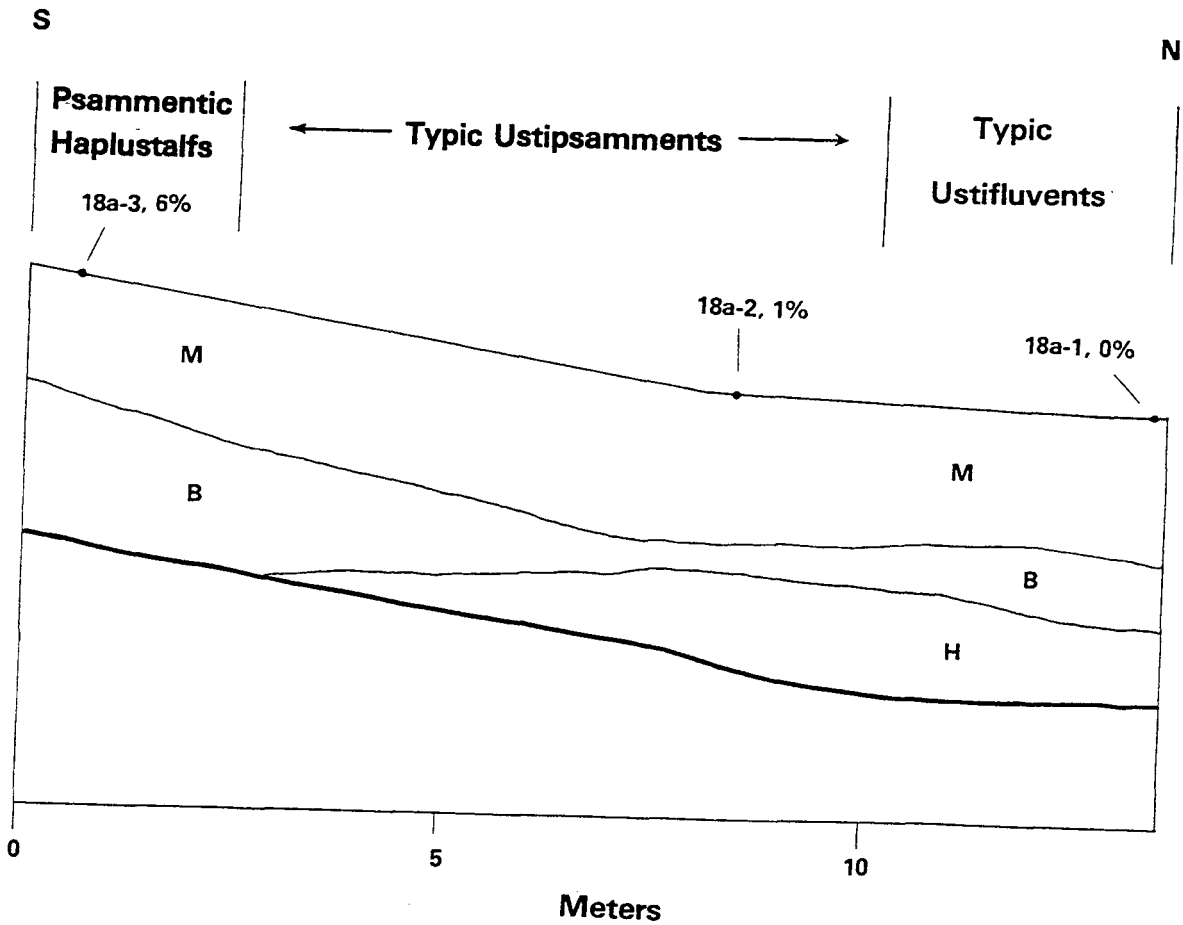


Figure 55. Diagram of the study trench at Site 18a, showing stratigraphy, subgroups, slope and location of the sampled pedons. M = Muleshoe, B = Birdwell, H = Hale. No vertical scale (see table 23 for thickness of sediments and horizons). The heavy lower line represents the bottom of the trench.

colluvium (see Sites 33-35 and 39). To study this further, a later trench was dug from the blowout into the adjacent dune (fig. 54). The lower buried soil has an A2 horizon and a reddish, high-chroma Bt horizon that descends below the bottom of the trench. Auger samples below the trench bottom showed that this Bt horizon is the typical thick one of Hale age.

Mottles in the buried soil of Hale age indicate a high water table at times in the past. The mottles are relict and no longer forming, since the water table is now at substantial depth due to irrigation (Cronin, 1969).

Side of dune. Sediments and soils in the blowout were traced upslope along the NS trench dug later (fig. 57). The thin Ab horizon of the upper buried soil at Pedon 18a-1 gradually thins and disappears upslope; it is not present in Pedon 18a-2 (table 23). The underlying thin Btb horizon at

Table 23. Characteristics of an Ustifluvent, an Ustipsamment and a Haplustalf at Site 18a[1/]

Sediments	Horizon	Depth, cm	Hue	Value/chroma Dry	Value/chroma Moist	Texture	Structure	Dry consistence	pH	Lower boundary
Typic Ustifluvent, Tivoli, thin variant #2, in blowout; Pedon 18a-1[2/]										
Muleshoe	A11	0-12	9YR	5/3	3/2	lfs	m,cr	s	6.4	cs
	A12	12-35	9YR	6/3	4/3	fs	m	s	6.8	cw
	A13	35-60	9YR	5/3	3/3	fs	m	s	7.0	cw
Birdwell	A1b	60-73	9YR	5/2.5	4/2	fs	m	sh	6.8	as
	B2tb	73-85	10YR	5.5/2	3.5/2	scl	lcsbk	eh	6.8	cs
Hale	A2b2	85-107	10YR	7/3	6/3	fs	lcsbk	vh	6.8	cs
	B2tb2	107-115	5YR	5/6	4/6	lfs	lcsbk	vh	6.8	
Typic Ustipsamment, Tivoli, thin variant #1, on lower side of dune; Pedon 18a-2[3/]										
Muleshoe	A11	0-20	7.5YR	5/3	3.5/2	fs	m	s	6.8	cs
	A12	20-49	7.5YR	6/3	4/2	s	m	s	6.8	cw
	B	49-64	7.5YR	6/3	4/3	s	m	sh	6.8	as
Birdwell	Btb	64-79	10YR	6/2	4.5/2	ls	lcsbk	vh	7.0	as
Hale	Btb2	79-103	2.5YR	5/4	4/4	ls	lcsbk	vh	6.6	
Psammentic Haplustalf, Texico, on side of dune; Pedon 18a-3[4/]										
Muleshoe	A1	0-12	7.5YR	5/3	3/2	s	m	s	7.0	cw
	A2	12-35	7.5YR	6/3	4/2	s	m	s,sh	6.6	cw
	B	35-49	7.5YR	6/4	3.5/4	s	m	sh	6.6	aw
Birdwell	B21tb	49-68	7.5YR	5.5/4	4/4	ls	lcsbk	vh	6.0	cw
	B22tb	68-93	5YR	6.5/6	5/6	s	m	h	6.2	cw
	B23tb	93-106	10YR	7/3	6/3	s	m	h	6.4	

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

2/ B2tb: parts 2.5YR 6/6, dry, and 7.5YR 7/4, dry; and dark stainings of organic carbon on prism faces. A2b2: has equal amount of 4YR 6/4, dry and small amount of 7.5YR 7/3, dry.

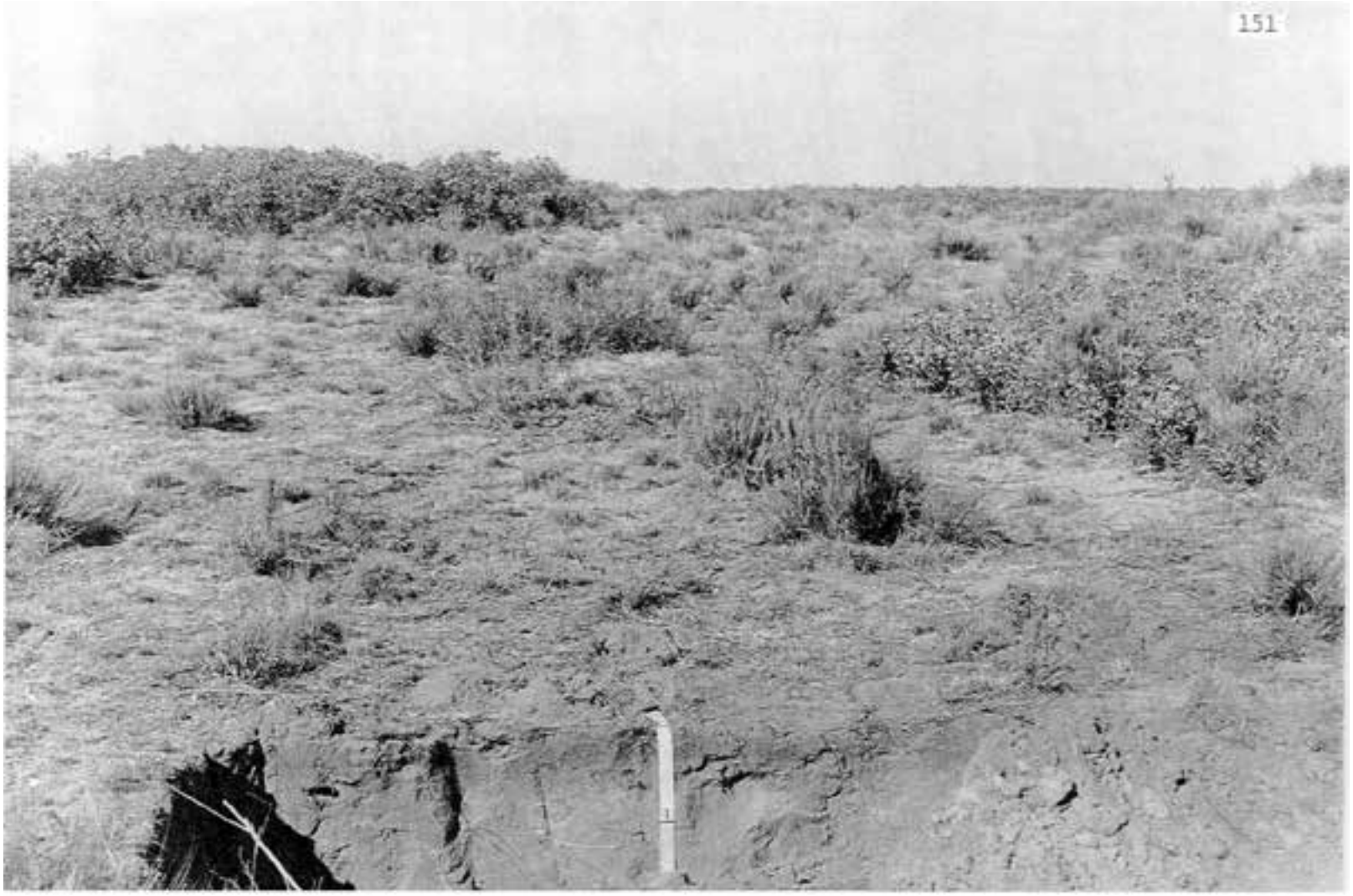
3/ Btb2: parts 5YR 7/3, dry, and 5YR 6/3, dry.

4/ B22tb: parts 10YR 8/3, dry. B23tb: parts 10YR 8/2, dry.

Pedon 18a-1 gradually becomes coarser-textured and lighter-colored upslope. It is still present in Pedon 18a-2 but grades out towards Pedon 18a-3. These morphological changes are typical of Bt horizons in Birdwell colluvium and show that the colluvium can occur in small blowouts and dunes as well as large ones. The three pedons illustrate the transition Ustifluvents-Ustipsamments-Haplustalfs as the buried horizons become coarser-textured and shallower upslope.

Site 18b, south side of dune and dune crest.

The study trench at Site 18b extends from the lower side of the dune southward to the crest of the dune (fig. 54). Figure 58 shows slope, stratigraphy, soil occurrence, and location of sampled pedons at Site 18b. Table 24 gives soil characteristics. A thin deposit of Muleshoe age overlies Longview sediments on the dune crest (fig. 58), but Longview



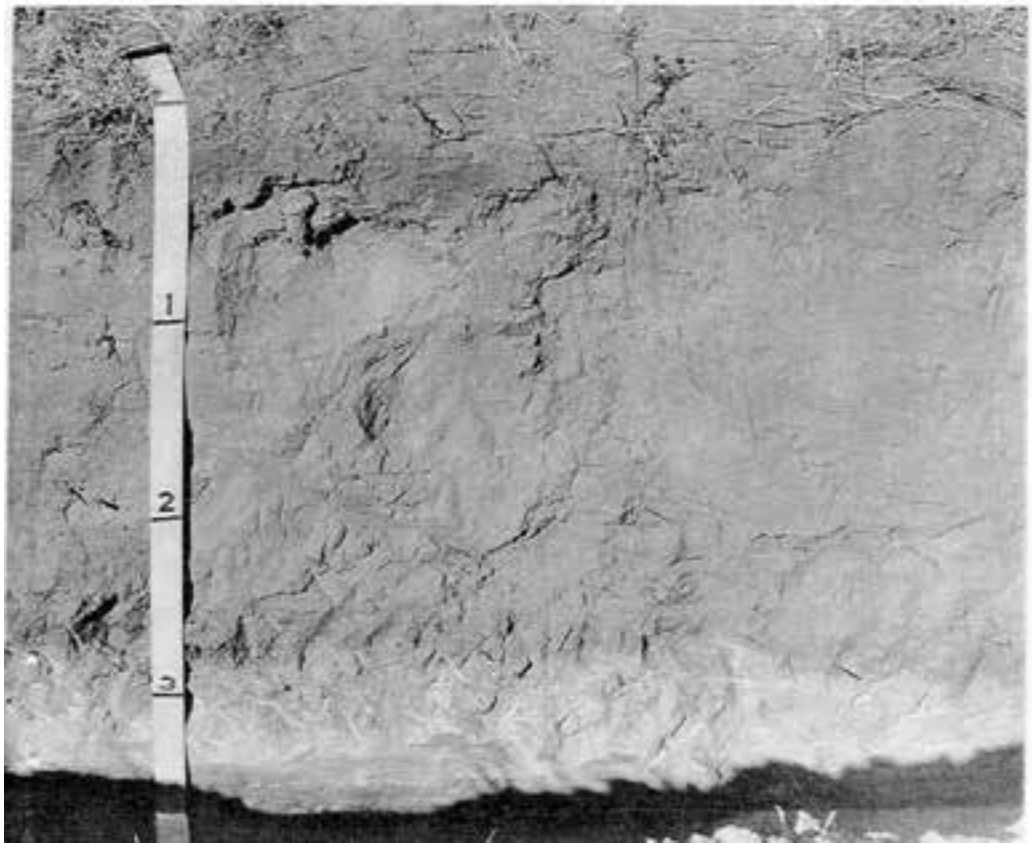


Figure 56. Top. Landscape of the Muleshoe surface in the blowout and bordering dune. The trench in the foreground is the initial east-west trench in the blowout.

Bottom. The Typic Ustifluvent, Tivoli, thin variant #2, Pedon 18a-1. Scale is in feet.

Figure 57. At left. Landscape of the trench at Site 18a. The filled-in trench at Site 18b may be seen at left. The view is south. Photographed November 1977.

Above. The Muleshoe surface and upper part of study trench at Site 13a. The Psammentic Haplustalf Texico, Pedon 18a-3, is at left. Note increase in roots under oak vegetation. Scale is in feet.

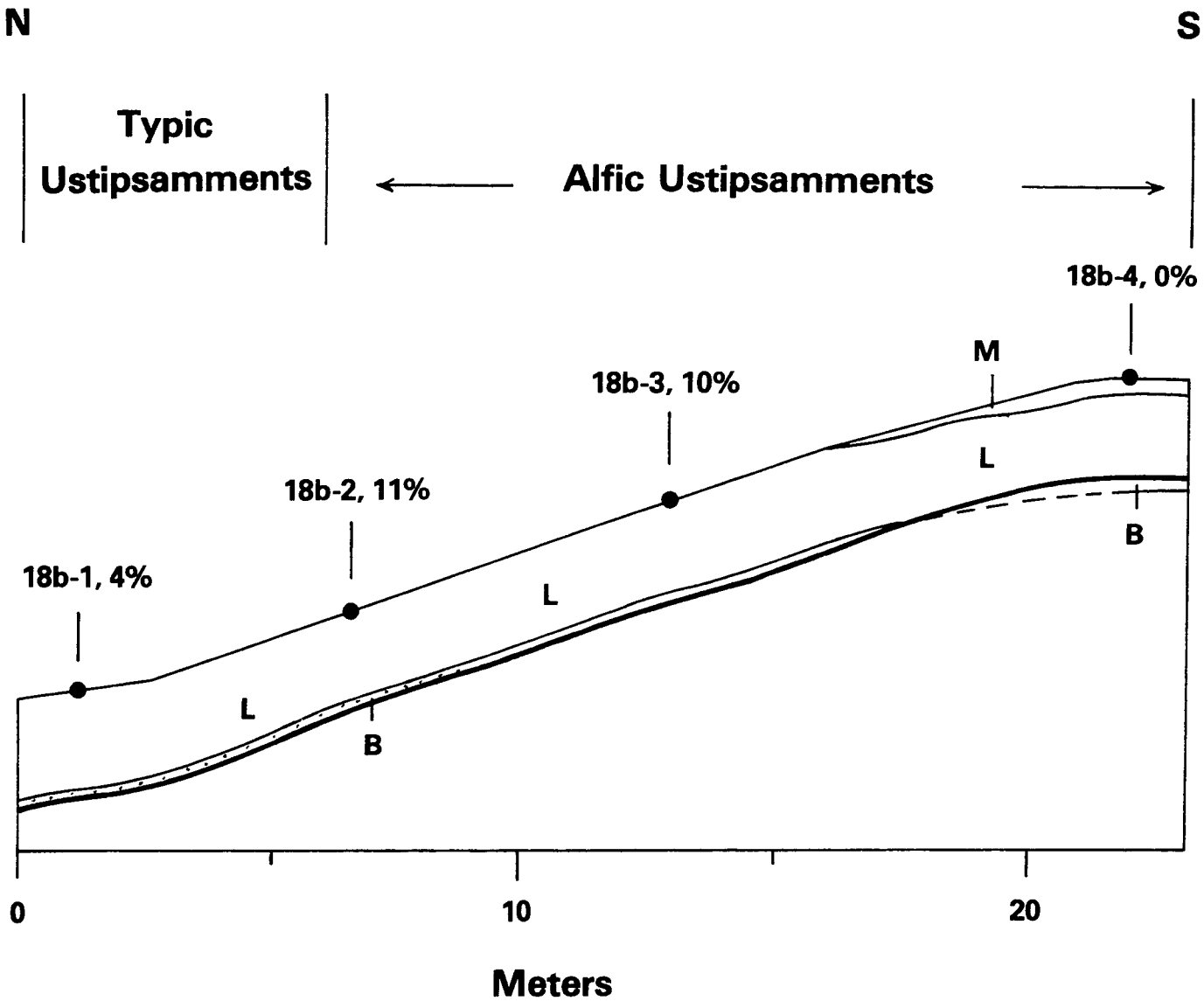


Figure 58. Diagram of the study trench at Site 18b, showing stratigraphy, subgroups, slope and location of the sampled pedons. M = Muleshoe, L = Longview, B = Birdwell. Black dots just below the top of the Birdwell sediments locate the top of a yellowish mottled zone. South of about 8 m the Btb horizon descends below the bottom of the trench. No vertical scale (see table 24 for thickness of sediments and horizons). The heavy lower line represents the bottom of the trench.

sediments are at the surface over the remainder of the exposure.

Pedon 18b-1 has a buried argillic horizon with texture of fine sand from 50 to 100 cm depth (Btb horizon, table 24), and is the Typic Ustipsamment Tivoli, thin variant #1. All other soils have clay bands and are Alfic Ustipsamments (fig. 58). All soils exposed in the trench have distinct A1 horizons, but horizons beneath differ markedly. In the lower part of the dune, a zone of yellowish mottles is in the buried Bt horizon of Birdwell age (fig. 58).

Lower side of dune. A2 horizon variation; clay band obliteration; mottles; past water tables. Important morphological changes take place on the lower side of the dune, in the vicinity of Pedons 18b-1 and 18b-2 (fig. 58, table 24). Both A2 horizon material and clay bands are discontinuous in Pedon 18b-1 (table 24). Upslope the B&A2 horizon changes to a thick A2 horizon in Pedon 18b-2 (table 24); in addition, volumes of light-colored A2 horizon material descend through the B horizon and join with the buried A2 horizon of Birdwell age.

That the A2b horizon in Pedon 18b-2 is in fact a buried A2 horizon is indicated by its light-colored, leached appearance; its continuity along the trench; and by the fact that upper horizons in protected situations can be buried with little or no erosion (see also Sites 18b-4, 33, 38, and 39). The occasional joining of land-surface and buried A2 horizons suggests that the soil is deeply leached at times under the present climate.

Mottles in the buried soil of Birdwell age (fig. 58) and hydrological data (Cronin, 1969) indicate that a water table must have been present at times during soil development, probably during minor pluvials of the early Holocene. Lateral movement from surface water can be augmented by lateral movement of the water table (Gile, 1958); effectiveness of this lateral movement should be enhanced if the materials differ in texture (Miller, 1963), as these do. Thus lateral movement of soil moisture would be expected at times in the buried A2 horizon because it overlies a Bt horizon that contains more clay and that is less pervious.

In Pedon 18b-2, two clay bands occur in the B&Bt horizon at 50-59 cm depth. Soil characteristics between Pedons 18b-1 and 18b-2 suggest an explanation for the disappearance of the two bands downslope towards Pedon 18b-1. Downslope the upper band comes closer to the surface, thins and then disappears within a distance of 1 m from Pedon 18b-2. Due to surface proximity the band did not form (see also Sites 1, 3, and 27).

Another mechanism appears to have been involved in disappearance of the lower of the two clay bands at Pedon 18b-2. As the upper band disappears towards Pedon 18b-1, the lower band drops to the top of the buried soil. At that point, the buried A2 horizon becomes browner, contains fewer light-colored A2 zones, and 1 1/2 m towards 18b-1 the light-colored zones above the buried soil stop altogether. This zone, which is quite uniformly brownish, apparently is a zone of clay accumulation related to lateral leaching along the buried A2 horizon upslope. At the point where the buried A2 horizon grades out, the slope is less than just south, being about 5 or 6 percent vs. 11 percent; this, together with the nearly level area just downslope, apparently cause clay accumulation rather than clay eluviation.

Table 24. Characteristics of Ustipsamments at Site 18b[1/]

Sediment	Horizon	Depth cm	Hue	Value/chroma Dry	Value/chroma Moist	Texture	Structure	Dry consistence	pH	Lower boundary
Typic Ustipsamment, Tivoli, thin variant #1, on lower side of dune; Pedon 18b-1[2/]										
Longview	A11	0-8	7.5YR	5/3	3/2	fs	m	sh	6.8	cw
	A12	8-15	10YR	6/3	3.5/2	fs	m	s	7.0	cw
	B&A2	15-38	7.5YR	6/2	4/2	fs	m	s,sh	7.0	cw
	B1	38-63	9YR	6.5/3	4.5/3	fs	m	sh,h	7.0	
	B2&Bt	63-80	9YR	6/4	4.5/4	s	m	sh,h	6.8	
Birdwell	Btb	80-102	9YR	6/4	5/4	ls	m	h	6.0	
Alfic Ustipsamment, Circleback, on side of dune; Pedon 18b-2[3/]										
Longview	A1	0-10	10YR	5/2	2.5/2	lfs	m	s	7.0	cw
	A21	10-23	9YR	6.5/3	4/3	fs	m	s	6.8	cw
	A22	23-39	9YR	7/3	5/3	fs	m	sh	6.8	cw
	A2&B	39-50	9YR	7/3	5/3	fs	m	h	6.8	as
	B&Bt	50-59	9YR	7/4	5/4	fs	m	h,vh	6.8	as
Birdwell	A2b&B	59-73	10YR	8/3	6.5/3	fs	m	h,vh	6.6	aw
	Btb	73-94	7.5YR	7/4	6/4	fs	lcsbk	vh	6.0	
Alfic Ustipsamment, Circleback, on side of dune; Pedon 18b-3[4/]										
Longview	A1	0-10	7.5YR	5/2	3/2	ls	m	s	7.2	cs
	A2	10-21	10YR	6/3	4/3	s	m	s	6.8	cs
	B1	21-34	7.5YR	6/4	4.5/4	s	lmsbk	sh	6.8	aw
	B21&Bt	34-52	7.5YR	6/5	4/5	s	lmsbk	sh,h	7.4	aw
	B22	52-94	7.5YR	6.5/4	5/4	s	m	sh,h	7.4	cw
	B3&Bt	94-118	7.5YR	7/5	5/4	s	m	sh	7.2	cw
Birdwell	A2b	118-137	10YR	8/4	6/4	s	m	sh	6.6	as
	Btb	137-147	7.5YR	6.5/4	5/4	s	lcsbk	vh	6.0	
Alfic Ustipsamment, Circleback, on south rim; Pedon 18b-4[5/]										
Muleshoe	A1	0-11	10YR	5/3	3/2	fs	m	s	7.2	cs
	A2	11-26	10YR	7/3	5/2	fs	m	s	7.0	cs
Longview	A1b	26-34	10YR	7/3	5/2	fs	m	s	6.8	cs
	A2b	34-50	10YR	7/3	5/2	fs	m	s	7.0	cw
	B1b	50-71	7.5YR	6.5/4	5/4	fs	m	sh,h	7.0	as
	B21&Bt	71-96	7.5YR	6.5/5	5/4	fs	m	h,vh	6.4	as
	B22b&Bt	96-135	7.5YR	7/6	6/5	s	m	h,vh	6.6	as
	B3b&Bt	135-180	7.5YR	7/5	6/5	s	m	sh	6.6	
Birdwell	A2b2	195-210	10YR	8/3	6/3	fs			6.6	

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

2/ A11: horizon also has lighter-colored parts. B&A2: parts 10YR 7/3, dry. B2&Bt: a few very discontinuous clay bands that appear to be in the process of disintegration. Btb: mottles of 7.5YR 6/8 and 10YR 7/3, dry, and occasional browner colors that may reflect accumulation of silicate clay.

3/ A1: some parts lighter-colored. A22: parts 9YR 6/3, dry. A2&B: occasional brownish volumes that appear to reflect accumulation of silicate clay. B&Bt: clay bands, 5YR 6/4, dry, ranging from 2 to 4 mm thick. (A2)&B: parts 10YR 7/3, dry. Btb: irregularly-shaped volumes 5YR 6/4, dry, which appear to be zones of greater clay accumulation. A few parts of 10YR 8/3 and 10YR 7/6, dry, are also present as irregular streaks one to several mm wide.

4/ A2: some parts slightly lighter and slightly darker than the given color. B21&Bt: clay bands 5YR 5/4, dry.

5/ A1b: parts 10YR 6/2, dry, and a few bits of 10YR 5/2, dry. A2b: a few slightly darker parts. B1b: parts 7/5YR 6.4, dry and 7.5YR 8/4, dry. B21&Bt: clay bands, 5YR 5/4, dry. B22b&Bt: clay bands, 5YR 5/4 and 5/6, dry. A2 : sampled by auger below the bottom of the trench.

Central side of dune. Longview deposits are thicker at Pedon 18b-3, which has a thinner A2 horizon and a thicker, redder B horizon than does Pedon 18b-2. Pedon 18b-3 lacks the thick A2 horizon that deeply extends into the B horizon just north, and marks the point of disappearance of this feature; the B&Bt horizon is mostly reddish brown throughout. Thus the combined deeply penetrating plus lateral movement appears to be much less at Pedon 18b-3. Greater depth to the buried B horizon and higher position on the slope (resulting perhaps in less lateral leaching) may be factors in the different expression of these horizons. But the prominent buried A2 horizon of Birdwell age is still present.

There are two continuous clay bands, and one discontinuous band in the B21&Bt horizon. The bands are 2-3 mm thick. Clay bands, not present in the B22 horizon of Pedon 18b-3, do appear laterally in this horizon. Two bands, about 2 mm thick, are present in the B3&Bt horizon but in places are absent laterally.

The mottled zone occurs continuously along the top of the buried Bt horizon (fig. 58). Just south of Pedon 18b-2, part of the yellow color changes to brown, suggesting improved drainage, but substantial yellow is still present at about 8 m along the trench (fig. 58).

Towards Pedon 18b-4 upslope, the Longview sediments and soil are buried by Muleshoe sediments (fig. 58). The buried A horizon could be readily and continuously traced along the exposure. North of the boundary between Muleshoe and Longview sediments, the soil surface is covered with oak leaves. South of the boundary, both sand and oak leaves are at the surface.

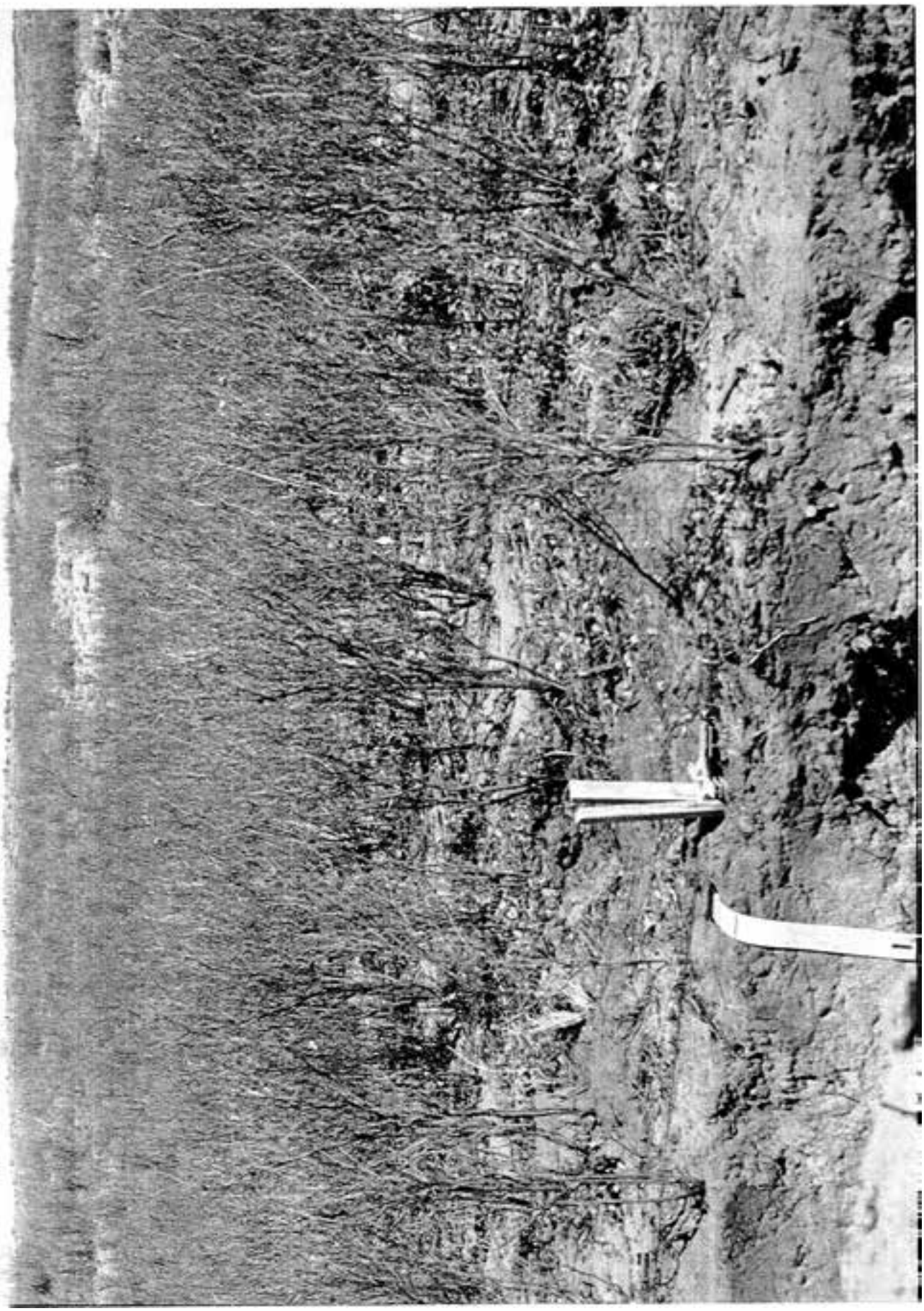
Dune crest. Pedon 18b-4 (fig. 59) occurs on the level south crest, where a thin Muleshoe deposit, with A1 and A2 horizons, buries the Longview sediments and soil. Because the Muleshoe deposit lacks diagnostic horizons and is <50 cm thick, soil classification is based on the buried soil, which is the Alfic Ustipsamment, Circleback. The Muleshoe deposit and buried soil of Longview age continue southward to at least the end of the trench (fig. 58).

Longview sediments are at their maximum thickness at the dune crest. Three continuous clay bands occur in the B21&Bt horizon; the upper and middle ones are about 2 mm thick and the lower one is about 5 mm thick. Four continuous bands occur in the B22&Bt horizon. The upper three are 2 mm thick and the lower one is 2-5 mm thick. The bands are from 6-10 cm apart. The B3b&Bt horizon has only a few very thin bands.

Clay band development is much more prominent at the dune crest than on the dune side below. This is attributed to lack of strong lateral leaching on the dune crest, and greater depth to the buried soil. This contrasts to other sites where clay bands become thicker and more numerous with increasing distance down the side of the dune (see Sites 3 and 32). Subsurface leaching, as previously discussed, is thought to be responsible for the decrease in clay band expression downslope.

Site 18c, east side of dune and dune crest

Figure 60 shows slope, stratigraphy, soil occurrence, and location of the sampled pedons at Site 18c. Characteristics of the sampled pedons are in table 25.



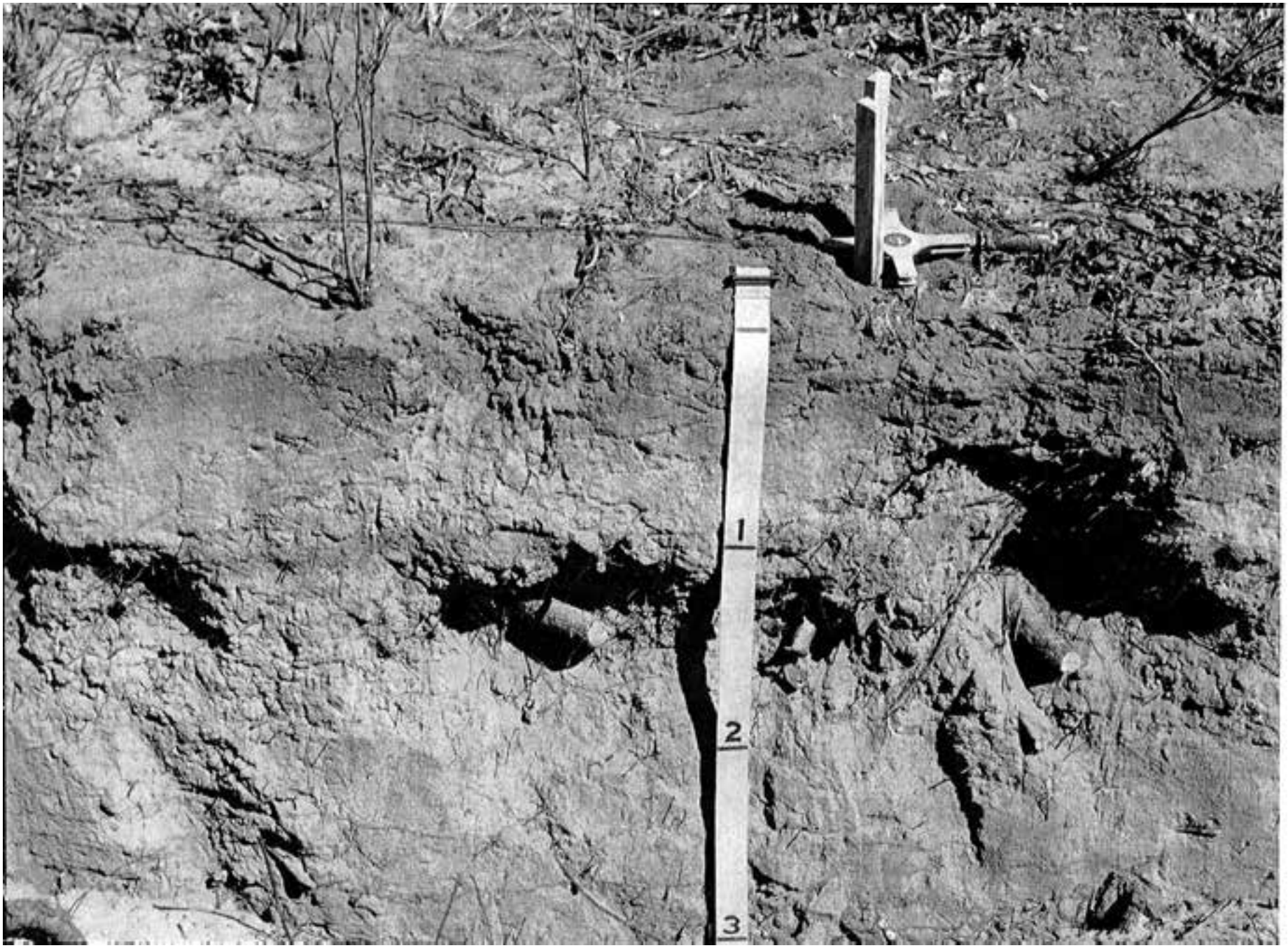


Figure 59. Upper. Landscape along south rim of dune at Site 18b. The view is east. Photographed November 1977.

Lower. The Alfic Ustipsamment, Circleback, Pedon 18b-4. Most of the buried A horizon (at about 1 ft, 0.3 m depth) has fallen in but parts remain at left. Scale is in feet.

Lower side of dune. Pedon 18c-1, on the lower side of the dune, is a Typic Ustipsamment (Tivoli, thin variant #1) since textures are sandy to a depth of more than 1 m. Upper horizons have the weak morphology typical of Muleshoe sediments. The B2b horizon has occasional clay bands and small volumes of irregular shape and may have been discontinuously impregnated with clay that moved laterally from upslope, as discussed previously at Site 18b.

Central side of dune. Mottles, past water tables. The Muleshoe sediments thin upslope and at Pedon 18c-2 (fig. 61) the buried argillic horizon is close enough to the surface (within 50 cm) to determine the classification. The argillic horizon averages sandy in the upper 50 cm and the pedon is a Psammentic Haplustalf (Texico series). A clay band horizon (A2b&Bt horizon, table 25) occurs beneath the argillic horizon. The interband zones have a whitish, leached appearance; clay is thought to have been moved downslope through these zones by laterally moving water, with some clay moving into underlying bands as the soil solution slowed and then dried.

Yellowish mottles, similar to those at Site 18b, deepen in upslope direction (fig. 60). The mottles are attributed to presence of a water table as discussed at Site 18b. In contrast to Site 18b, here the trench descends well below the top of Birdwell sediments, and the relation between depth of mottling and the soil of Birdwell age is apparent. Only the lower

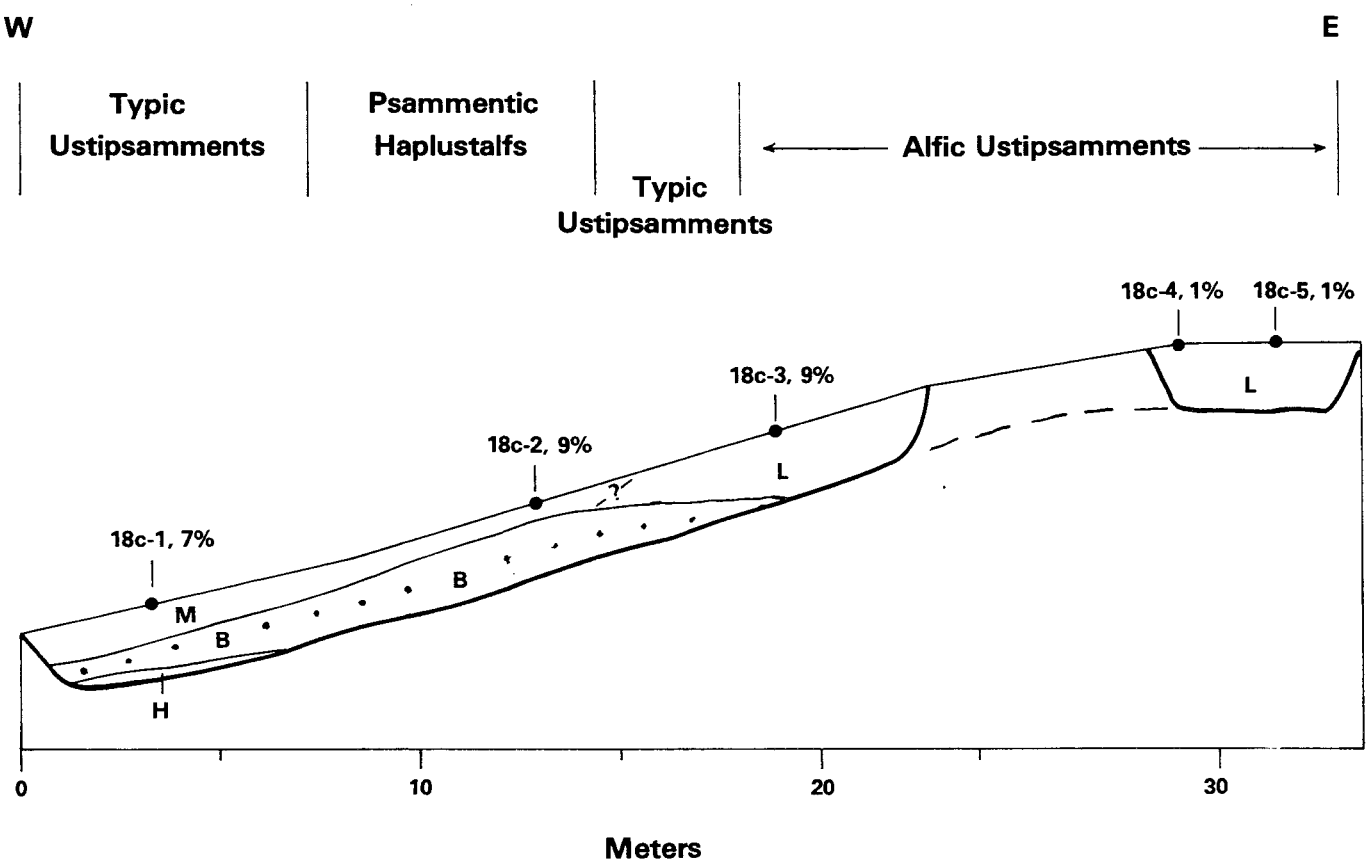


Figure 60. Diagram of the study trench at Site 18c, showing stratigraphy, subgroups, slope and location of the sampled pedons. M = Muleshoe, B = Birdwell, L = Longview, H = Hale. Black dots represent the top of a yellowish, mottled zone. East of about 18 m, the mottled zone descends below the bottom of the trench. No vertical scale (see table 25 for thickness of sediments and horizons). The heavy lower line represents the bottom of the trench.

Table 25. Characteristics of Ustipsamments and a Haplustalf at Site 18c 1/

Sediment	Horizon	Depth cm	Hue	Value/chroma Dry	Value/chroma Moist	Texture	Structure	Dry consistence	pH	Lower boundary
Typic Ustipsamment, Tivoli, thin variant #1, on lower side of dune: Pedon 18c-1 2/										
Muleshoe	A11	0-10	7.5YR	5/3	3/3	s	m	s	6.8	cw
	A12	10-24	7.5YR	5/3	3/3	fs	m	s	7.0	cw
	B2	24-68	7.5YR	6/4	4/4	fs	m	s,sh	7.0	cs
Birdwell	Bb	68-87	10YR	6.5/3	5/3	ls	lcsbk	h	7.2	cs
	B21b	87-107	10YR	6.5/3	5/3	s	lcsbk	vh	7.0	cs
	B22b	107-118	7.5YR	6/4	5/4	s	lcsbk	vh	6.8	cs
Hale	Bb2	118-125	5YR	6/4	5/4	ls	lcsbk	vh	6.6	
Psammentic Haplustalf, Texico, on side of dune: Pedon 18c-2 3/										
Muleshoe	A11	0-11	7.5YR	5/3	3/2	fs	m	s	7.4	cw
	A12	11-31	10YR	6/3	4/3	fs	m	s	7.0	cw
	B1b	31-48	9YR	6.5/3	5/3	fs	m	sh	7.0	cw
Birdwell	B21tb	48-62	9YR	6.5/4	5/4	lfs	lcsbk	vh	6.2	cw
	B22tb	62-71	9YR	6.5/4	5/4	fs	lcsbk	vh	6.2	cw
?	A21b	71-86	10YR	8/4	6/4	s	m	sh,h	6.4	cw
	A22b&Bt	86-130	10YR	8/3	6/4	s	m	h	6.2	as
	A23b	130-140	10YR	8/3	7/3	s	m	vh	6.6	
Alfic Ustipsamment, Circleback, on side of dune; Pedon 18c-3 4/										
Longview II	A1	0-9	10YR	6/4	4/3	s	m	s	7.2	cw
	B&A	9-30	10YR	7/6	5.5/4	s	m	s	7.0	cw
	B1	30-45	7.5YR	6/4	4.5/4	s	m	sh	7.0	as
	B2&Bt	45-56	7.5YR	7/4	5/4	s	m	sh	7.0	as
	B3&Bt	56-97	7.5YR	7/4	5/4	s	m	h	6.8	cw
	B21b&Bt	97-118	7.5YR	7/4	5/4	s	m	sh,h	6.8	
	B22b&Bt	118-127	7.5YR	7/4	5/4	s	m	sh,h		
Alfic Ustipsamment, Circleback, on dune crest; Pedon 18c-4 5/										
Longview		3-0 - oak leaves and twigs								
	A1	0-15	9YR	5/3	3/3	s	m	s	7.0	cw
	A2	15-28	9YR	7/4	5/4	fs	m	s	6.4	cw
	B1	28-49	5YR	6/4	5/4	s	m	sh	6.8	aw
	B21&Bt	49-69	5YR	6/4	5/4	s	m	sh	6.8	as
	B22&Bt	69-94	6YR	6.5/4	5/4	fs	m	sh	6.8	as
	C	94-114	6YR	6.5/4	5/4	fs	m	sh	6.6	
Alfic Ustipsamment, Circleback, on dune crest; Pedon 18c-5 6/										
Longview	A11	0-14	7.5YR	5/3	3/3	fs	m	s	6.8	cw
	A12	14-30	7.5YR	6/4	4/3	fs	m	sh	6.8	cw
	B1	30-44	7.5YR	6.5/4	5/4	fs	m	sh	6.8	aw
	B21&Bt	44-65	7.5YR	6.5/5	5/4	fs	m	sh	6.8	aw
	B22&Bt	65-88	7.5YR	6.5/5	5/4	fs	m	sh	6.8	aw
	C	88-106	7.5YR	6.5/5	5/4	fs	m	s	6.6	

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

2/ Bb: parts 7.5YR 5/3, dry. B21b: parts 10YR 8/2, dry, and 7.5YR 7/8, dry. Bb2: parts 2.5YR 5/3, dry, and 7.5YR 7/6, dry.

3/ B22bt: parts with slightly higher value and parts with higher chroma. A22b&Bt: clay band, 5YR 5/4, dry. A23b: parts 10YR 7/6, dry.

4/ B21b&Bt: clay bands that are thicker and more distinct than above.

5/ A1, B1, B21&Bt, and B22&Bt: few parts with about the same color as the A2 horizon. A2: few parts with about the same color as the A1 horizon.

6/ B2&Bt: clay bands, 5YR 5/4, dry.

Figure 61. View of the study trench at Site 18c. The tape is at Site 18c-2. Note that the Birdwell sediments, dark band this side of tape, dip downward upslope where they are buried by Longview sediments. The view is west. Photographed November 1976. Scale is in feet.

part of this soil is mottled near the dune crest that existed in Birdwell time, reflecting better drainage in the dune-crest position.

The Longview sediments thicken upslope. At 14.6 m (fig. 60) the top of the argillic horizon descends below 50 cm; classification is again based on the 0-50 cm zone and the soils are Psamments. This area must have been very near the dune crest in Birdwell time (fig. 61). Later the Birdwell sediments were buried by deposits of Longview age, resulting in the present, substantially higher dune crest.

At the point where the banded B horizon of Longview age becomes visible, the buried Bt horizon of Birdwell age descends and finally dips below the bottom of the trench. The Bt horizon of Birdwell age becomes progressively harder as it gradually descends further below the surface. As discussed at Sites 4-7, this increase in hardness is apparently due to less biotic activity at the greater depths.

Pedon 18c-3 (fig. 61, table 25) is an Alfic Ustipsamment in Longview II and I sediments. The banded B horizon from 97-127 cm is more prominent and is thought to be of Longview I age.

Dune crest. Alfic Ustipsamments in Longview sediments are on the crest of the dune (fig. 60). Pedons 18c-4 (oak vegetation) and 18c-5 (nonoak vegetation) are on the margin of the dune crest (fig. 62, table 25). The A1 horizon of Pedon 18c-4 has light-colored, circular parts in cross section that contrast with the darker adjacent material. The B horizon also has occasional light-colored zones, of irregular shape and 1 to 5 cm in diameter. These light-colored zones are interpreted as fillings of rodent burrows.

Pedon 18c-4 has an A2 horizon that is lighter in color than the analogous horizon under nonoak vegetation, and also has lower pH. The clay bands are generally similar under both types of vegetation, and there is also good gradation to C horizon material beneath the bands under both types. As usual there are more roots under the oak than under nonoak, although the roots here are not as prominent as in some oak patches.

In Pedon 18c-5, the B21&Bt horizon usually has two bands 1-2 mm thick but they disappear in places along the exposure. The B22&Bt horizon has the most bands, usually about five. They are about 2 mm thick in the upper part of the horizon and about 1 mm thick in the lower part.

Particle size distribution and pH for soils under oak and nonoak vegetation

Table 26 shows particle size distribution for Pedon 18c-4, under oak, and for Pedon 21, under nonoak vegetation. For Pedon 18c-4, percentages of silt and clay are slightly higher in the surface horizon than in underlying horizons, and are similar to soils of Muleshoe age in this respect (table 14). This higher percentage of silt and clay is particularly the case under oak vegetation, which, with its mulch of oak leaves and twigs, serves as a sort of "trap" for silt and clay in the dustfall. In contrast, the surface horizon of Pedon 21 contains less silt and clay than the underlying horizon. But the surface horizon of some older soils of dune crests and under nonoak vegetation do have more silt than underlying horizons (see Sites 28, 29, and 38).

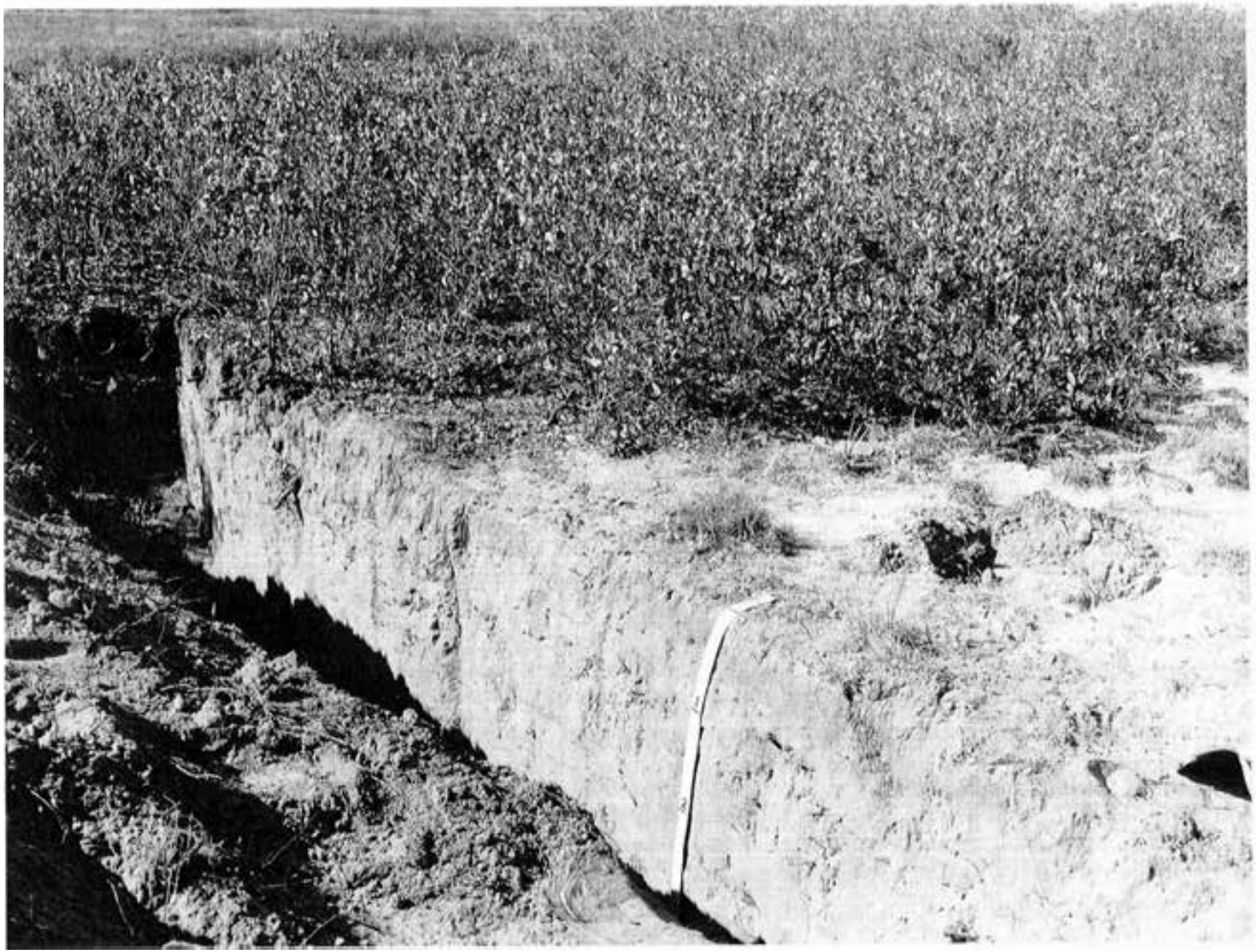


Figure 62. Landscape of the Longview surface at Sites 18c-4 and 18c-5. The trench is the initial one in the dune crest. Pedon 18c-4 is under the oak, at left, and Pedon 18c-5 is under nonoak vegetation by the tape at right. Photographed November 1976. Scale is in feet.

Table 26. Particle size distribution and pH for Alfic Ustipsamments (Circleback) under oak and nonoak vegetation[1/]

Horizon	Depth	Particle size distribution, mm: Sand 2-1	1-0.5	0.5-0.25	0.25-0.1	0.1-0.05	Silt 0.05-0.002	Clay <0.002	Textural class	pH
	cm	%								
Pedon 18c-4,S78TX-17-1, under oak vegetation [2/]										
A1	0-15	0.3	9.6	28.5	46.3	7.5	4.6	3.2	s	6.9
A2	15-28	0.2	8.7	27.1	52.5	7.3	1.8	2.4	fs	6.3
B1	28-49	--	7.7	34.1	48.3	5.8	1.3	2.8	s	6.7
B21&Bt	49-69	0.1	8.8	31.0	49.3	5.9	1.7	3.2	s	6.7
B22&Bt	69-94	0.1	9.3	27.3	50.0	8.7	2.6	2.0	fs	6.7
C	94-114	0.2	8.1	26.3	51.5	9.3	3.0	1.6	fs	6.4
Pedon 21, S78TX-17-2, under nonoak vegetation [3/]										
A11	0-5	--	6.3	31.9	50.7	6.4	2.3	2.4	fs	7.0
A12	5-16	--	4.4	22.5	59.3	8.6	2.4	2.8	fs	6.9
B11	16-25	--	3.0	20.4	57.8	13.5	2.1	3.2	fs	6.7
B12	25-32	--	4.2	23.1	59.1	9.0	1.8	2.8	fs	6.7
B21&Bt	32-53	--	4.4	23.2	58.8	9.6	2.0	2.0	fs	6.7
B22&Bt	53-71	--	3.9	22.1	51.4	10.3	9.5	2.8	fs	6.7
B23&Bt	71-86	--	3.2	12.9	69.3	10.9	1.7	2.0	fs	6.9
B3&Bt	86-106	0.2	10.3	22.5	48.7	11.3	5.1	1.9	s	6.6
C	106-128	0.1	8.8	20.9	51.9	13.4	3.3	1.6	fs	6.2

1/ Particle size distribution is by method 3A1; pH by method 8C1a (1:1 H_2O); (Soil Conservation Service, 1972).

2/ The B21&Bt horizon usually has two discontinuous clay bands, 1 to 2 mm thick. The B22&Bt horizon has the most clay bands - usually about five - and they are continuous. In the upper part of the horizon the bands are about 2 mm thick but are thinner (about 1 mm thick) in the lower part.

3/ The B2&Bt horizon has six continuous clay bands: two in the B21&Bt, three in the B22&Bt, and one in the B23&Bt horizon. The bands are 5YR 5/4, dry, and most are from 2 to 3 mm thick. The B3&Bt horizon has two discontinuous bands about 1 mm thick.

A slight maximum in silicate clay occurs in the clay band horizon of both pedons (table 26). In general, however, there is little difference in total clay content as compared to the soils of Muleshoe age (table 14). Although most clay bands are continuous and some are thicker than in soils of Muleshoe age, the bands do not contribute greatly to the total clay content of the horizon in which they occur. Clearly, clay bands are very sensitive morphological indicators of slight clay accumulation.

Both pedons contain high percentages of fine sand. Textures of all horizons are either fine sand, or sand that is near the margin to fine sand.

In upper horizons, pH is lower under oak than under nonoak vegetation, but for deeper horizons, pH is similar for both soils. The pH of the A2 horizon in the soil under oak is lower than pH of the horizon in the same position under nonoak vegetation.

Site 19, dune crest; oak-nonoak transition

The dune crest at Site 18c, discussed in the previous section, extends eastward as a long dune ridge at about the same elevation. All soils at Site 19 have formed in sediments of Longview age, and no evidence of post-Longview sediments can be seen.

The study trenches at Site 19 (fig. 40, table 27) are across an oak-nonoak contact (Pedon 19a and 19b) and in a nonoak area just east (Pedon 19c). Fine strata, about 1 mm thick, are apparent in much of the Bt

Table 27. Characteristics of Alfic Ustipsamments, Circleback, on the crest of a Longview dune at Site 19[1/]

Horizon	Depth cm	Hue	Value/chroma Dry	Value/chroma Moist	Texture	Structure	Dry consistence	pH	Lower boundary
Pedon 19a, oak[2/]									
A1	0-12	7.5YR	5/3	3.5/3	s	m	s	7.2	cs
A2	12-36	7.5YR	6/3	4.5/3	s	m	s	6.8	
A2&Bt	36-60	7.5YR	6.5/4	5/4	s	m	s	6.6	
B21&tb	60-71	5YR	6.5/4	5/4	s	m	sh	6.4	aw
B22&Bt	71-100	6YR	6.5/4	5/4	s	m	sh	6.6	as
B23&Bt	100-138	6YR	7/4	5.5/4	s	m	sh	6.6	as
C1&Bt	138-150	7.5YR	6/4	4.5/4	s	m	sh	6.6	cw
C2	150-168	7.5YR	6/4	4.5/4	s	m	s,sh	6.8	
Pedon 19b, nonoak[3/]									
A1	0-20	7.5YR	5/3	3.5/3	s	m	s	7.0	cw
A2	20-37	7.5YR	6/3.5	4.5/3	s	m	s	7.0	as
A2&Bt	37-62	7.5YR	6/4	4/4	s		s	7.0	as
B21&Bt	62-77	5YR	6.5/4	5/4	s	m	s sh	6.8	aw
B22&Bt	77-101	6YR	6.5/4	5/4	s	m	s,sh	6.8	aw
B3&Bt	101-118	7.5YR	6.5/4	5/4	fs	m	sh	6.8	aw
C	118-148	7.5YR	6.5/4	5/4	fs	m	s,sh	6.8	
Pedon 19c, nonoak[4/]									
A1	0-20	7.5YR	5/3	3.5/3	s	m	s	7.0	cw
A2	20-40	7.5YR	6.5/3.5	4/3.5	s	m	s	7.0	aw
A2&Bt	40-52	7.5YR	6.5/4	5/4	s	m	s,sh	6.8	as
B2&Bt	52-84	7.5YR	6.5/4	5/4	s	m	sh	6.8	as
B3&Bt	84-104	7.5YR	6.5/4	5/4	s	m	s,sh	6.8	as
C	104-141	7.5YR	6.5/4	5/4	s	m	s,sh	6.8	

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

2/ A2&Bt and B2&Bt: clay bands 5YR 5/4, dry. B3&Bt: clay bands 6YR 6/4, dry.

3/ A2&Bt and B&Bt: clay bands 5YR 5/4, dry.

4/ A2&Bt and B2&Bt: clay bands are 5YR 5/4, dry. B3&Bt: clay bands 5YR 5.5/4, dry.

horizon of all three pedons. The strata are not apparent in the A1 and most of the A2 horizons, and in these horizons have apparently been obliterated by biotic mixing. Also present in all three pedons are volumes of light-colored material, one to several centimeters wide and roughly circular to elongate in the cross section. Some of these light-colored parts are isolated and occur in no particular pattern; others occur vertically and descend irregularly through the B horizon. These features are interpreted as fillings of former root channels and rodent burrows.

In soils of Muleshoe age, and at Site 18c discussed earlier, little or no difference in morphology and number of clay bands is apparent across oak-nonoak contacts. But at Site 19 distinct differences are apparent.

Pedon 19a, under oak.

The clay band horizon under oak is thicker and more prominent than the one under nonoak vegetation. Some of the individual clay bands are also thicker under oak. The A2 horizon of Pedon 19a is lighter-colored in part

and has lower pH than the soils under nonoak vegetation. Soils of Longview age under (long-standing?) oak vegetation have the most prominent A2 horizons in the study area; see Site 22 for a photograph of an example.

The A2&Bt horizon has clay bands that are thin and discontinuous. In the A2 material the sand is prominently light-colored, as though clay had been stripped from the grains. There are also a few light-colored zones in the B2&Bt horizon, suggesting some stripping of grains even there.

Because these morphological differences coincide with the oak-nonoak boundary, they are attributed to the differences in vegetation. The mulch of oak leaves and twigs should trap more clay from dustfall, and could explain the more prominent clay band horizon. The morphological differences suggest that the boundary between oak and nonoak has been stable for a substantial, but unknown period of time.

The distinctive morphological evidence of clay stripping has been observed in another soil of Longview age (Site 22) and in a number of soils of Pleistocene age (for an illustration and discussion, see Gile, 1981, p. 27, 28 and 41). In soils of middle and late Holocene age, the feature of clay stripping has been observed only in soils that are under oak vegetation and that have clay only in banded form.

Clay stripping in soils with continuous Bt material, as contrasted to clay bands, has been observed only in soils of early Holocene or Pleistocene age that have been preserved by burial. The weathering of the middle and late Holocene apparently has not been sufficiently rigorous for clay stripping in continuous Bt horizons. The converse appears to be true; the consistent occurrence of Bt material in the upper part of the Bt horizon of land-surface soils indicates clay illuviation (instead of clay stripping) in these Bt horizons. All this is additional evidence of a stronger leaching regime in the early Holocene and in the Pleistocene than exists today (see Site 14-17 for additional evidence).

The A2&Bt horizon (table 27) has three clay bands 1 mm thick near the center of the horizon. The B21&Bt horizon has two clay bands, the upper one being nearly 1 cm thick and the lower one several mm thick. The upper 11 cm of the B22&Bt horizon has no bands; a band about 1 cm thick is from 82-83 cm depth. From 83-98 cm there are two indistinct, discontinuous bands.

The B23&Bt horizon has six clay bands, ranging from 1 to 5 mm thick, at depths of 102, 106, 115, 119, 131, and 139 cm. The 4th and 5th bands are the thickest (4-5 mm). Clay bands of this zone become thinner and then disappear under the grass. The B3&Bt horizon has several bands, 1-2 mm thick, faintly expressed and not present under grass. The C horizon has no clay bands.

Pedon 19b, under nonoak vegetation

Although the A2 horizon extends from the oak into the nonoak, the clay bands tend to be thinner under grass than under oak, and also have more undulations. The lowermost clay bands under oak thin towards the grass and finally disappear.

The A2&Bt horizon (table 27) has three clay bands, about 2 mm thick. The B21&Bt horizon has three clay bands: two are ½ cm thick and one is 1-2 mm

thick. The B22&Bt horizon has four clay bands, 3-4 mm thick, at 77, 83, 97, and 100 cm depths; there are many undulations. The B3&Bt horizon has two clay bands, 1 mm thick, at 104 and 117 cm depths. No bands occur in the C horizon.

Pedon 19c, under nonoak vegetation

Pedon 19c is under nonoak vegetation and is about 6 m further east along the ridge crest. This pedon is similar to Pedon 19b, but the clay band horizon is thinner (table 27). A third study trench under nonoak vegetation, 25 m further east along the ridge crest, was not sampled, but the soil was very similar to the other two pedons under nonoak vegetation.

Sites 20-22, dune crests

Site 20

Site 20 (figs. 40, 63; table 28) occurs on a slight ridge of Birdwell sediments. There is no A2 horizon, and the present A1 horizon is not particularly low in clay. But it is thought that thicker, coarser horizons were once present, as they now are in younger soils at stable sites. The sand texture and surficial position of such A horizons would have made them susceptible to erosion. Thus post-Birdwell erosion could have stripped the original A horizon, leaving the finer-textured and more resistant B horizon at the surface. The present A1 horizon (so designated because of its position, color, and accumulation of organic carbon) may have formed in what was once a B horizon.

Table 28. Characteristics of a Psammentic Haplustalf, Texico, on the crest of a Birdwell dune at Site 20

Horizon	Depth cm	Hue	Value/chroma Dry	Value/chroma Moist	Texture	Structure	Dry consistence	pH	Lower boundary
A1	0-4	9YR	5/3	3/3	lfs	m	s	7.0	as
B1t	4-18	7.5YR	5/4	3/3	lfs	m	sh	7.0	as
B2t	18-35	5YR	5.5/4	4/4	ls	lcsbk	h	7.2	as
B3t	35-59	6YR	6/4	4.5/4	s	lcsbk	sh	7.0	cw
C	59-73	7.5YR	6.5/5	5/5	s	m	sh	7.0	as
A1b	73-83	7.5YR	5.5/3	4/3	s	m	sh	6.8	cw
A2b	83-112	7.5YR	6.5/4	5/4	s	m	sh	7.0	as
B2tb2	112-125	5YR	5/4	4/4	scl	lcsbk	vh	6.8	

Development of the Bt horizon is most prominent in the level-transversely crest of the slight dune. The Bt horizon is continuous, though thin, and the soil as a whole is similar to soils of other dunes of Birdwell age (see Chapter 7). Clay bands in the Bt horizon are thin (2-3 mm) except for one at 22-23 cm depth, which is about 1 cm thick. A band at 31 cm is

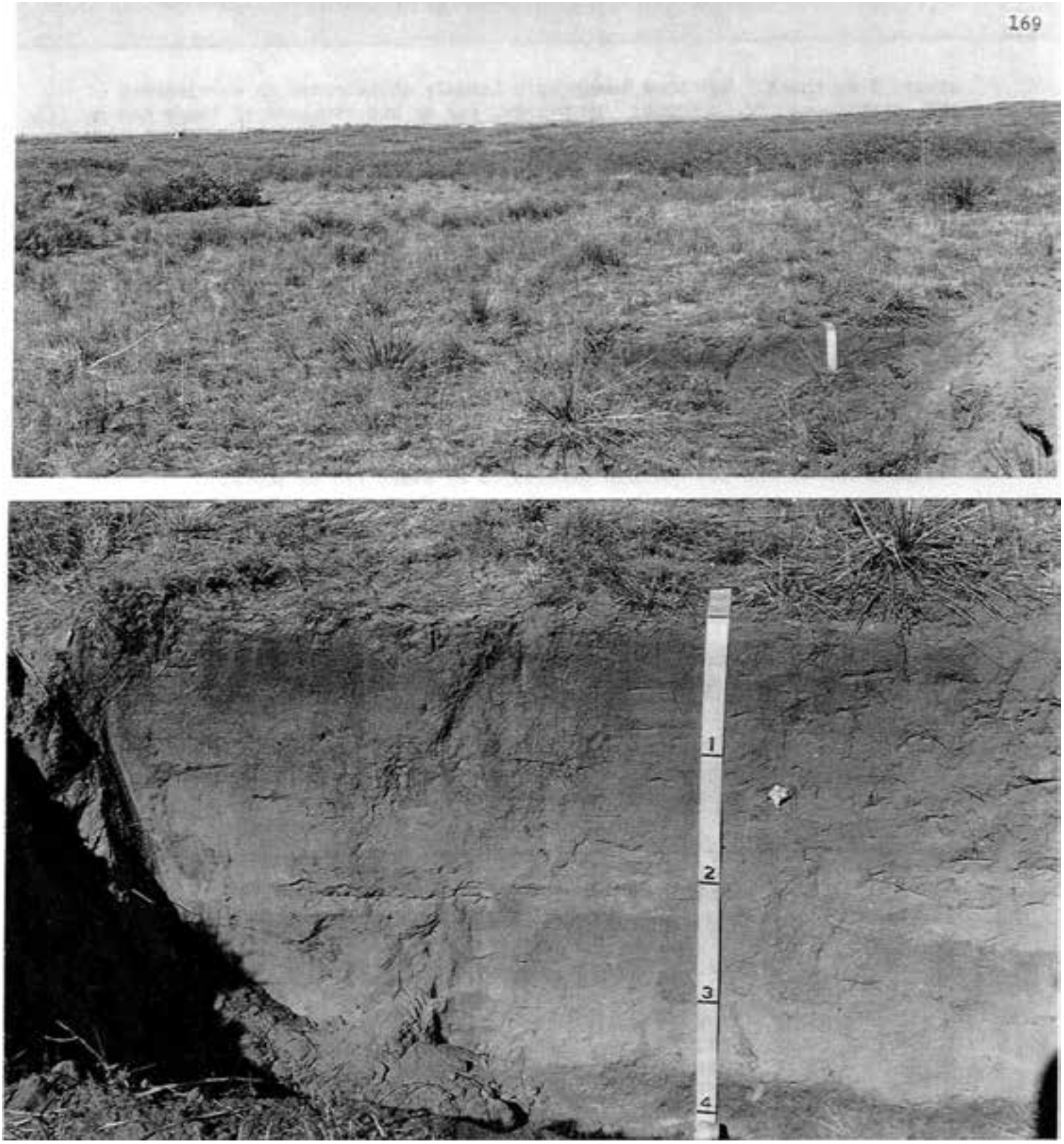


Figure 63. Upper. Landscape view of the low Birdwell dune at Site 20. The view is north. Photographed November 1976.

Lower. The Psammentic Haplustalf, Texico, at Site 20. Birdwell sediments extend to slightly below 2 ft (0.6 m) depth, and are underlain by an A horizon of apparent Hale age. Scale is in feet.

about 2 mm thick. But some bands were largely obliterated in development of the continuous Bt horizon; in places, one or two remnants of bands can be observed in the upper part of the Bt horizon. One clay band, about 1 mm thick and discontinuous, has formed along the contact between the B32 and the A1b horizon.

The buried A1b horizon appears to be a valid A1 horizon associated with the soil of Hale age. A similar dark horizon was noted at Site 28. At first it seems surprising that such a coarse-textured surficial horizon was not removed by wind erosion; but broad crests of some dunes may be sites of little or no erosion prior to deposition (see Sites 1b and 18b).

Two crotovinas are apparent in the buried A2b horizon (fig. 63). One, about 9 cm diameter, is filled with brown, fine earth. Another, about the same size, is filled with reddish material similar in color to the Bt above. The buried Bt horizon is of Hale age and mottled in part but mostly reddish with some black (Mn, Fe?) spots. Augering below the base of the trenches showed the Btb horizon extends to at least 170 cm depth.

Site 21, dune crest

Site 21 (fig. 40) represents an area apart from the main area of Longview sediments, and illustrates their sporadic nature in the southern part of the area of occurrence.

Particle size distribution and pH for Pedon 21 were given in table 26; table 29 gives other characteristics.

Table 29. Characteristics of the Alfic Ustipsamment, Circleback, on crest of Longview dune at Site 21

Horizon	Depth cm	Hue	Value/chroma Dry	Value/chroma Moist	Texture	Structure	Dry consistence	Lower boundary
A11	0-5	7.5YR	6/3	4/3	fs	m	s	as
A12	5-16	7.5YR	5/4	3.5/4	fs	m	s	cw
B11	16-25	5YR	6/4	4/4	fs	m	s	cw
B12	25-32	5YR	6/4	4/4	fs	m	sh	as
B21&Bt	32-53	5YR	6/4	5/4	fs	m	sh	as
B22&Bt	53-71	5YR	6/4	5/4	fs	m	sh	as
B23&Bt	71-86	5YR	6/4	5/4	fs	m	sh	aw
B3&Bt	86-106	6YR	6/4	4.5/4	s	m	sh	cw
C	106-128	6YR	6/4	4.5/4	fs	m	sh	

Site 22

Site 22 (figs. 40 and 64; table 30) occurs on the crest of a blowout dune of Longview age. The sampled pedon (S75TX-17-6, table 30) is in Soil Moisture Site 6 (Appendix). A landscape view has been presented (Gile, 1979, p. 999). A buried soil of Birdwell age occurs in the lower part of Pedon 22; sedimentary strata are preserved in the overlying B3&Bt horizon.

Table 30. Characteristics of the Psammentic Haplustalf, Texico S75TX-17-6, on the crest of a Longview dune at Site 22[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	Organic C	Ext. Fe	Bulk density	pH	Textural class	Dominant dry color
		cm	%									g/cc			
L	A1	0-12	0.1	4.3	21.4	51.4	13.6	6.6	2.6	0.81	0.2		7.0	fs	10YR 5.5/3
	A2	12-46	tr	5.9	25.9	56.3	9.1	2.4	0.4	0.13	0.2		6.8	fs	10YR 7/3
	A2&Bt	46-66	tr	5.9	27.4	54.4	6.7	2.2	3.4	0.11	0.2		6.7	fs	10YR 7/3
	B2&Bt	66-92	0.1	8.3	27.5	51.8	6.8	1.1	4.4	0.08	0.2	1.72	7.0	fs	5YR 6/4
	B31&Bt	92-112	0.1	10.6	29.2	48.0	6.6	1.3	4/2	0.05	0.2	1.71	7.0	s	6YR 6/4
	B32&Bt	112-131	0.2	7.2	26.9	50.6	9.4	1.7	4.0	0.09	0.2	1.72	6.5	fs	6YR 6/5
B	B1tb	131-141	0.1	6.3	23.8	49.7	9.6	1.4	9.1	0.07	0.3	1.70	6.4	ls	5YR 6/4
	B2tb	141-164	tr	6.3	21.7	47.5	7.8	2.8	13.9	0.11	0.4	1.78	6.1	fsl	2.5YR 5/6
	B31tb	164-205	0.2	10.9	26.7	45.1	5.9	3.5	7.7	0.04	0.3	1.78	6.4	ls	5YR 6/6
	B32tb	205-235	0.1	8.7	27.3	50.4	6.2	2.3	5.0	0.02	0.2	1.76	6.8	fs	5YR 6/6

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 : 1H_2O). L = Longview, B = Birdwell.

Most soils of Longview age do not meet the requirements of the argillic horizon, but this one does. Pedon 22 has the most prominent A2 horizon observed in the study area, with very little clay (table 30). Some of the clay bands are thicker than in other soils of Longview age. The B2&Bt horizon has four clay bands, 5YR 4.5/6 dry; the upper two are usually about 1 cm thick and the lower two from 1 to 4 mm thick. The bands are from 6 to 10 cm apart. The B31&Bt horizon has four to six clay bands from 1 to 3 mm thick and from 1 to 3 cm apart. The B32&Bt horizon has one discontinuous clay band about 1 mm thick. The data and field evidence illustrate the incipient nature of the argillic horizon in this soil of Longview age.

The A2 horizon is continuous along the exposure and in places descends into the reddish brown Bt material to form the A2&Bt horizon. The character of the A2&Bt horizon suggests downward encroachment of the A2 horizon into a clay band horizon that once had thicker bands. The Bt material occurs in two ways: in irregularly-shaped masses and as bands from 2 to 10 mm thick. In the latter case, the A2 material occurs horizontally between the bands. In the former case, the A2 material occurs as light-colored, irregular masses and as mottles in the redder, more clayey material. Thus the A2 material appears to reflect stripping of clay from former Bt parts of the horizon.

Several factors may be responsible for increased development of the A2 and clay band horizons at Site 22. A long-time cover of oak would tend to promote development of the A2 horizon and the associated eluviation of clay,

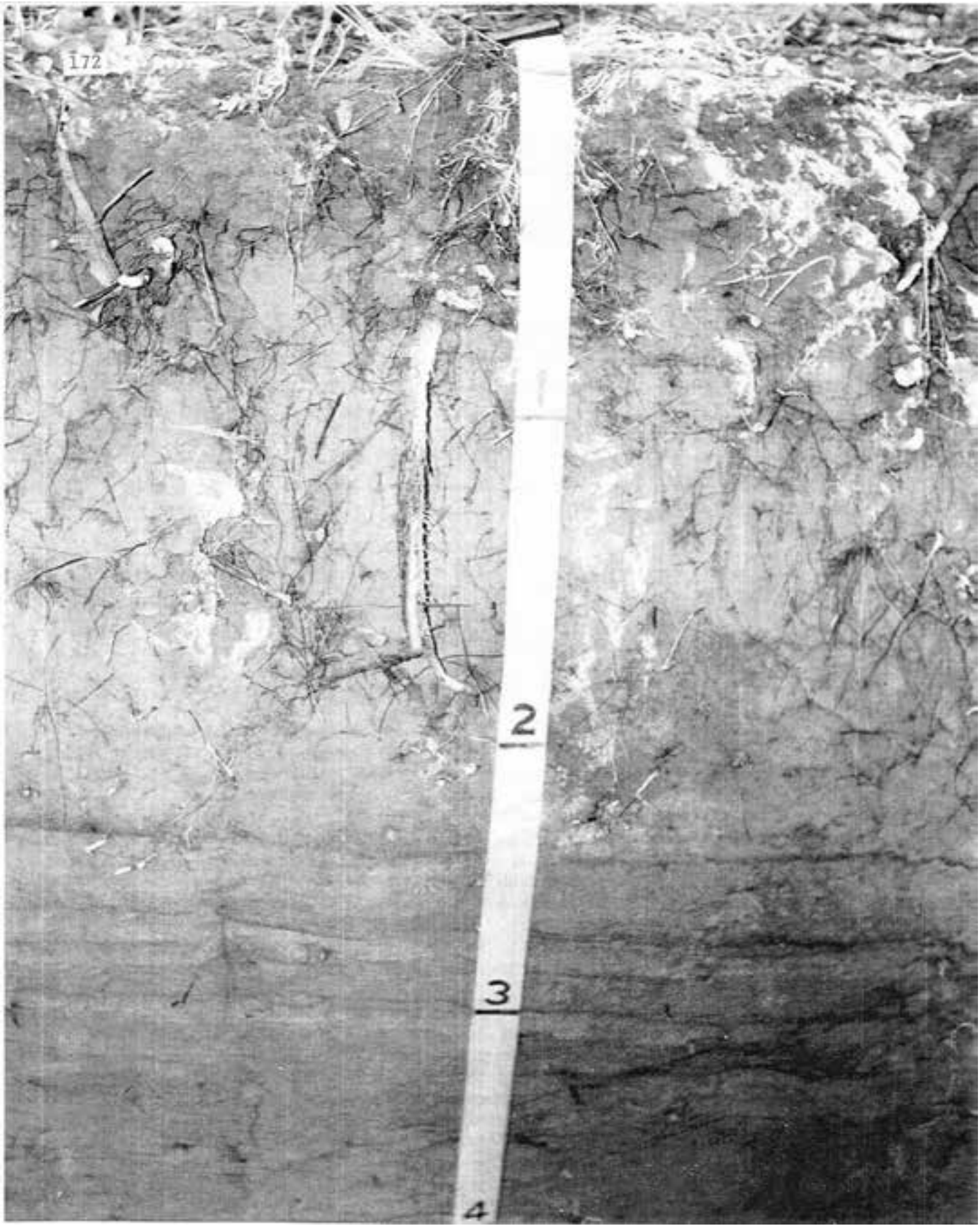


Figure 64. The Psammentic Haplustalf, Texico, S75TX-17-6, formed in sediments of Longview age at Site 22. This pedon has the most prominent A2 horizon observed in the study area. Photographed October 1975. Scale is in feet.

because increased development of the A2 horizon due to oak vegetation has been seen in some of the younger soils of Muleshoe age. The oak mulch of leaves and twigs tends to protect the soil from erosion; in addition, it should trap more dust than nonoak vegetation. The soil may be of Longview I age instead of Longview II. Finally, the buried argillic horizon at shallow depth (table 30) could also be a factor because the buried horizon would tend to slow downward movement of the wetting front and confine the clay accumulation in the overlying sediments to a thinner zone.

Sites 23 and 24, active small blowouts and dunes

Small active blowouts and steep slopes are fairly common in oak, because oak can grow thickly on steep slopes and protect them from erosion. In places, small vertical scarps have formed along the eastern margin of the blowouts. This is illustrated in the vicinity of Site 23 (figs. 42, 65) where the topography is very irregular; steep hummocks alternate with small blowouts and occasional vertical scarps. In aerial photographs the blowouts show as light-colored areas of irregular shape (fig. 42).

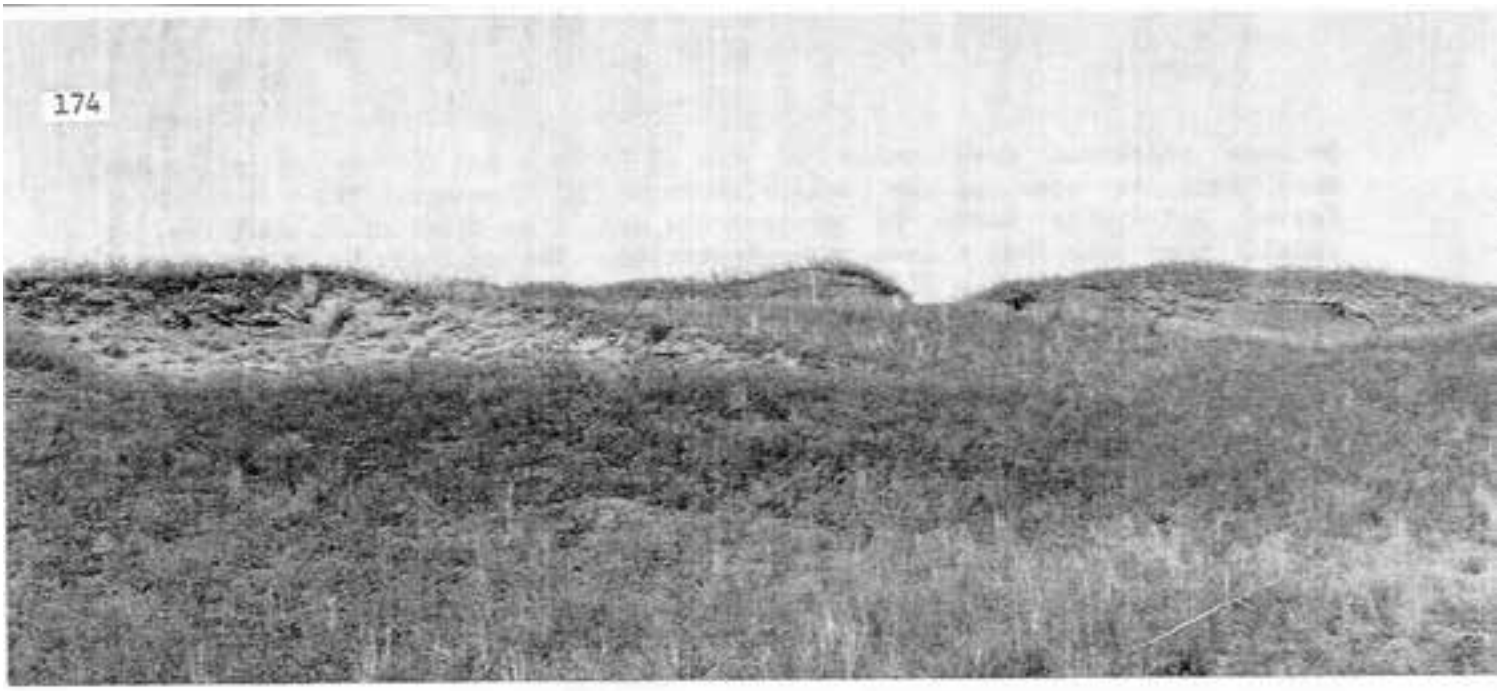
Site 23 consists of a thin deposit of Fairview sediments and underlying Longview sediments exposed in a scarp. The soil of Longview age has a distinct A2 horizon, a thick A2 horizon, and a banded B horizon underlain by a C horizon (table 31).

Table 31. Characteristics of an Alfic Ustipsamment, Circleback, on the crest of a Longview dune at Site 23[1/]

Sediment	Horizon	Depth cm	Hue	Value/chroma Dry	Value/chroma Moist	Texture	Structure	Dry consistence	pH	Lower boundary
Fairview	C1	0-16	6YR	6/4	4.5/4	fs	m	s	6.8	cw
	C2	16-34	6YR	6/4	4.5/4	fs	m	s,sh	6.8	cw
Longview	A11b	34-47	6YR	6/4	4.5/4	fs	m	sh	6.8	cw
	A12b	47-65	6YR	6/4	4.5/4	fs	m	sh	7.0	cw
	A21b	65-78	7.5YR	6.5/4	4.5/4	fs	m	sh	7.2	ci
	A22b	78-102	7.5YR	6.5/4	5/4	s	m	sh	7.0	ci
	B1b	102-126	5YR	6/4	4.5/4	s	m	sh	6.8	cw
	B21&Btb	126-138	5YR	6/5	5/5	fs	m	sh,h	6.8	as
	B22&Btb	138-147	5YR	6/5	5/5	fs	m	sh,h	6.6	as
	B23&Btb	147-158	5YR	6/5	5/5	fs	m	sh,h	6.4	as
	B31&Btb	158-179	5YR	6/4	4.5/4	s	m	sh	6.6	as
	B32&Btb	179-206	5YR	6/4	4.5/4	s	m	sh	6.6	cw
	B33b	206-236	5YR	6.5/4	5/4	s	m	sh	6.6	cw
	Cb	236-260	7.5YR	6.5/4	5/4	s	m	s,sh	6.6	

1/ Subordinate colors and additional characteristics follow. A1b: parts 5YR 5/3, dry, and 7.5YR 7/3, dry, occur throughout. A21b: parts 7.5YR 7/3, dry, occur throughout. A22b: parts 5YR 5/4, dry, occur throughout; few parts 7.5YR 7/4, dry. B1b: very few parts 7.5YR 7/4, dry. B21&Btb: two clay bands from 2 to 4 mm thick. B22&Btb: two continuous bands from 3 to 5 mm thick. B23&Btb: three bands 2 mm thick and 3 bands 1 mm thick. Most bands are continuous but they bifurcate in places. B31&Btb: three continuous bands, about 1 mm thick, and three discontinuous bands less than 1 mm thick. B32&Btb: several very discontinuous bands.

On the north margin of the dune, Fairview deposits are absent and the buried A horizon of Longview age has been truncated by wind erosion (fig. 65, lower, at left). The B21tb horizon has two distinct, continuous clay bands that crop out on the beveled surface, which is littered with dead oak branches. The 1941 airphoto (but not the 1953 airphoto) shows the oak



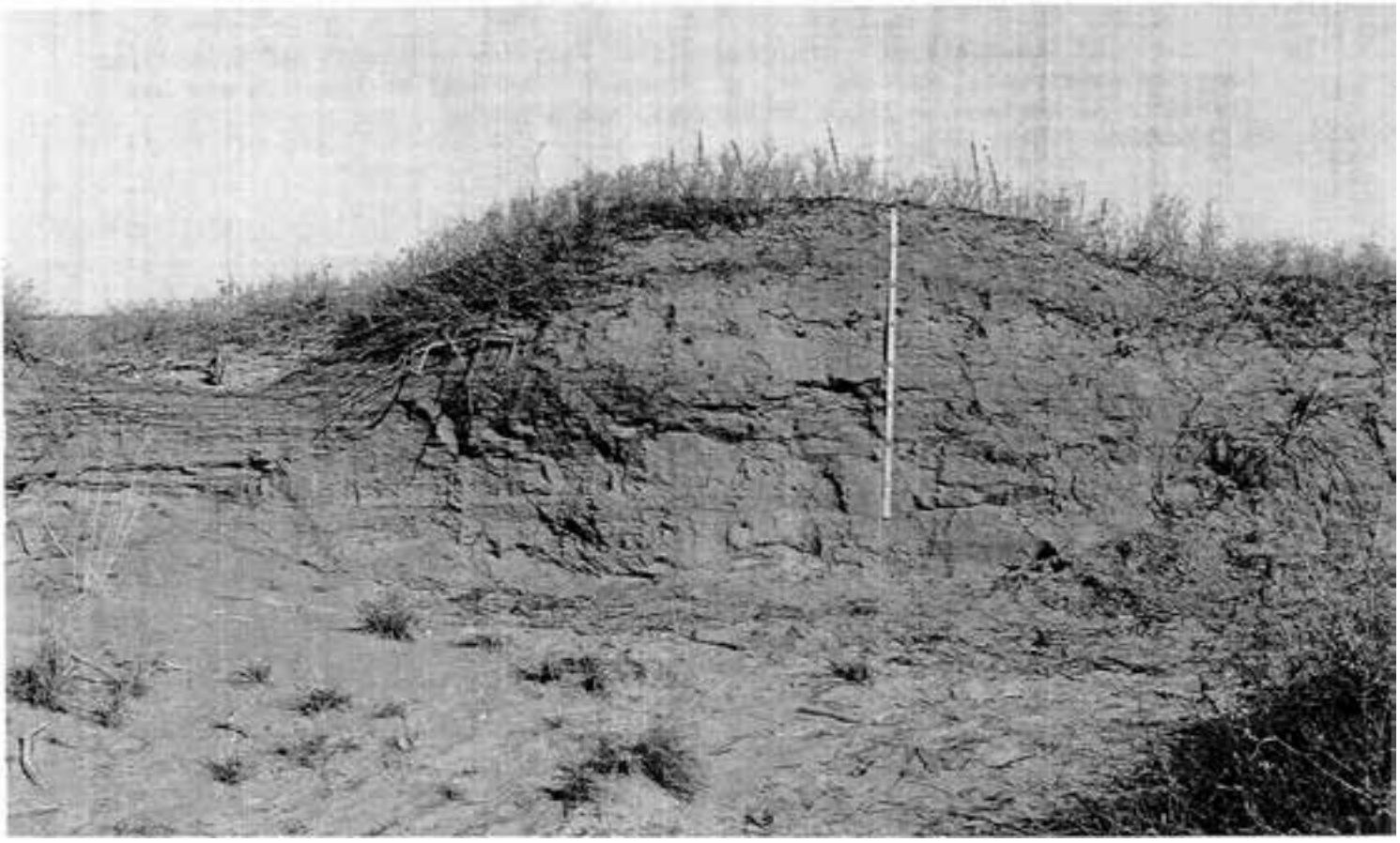


Figure 65. Upper. Landscape of a complex of Muleshoe and Longview surfaces in the vicinity of Site 23. Steep slopes are common in the oak-dominated terrain. The view is east. Photographed March 1978.

Lower. Site 23 and the Alfic Ustipsamment, Circleback, exposed on eastern margin of small active blowout (foreground) and buried by a thin deposit of Fairview age. Note the sloping relief on the buried A1 horizon of Longview age. Scale is in feet.

continuing across to the dune just north. Thus much of the erosion must have taken place between 1941 and 1953.

The surface topography of the A1b horizon is slightly rounded and denotes the land surface before it was buried by overlying sediments. The soil of Longview age must have been truncated before the A1 horizon developed. The prominent A2 horizon suggests long-time occurrence of oak in this area (few A2 horizons have been found under grass except near the oak).

Site 24 (fig. 42), not sampled, illustrates gradual enlargement of a small, linear blowout in oak vegetation (figs. 13-17). The blowout is barren and has a scattering of dead oak branches and roots. In the 1941 aerial photograph, faint traces of a trail may be seen north of the blowout. By 1953 the blowout had enlarged and a trail may also be seen south of the blowout. But faintness of the trail suggests that the part played by cattle in initial development of the blowout was slight, as does the occurrence of nearby blowouts that have enlarged where no evidence of a trail can be seen.

Tivoli soils are in the upper sediments of the west-facing, near-vertical face along the western edge of the blowout. The general stratigraphy, similar to that at Site 3a, is as follows. A few centimeters of Fairview sediments are at the surface. Muleshoe sediments underlie Fairview and extend to about 120 cm depth. Below the Muleshoe sediments are these generalized horizons in Longview II sediments: A2b2, 120-150 cm; B1b2 and B2b2, 150-200 cm; B3b2, 200-260 cm; Cb2, 260-288 cm. From 288-328 cm is a horizon like the buried A horizon in Longview I sediments at Site 3b. The typical clay bands occur in the soil of Longview age.

Site 24 and vicinity illustrate typical occurrence of Tivoli and Circleback in mapping unit C. Although Circleback soils are buried here, elsewhere in unit C they are at the land surface and Muleshoe deposits are absent.

PSAMMENTIC HAPLUSTALFS AND ALFIC USTIPSAMMENTS: MAPPING UNIT D, TEXICO-CIRCLEBACK COMPLEX

MAPPING UNIT COMPOSITION

Series or variant	Subgroup	Particle-size family	Percentage of mapping unit
TEXICO	PSAMMENTIC HAPLUSTALFS	SANDY	45
CIRCLEBACK	ALFIC USTIPSAMMENTS	SANDY	40
Tivoli, thin variant #1	Typic Ustipsamments	Sandy	5
Tivoli	Typic Ustipsamments	Sandy	10

LOCATION, LANDSCAPE, SOIL OCCURRENCE, VEGETATION

Soils of unit D occur on dunes in the central part of the study area. Texico soils occur on crests and upper sides of dunes. Circleback soils occur in areas of Longview sediments, on ridge crests (mainly in the north-central part of the area) and on sides of some dunes. Tivoli, thin variant #1 occurs in depressions; Tivoli occurs on lower sides of some dunes.

Vegetation observed in mapping unit D consists of sand sagebrush, soapweed, sumac, dropseed, hairy grama, three-awn, catclaw, snakeweed, and queen's delight.

TYPICAL PEDONS AND RANGES IN SELECTED PROPERTIES

See mapping unit C for typical pedons and ranges for Texico and Circleback.

STUDY SITES

Site 25, episodic development of dune; west aspect

Site 25 (figs. 42 and 66, table 32) is on the west-facing side of a blowout dune. The long trenches at Sites 25 and 26, dug October 1977, are visible in the 1981 aerial photograph (fig. 17). On the ground in October, 1982, the trench sites were visible in faint linear pattern with less vegetation than adjacent areas. Small oak had started to grow in the disturbed area, reflecting the speed of oak growth and advance in sandy sediments (see also Site 13).

Originally it was thought that Birdwell sediments consisted of only one major sediment. However, evidence at Site 25 and at Site 38, to be discussed, illustrates two ages for the sediments concerned -- that is, sediments older than Longview and younger than Roosevelt. Site 25 illustrates a dune of Birdwell II age, and episodic upbuilding of a dune from Birdwell I through Longview time.

Site 25 consists of a short east-west trench near the blowout and a longer east-west trench up the side of the blowout dune (fig. 66). All soils at Site 25 are Psammentic Haplustalfs except for Alfic Ustipsamments on the dune crest. Pedons 25a and 25b are under nonoak vegetation; Pedons 25c and 25d are under oak. Figure 66 shows the stratigraphy, soil occurrence, and slope and location of the sampled pedons. Table 32 gives soil characteristics.

Lower side of dune

Pedon 25a (fig. 66, table 32) is in the short east-west trench. The A horizon is thick and may have originated partly by colluviation from slopes to the east. Evidence to be presented in the following section indicates that Pedon 25a actually consists of soils of two ages: a thin land-surface soil in Birdwell II sediments, and an underlying buried soil in Birdwell I sediments. The Birdwell II deposit is so thin that no C horizon has been preserved, and any boundary between the two sediments has been masked by pedogenesis.

Pedon 25b (figs. 66 and 67, table 32) is of Birdwell II age in the upper part and of Birdwell I age in the lower part. In this trench the horizon and sediments were traced eastward to where the B horizons are separated by C horizon material as the Birdwell II sediments thicken upslope (fig. 66).

Central side of dune

Upslope from Pedon 25b, the expression of clay bands shows the effect of slope position on their development because they become thinner and less

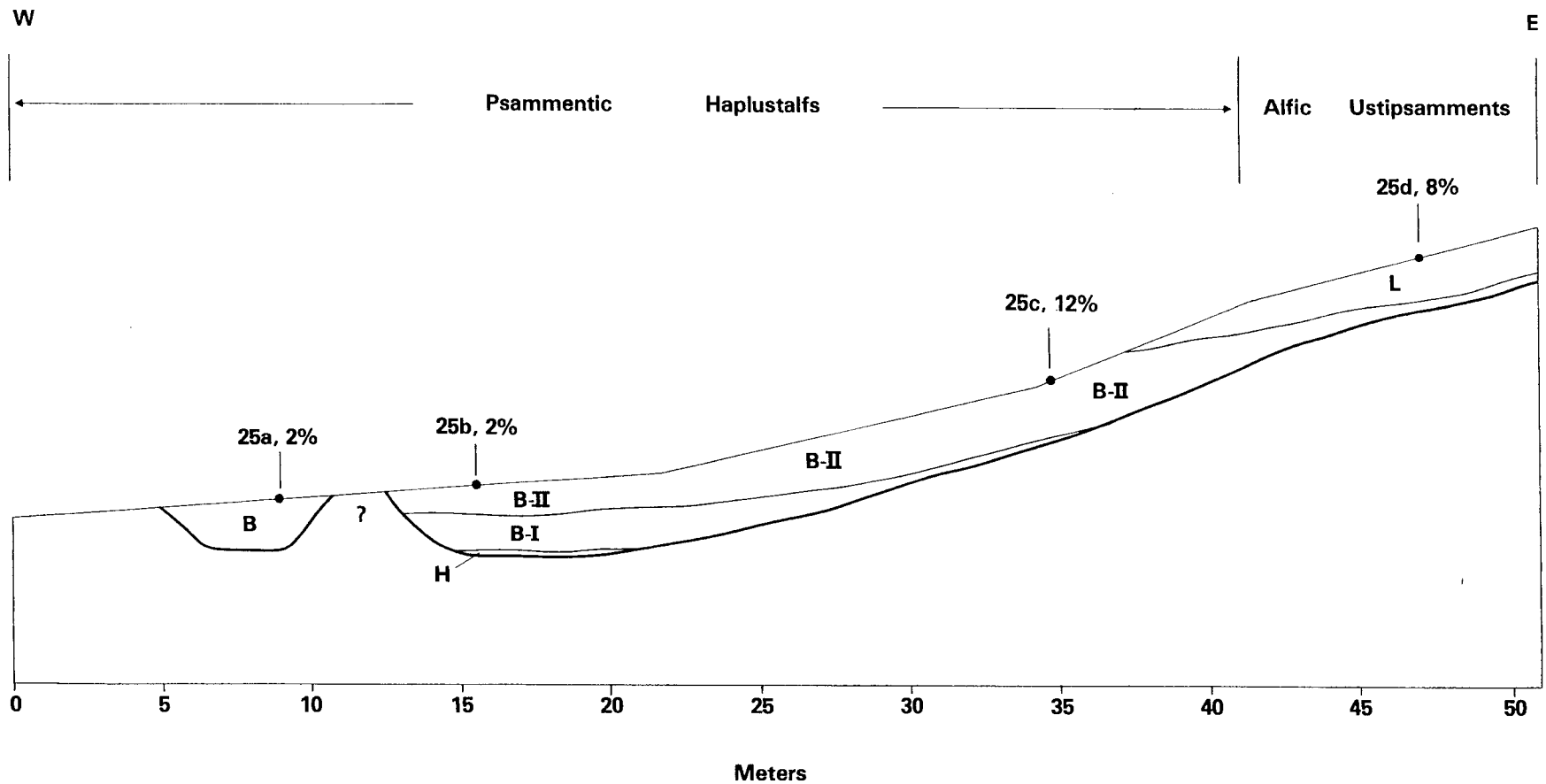


Figure 66. Diagram of study trenches at Site 25, showing stratigraphy, subgroups, and slope and location of sampled pedons. L = Longview, B-II = Birdwell II, B-I = Birdwell I, Hale = Hale. No vertical scale (see table 32 for the thickness of sediments and horizons). The heavy lower line represents the bottom of the trench.

Table 32. Characteristics of Haplustalfs and an Ustipsamment at Site 25 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 lower side of dune; Pedon 25a 2/													
B-I, II	A11	0-10	7.5YR	4.5/3	3/3	m	s	6.8	aw	lfs			
	A12	10-35	5YR	5/3	4/3	m	s	6.8	cw	fs			
	B1t	35-54	5YR	5/3	4/3	m	sh	7.4	aw	fs			
	B2tb	54-70	5YR	5/4	4/4	lmsbk	vh	7.2	as	lfs			
	B3&Btb	70-94	5YR	6/6	4.5/6	m	h	7.2	aw	lfs			
	Cb	94-106	5YR	6/6	4.5/6	m	sh,h	7.2		fs			
Psammentic Haplustalf, Texico, on lower side of dune; Pedon 25b 3/													
B-II	A11	0-9	7.5YR	5/3	3.5/3		s	7.0		lfs	88.1	5.1	6.8
	A12	9-23	7.5YR	5.5/3	3.5/3.5	m	sh	7.2		fs	92.4	2.3	5.3
	B1t	23-36	7.5YR	5.5/3	3.5/3.5	m	sh	7.2		lfs	84.5	9.2	6.3
	B21t	36-44	5YR	5/4	4/4	lcsbk	h	7.2		lfs	88.1	1.5	11.4
	B22t	44-52	5YR	5/5	4/5	lcsbk	h	7.0		lfs	84.5	2.6	12.9
B-I	B1tb	52-62	5YR	5/5	4/5	lcsbk	h,vh	7.0		lfs	83.6	3.5	12.9
	B2tb	62-79	5YR	5.5/5	4/5	lcsbk	vh	7.0		fsl	81.3	5.3	13.4
	B31tb	79-102	5YR	5/4	4/4	lcsbk	h	7.0		lfs	87.9	3.8	8.3
	B32tb	102-119	5YR	6.5/4	5/4	m	sh	7.2		fs	90.5	3.2	6.3
	Cb	119-134	6YR	7/4	5.5/4	m	sh	7.2		fs	90.6	3.6	5.8
H	Btb2	134-144	2.5YR	5/6	4/6	lmsbk	h,vh	7.4		scl	73.8	3.0	23.2
Psammentic Haplustalf, Texico, central side of dune; Pedon 25c 4/													
B-II	A1	0-9	7.5YR	5/3	3.5/3		s	7.4	cw	lfs			
	A2	9-28	7.5YR	6/3	4.5/3	m	sh	7.0	cw	fs			
	B1	28-42	7.5YR	6/4	4.5/4	lmsbk	sh,h	7.0	as	fs			
	B21t	42-56	5YR	5.5/4	4.5/4	lcsbk	vh	6.6	as	lfs			
	B21t	56-66	4YR	5/5	3.5/5	lcsbk	h,vh	6.6	as	fs			
	B3t	66-77	5YR	6.5/6	5/6	m	sh	6.4	cw	fs			
	C&Bt	77-90+	7.5YR	5.5/5	4/5	m	sh	6.4		fs			
Alfic Ustipsamment, Circleback, on upper side of dune; Pedon 25d 5/													
L	A1	0-7	7.5YR	4.5/3	3/3		s,sh	7.0	as	lfs			
	B&A2	7-18	5YR	5.5/4	4/4	lcsbk	h	7.0	as	fs			
	B2&Bt	18-39	5YR	5.5/5	4/5	lcsbk	h	7.0	cw	s			
	B3&Bt	39-72	5YR	6/4	5/4	m	sh	6.8	cw	s			
	C	72-90	5YR	6/4	4.5/4	m	sh	6.6		fs			

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

2/ B3&Btb: clay bands are 5YR 5/6, dry.

3/ B21t: parts 7.5YR 5.5/4, dry. B1tb: parts 5YR 4/2, dry. B3tb: this horizon dominated by eight clay bands ranging from ½ to 5 cm thick and from 5YR 5/4 to 5YR 6/4, dry.

4/ B21t: parts 4YR 5/5, dry. B22t: parts 5YR 5.5/4, dry. C&Bt: few discontinuous bands and spots of 5YR 5/4, dry.

5/ B&A2: parts 7.5YR 7/3, dry; 10YR 7/2, dry; and 7.5YR 4/2, dry. B2&Bt: clay bands colored 5YR 4/4, dry. B3&Bt:clay bands colored 5YR 5/4, dry.

Figure 67. View of study trench and Psammentic Haplustalfs at Sites 25b and 25c. The Birdwell surface is in the foreground and middle ground, and the Longview surface is on the skyline. Horizons of two ages are present in Pedon 25b, at the tape. Birdwell II sediments extend to a depth of slightly less than 2 ft (0.6 m). The Birdwell II deposit is so thin that no C horizon occurs between it and underlying Birdwell I sediments. The thick clay bands (at and below 3 ft, 0.6 m depth) occur in many Birdwell pedons. Scale is in feet.

numerous upslope (see also Sites 1, 3, 32, and 36). Also upslope from Pedon 25b, the soils of Birdwell II and I are separated by C horizon material as Birdwell II sediments become thicker (fig. 66, table 32). This C horizon material contains only a few visible sedimentary strata, whereas the overlying B horizon has developed primarily in sediments that are distinctly stratified. Deposition of the C horizon material is thought to have taken place during a minor erosive episode prior to the main period of erosion and deposition, which is marked by the distinct strata in which the B horizon has formed.

Only a very few thin clay bands descend below the lowermost thick band, which marks the base of the stratified sediments and the boundary between the B and C horizons. The B horizon is remarkably thin for some distance due to the nature of the sedimentary contact: sand grains above the contact are slightly coarser than those below it and would tend to enhance the lateral movement of clay-carrying water downslope.

Post-Birdwell erosion may be another factor involved in thinness of the B horizon. Longview sediments are present at the top of the slope (fig. 66), and may have been partly derived from the side of the dune. The original soil in Birdwell II sediments may have been thicker before the start of Longview erosion.

At Pedon 25b, clay bands are barely visible in the soil of Birdwell II because they have been largely obscured by clay accumulation. One band at 43 cm depth is about 2 mm thick and another at 49 cm depth is 1 cm thick. In contrast, prominent clay bands are in the B3tb horizon of the buried soil in Birdwell I sediments (table 32, fig. 67). West of Pedon 25b, in the west end of the trench (fig. 66) the B3tb horizon has three bands ranging from about 1 to 5 cm thick. The bands split eastward and at Pedon 25b there are eight separate bands ranging from 1/2 to 5 cm thick. The bands are separated by light-colored, less red material with less clay.

Although the colluvium typical of many Birdwell dunes was not found at Site 25, a discontinuous zone of finer texture did occur in the B horizon from about 20 to 21 m along the north bank of the trench (fig. 66). This zone occurred from about 50 to 60 cm depth and is a fine sandy loam, as compared to a loamy fine sand of adjacent material at the same depth. Origin of this finer-textured zone is not known. It could be a remnant of Birdwell colluvium that was eroded elsewhere.

Pedon 25c (fig. 68, table 32) is under oak vegetation and has an A2 horizon, as is common under oak. Tracing downslope into the nonoak vegetation there is little change for about a meter and then the A2 horizon gradually darkens to an A1 horizon.

In contrast to Pedon 25a and 25b, Pedon 25c has formed entirely in sediments of Birdwell II; C horizon material separates the land-surface soil from the buried soil, the top of which occurs at 186 cm depth. The top of the B21t horizon is marked by a clay band 2 cm thick, and the bottom by a band 1 cm thick. The lower part of the B22t horizon also has a zone, 2 to 3 cm thick, in which thinner clay bands have accumulated. This is a zone of relatively coarse sand, which should expedite lateral movement of soil solution and development of clay bands.

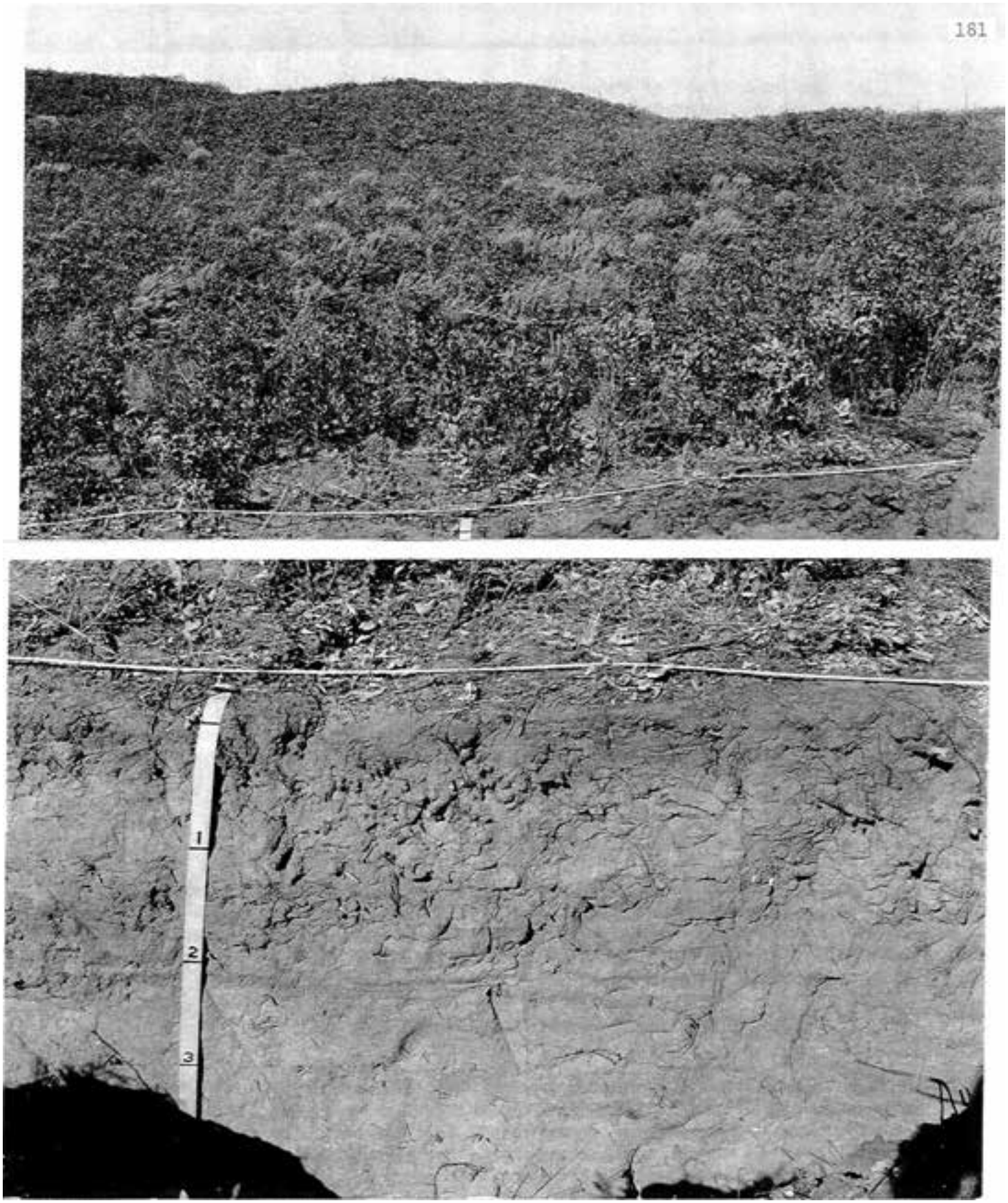


Figure 68. Upper. Landscape view of oak-covered Birdwell surface in foreground. The view is north. Photographed October 1977.

Lower. The Psammentic Haplustalf, Texico, at Site 25c. In the vicinity of the tape, the clay band just below 2 ft (0.6 m) depth marks the contact between prominently and weakly stratified sediments. At center and right, note that clay bands have started to deepen in the soil. This marks the start of burial of Birdwell II sediments by Longview sediments (fig. 66).

In the Bt horizon of Pedon 25c, the lowermost clay band is at a depth of only 65 cm; but eastward the band deepens, splits and a lower band drops to a depth of 1 m at the east end of the original trench. Here, this lower band is actually part of a buried soil as discussed in the following section.

Upper side of dune

The original trench did not extend to Pedon 25d, but to be certain of the stratigraphy, the two trenches were connected before they were filled. The connecting trench showed that Longview sediments on the dune crest bury the soil of Birdwell II. The dune crest must have been substantially lower in Birdwell time; deposition of Longview sediments made the dune higher and steeper. The present land surface does not suggest a younger deposit because the slope grades smoothly across the contact between the Birdwell and Longview sediments.

Pedon 25d (fig. 66, table 32) has a thin A1 horizon, a thin A2 horizon and a distinct clay band horizon. Clay bands occur at depths of 32, 46, 56, 60 cm; all are 2-3 mm thick. C horizon material occurs beneath the banded B horizon, and the buried Bt horizon of Birdwell age is at a depth of about 125 cm. The soil is steepest at the west end of the trench; soil truncation there is indicated by partial engulfment of B horizon material by a downward-encroaching A horizon, and by thinness of the B horizon. The B horizon is thicker and there are more clay bands toward the east end of the trench, where the soil nears the dune crest and is not as steep.

Site 26, trough and adjacent north and south aspects

Figure 42 locates Site 26, which shows the character of soils on north and south aspects of high dunes, and in the trough between them. Site 26 consists of one short east-west trench in the trough and three trenches that extend northward from a dune crest, down into the trough, and up the dune north of the trough. Two segments of the transect were not dug because they were too steep for the backhoe to operate.

Two pedons were sampled, one in the short trench in the trough, and one in the side of the adjacent dune (table 33). Figure 69 shows the stratigraphy, soil occurrence, and slope and location of the sampled pedons. Table 33 gives characteristics of the soils. Figure 70 gives a general view of the landscape and trenches.

Dune crest and small active blowout, south end

Muleshoe sediments are in the narrow crest of the dune. These thin Muleshoe deposits are quite common but do not represent a part of an extensive sheet of Muleshoe age. Instead, they constitute isolated deposits on the crest and sides of dunes and in depressions. The dune crest has oak vegetation, is at the south edge of the transect (0 mark in fig. 69), and is the steepest part of the transect. Some of the active blowouts are quite small, only a few meters in diameter, and range in shape from roughly circular to linear and curved. They show as white spots in aerial photographs; many of them are not near cattle trails and appear to have formed naturally. For example, the small blowout just north of the crest (fig. 70) can be seen in both the 1941 and 1981 photographs and appears

Table 33. Characteristics of Psammentic Haplustalfs, Texico, at Site 26[1/]

Sediment	Horizon	Depth cm	Hue	Value/chroma Dry	Value/chroma Moist	Texture	Structure	Dry consistence	pH	Lower boundary
In trough; Pedon 26a[2/]										
Fairview	C	0-7	7.5YR	5.5/3	3.5/3	fs	m	s	7.0	as
Birdwell	A1	7-18	7.5YR	5/3	3/3	fs	m	s	7.0	cw
	A2	18-35	7.5YR	6/3	4/3	fs	m	s	7.2	cw
	B11	35-50	6YR	6/4	4/4	fs	m	sh	7.4	cw
	B12	50-60	5YR	6/4	4.5/4	fs	lcsbk	sh	7.2	as
	B2t	60-70	5YR	6/4	4.5/4	lfs	lcsbk	h	7.4	as
	B3t	70-95	5YR	6/4	4.5/4	lfs	m	sh,h	7.4	aw
Hale	B2tb	95-113	2.5YR	5/6	3.5/6	scl	lcsbk	vh	6.0	
On lower side of dune; Pedon 26b[3/]										
Birdwell	A11	0-6	7.5YR	5/3	3/3	fs		s	7.0	
	A12	6-20	7.5YR	5.5/3	3.5/3	fs	m	s	7.2	
	A2	20-34	7.5YR	6/4	4.5/4	fs	m	sh	7.2	
	B1	34-48	5YR	6/4	4.5/4	fs	m	sh	7.2	
	B21t	48-62	4YR	5/6	4/6	lfs	lm,csbk	h, vh	7.4	
	B22t	62-90	4YR	5/6	4/6	lfs	lm,csbk	h, vh	7.4	
	B31t	90-104	2.5YR	5/6	4/6	fs	m	sh	7.2	
	B32t	104-124	5YR	5.5/6	4/6	fs	m	sh	6.8	

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

2/ B2t: clay bands and other zones of higher clay content are 5YR 5/4, dry.

3/ B31t: parts 5YR 5.5/4, dry. B32t: parts 4YR 5/5, dry.

about the same size in both. Commonly these small blowouts are nearly barren of vegetation, and this causes the white color on the airphotos.

The top of the banded B horizon is very near the surface in the small blowout, and this is the common situation in blowouts formed in Longview dunes. The sandy A horizon, which is generally quite thick in these soils at stable sites, erodes readily where not protected by vegetation, so that the more resistant clay band horizon is at, or very near the soil surface.

Small eolian lobe

The north-facing upper side of the dune gives the impression of occasional small lobes of youthful eolian sediments emplaced on older deposits. A study trench across a small dune just north of the blowout showed the typical Longview clay bands all along the exposure, just above the trench bottom. Muleshoe deposits are present above the Longview sediments, as indicated by thin, discontinuous clay bands in a zone well above the Longview clay bands.

Lower sides of dune and the trough

The study in the north aspect of the dune showed that sediments in the upper part of the section have the distinctive youthful appearance of

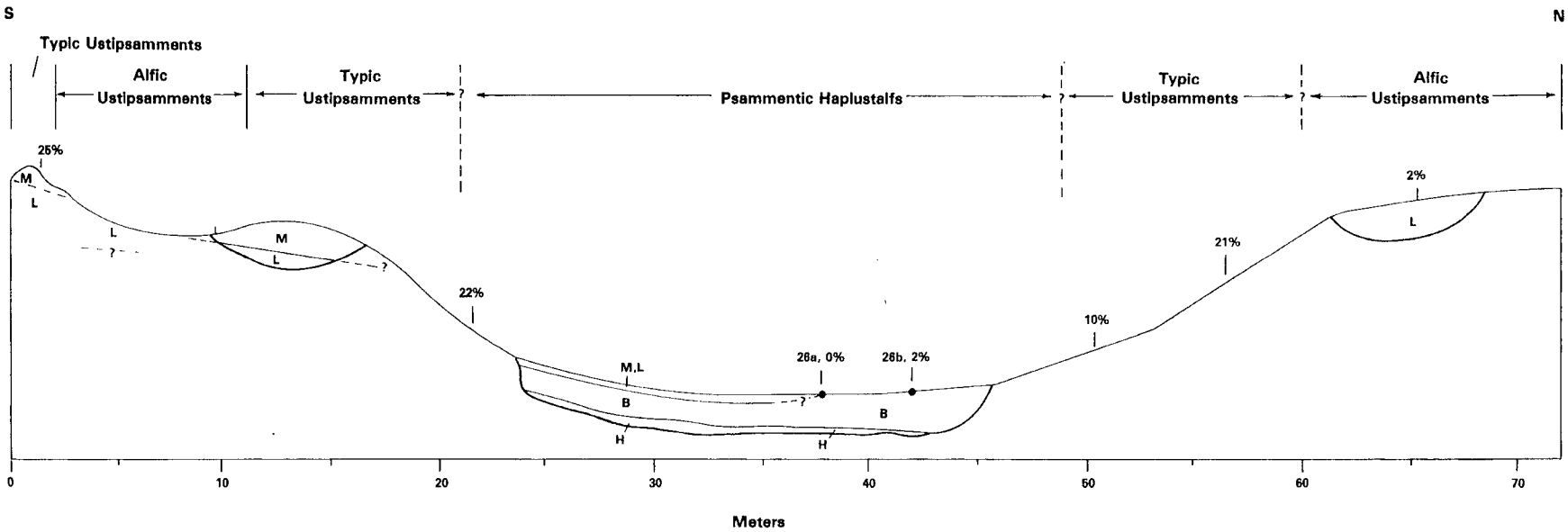


Figure 69. Diagram of study trenches at Site 26, showing stratigraphy, subgroups, and slope and location of sampled pedons. M = Muleshoe, L = Longview, B = Birdwell, H = Hale. No vertical scale (see table 33 for thickness of sediments and horizons). The heavy line represents the bottom of the trenches.

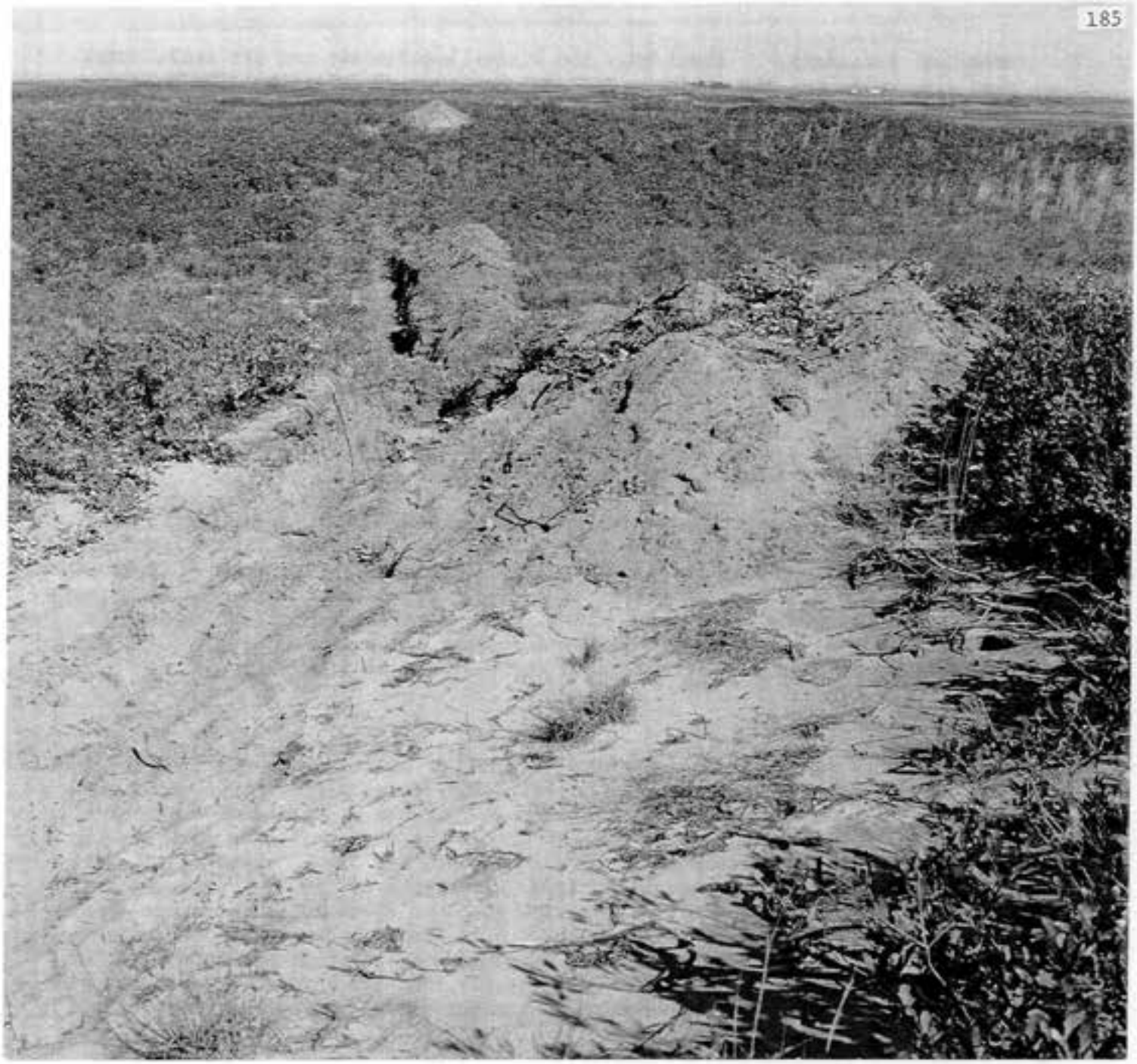


Figure 70. Landscape view of study trenches at Site 26. A small, active, nearly barren blowout is in the foreground. The Longview surface and Circleback soils are in the small blowout; the Muleshoe surface and Tivoli soils are in the small dune at the tape; the Birdwell surface and Texico soils dominate the trough; and the Longview surface and Circleback soils are on the dune crest beyond the trough. Photographed October 1977.

Muleshoe sediments. They bury the Birdwell sediments and its soil, which rest in turn on the thick, red Bt horizon of Hale age. The Muleshoe deposits thin to the north and are very thin or absent on the north side of the blowout (fig. 69).

The distinctive soil in colluvium that occurs on the lower side of many Birdwell dunes is not apparent here in either the north or south aspects. Absence of the colluvium may be due to sporadic erosion and deposition of post-Birdwell sediments. In addition, the mulch of oak twigs and leaves should tend to reduce runoff, though duration of oak cover is not known.

At 25 m (fig. 69) the Muleshoe sediments extend from 0-40cm; Birdwell sediments, from 40-116 cm; and Hale sediments, from 111-132 cm, the bottom of the trench. An A1 and a B horizon has formed in the Muleshoe sediments and an A, B1, B25, and B3 horizon has formed in the buried Birdwell sediments. But the Muleshoe sediments have been in place long enough for a distinct A1 horizon to form. Presumably, the A horizon of Birdwell age was eroded to form the Longview deposits to the east.

The characteristic red, prominent Bt horizon is in Hale sediments along the bottom of the trench. The Birdwell and Hale sediments are continuously exposed in the trench (fig. 69), but Muleshoe sediments are not apparent north of the 35 m mark in the study trench (fig. 69). A few centimeters of Muleshoe sediments could be mixed with surficial Birdwell sediments, however. The clay bands in Birdwell sediments are distinct, discrete, and are similar to those in Birdwell I at the west end of Site 25.

Dune crest, north end

The northern segment of Site 26 is a short north-south trench in Longview sediments on the dune crest. This is an Alfic Ustipsamment that shows effect of post-Longview erosion. At the north end of the trench, depth to the banded B is only 26 cm; at the south end, the depth to the banded B is about double that. Over the north 2/3 of the exposure the soil has a distinct, though thin A2 horizon. Thus both of the high dunes at Site 26 are capped by a deposit of Longview age, but these deposits do not occur in the trough. These relationships at Site 26 indicate erosion of sediment from troughs, blowouts and sides of dunes in Longview time and deposition of this sediment to the leeward. Subsequently, Muleshoe erosion removed upper horizons of pre-Muleshoe deposits at various places and sporadically buried the Longview sediments.

Site 27, dune crest and east aspect

Site 27 (fig. 40) consists of Site 27a, a trench in the dune crest and adjacent east-facing dune side, and Site 27b, a trench in the east-facing dune side about 12 m northeast of Site 27a.

Site 27a, dune crest and upper side of dune

The crest of the blowout dune is several meters higher than the blowout just west. The study trench extended from the center of the dune crest 8 m down the east-facing dune side. Soil characteristics are in table 34.

Table 34. Characteristics of a Psammentic Haplustalf, Texico, on crest of Birdwell dune at Site 27a

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	0-10	7.5YR	5/3	3.5/3	m,sg,cr	s	6.8	as	s	89.2	6.2	4.6
B1t	10-18	6YR	5.5/4	3.5/4	m	s	6.8	as	fs	90.8	3.5	5.7
B2t	18-34	5YR	6/5	5/5	m	sh	7.0	as	fs	89.9	2.2	7.9
B31t	34-56	5YR	6/6	4.5/6	m	sh	7.0	as	fs	91.9	2.1	6.0
B32t	56-78	5YR	6/6	4.5/6	m	sh	7.2		fs	92.3	2.0	5.7
C	78-101	7.5YR	7.5/5	6/5	m	s	6.8		fs	97.0	2.3	0.7

Pedon 27a (fig. 71, table 34) is in the center of the dune crest. The pedon has a thin A horizon and a relatively thin Bt horizon. Particle size analyses (table 34) show the silicate clay bulge to be small but distinct, and enough for an argillic horizon. The exposure shows excellent gradation to C horizon material, and striking coincidence of the clay band horizon with the horizon of clay accumulation as a whole. The coincidence indicates pedogenic origin of clay between the bands as well as in them. Distinct clay bands have not yet been obliterated by the mixing process of soil formation, however (fig. 71). The B2t horizon has the main concentration of bands. Once there may have been a clay band at the top of this horizon, as suggested by occasional spots of darker and redder color that occur at the same depth along the exposure. There are two main clay bands, 2 to 3 mm thick, at 31 and 34 cm depths. They have been obliterated in a few places but are generally continuous. Two clay bands occur about in the center of the B31t horizon and one at the base of the horizon; all are 1 to 2 mm thick and quite continuous. Several thin bands occur in the center of the B32t horizon and a discontinuous one occurs in the C horizon, at a depth of about 98 cm. Augering below the trench bottom showed that the sandy C horizon extends to at least 210 cm depth.

The Bt horizon of Pedon 27a illustrates the minimal end of the Texico series. Although the Bt horizon is distinct (fig. 71, table 34) it is markedly lower in clay content and is much less hard than other Texico Bt horizons.

The C horizon contains almost no clay (table 34), contrasting with other C horizons of Birdwell age, particularly to the south (e.g., see Sites 32-39). The low clay content may be due to the considerable thickness of sandy C horizon material of Hale age in this general area (see stop 5, Gile 1981).

A trench was dug 8 m down the east-facing side of the dune to see if evidence of a younger eolian deposit could be found just east of the crest (see Site 38 for a Birdwell II eolian deposit on the east-facing side of a

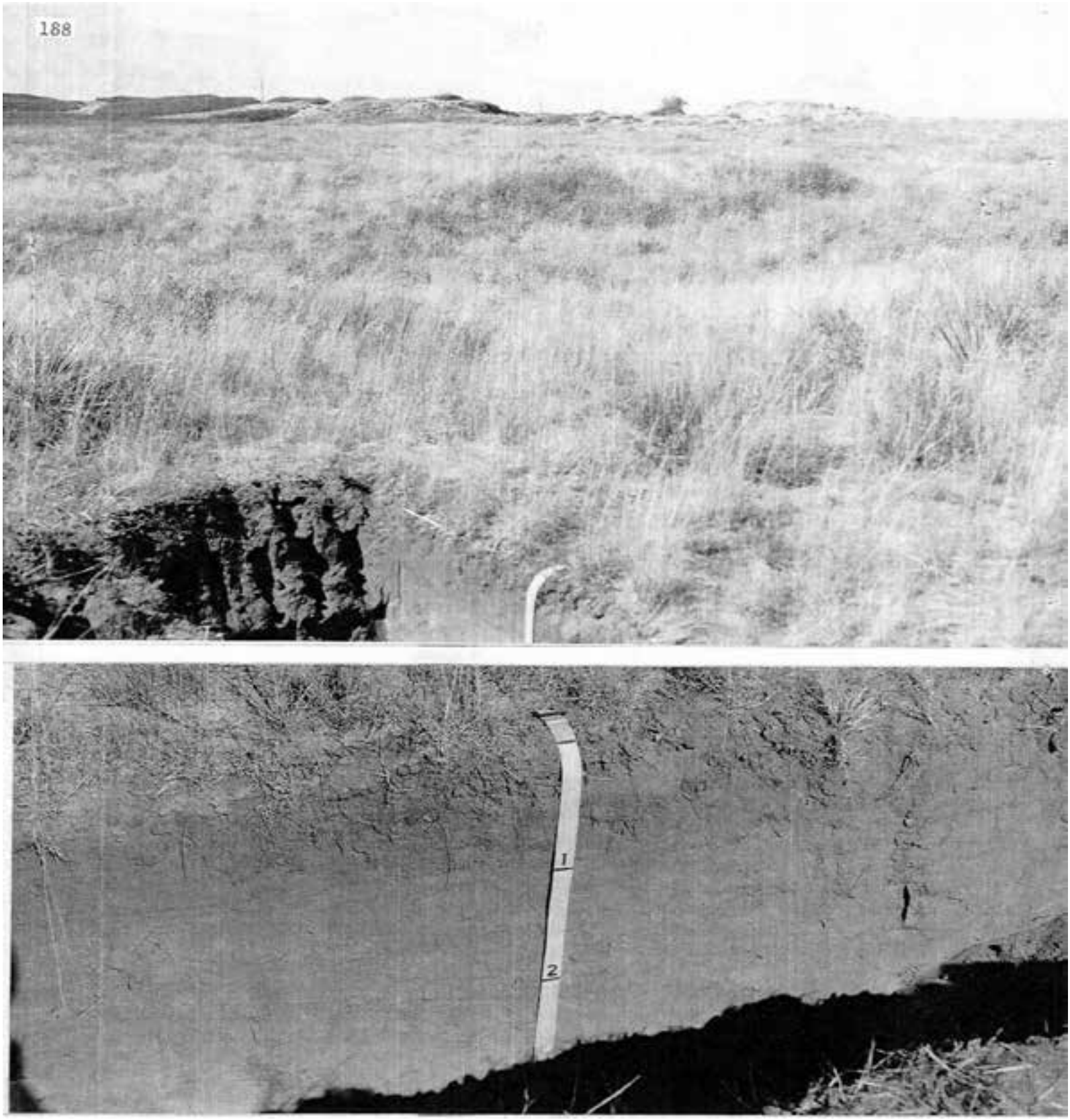


Figure 71. Upper. Landscape view of the Birdwell surface, on dune crest in the foreground. On the skyline at left are oak-covered dunes of the Muleshoe and Longview surfaces; at right is the high dune at Site 1. The view is north. Photographed November 1975.

Lower. The Psammentic Haplustalf, Texico, at Site 27a. The argillic horizon is very near the surface due to erosion. Scale is in feet.

Birdwell dune). The Psammentic Haplustalf in Birdwell sediments was found to extend continuously across the dune crest and down the east-facing dune side. Only a thin deposit with an A horizon was found on the dune side. Depth to the Bt horizon is only 10 cm on the ridge crest (table 34), but on the dune side, depth to the Bt horizon is about 35 cm. The thin deposit with the A horizon buries the A horizon of Birdwell age, and is attributed to eolian sedimentation in Muleshoe and Longview time. Similar thicknesses of eolian sediments were found in post-Birdwell II deposits elsewhere (see Site 38). The sand is eroded from the west-facing side of the dune and from the dune crest, and accumulates on the lee side of the dune. Since no Birdwell II deposit was found east of this dune, the Birdwell sediments of the dune crest are considered to be of Birdwell II age.

Thicknesses of the A and Bt horizons and depth to the C horizon were remarkably similar all along the trench. Auger samples east of the trench showed the Bt horizon to become weaker downslope, and it disappeared altogether 20 m east of the ridge crest. Details of the morphological change could not be determined by auger.

Site 27b, side of dune

Another trench was dug about 12 m northeast of the first, to study the east aspect in another place. Figure 72 is a photograph and diagram of the study trench. The trench shows the gradation from Psammentic Haplustalfs on the upper side of the dune to Typic Ustipsamments on the lower side of the dune. Table 35 gives soil characteristics.

Pedon 27b-1 is on the upper side of the dune (fig. 72). As on the east aspect at Site 27a, a thin post-Birdwell deposit occurs at the surface. The A horizon material just above the B horizon is lighter-colored than adjacent

Table 35. Characteristics of soils at Site 27b[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 27b-1													
M, L	A11	0-12	7.5YR	5/3	3.5/3	m,sg,cr	s	7.0	aw	fs	91.9	2.8	5.3
	A12	12-25	7.5YR	5/4	3/4	m	s	7.2	aw	fs	92.3	3.6	4.1
B	A2b	25-41	7.5YR	6/4	4/4	m	s	7.4	cw	fs	93.7	0.0	7.4
	B21tb	41-59	5YR	5.5/4	4/4	m	sh	7.0	cw	fs	91.7	0.9	7.4
	B22tb	59-76	5YR	6/4	4/4	m	sh	7.2	cw	fs	92.1	0.4	7.5
	Cb	76-93	7.5YR	7/4	5/4	m	s	7.0		fs	96.1	0.0	5.0
Typic Ustipsamment, Tivoli, on lower side of dune; Pedon 27b-2													
M	A1	0-12	7.5YR	5/3	3/3	m,sg,cr	sl	7.4	as	fs			
	B1	12-36	7.5YR	5.5/4	3.5/4	m	s	7.4	cw	fs			
	B21&Bt	36-60	7.5YR	6/4	4/4	m	s	7.2	cw	fs			
	B22	60-78	6YR	6.5/4	5/4	m	s	7.2	cw	fs			
	C	78-109	7.5YR	6.5/4	5/4	m	s	7.4		fs			

1/ Sediments identified as: M = Muleshoe, L = Longview, B = Birdwell.

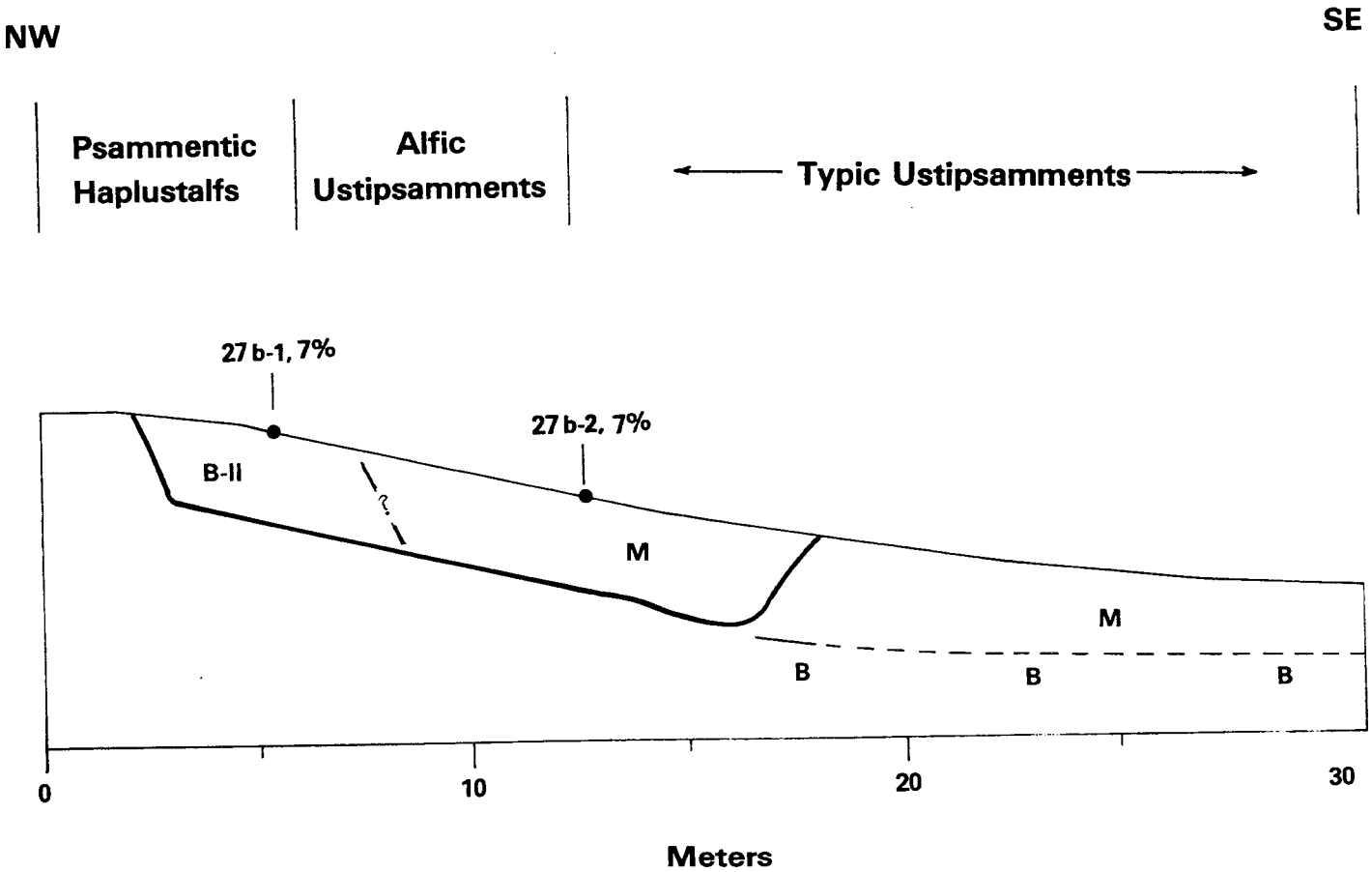


Figure 72. Upper. View of study trench at Site 27b. The Birdwell dune crest is on the skyline, but downslope at the tape the sediments are of Muleshoe age.
Lower. Diagram of study trench at Site 27b, showing stratigraphy, subgroup, slope and location of sampled pedons. M = Muleshoe, B-II = Birdwell II, B = Birdwell. Minor thickness of Muleshoe and Longview sediments at surface in the upper part not shown. No vertical scale (see table 35 for thickness of sediments and horizons). The heavy lower line represents the bottom of the trench.

horizons and is considered to be an A2 horizon, although its present clay content is similar to the Bt horizon beneath (table 35). The Bt horizon is reddish and barely has enough clay increase for an argillic horizon.

Downslope, the post-Birdwell deposit gradually thins and at Pedon 27b-2 cannot be distinguished. Also downslope, clay decreases and the reddish zone that characterizes the Bt horizon gradually disappears; the clay bands persist, however, and Alfic Ustipsamments are present (fig. 72). Still further downslope, the banded zone comes closer to the surface, its top being about 40 cm from the surface where the bands disappear. The bands grade from two continuous, and two discontinuous bands in the west end of the trench to two continuous bands, then one, and finally none on the east end of the trench. The boundary between the Typic and Alfic Ustipsamments occurs where less than two clay bands are present, and is quite sharp at the lower end of the trench, occurring within a distance of about 1/2 m. The zone in which the clay bands occur also becomes less red. The upper two bands -- the most prominent ones -- are 1-2 mm thick and disappear abruptly. The lowermost band extends almost continuously into the Typic Ustipsamment. Pedon 27b-2 illustrates the Typic Ustipsamments.

Although there is gradation from Birdwell sediments in the upper side of the dune to Muleshoe sediments downslope, the exact location of the contact is not apparent because of mixing by soil biota and by percolating soil water. The original Birdwell dune side is thought to have been removed by post-Birdwell slump and erosion associated with the large blowout just to the east. The contact is thought to be located approximately as shown in Figure 72, where the continuous Bt horizon disappears. The smooth slopes that cross the boundary between sediments of different ages is common as discussed previously. This is a major reason why soil occurrence is difficult to predict. Predictions can be made with somewhat more assurance in the high Birdwell dunes to the south (see Sites 33-39).

The surficial sandy horizons in Pedon 27b-2 are thinner than upslope and the soil as a whole is not as red (table 35). There are two discontinuous bands in the B21&Bt horizon; they are about 5 cm apart and about 1 mm thick.

To determine the character of the boundary between the Alfic and Typic Ustipsamments in another place, a study trench was also examined about 1 m north of Pedon 27b-2. Here also the boundary between the Alfic and Typic Ustipsamments was marked by the disappearance of two continuous clay bands. Thus, this kind of boundary is not an isolated case.

Sites 28 and 29, dune crests

Sites 28 and 29 (fig. 40, table 36) illustrate soil development on small dune crests of Birdwell age. Pedons at both sites are similar to Pedon 27a, on the dune crest at Site 27, in several respects. Particle-size data indicate an accumulation of silt, and possibly some clay, from dustfall in the surface horizon. Both pedons have distinct, although slight, accumulations of silicate clay in Bt horizons that are underlain by C horizons (table 36). The Bt material occurs continuously in a Bt horizon, instead of occurring only in bands as is the case in soils of Longview age. Clay bands are still plainly visible in the Bt horizon, however.

In Pedon 28, the B2t horizon has the maximum development of clay bands, approximately 1 cm thick and usually two in number, one at the top and one

Table 36. Characteristics of a Haplustalf and an Ustipsamment on crests of Birdwell dunes, Sites 28 and 29

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 28												
A11	0-12	6YR	5/3	3.5/3	m,sg, 1fcr	s	6.8	as	s	88.5	5.5	6.0
A12	12-25	5YR	5/3.5	4/3.5	m	sh	6.8	cw	s	92.1	0.9	7.0
B1t	25-35	5YR	5/4	3.5/4	m	sh	7.0	as	s	90.0	2.5	7.5
B2t	35-47	5YR	5/4	3.5/4	1cpr-m	h	7.0	as	ls	85.7	2.9	11.4
B3t	47-61	5YR	5.5/5	4/5	1csbk	sh	7.0	cw	lfs	89.0	0.5	10.5
C	61-77	5YR	6/4	5/4	m	s,sh	7.2	as	s	94.6	0.9	4.5
B1b	77-102	5YR	5.5/4	4.5/4	m	sh	7.2		s	93.4	1.0	5.6
Alfic Ustipsamment, Circleback: Pedon 29												
A11	0-7	7.5YR	5/3	3.5/3	m	s	7.0	aw	s	90.3	3.7	6.0
A12	7-17	7.5YR	5.5/3.5	4/3.5	m	s	7.0	cw	fs	95.5	0.0	4.5
B1t	17-30	5YR	5/4	3.5/4	m	s,sh	7.0	as	s	94.3	0.6	5.1
B21t	30-47	5YR	5.5/5	4/5	m	sh	7.0	as	s	93.4	0.0	6.9
B22t	47-64	5YR	6/5	4.5/5	m	sh	7.0	as	s	93.9	0.5	5.6
B3t	64-97	5YR	6/5	4.5/5	m	sh	7.0		fs	93.1	0.5	6.4
C	97-121	5YR	6.5/5	5/5	m	s	7.0		s	94.6	0.0	5.4

at the bottom of the horizon. The B3t horizon has a crotovina, 8 cm in diameter, filled with material like that of the A12 horizon. Pedon 28 has a buried horizon in its lower part (table 36). A thin, discontinuous A1b horizon, slightly darker than the B1b horizon, occurs above the B1b horizon but was not sampled.

Augering below the bottom of the trench showed a loamy fine sand B2t horizon that grades to sandy C horizon material at a depth of about 185 cm. This buried soil is thought to be Birdwell I.

Pedon 29 occurs on the crest of a high dune of Birdwell age. The pedon illustrates the occurrence of Alfic Ustipsamments on a very narrow ridge crest of Birdwell age. In this situation the clay increase required for the argillic horizon is not met (table 36). The low clay at this site, as compared to Site 28, may be related to its landscape position, on the very crest of this high dune. Less clay would be expected to move into such soils because runoff should be greater (and infiltration less) on narrow ridges as compared to broader, stabler sites such as Site 28. The B2t horizon has the most prominent clay bands, which are about 1/2 cm thick and quite continuous across the exposure.

Site 30, southernmost major deposit of Longview age

Site 30 (fig. 40, table 37) occurs on the crest of a dune with Longview deposits. This dune is the southernmost major deposit of Longview age in the study area (see fig. 19). Occasional thin deposits have been observed on the lee side of Birdwell ridges and will be discussed later.

Table 37. Characteristics of the Alfic Ustipsamment, Circleback, on the crest of a Longview dune at Site 30 1/

Horizon	Depth, cm	Hue	Value/chroma Dry	Value/chroma Moist	Texture	Structure	Dry consistence	pH	Lower boundary
A1	0-21	7.5YR	5.5/4	3.5/4	fs	m	s	7.0	cw
B11	21-42	7.5YR	6/4	4/4	fs	m	s	7.0	cw
B12	42-63	7.5YR	6.5/4	5/4	fs	m	sh	7.0	aw
B21&Bt	63-91	5YR	6.5/4	5/4	fs	m	sh	7.0	aw
B22&Bt	91-123	5YR	6.5/4	5/4	fs	m	sh	6.8	cw
B3&Bt	123-160	7.5YR	6/4	4.5/4	fs	m	sh	6.8	aw
C&Bt	160-206	4YR	5/5	4/5	fs	m	sh	6.6	aw
Btb	206-218	2.5YR	5/5	4/5	fs	m	sh	6.6	

1/ Subordinate colors and other characteristics follow. B21&Bt: clay bands range up to 5 mm thick, and are 2.5YR 4/5, dry. C&Bt: parts are lighter and less red. Longview sediments occur from 0-206 cm; Birdwell sediments from 206-218 cm.

The two most prominent clay bands are continuous, are in the B21&Bt horizon and range from 1/2 to 1 cm thick. Bands beneath are generally 1-3 mm diameter; there are eight to ten of these, some discontinuous, to the top of the C&Bt horizon.

The soil at Site 30 is thicker than many soils of Longview age. Sedimentation could encompass all of the Longview I and II time. Thickness of the banded zone; apparent pedogenic clay in the C horizon; and a fairly thick zone (tens of centimeters) without bands in the B3&Bt horizon all suggest the possibility of a halt during deposition of Longview sediments -- possibly at about 1 m depth -- followed by a time of stability and soil formation. Then sedimentation could have continued to the top of the present land surface, followed by stability and subsequent development of the most prominent zone of clay bands.

Some stratification is visible in the B3&Bt horizon. The C&Bt horizon is clearly stratified, has some clay bands that could be pedogenic, and has occasional lenses of whitish grains. The buried Bt horizon becomes less red and less clayey with depth and C-like material was found with the auger at 250 cm depth. This continues to at least 325 cm depth where color of the C horizon is 5YR 5.5/4, dry and texture is fine sand.

Site 31, blowout and dune

Site 31 (figs. 40, 73, 74) consist of a study trench in a blowout and in the crest of a blowout dune to the east. Figure 73 shows slope, stratigraphy, soil occurrence and location of the sampled pedons. Table 38 gives soil characteristics.

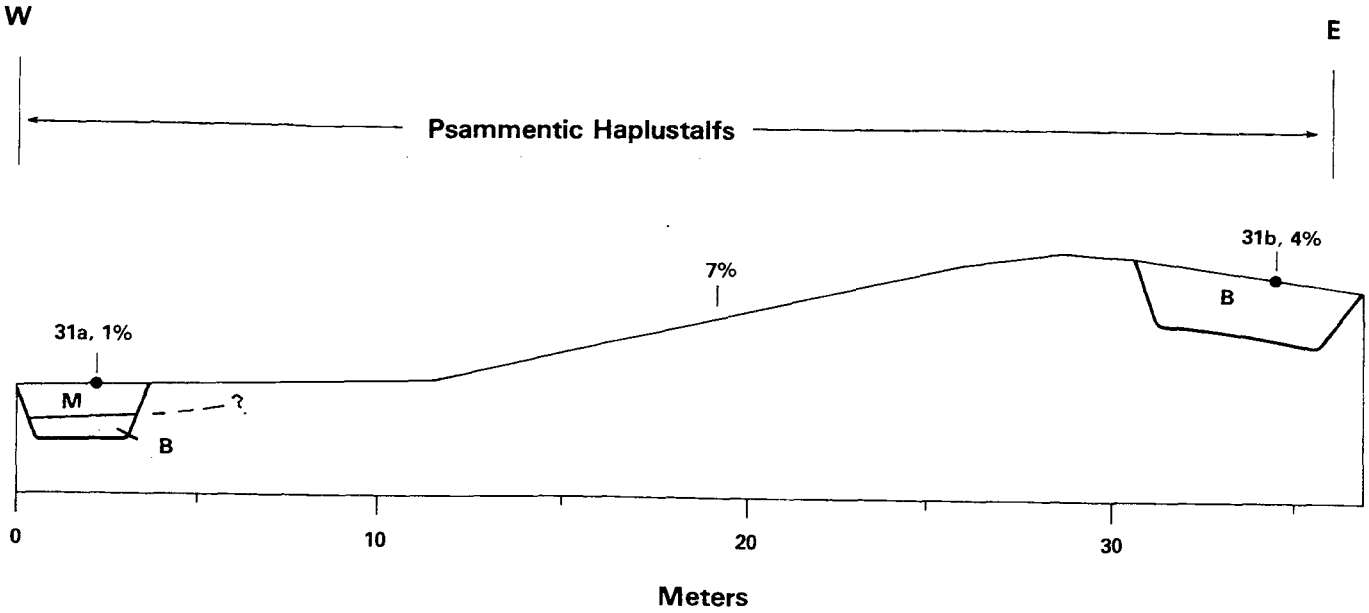


Figure 73. Upper. Landscape view of the blowout and dune at Site 31. Site 31a is in the blowout, foreground, and Site 31b is in the dune in the middle ground. The high dune at Site 32, to be discussed next, is on the skyline at center. The view is east. Photographed March 1976.

Lower. Diagram of study trenches at Site 31, showing stratigraphy, subgroup, slope and location of sampled pedons. M = Muleshoe, B = Birdwell. No vertical scale (see table 38 for thickness of sediments and horizons). The heavy line represents the bottom of the trenches.

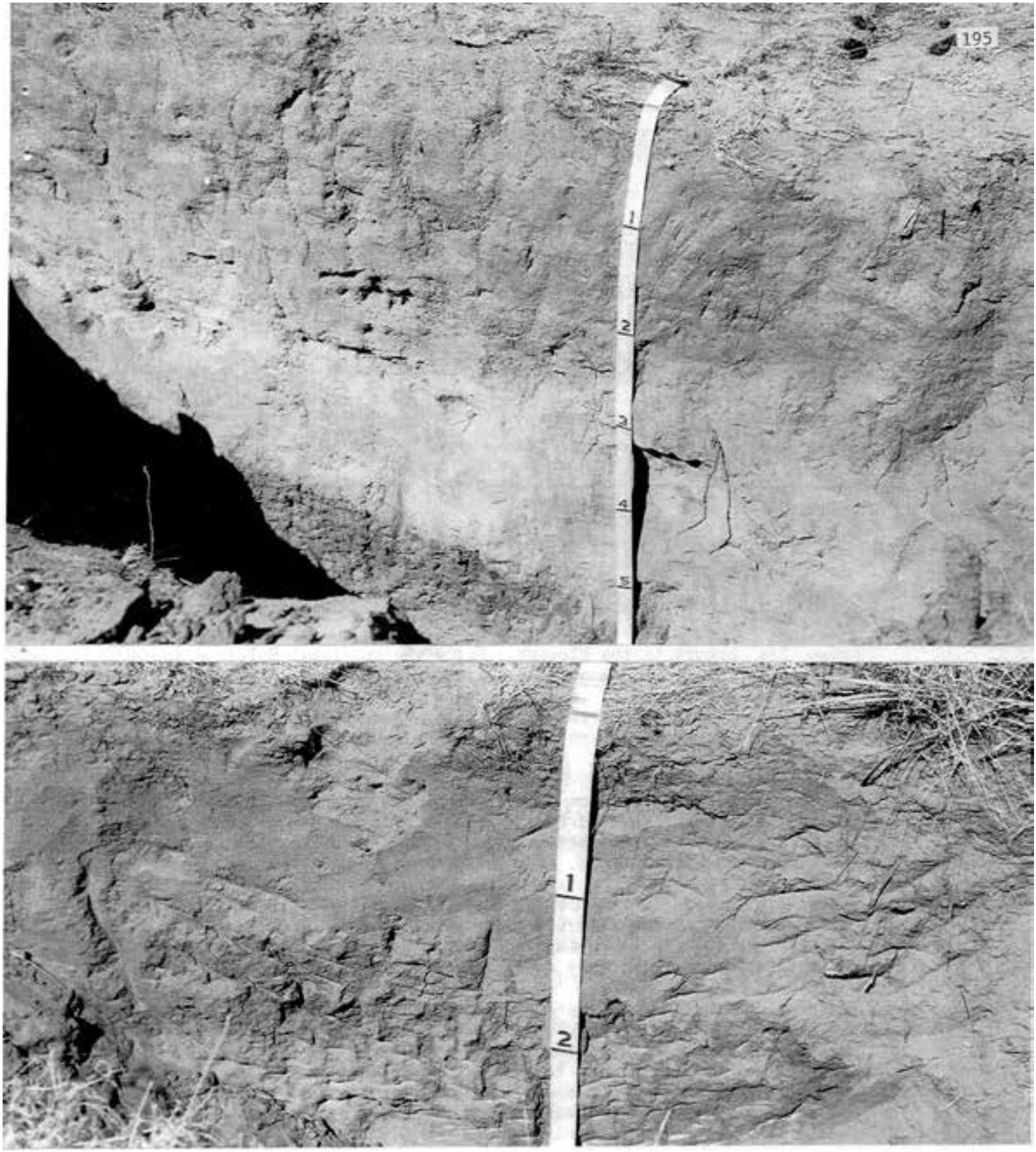


Figure 74. Upper. The Psammentic Haplustalf, Texico, at Site 31a, on the dune crest. The boundary to Roosevelt sediments is just below the 5 ft (1.5 m) level. Scale is in feet. Photographed March 1976.

Lower. The Psammentic Haplustalf, Texico, at Site 31b, in the blowout. Muleshoe sediments extend to below the 1 ft (0.3 m) mark, and are underlain by Birdwell sediments. Scale is in feet.

Table 38. Characteristics of Psammentic Haplustalfs, Texico, at Site 31

Sediment[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
In blowout; Pedon 31a													
M	A11	0-3	7.5YR	5/3	3.5/3	1mpl	sh	7.4	as	1fs			
	A12	3-15	7.5YR	5/3	3.5/3	m	s	7.4	as	fs			
	B2	15-34	7.5YR	5/3	3.5/3	m	sh	7.2	as	fs			
B	B1tb	34-52	6YR	5/3	3.5/3	m	h,sh	7.2	as	1fs			
	B2tb	52-72	2.5YR	4.5/6	4/6	1cpr-1csbk	vh	7.2	as	fsl			
	B3b	72-83	2.5YR	5/6	4/6	1cpr	h,vh	7.0		1fs			
Near crest of blowout dune; Pedon 31b													
B	A1	0-8	6YR	5/3.5	4/3.5	m,sg 1fcr	s	7.0	as	s	91.1	3.8	5.1
	B1t	8-23	5YR	5/4	4/4	m	a	7.0	as	fs	91.5	2.6	5.9
	B2t	23-42	4YR	5/6	4/4	m	sh,h	7.0	cw	1s	85.8	3.4	10.8
	B31t	42-65	4YR	5/4	4/4	m	sh	7.0	cw	1s	87.9	3.2	8.9
	B32t	65-94	5YR	5.5/4	4/4	m	sh	7.0	cw	s	93.6	0.8	5.6
	C	94-106	7YR	6.5/4	5/4	m	s,sh	7.0		s	97.0	0.1	1.9

1/ M = Muleshoe, B = Birdwell

Pedon 31a occurs in the blowout. Since the surficial Muleshoe deposits are less than 50 cm thick and lack diagnostic horizons, classification is based on the buried soil, and the pedon is a Psammentic Haplustalf. Although the blowout receives run-in from adjacent slopes, upper horizons are not quite dark enough and organic carbon would be too low for a mollic epipedon.

Up the side of the dune towards Pedon 31b, the reddish Bt horizon of Texico is very near the surface. This is probably due to strong erosion during Birdwell II, Muleshoe and Longview time. The Bt horizon is deeper on gentler slopes near the blowout.

Pedon 31b occurs in the blowout dune. The soil has a distinct bulge in silicate clay that averages in the sandy particle-size class. Clay bands in the Bt horizon are discontinuous and only faintly visible because of large-scale obliteration and mixing by soil biota and by percolating soil water.

Horizons below 106 cm were not sampled. At 160 cm depth there is an abrupt smooth boundary from whitish sand in the C horizon to the prominent Bt horizon in Roosevelt sediments (see stops 5 and 6 in Gile, 1981 for characteristics of soils in Roosevelt and Hale sediments along Farm Road 1731, just west). The Bt horizon in Roosevelt sediments becomes coarser and less red with depth. At about 230 cm the color again becomes redder and this marks the top of the Bt horizon of Hale age.

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.

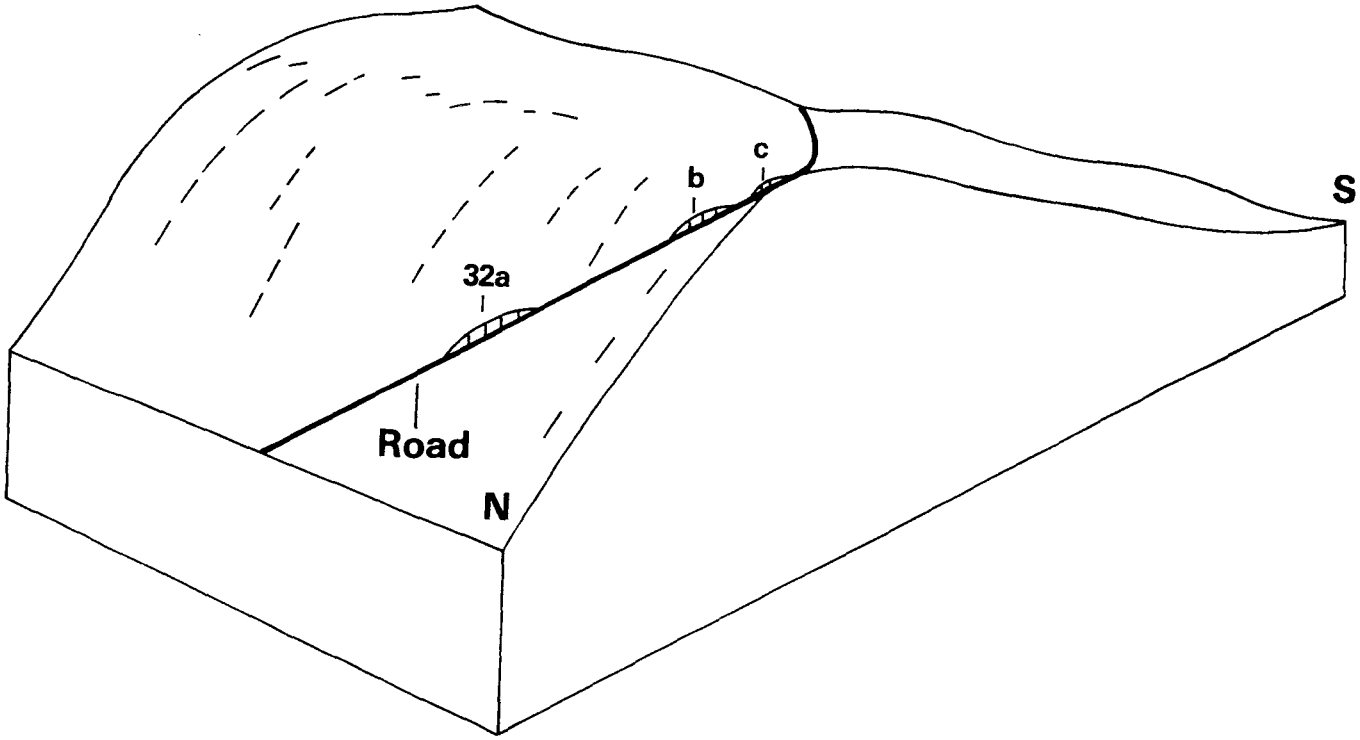
STUDY SITES

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.



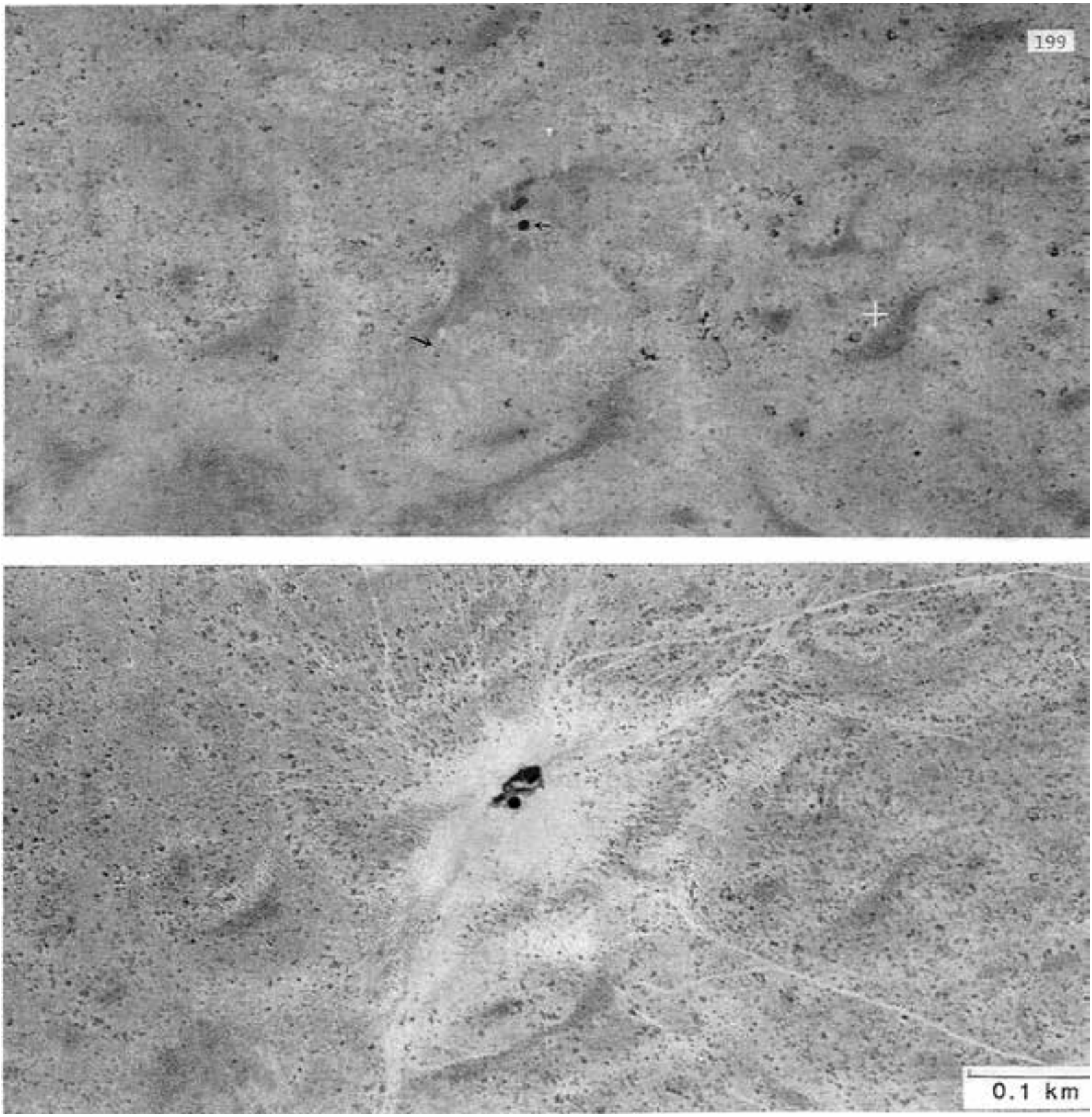


Figure 76. Upper. Aerial photograph taken August 3, 1941. Arrows point to water tank in blowout and faint trail up the dune just southwest; except for these features, little evidence of landscape alteration is apparent. Note changes with passage of time through 1970 (fig. 77, lower).

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.

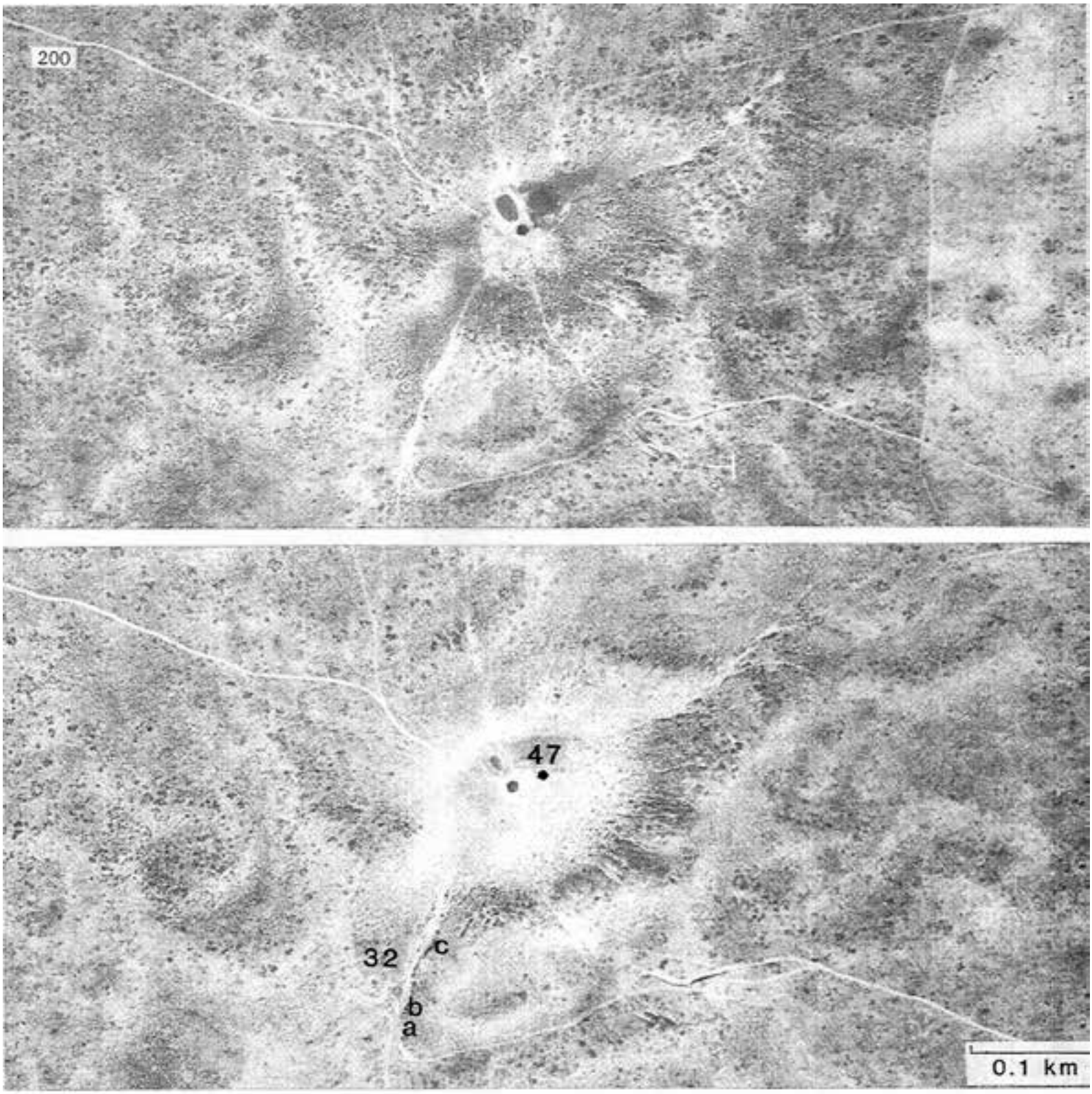


Figure 77. Upper. Aerial photograph taken October 31, 1962. Vegetation is visible in the Fairview deposit next to the road. Several new roads have been started since 1953.

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

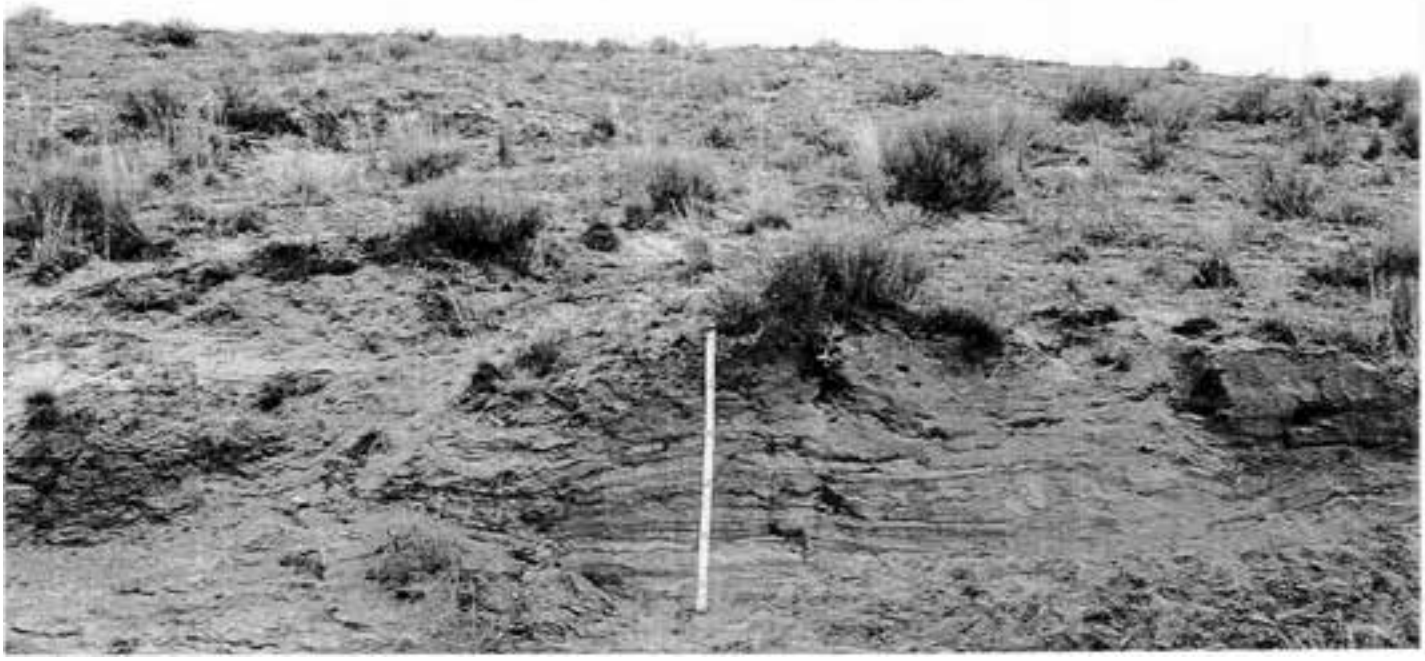


Figure 78. Landscape view along east bank of road at Site 32a. Fairview sediments are still preserved beneath the shrub at the tape, but both Fairview and underlying Birdwell sediments have been eroded nearby as indicated by drains graded to the road. Note the circular forms at 3 ft (0.9 m) depth, about 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.

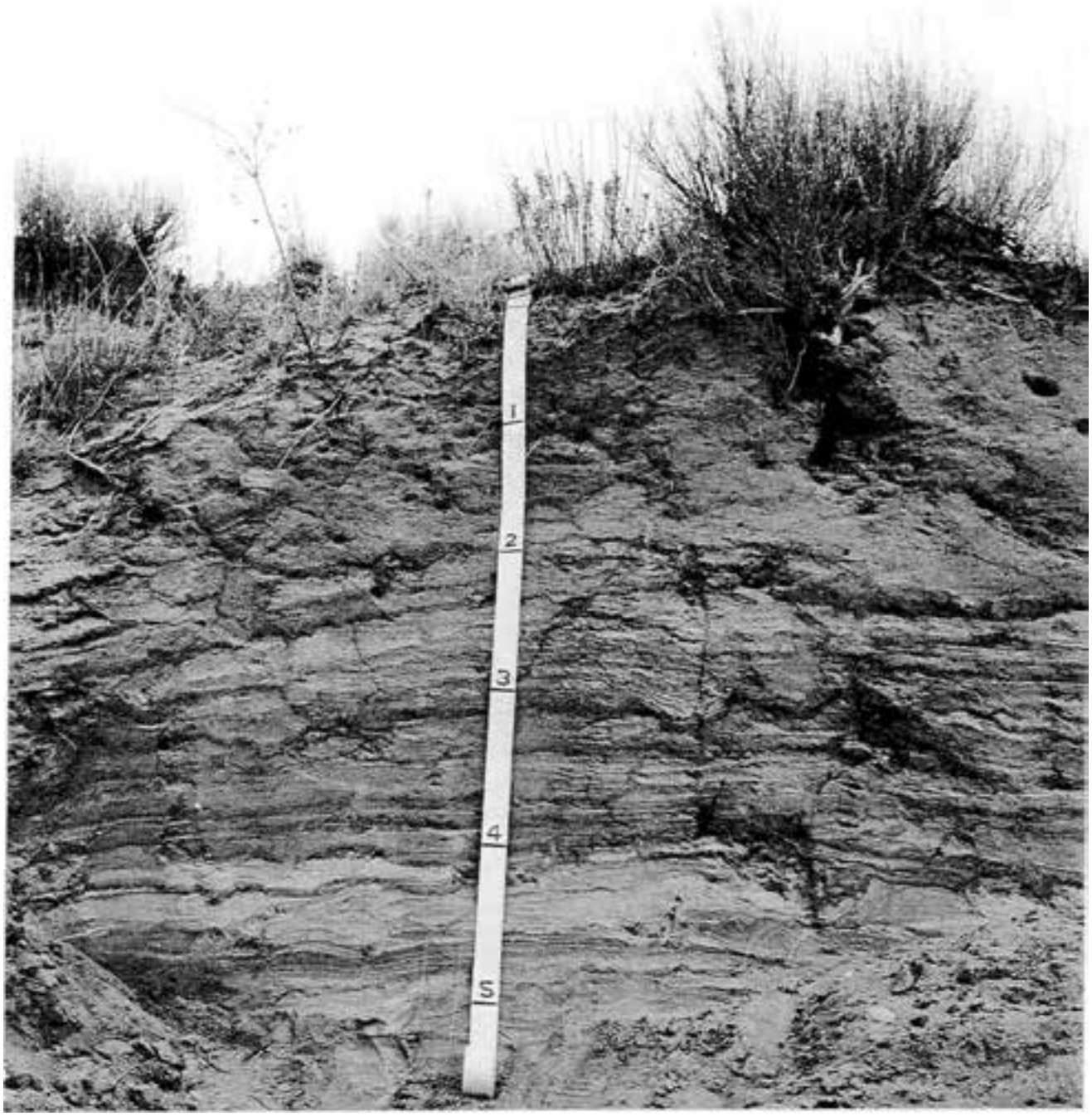


Figure 79. The Alfic Ustipsamment, Circleback, at Site 32a. Note prominent clay bands; compare with clay bands on dune side of Longview age at Site 3. Scale is in feet.

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.

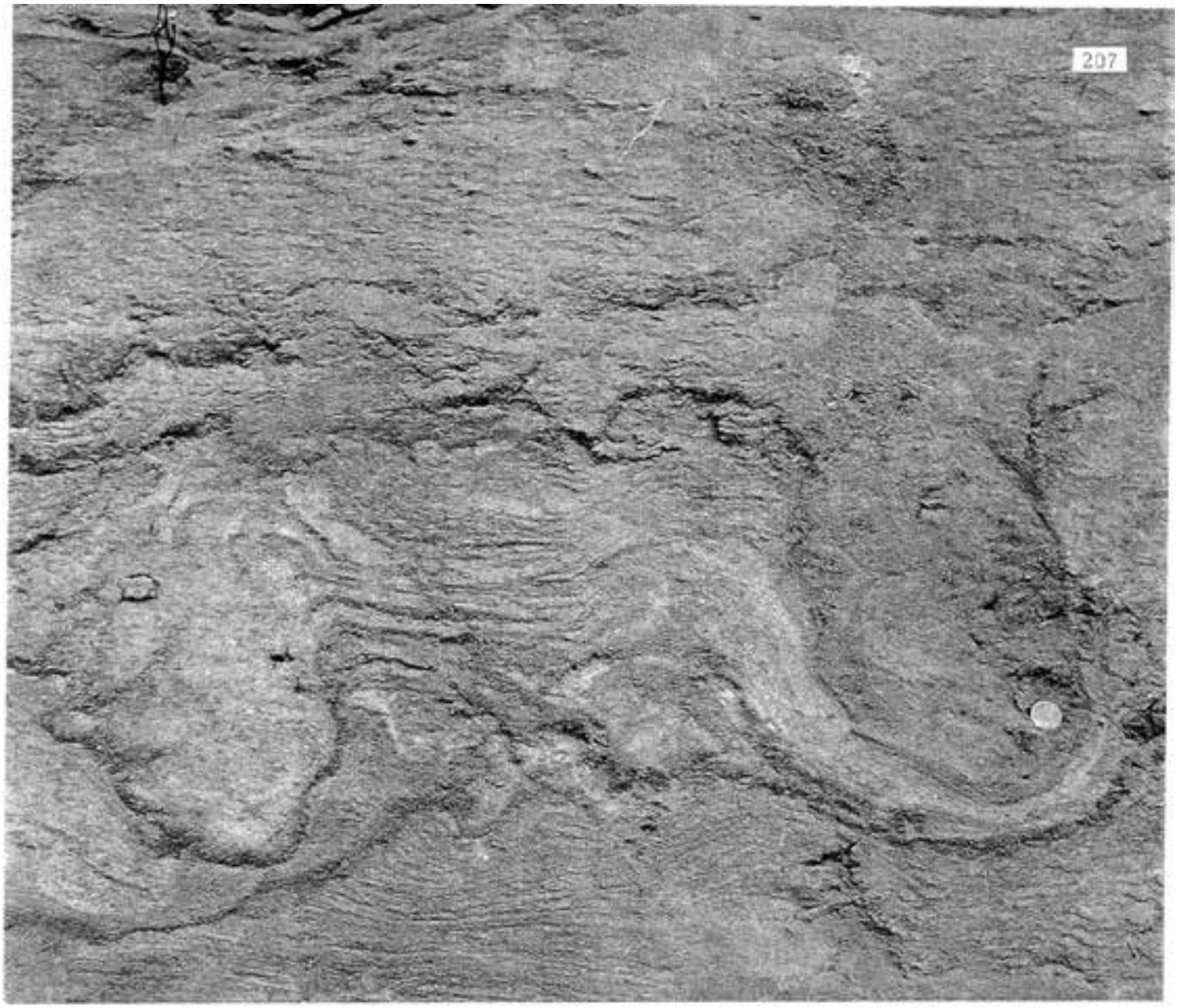


Figure 80a. Closer view of crotovinas shown in figure 80. The central part of crotovina at right is filled with darker material, and discontinuous clay bands have started to form around it; this central part represents a later excavation by rodents, and subsequent filling. Outlines of the younger part 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

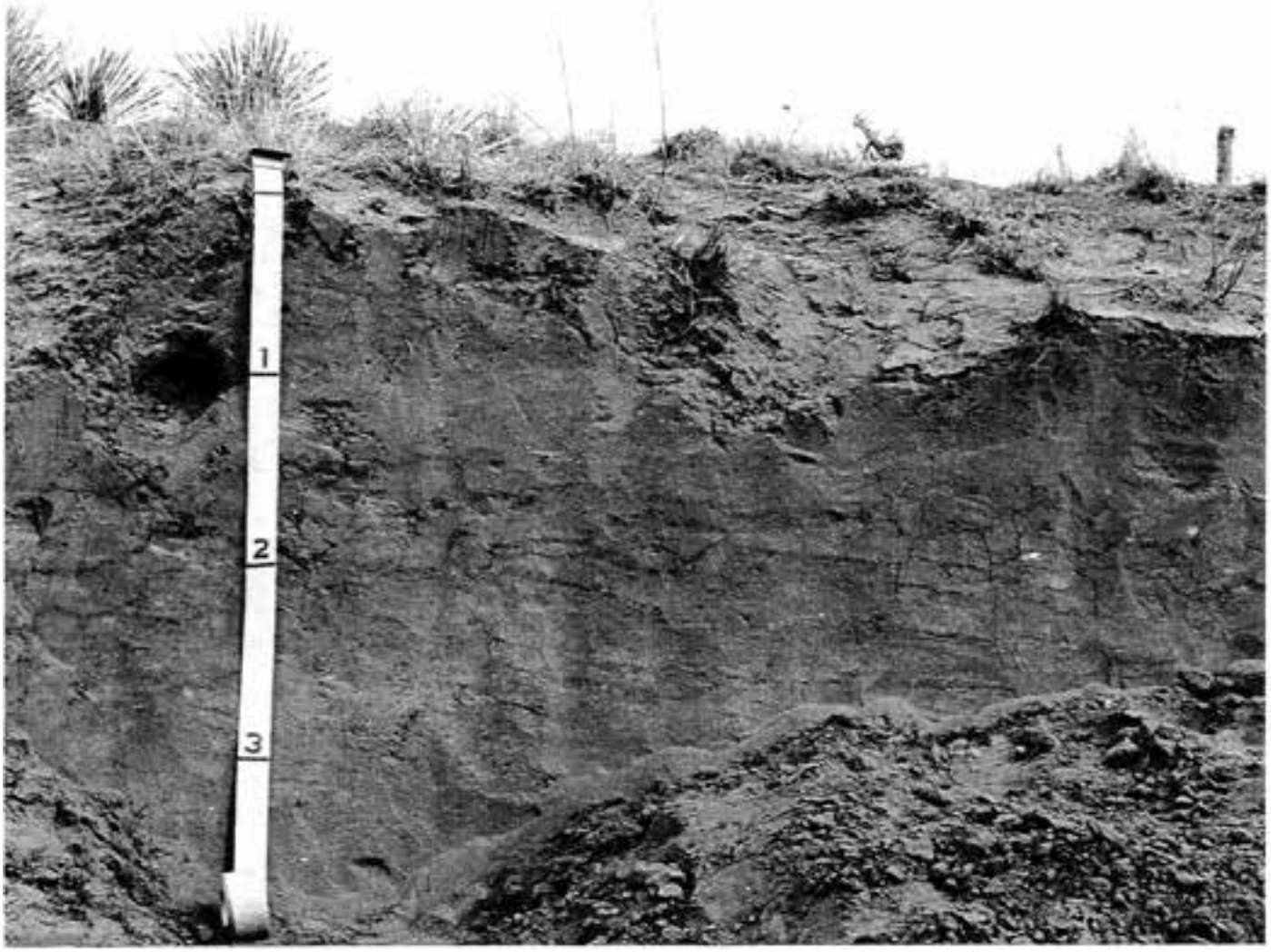


Figure 81. Upper. Landscape of the Birdwell dune at Site 32c, on the ridge crest. Strong erosion has taken place even on the ridge crest. The view is east. Photographed March 1981.

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.

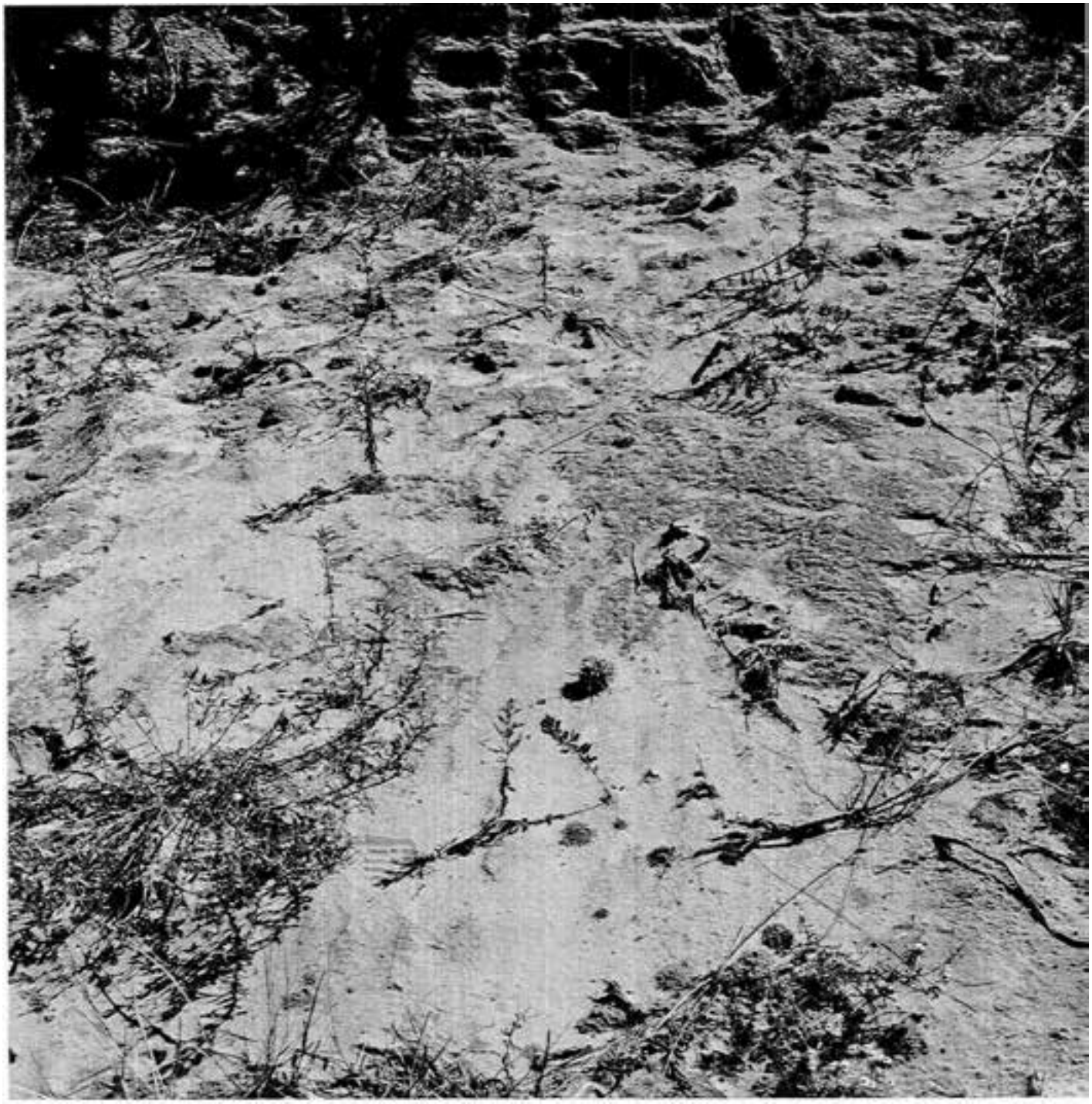


Figure 82a. Closer view of the fresh deposit of whitish sand that covers most of the slope below the cut at Site 32a, and of the smooth surface crust at right center. Penny at left of smooth crust gives scale, as does a heel print at lower left; the top of the heel print is 8 cm across.

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

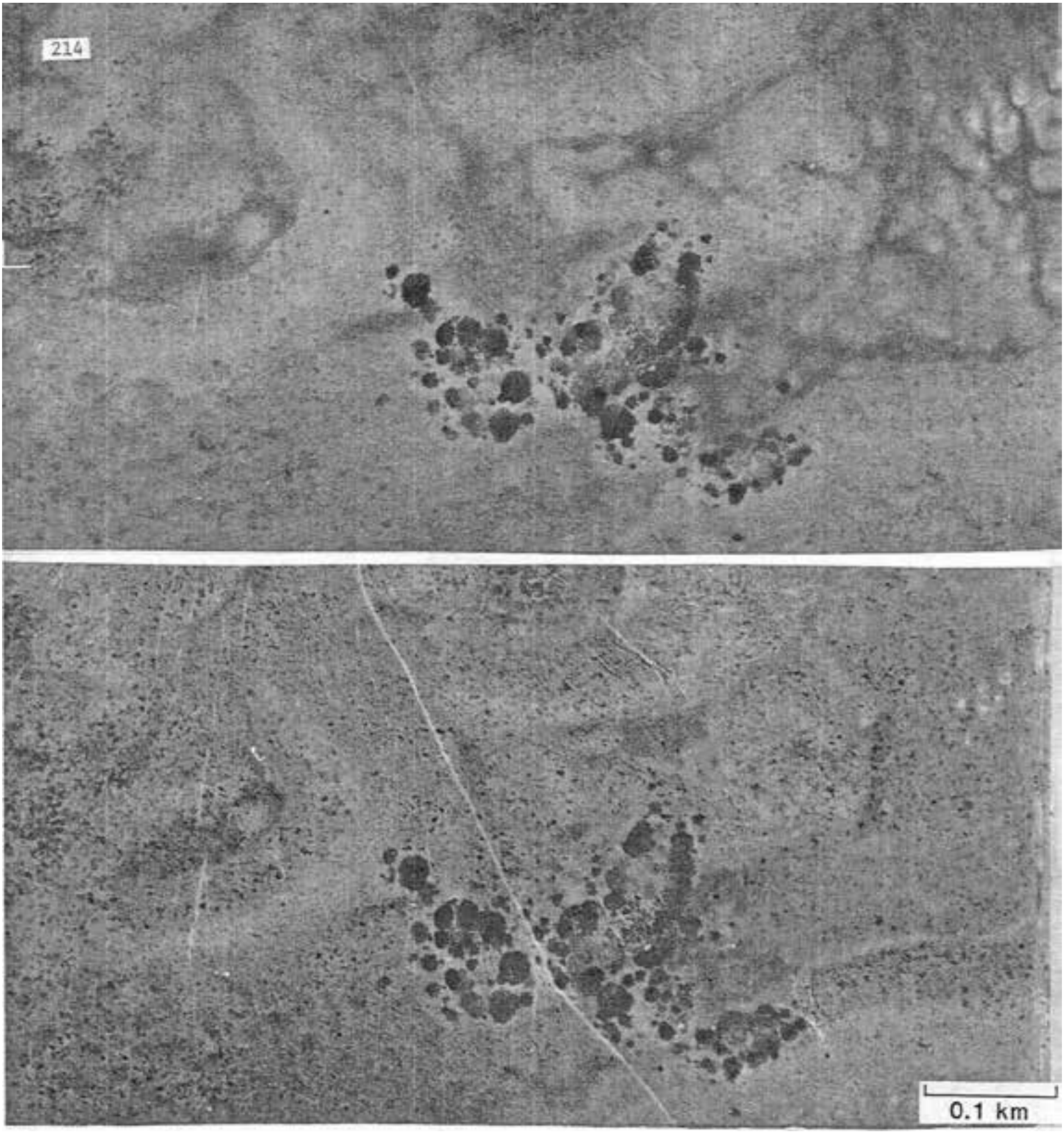


Figure 83. Upper. Aerial photograph taken August 3, 1941. 1941 was a year of record rainfall (see text discussion), and the dark colors suggest moist conditions. Lightest colors, at top right, are shallow high-carbonate horizons that occur in small knolls. Other light-colored, rounded shapes nearby represent 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.

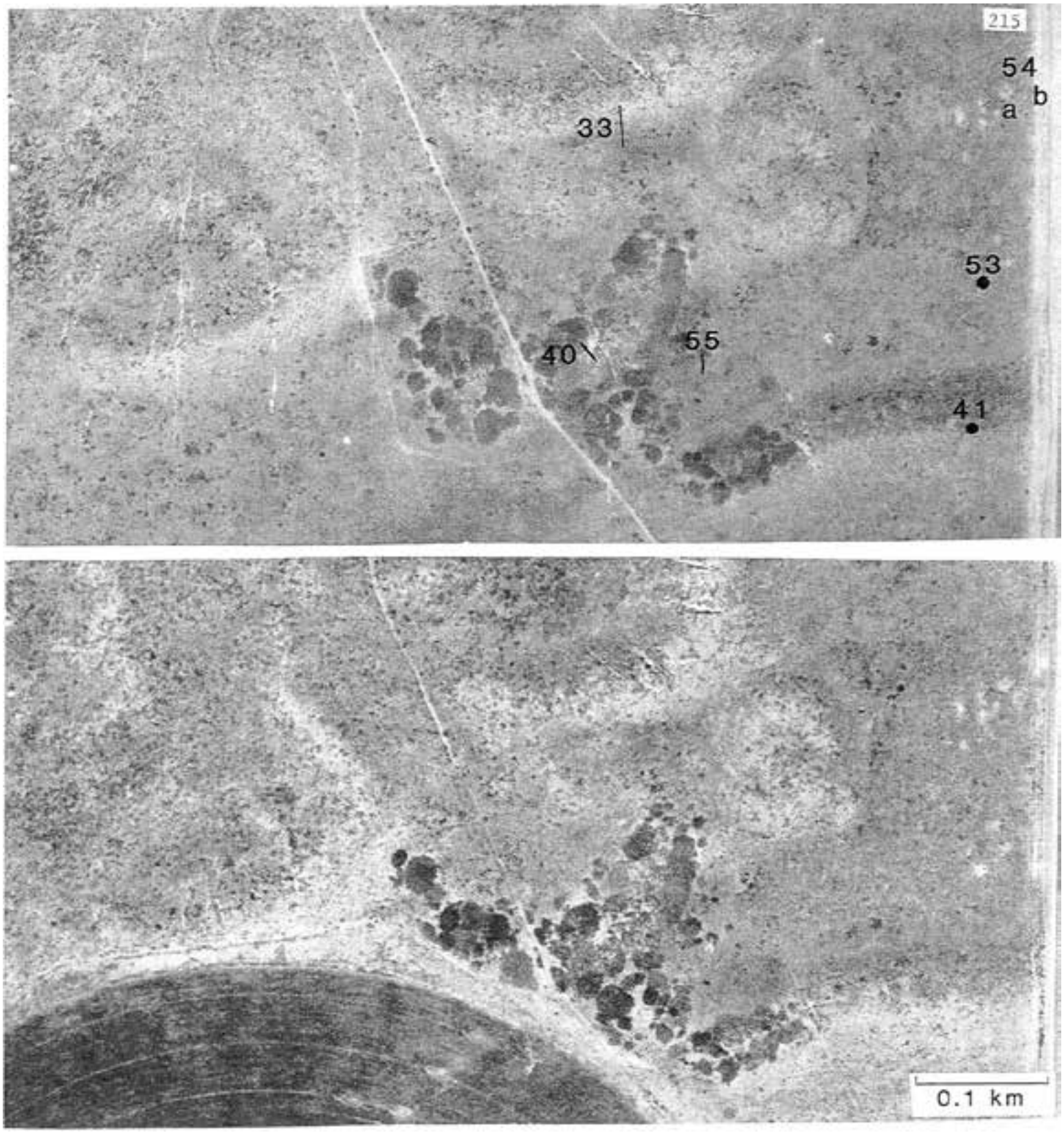


Figure 84. Upper. Aerial photograph taken December 13, 1970. Sites 33, 40, 41, and 53-55 are located.

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.

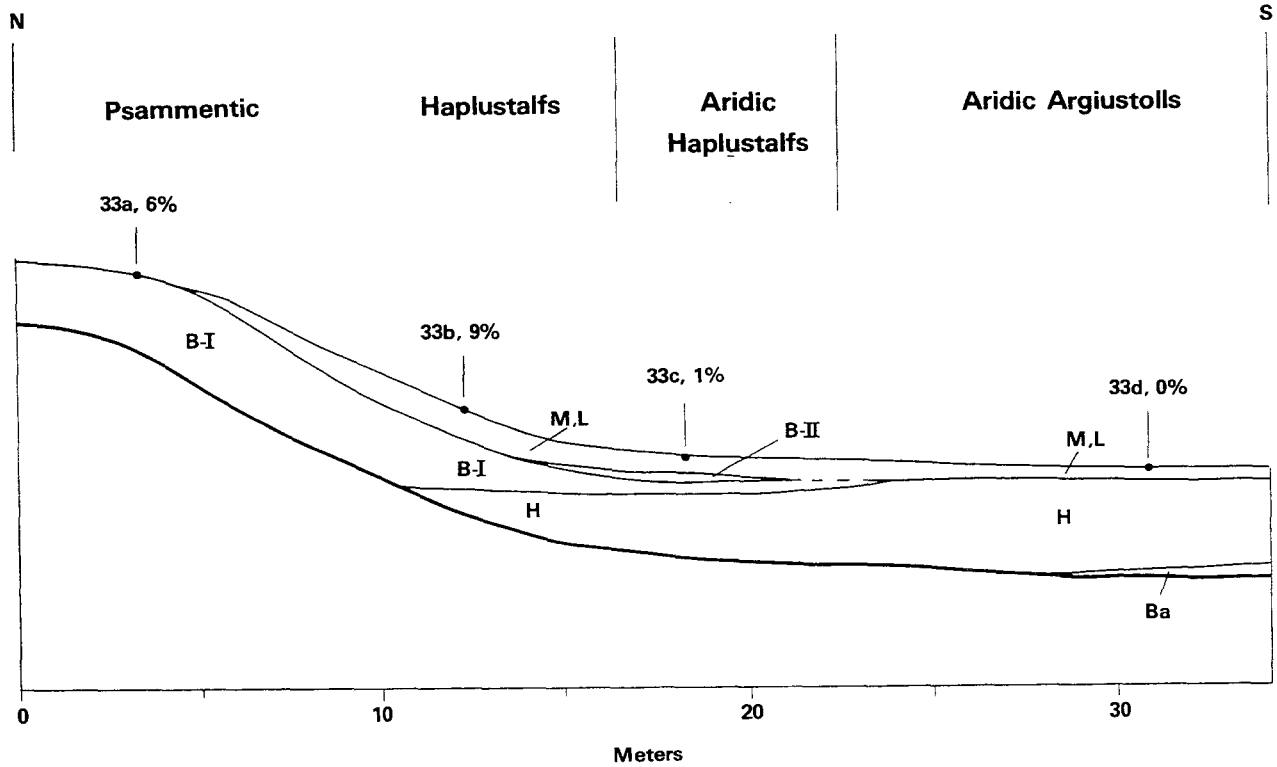


Figure 85. Diagram of study trench at Site 33, showing stratigraphy, subgroup, slope and location of sampled pedons. M = Muleshoe, L = Longview, B-I = Birdwell I, H = Hale. No vertical scale (see table 40 for thickness of sediments and horizons). The heavy lower line represents the bottom of the trench.

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.

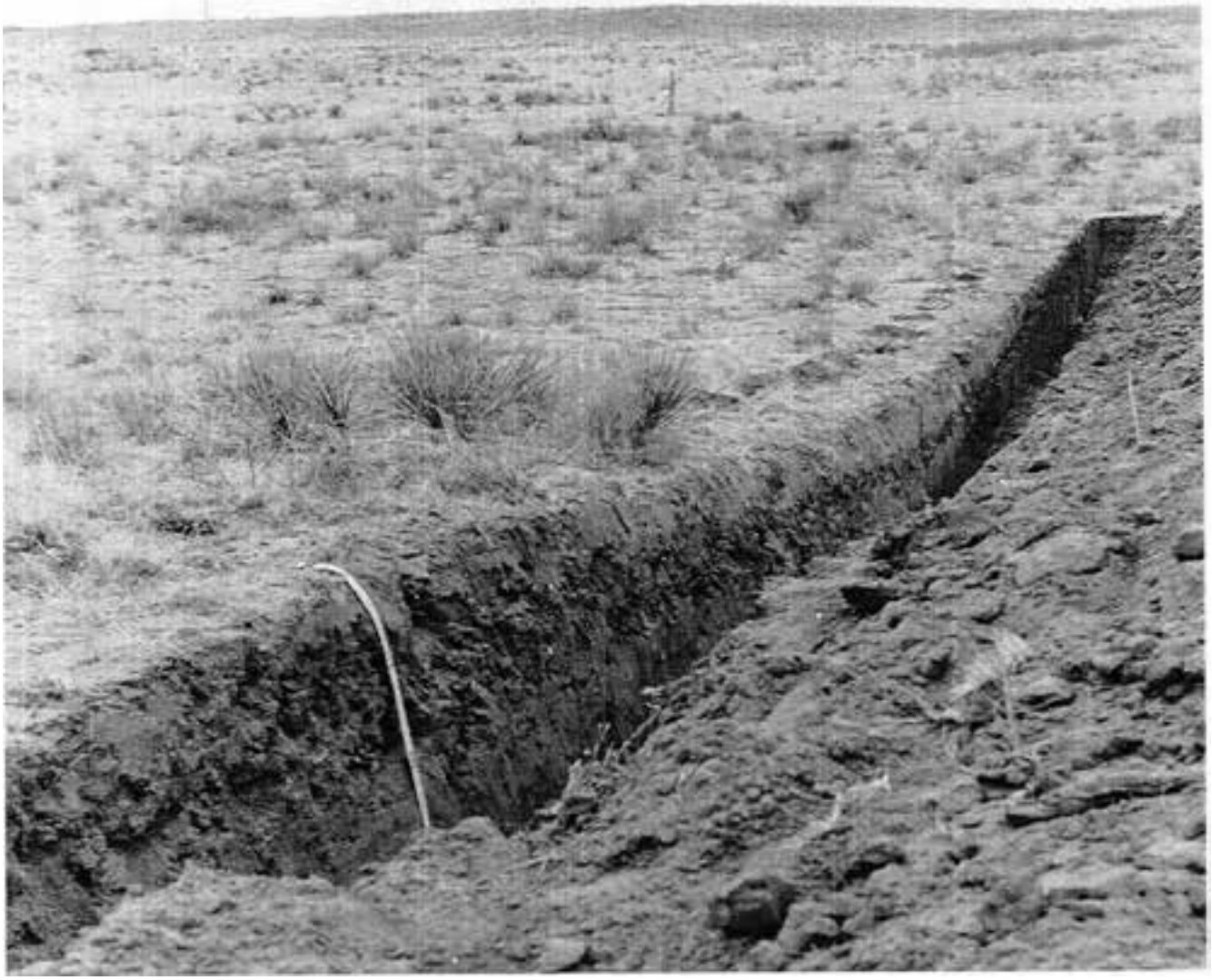


Figure 86. View of study trench at Site 33. The foreground dune is Birdwell, with a thin deposit of Muleshoe and Longview sediments on the dune side. The trough (at far end of trench) is in sediments of the Hale surface. At left is the Psammentic Haplustalf Texico, at Site 33a. Scale is in feet. The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

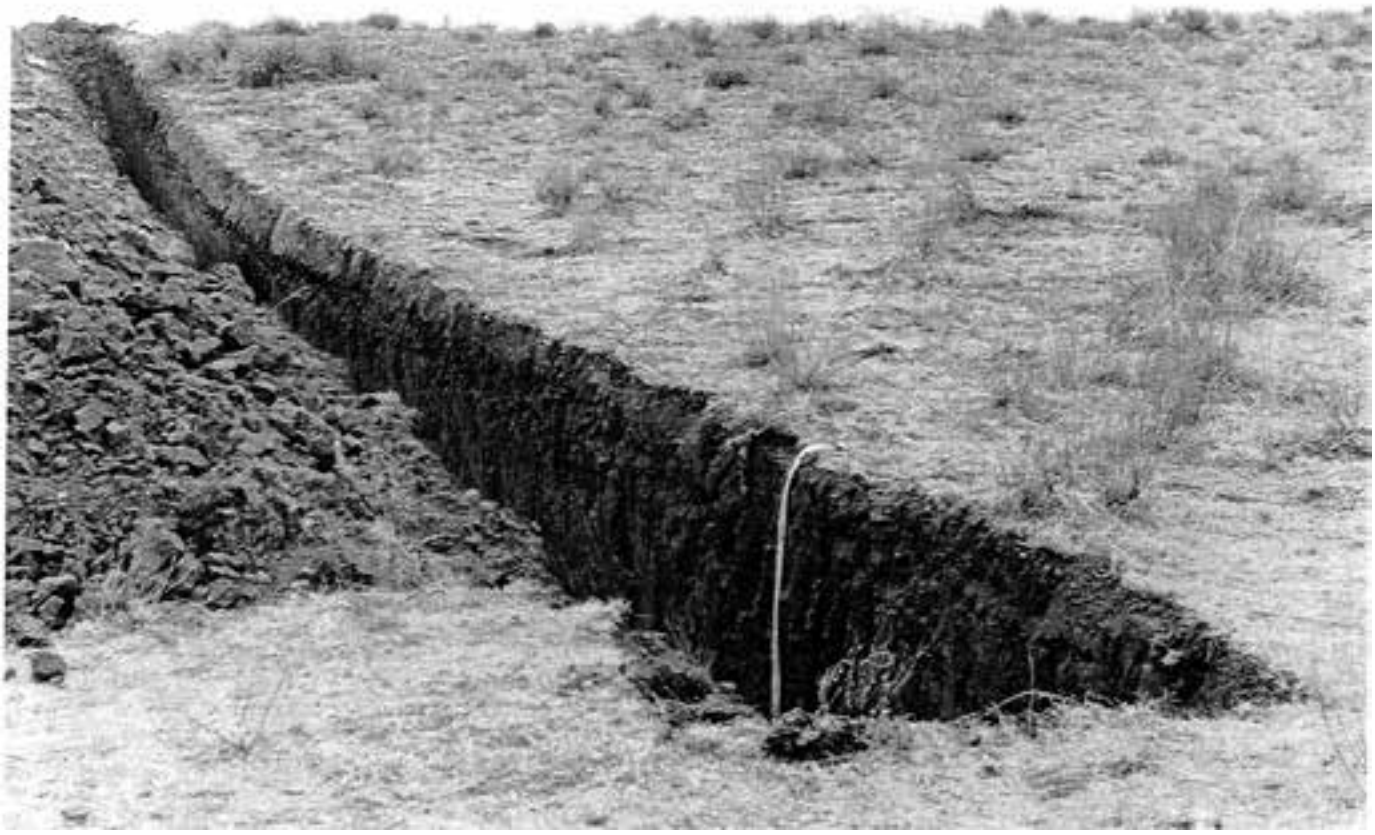


Figure 87. The Aridic Argiustoll, Newell, Pedon 33d, in the trough at the tape. The Alfisol-Mollisol boundary occurs at the margin of the trough, which receives run-in from the dune. Scale is in feet. The view is north. Photographed March 1977.

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.

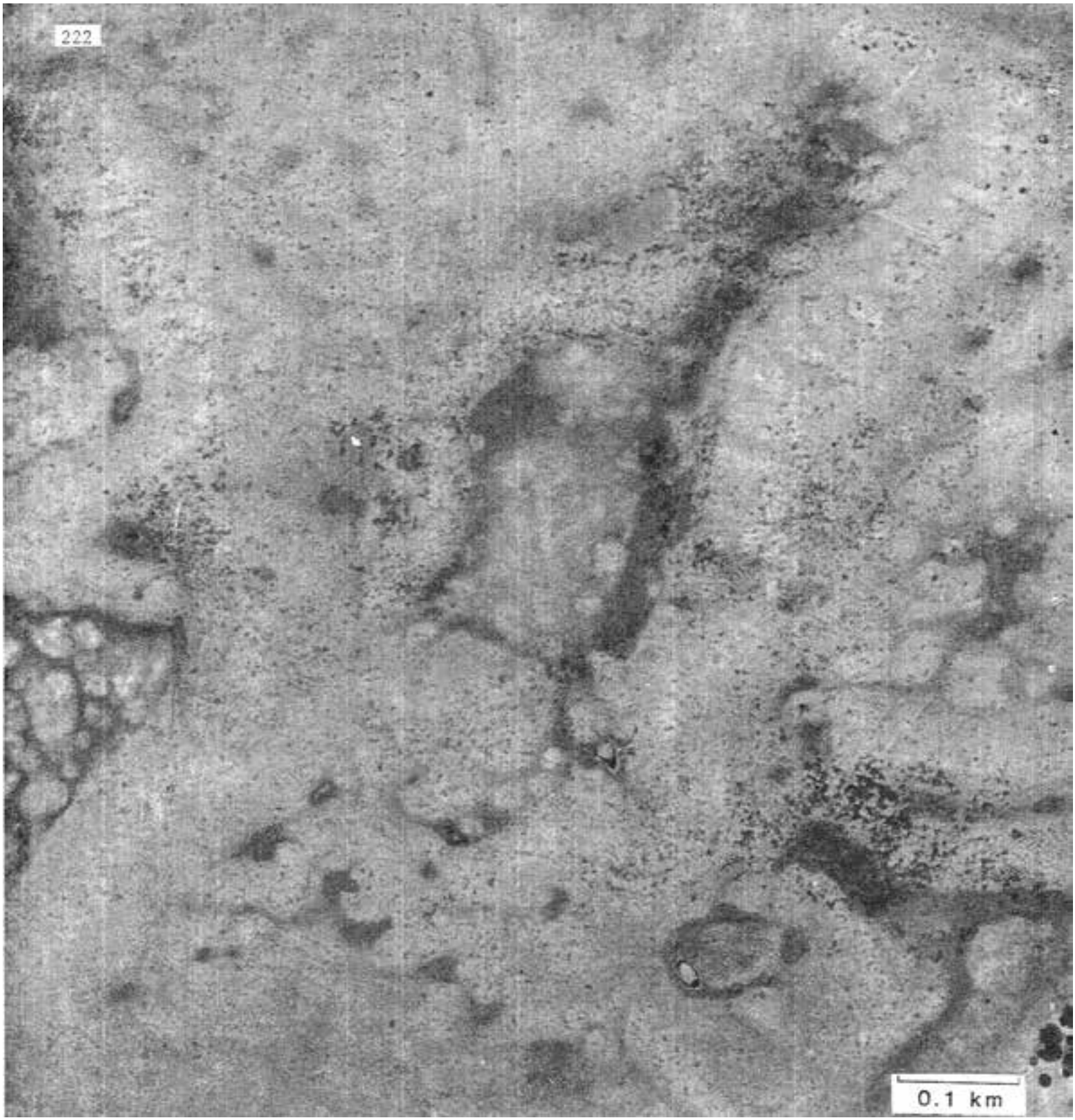


Figure 88. Aerial photograph taken August 3, 1941. North-south lines crossing the high dunes at left are traces of the old XIT trail, which are also visible in all later photographs. Heavy rains fell in 1941, and the dark areas, which are in depressions, represent moist soil. The small, roundish areas 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.

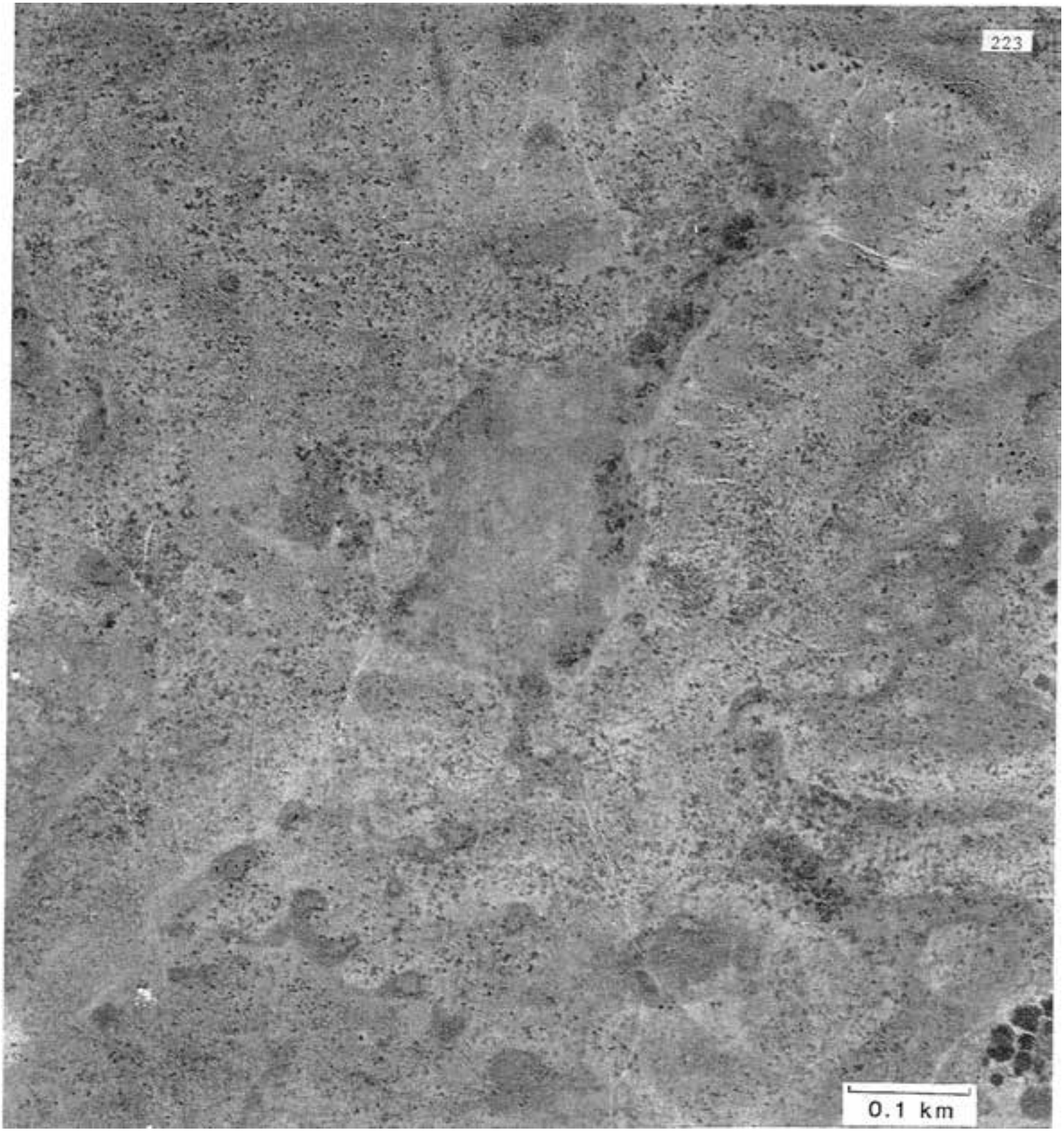


Figure 89. Aerial photograph taken February 25, 1953. A number of gullies are apparent in the west-facing side of the large dune at upper right. Note that the trails in the upper center head toward the gullies; to the north, the trails connect to a water tank (see Sites 32 and 47).

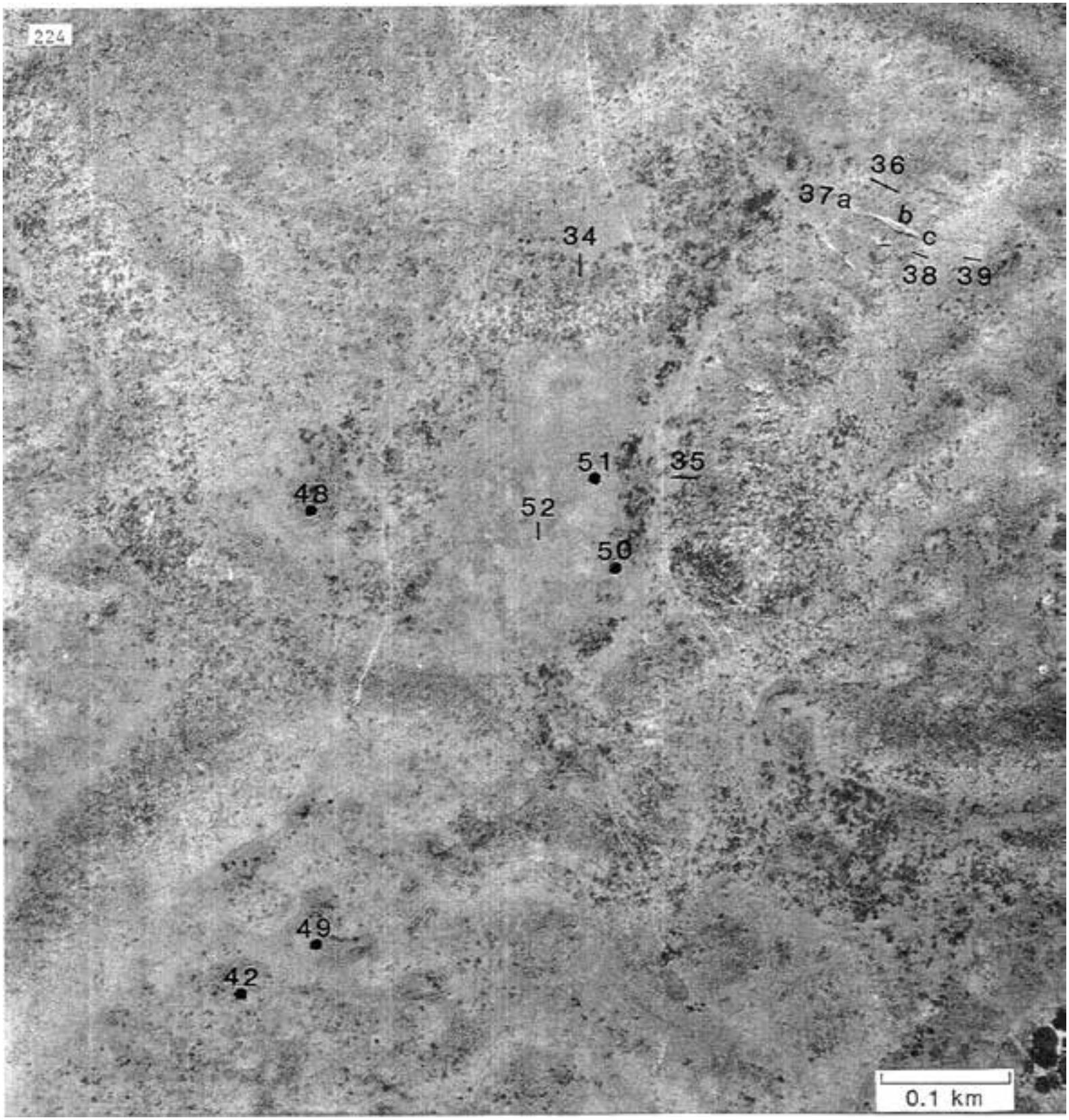


Figure 90. Aerial photograph taken December 13, 1970. Sites 34-39, 42 and 48-52 are located. Most gullies have enlarged since 1953. A small gully has formed in a north-facing dune side at left center.

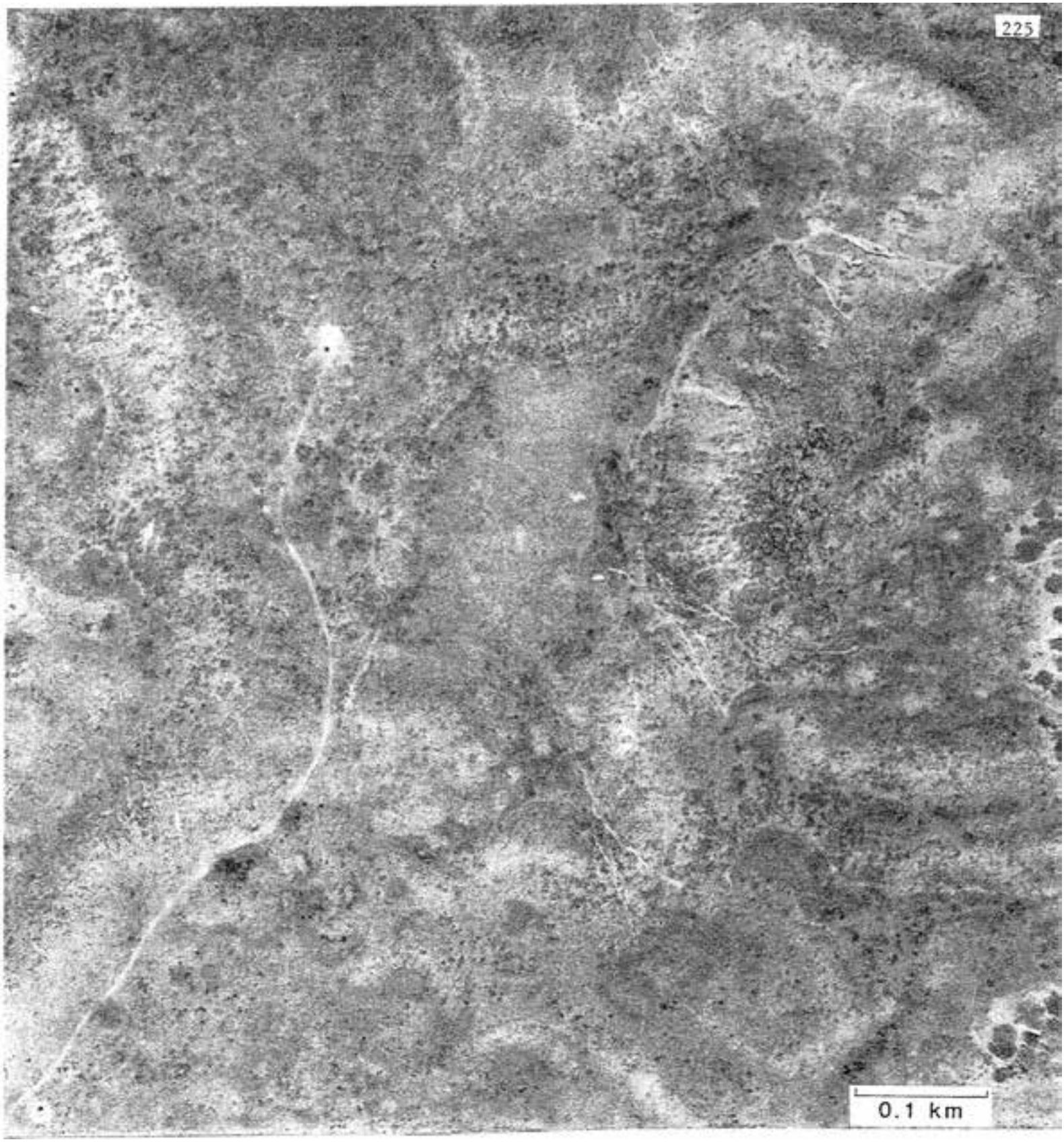


Figure 91. Aerial photograph taken November 26, 1981. Gullies have enlarged and extended headward since 1970. Road at left leads to a new tank and cattle feeding station. Light spots at Sites 50-52 reflect high-carbonate material in the trench fills (see fig. 90).

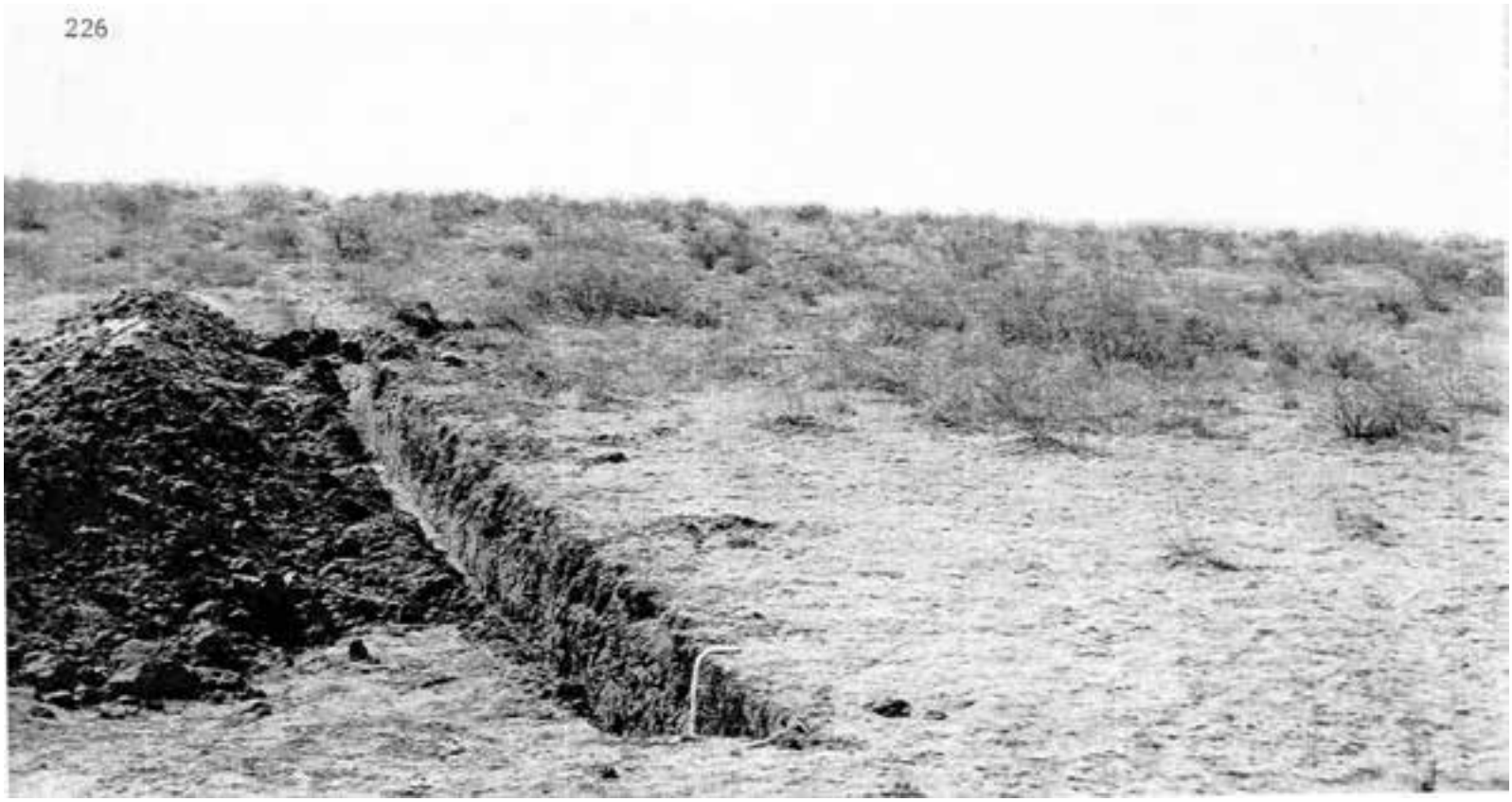


Figure 92. Above. View of Birdwell trough and dune at Site 34. The tape marks the location of the Aridic Argiustoll, Newell, Pedon 34c. Although the study trench is short, it displays prominent changes in soils. The view is south. Photographed March 1976.

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.

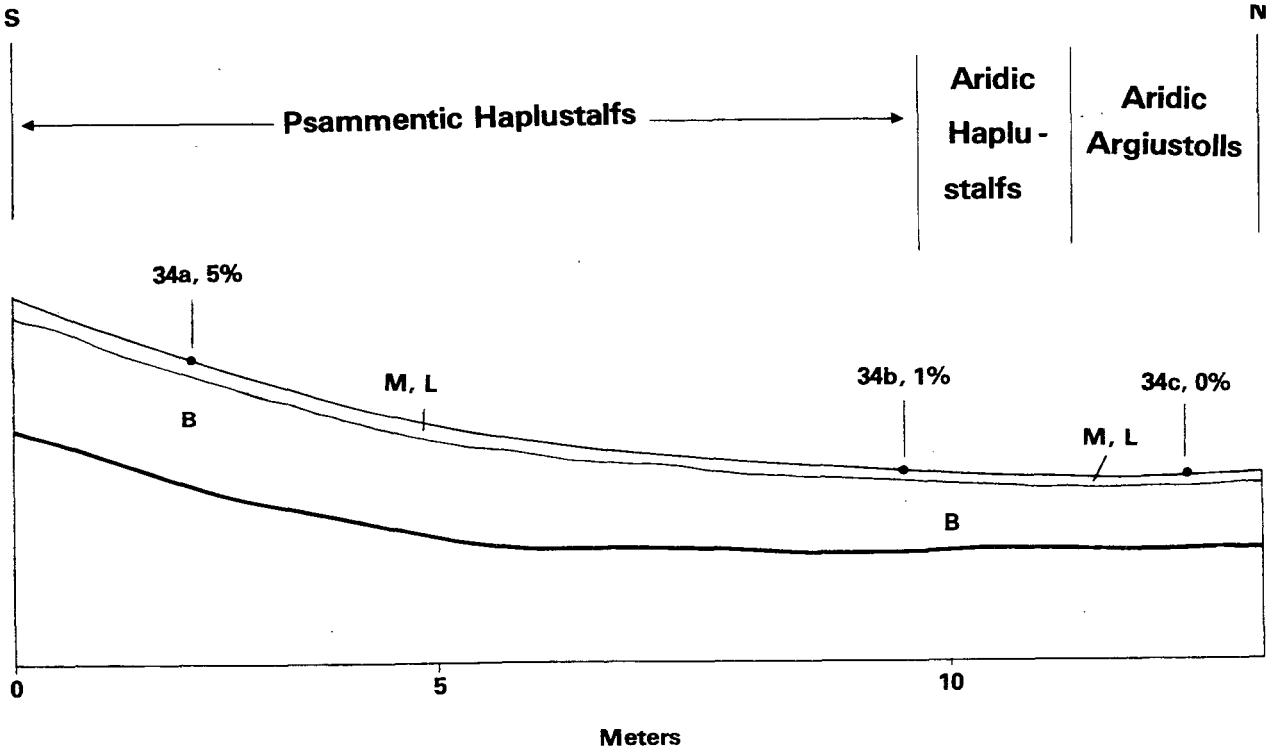


Table 41. Characteristics of Haplustalfs and an Argiustoll at Site 34[1/]

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.

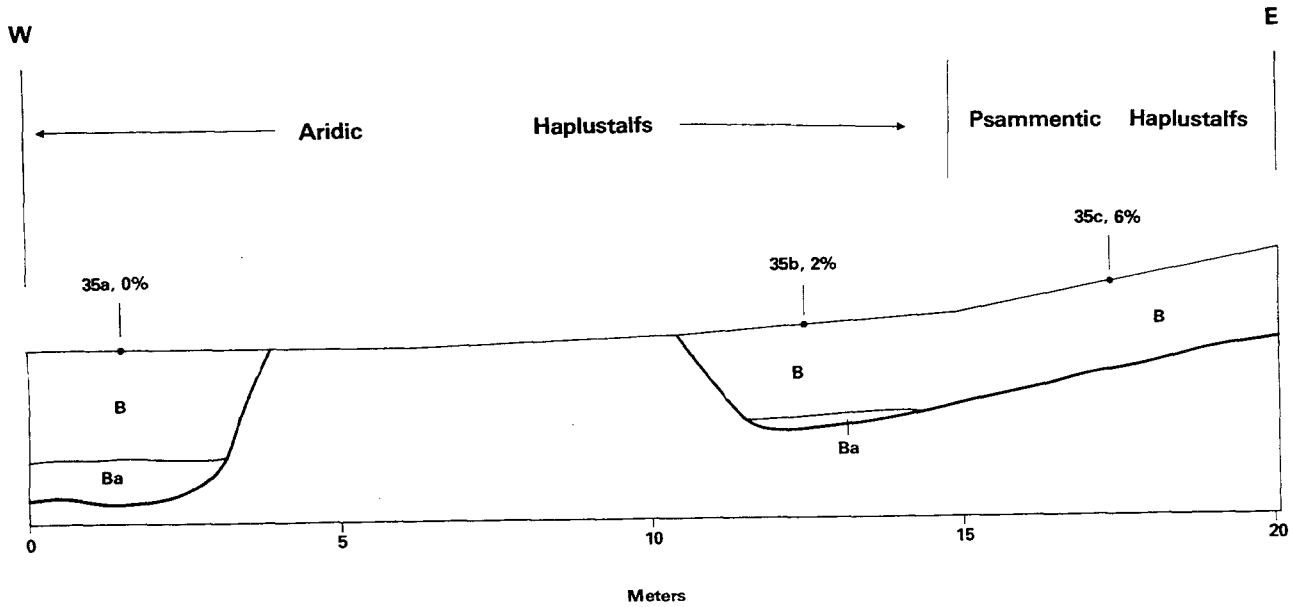


Figure 93. Diagram of study trench at Site 35, showing stratigraphy, subgroups, and slope and location of sampled pedons. B = Birdwell, Ba = Bailey. No vertical scale (see table 42 for thickness of sediments and horizons). The heavy lower line represents the bottom of the trenches.

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.

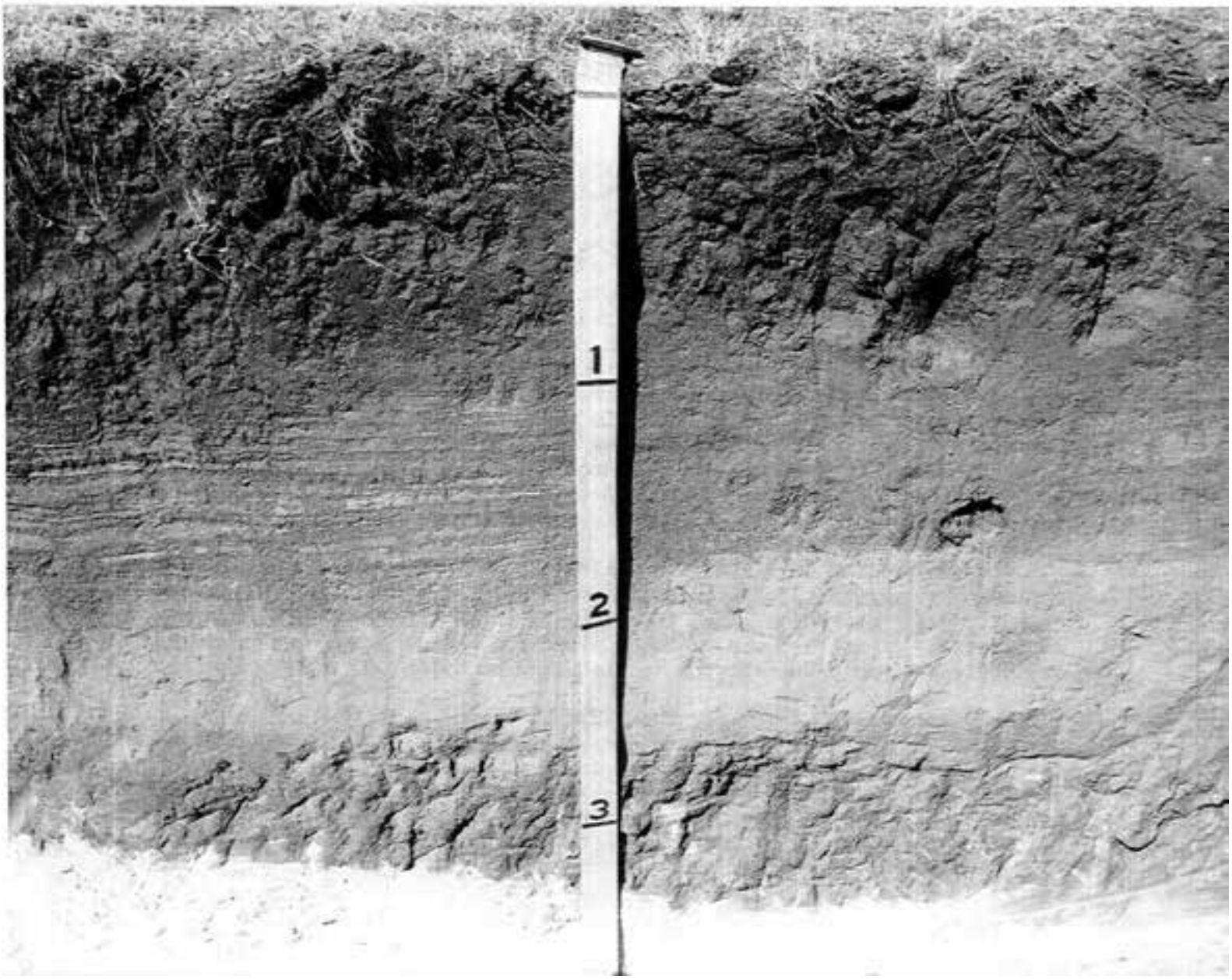
Pedon 35b has dark upper horizons although it is slightly higher than the blowout. This indicates that runoff has influenced soil moisture and vegetation on the lower side of the dune as well as in the blowout. The epipedon does not quite qualify as mollic because of high chroma, but calculations show 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

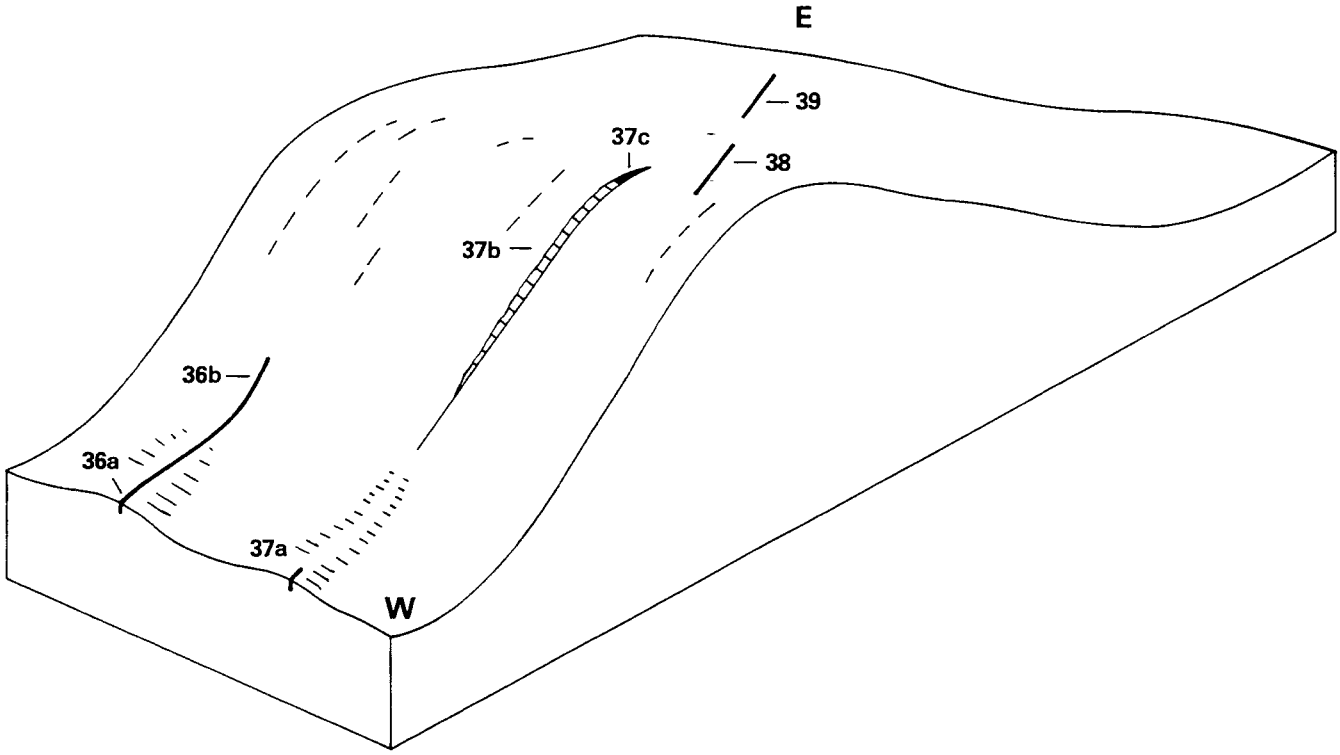


Figure 95. Above. Diagram of portion of dune at Sites 36-38. Site 36 is a bench (36a) and upslope dune of Birdwell age. Site 37 consists of deposits exposed by and related to a gully. Sites 38 and 39 are on the crest and east-facing dune side.

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.

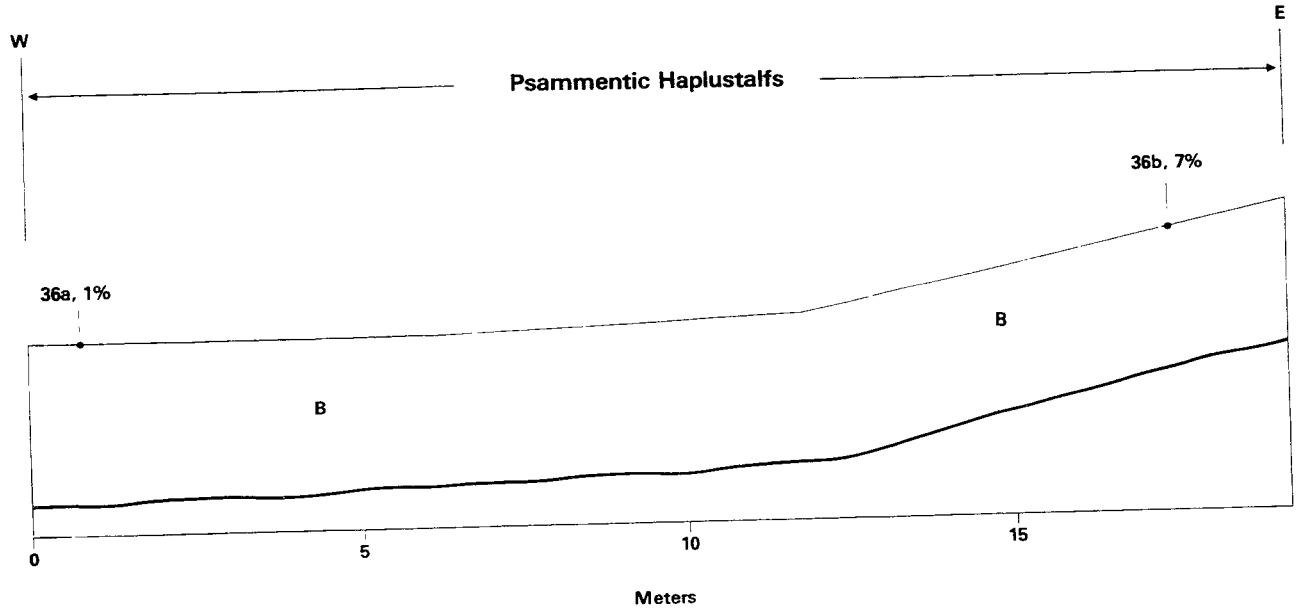


Table 42. Characteristics of Haplustalfs at Site 35[1/]

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.

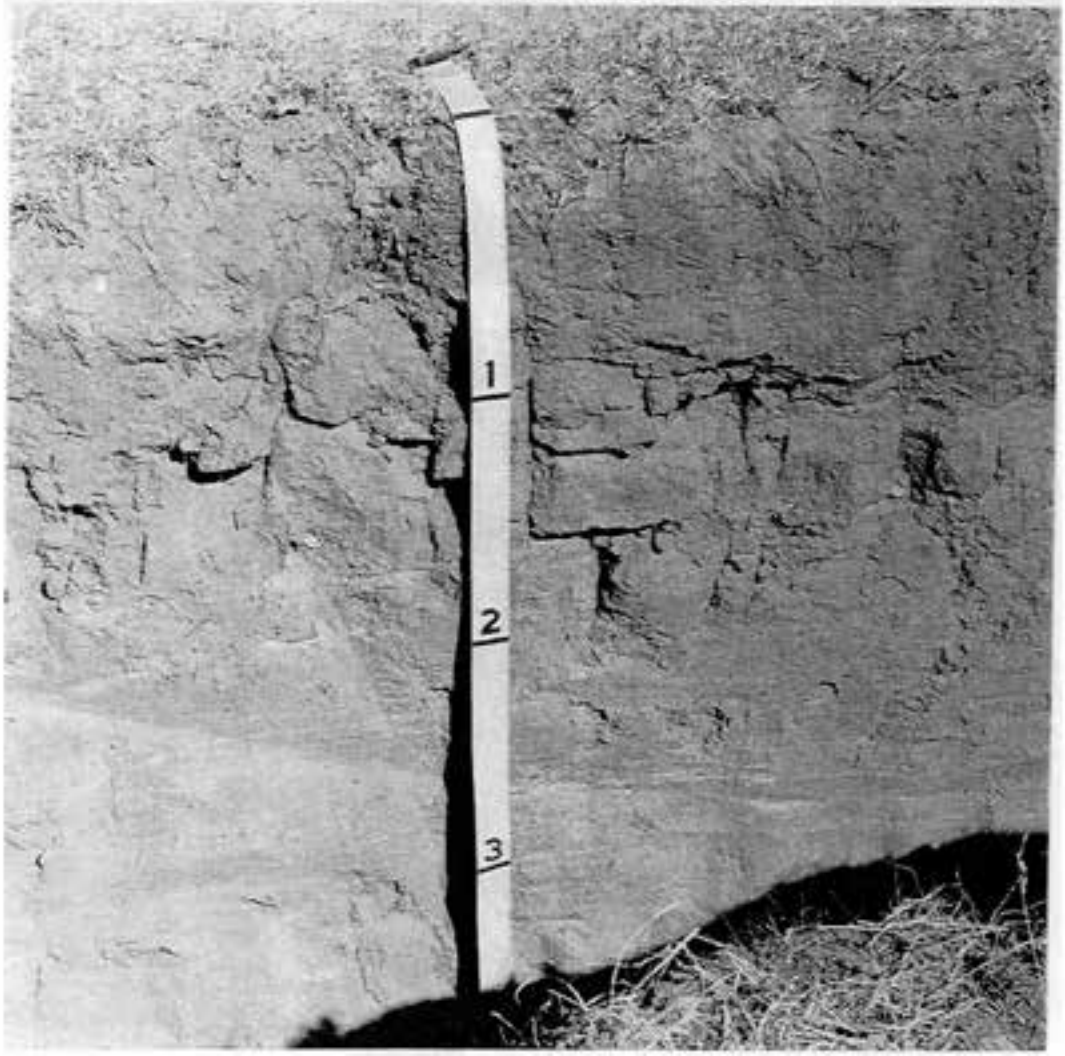
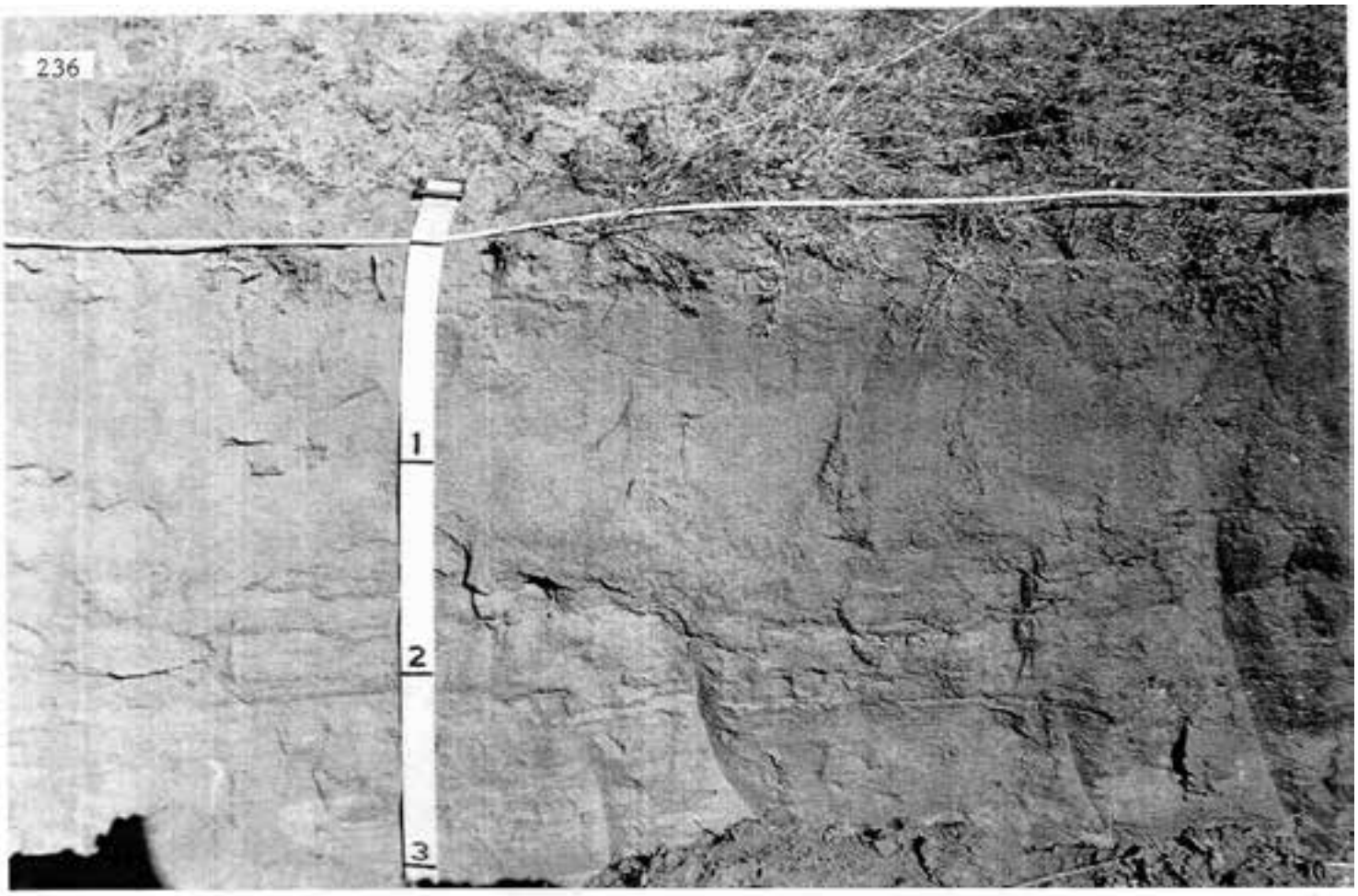


Figure 96. Upper. Landscape view of Birdwell bench and side of dune at Site 36. The view is east. Photographed October 1977.

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.



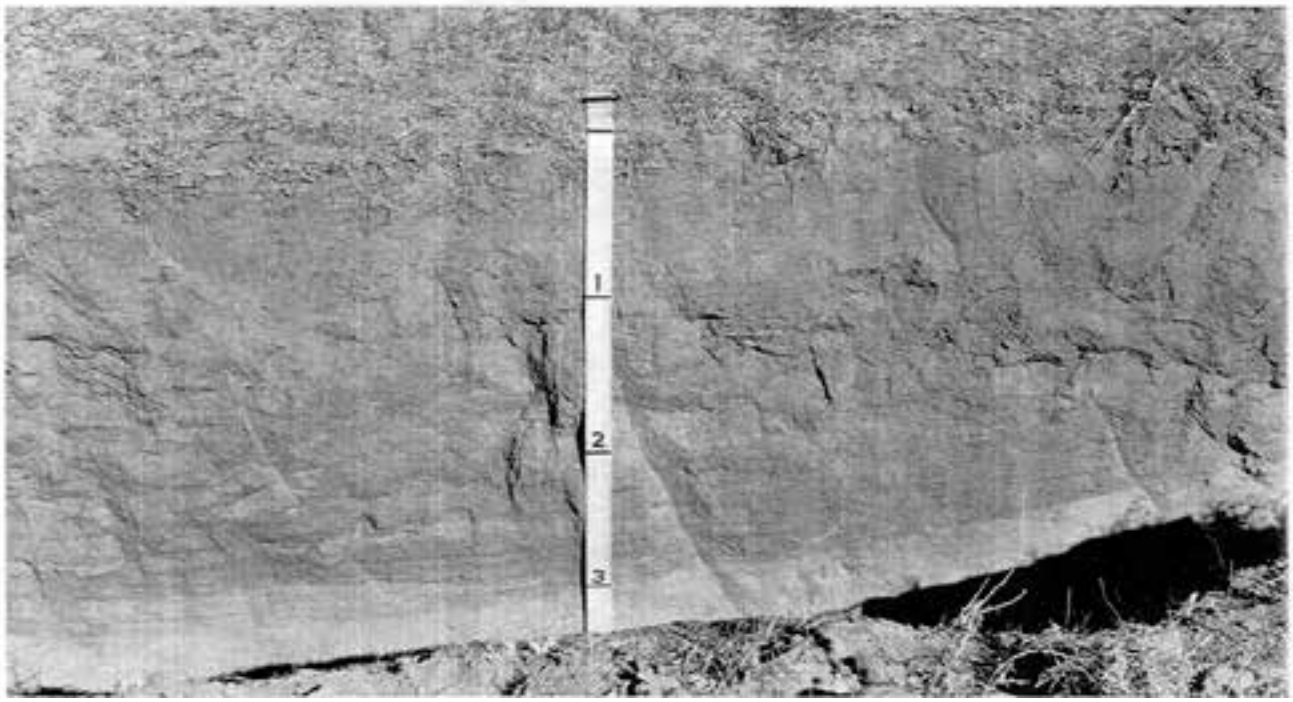


Figure 97. Upper. The Psammentic Haplustalf, Texico, at about 13 m (fig. 95). Clay bands along whitish lenses are thicker than at Pedon 36a, but whitish parts of the lenses are still preserved. Photographed October 1977. Scale is in feet.

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.

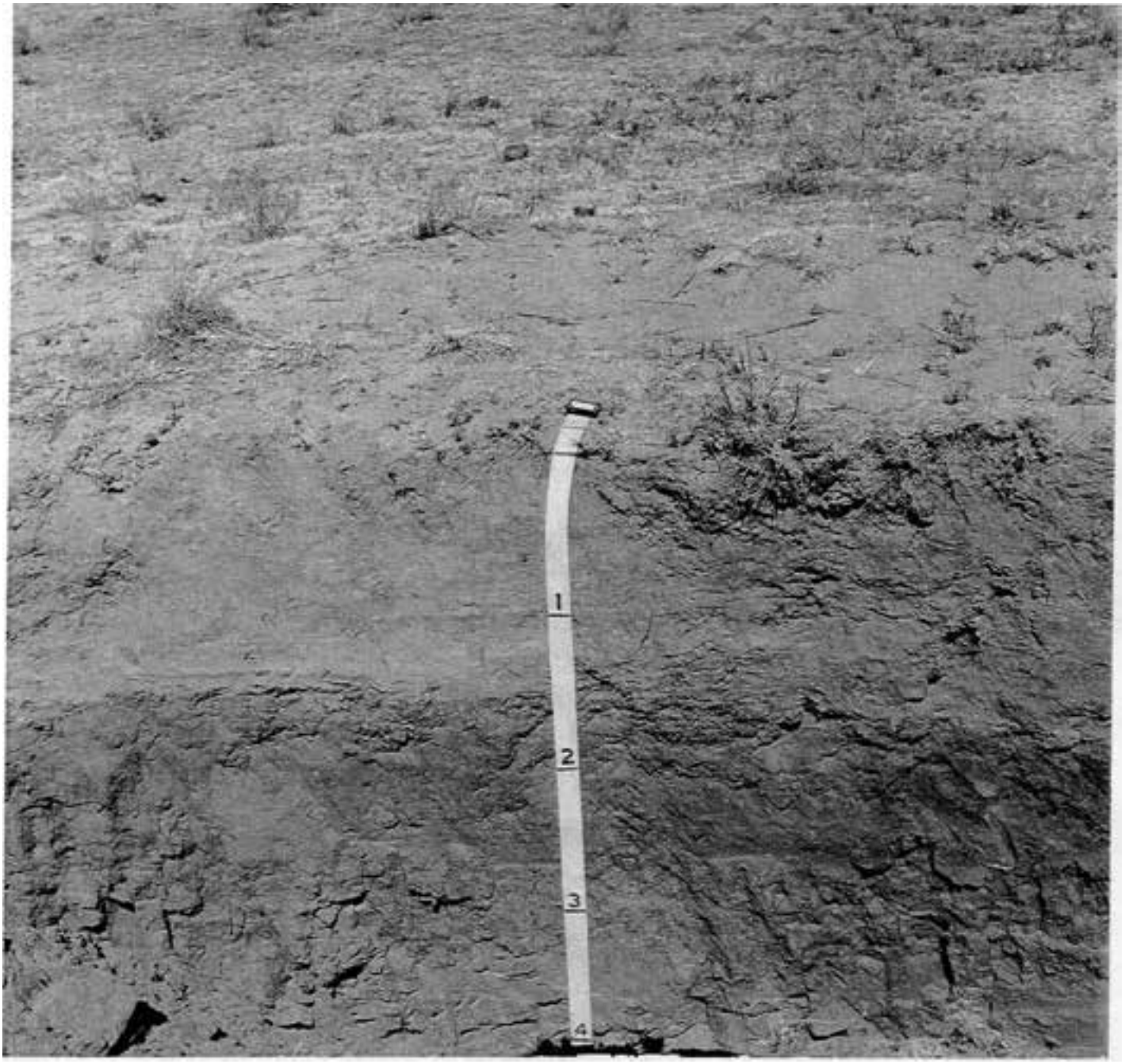
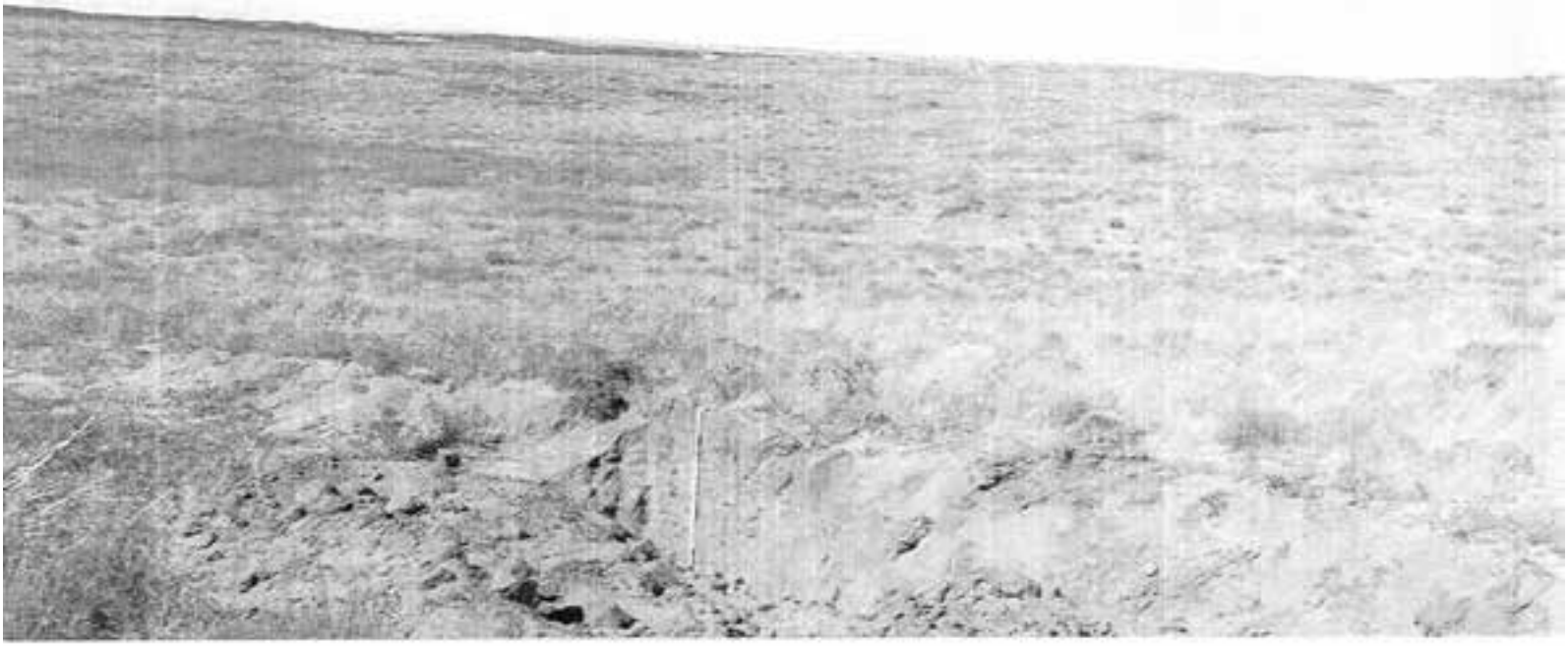
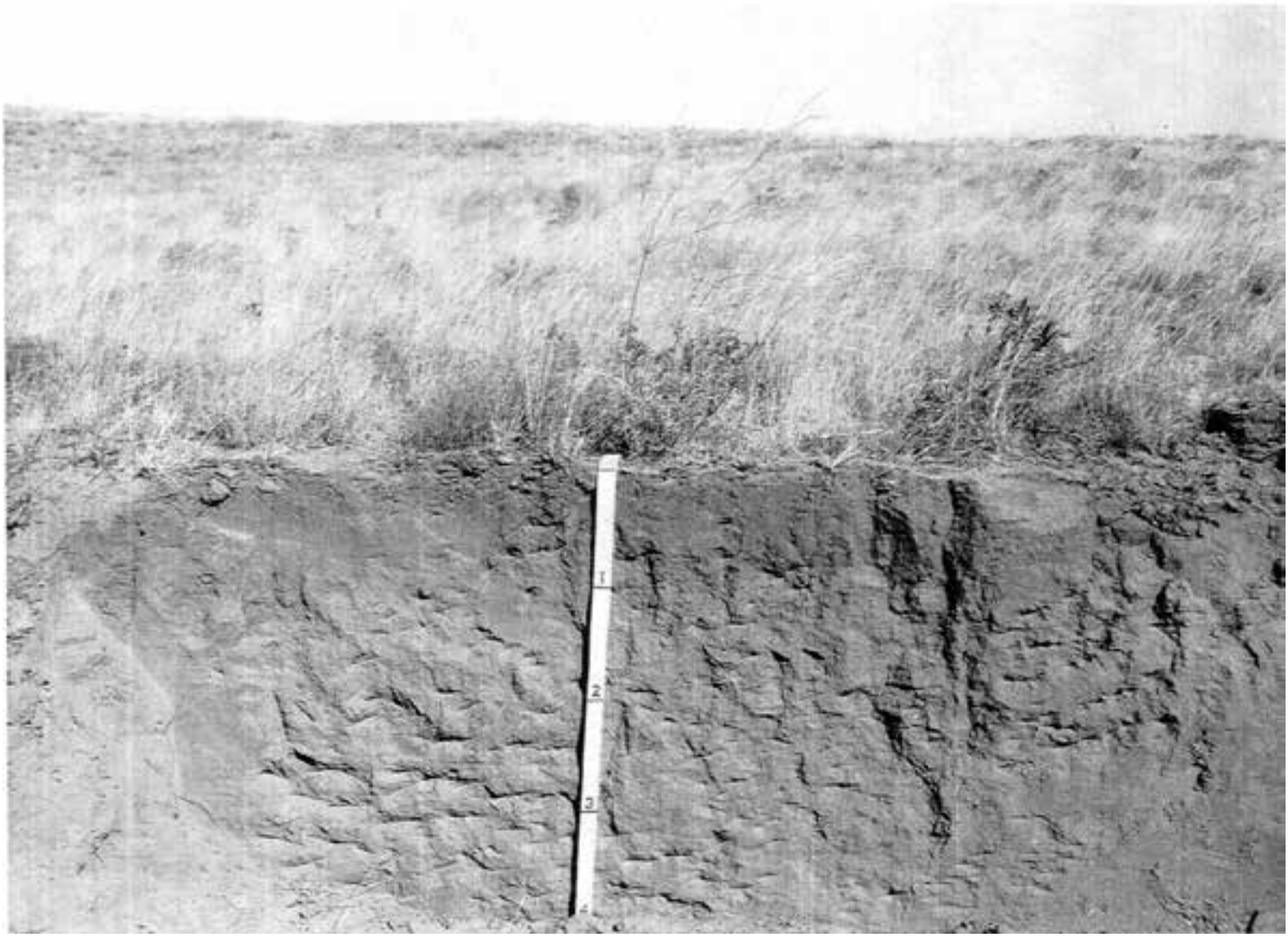


Figure 99. The Typic Ustifluvent, Tivoli, thin variant #2, at Site 37a. The alluvium is fresh-appearing and faintly stratified, but has been in place long enough for growth of plants. Scale is in feet.

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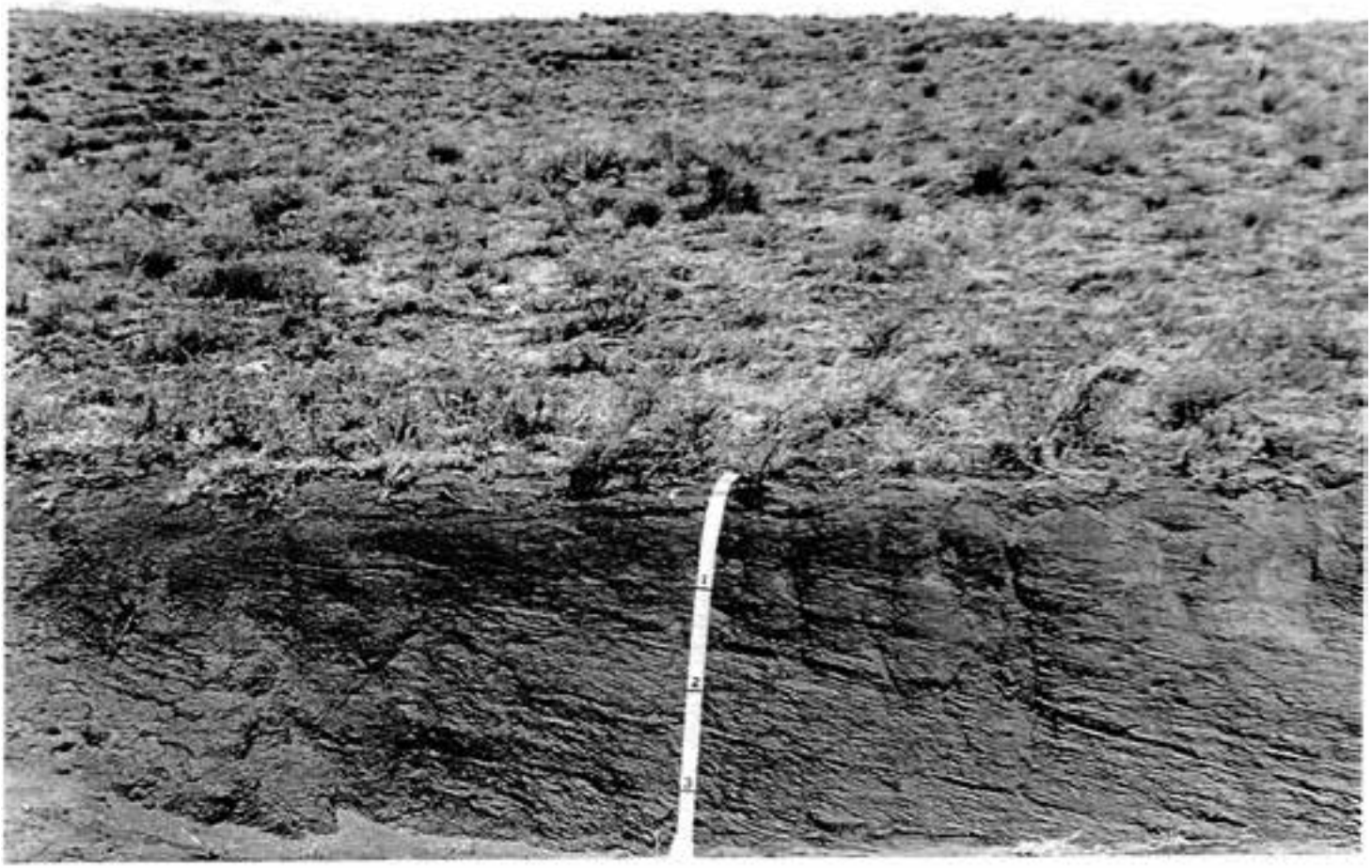


Figure 100. Opposite page, upper. Landscape view of Birdwell II surface on west-facing dune side at Site 37b. The tape is in the north wall of the gully (see fig. 98). Note that the gully wall is rounded except where straightened with the backhoe, and that the gully bottom is vegetated (left). The view 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	1m,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	1cpr-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

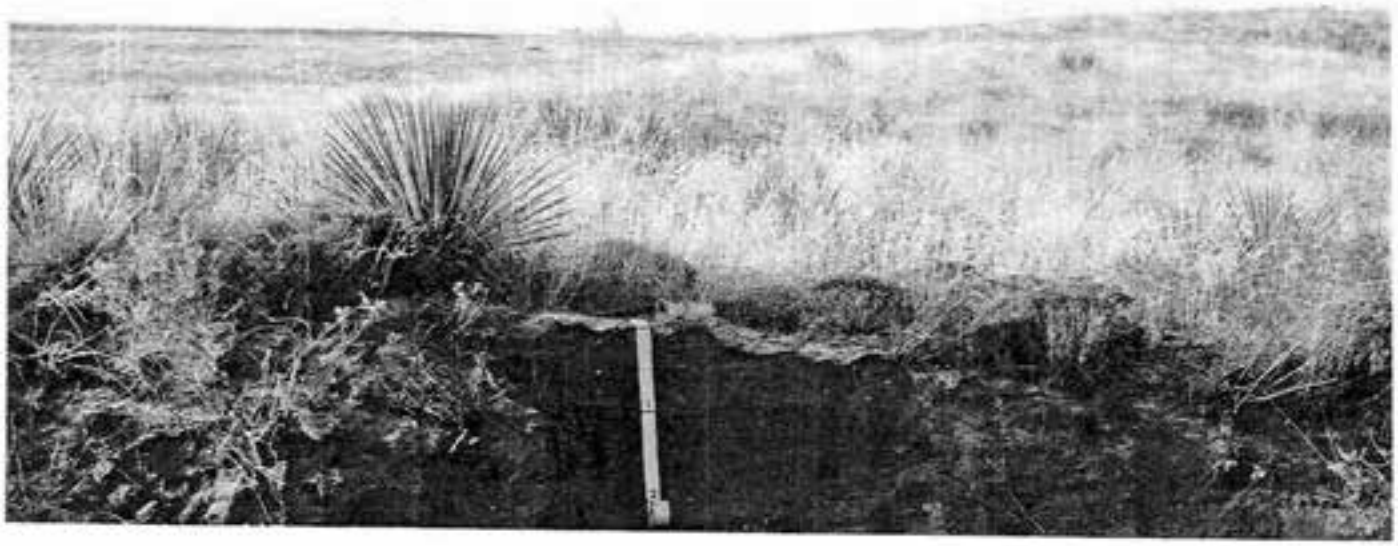
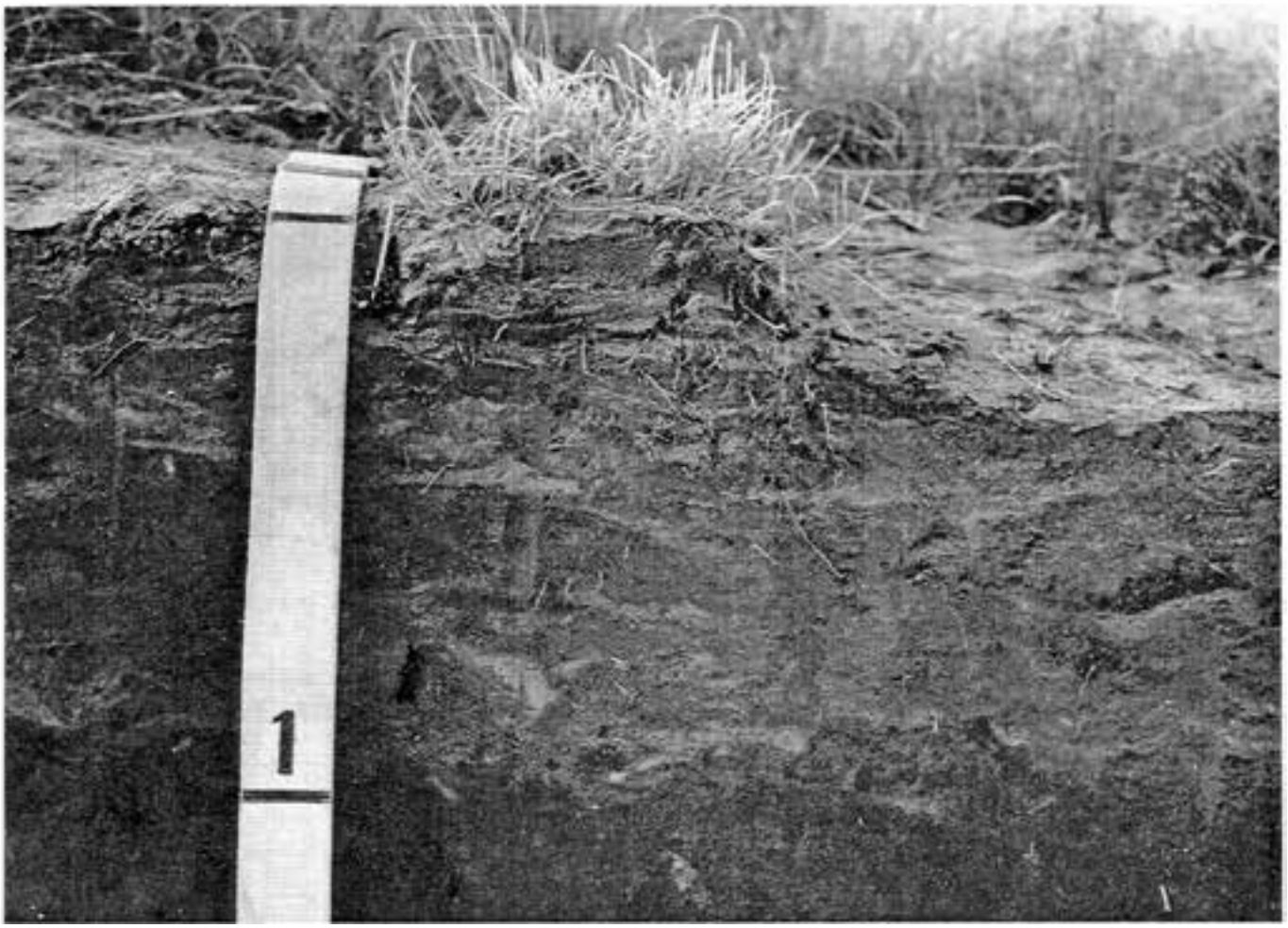


Figure 101. Above. Landscape view of post-gully, Fairview eolian sediments on south bank of gully, near crest of dune at Site 37c. The view is south. Photographed October, 1982. Scale is in feet.

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.



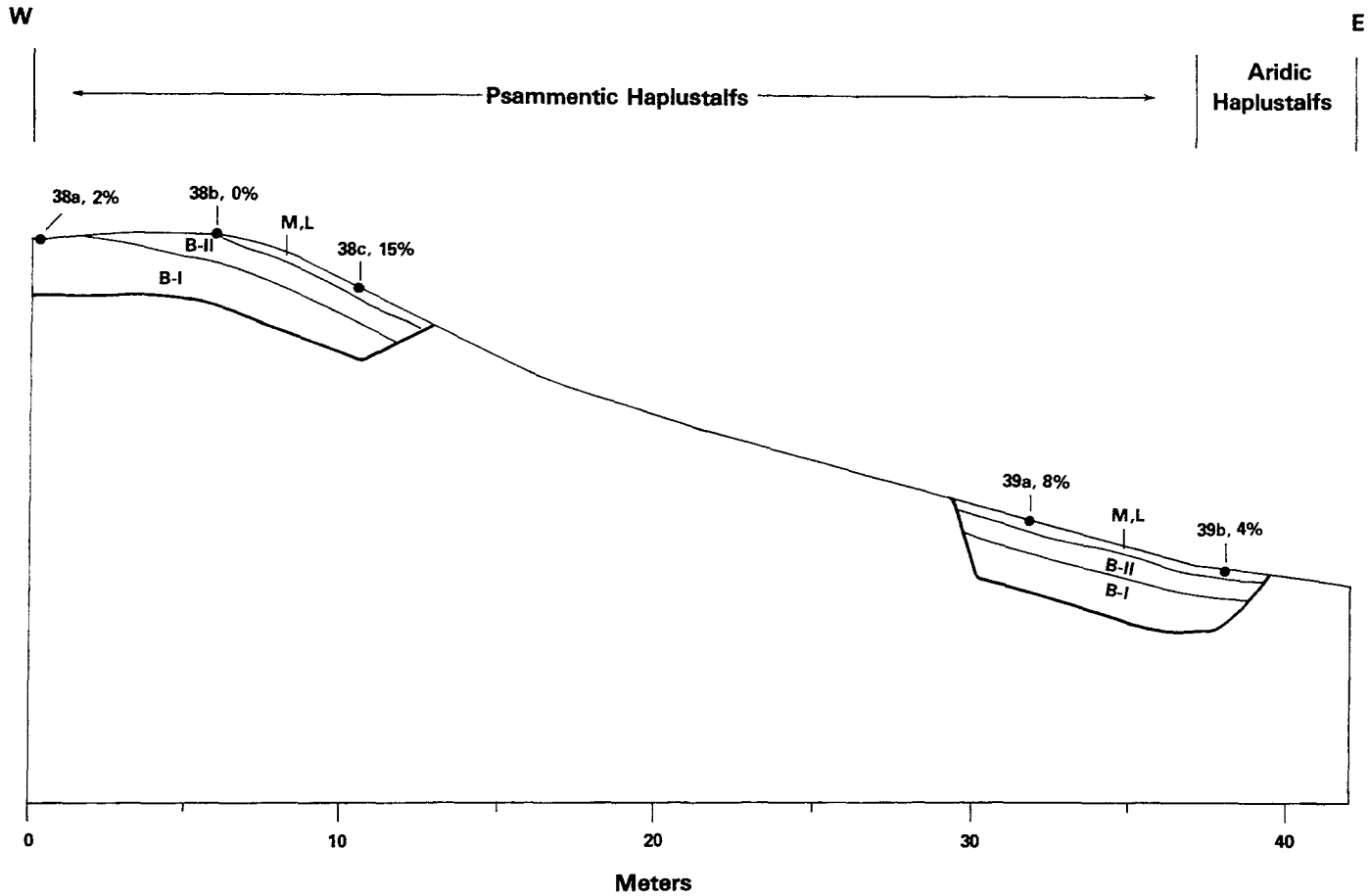


Figure 102. Diagram of study trenches at Sites 38 and 39, showing stratigraphy, subgroup, and slope and location of sampled pedons. M = Muleshoe, L = Longview, B-II = Birdwell II, B-I = Birdwell I. No vertical scale (see tables 47 and 48 for thicknesses of sediments and soils). The heavy lower lines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

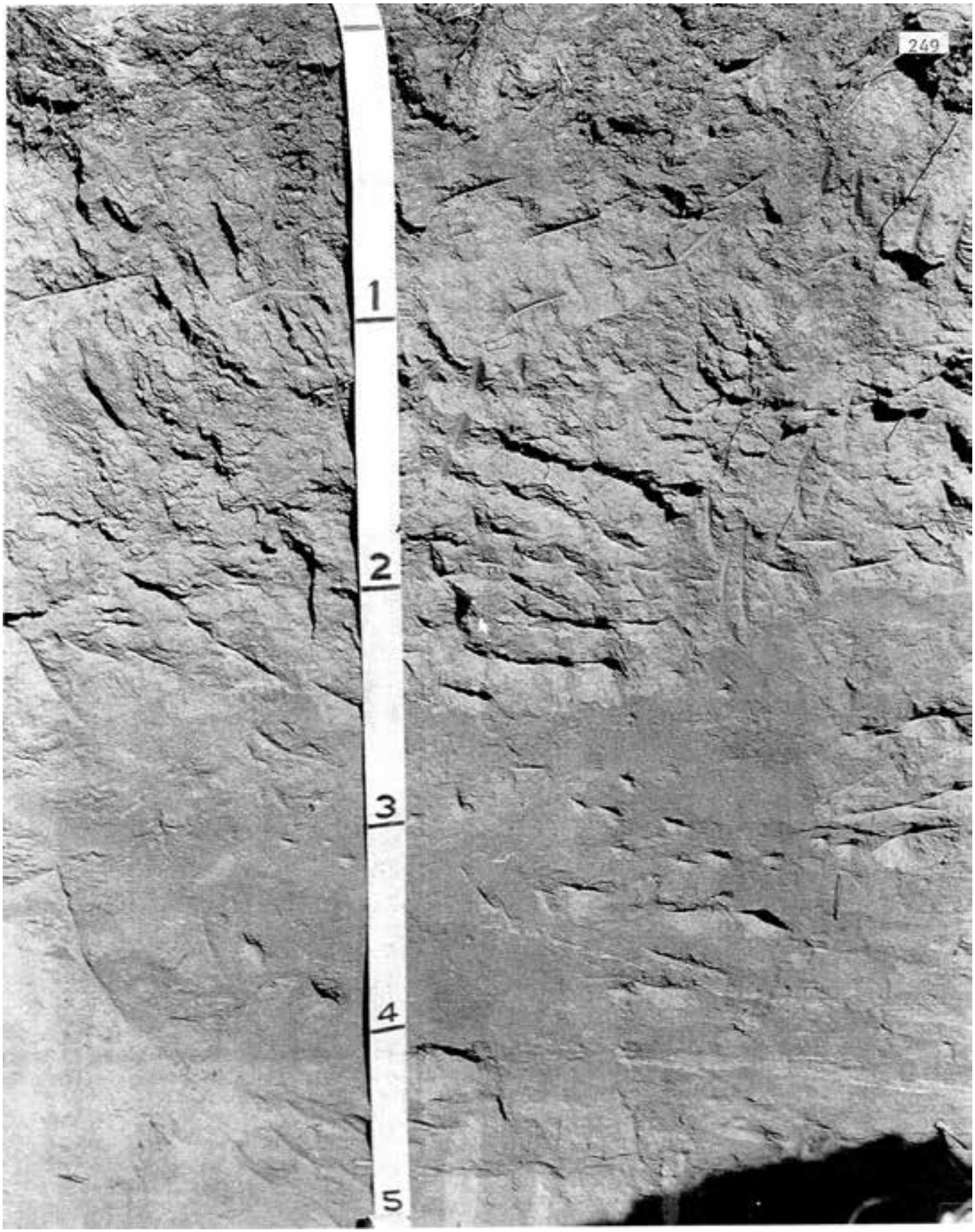


Figure 103. The Psammentic Haplustalf, Texico, at Site 38a, in Birdwell I sediments at the dune crest. Note presence of primary strata in the C horizon at about the 4 ft (1.2 m) mark, right of tape. Photographed March 1977. Scale is in feet.

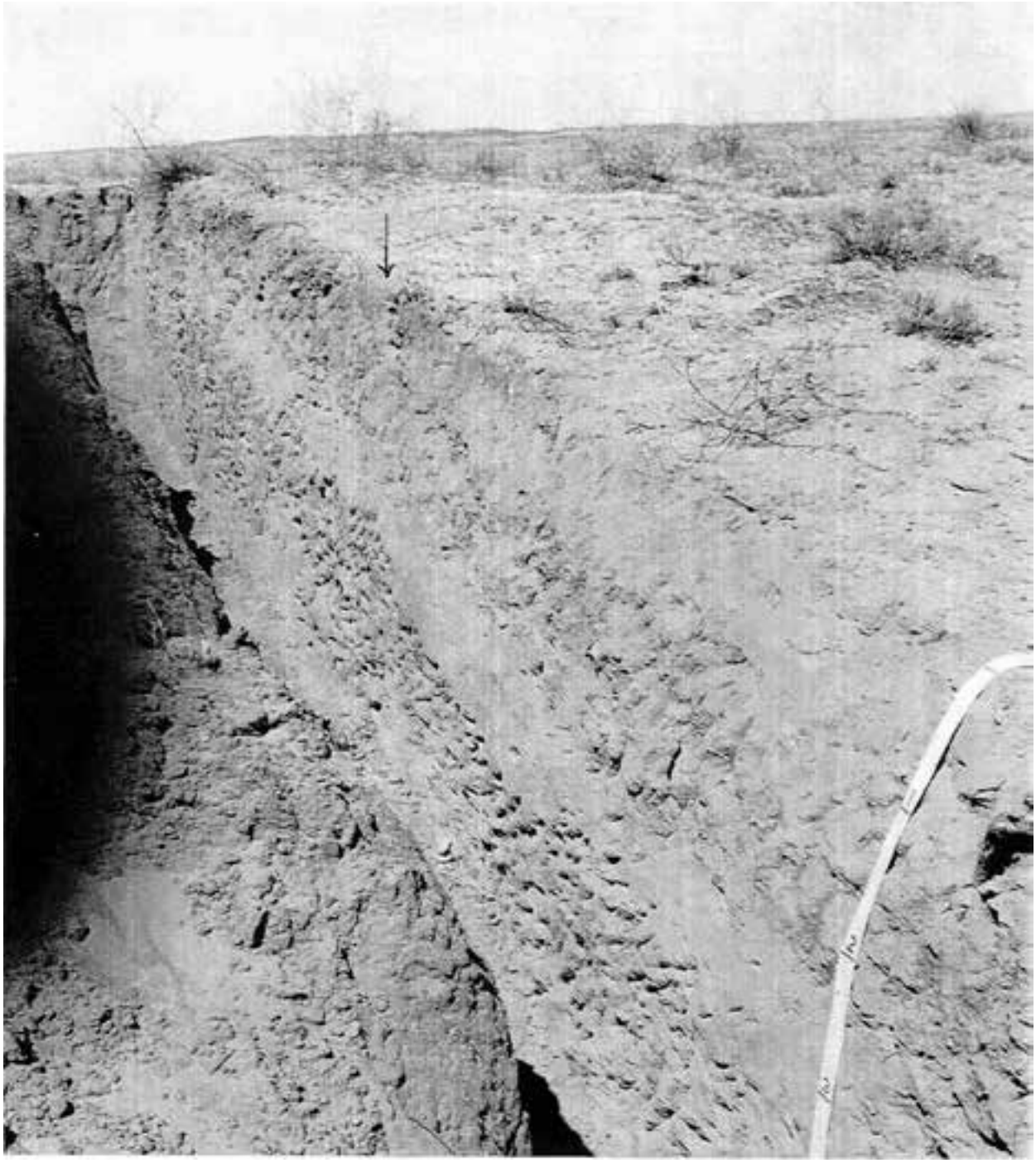


Figure 104. Westward view along study trench at Site 38. Arrow locates Pedon 38b (see also fig. 23). Pedon 38a is at upper left. The Psammentic Haplustalf, Texico, Pedon 38c, is at the tape. Note the buried soil, with its A horizon starting below the 2 ft (0.6 m) mark. Photographed March 1977. Scale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

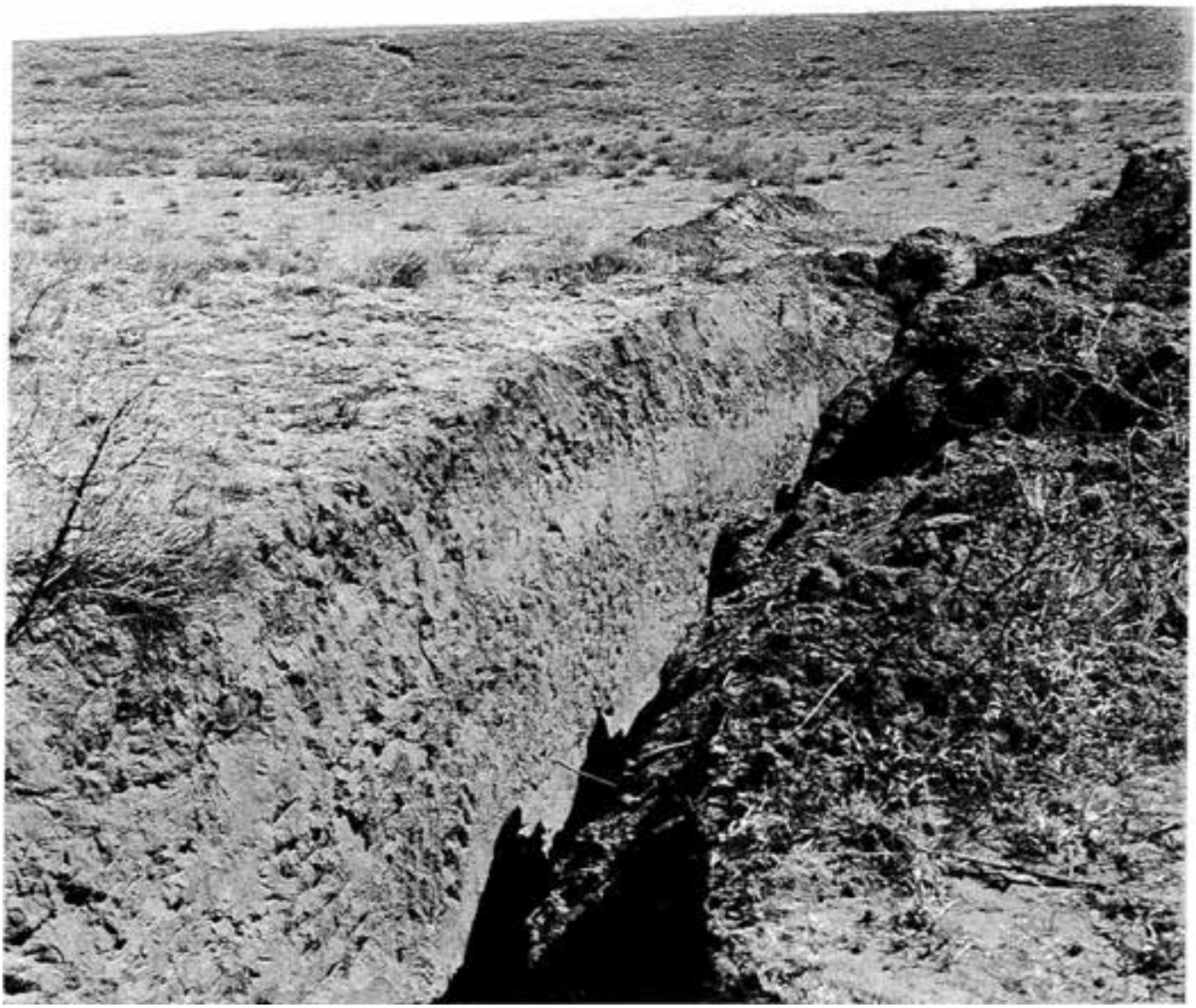


Figure 105. Landscape view of Site 38, foreground, and Site 39, on slope beyond Site 38. The view is east. Photographed March 1977.

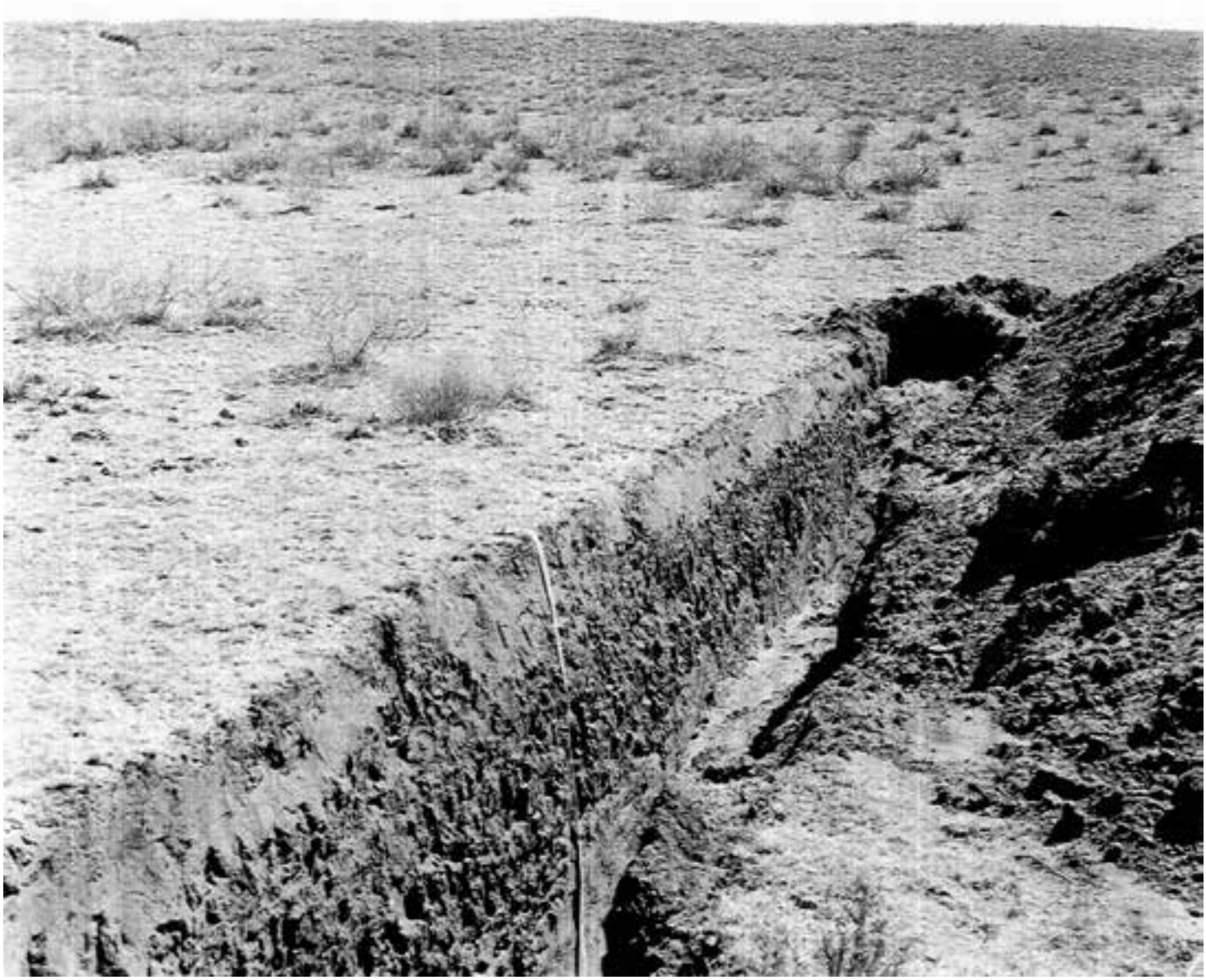


Figure 106. The study trench at Site 39. The tape is at the Psammentic Haplustalf, Texico, at Site 39a. Scale is in feet.

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-II	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	58.8	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.

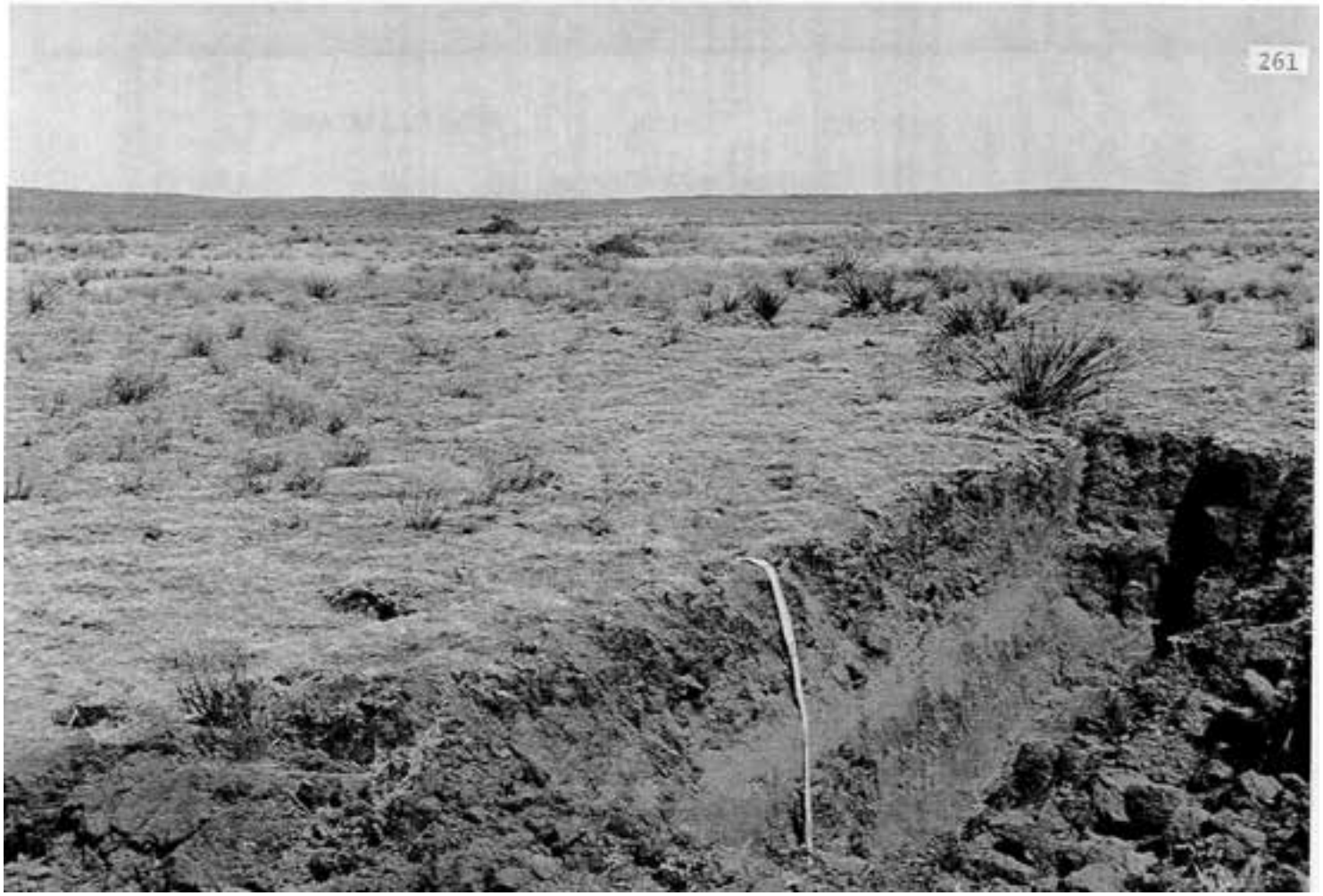


Figure 108. View of the Birdwell surface, study trench, and the Aridic Haplustalf, Farwell, at Site 42. The light-colored band at about 2 ft (0.6 m) is C horizon material of Birdwell age, and overlies Roosevelt sediments. The view is northeast. Scale is in feet. Photographed March 1977.

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

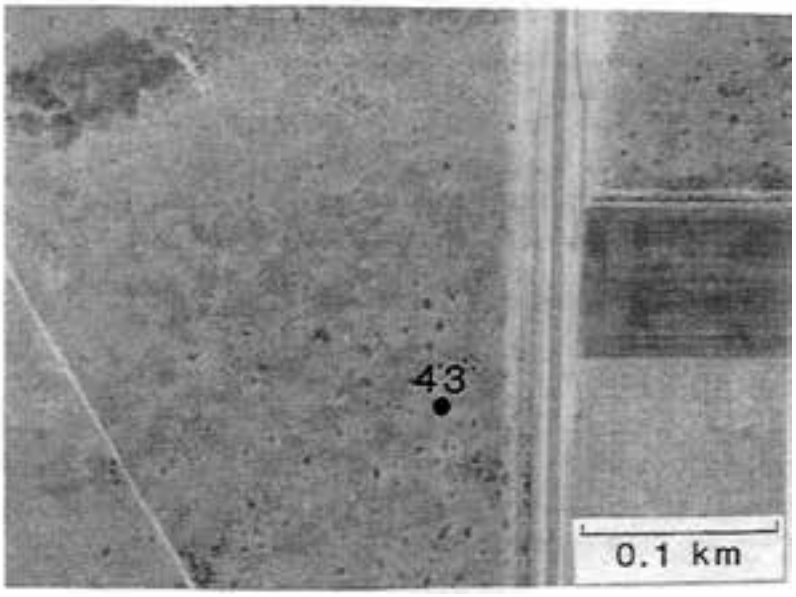


Figure 109. Location of Site 43. Farm Road 1731 is at right. 1970 aerial photograph.

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).

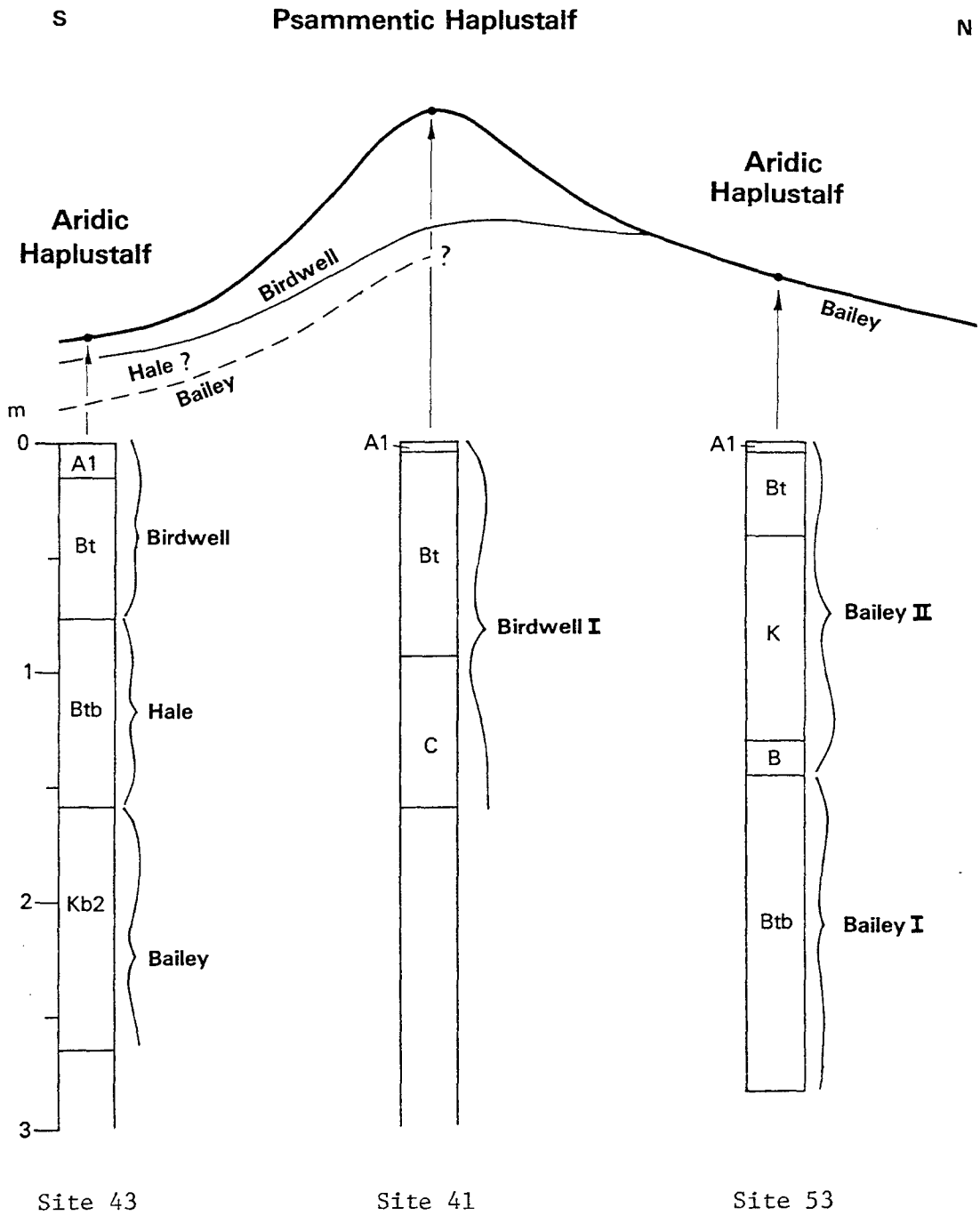


Figure 110. Upper. Sketch of cross section from Sites 43, 41 and 53 west of Farm Road 1731. Birdwell sediments continue southward from the high dune to Site 43 and possibly beyond. Bailey sediments also had dune form, indicating that the dune started to form in mid-Pleistocene time or earlier. No scale.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

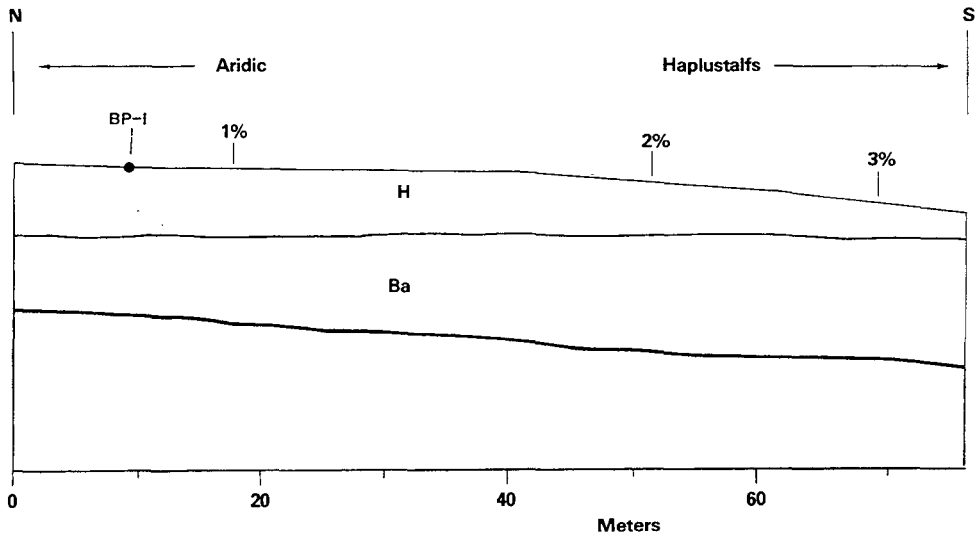


Figure 111. Diagram of caliche pit exposure along the margin of the inner Portales Valley. No vertical scale (see table 54 for horizon thicknesses for Pedon BP-1, located at left). Sediments tentatively identified as H = Hale, Ba = Bailey. A reddish Bt horizon is in Hale sediments and a thick K horizon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

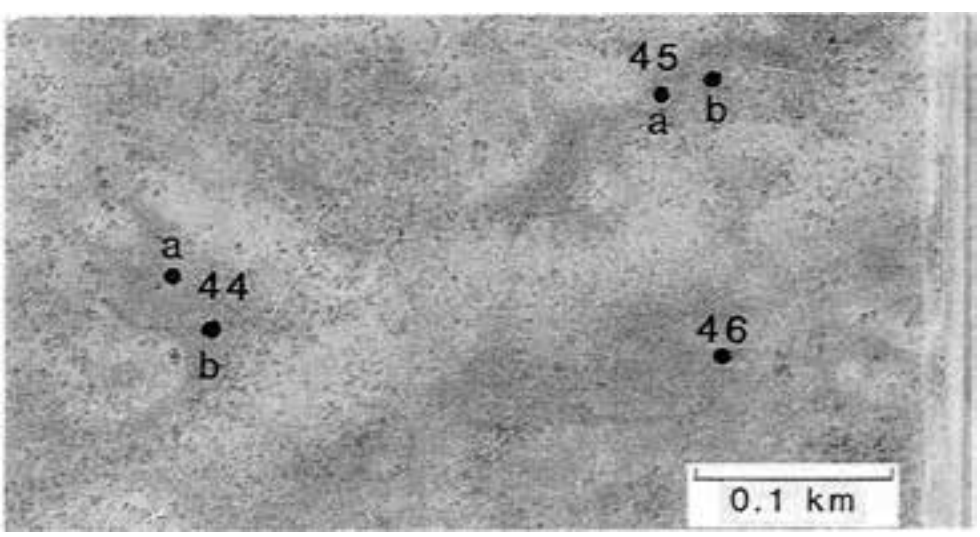


Figure 113. Location of Sites 44-46. Farm Road 1731 is at right. 1970 aerial photograph.

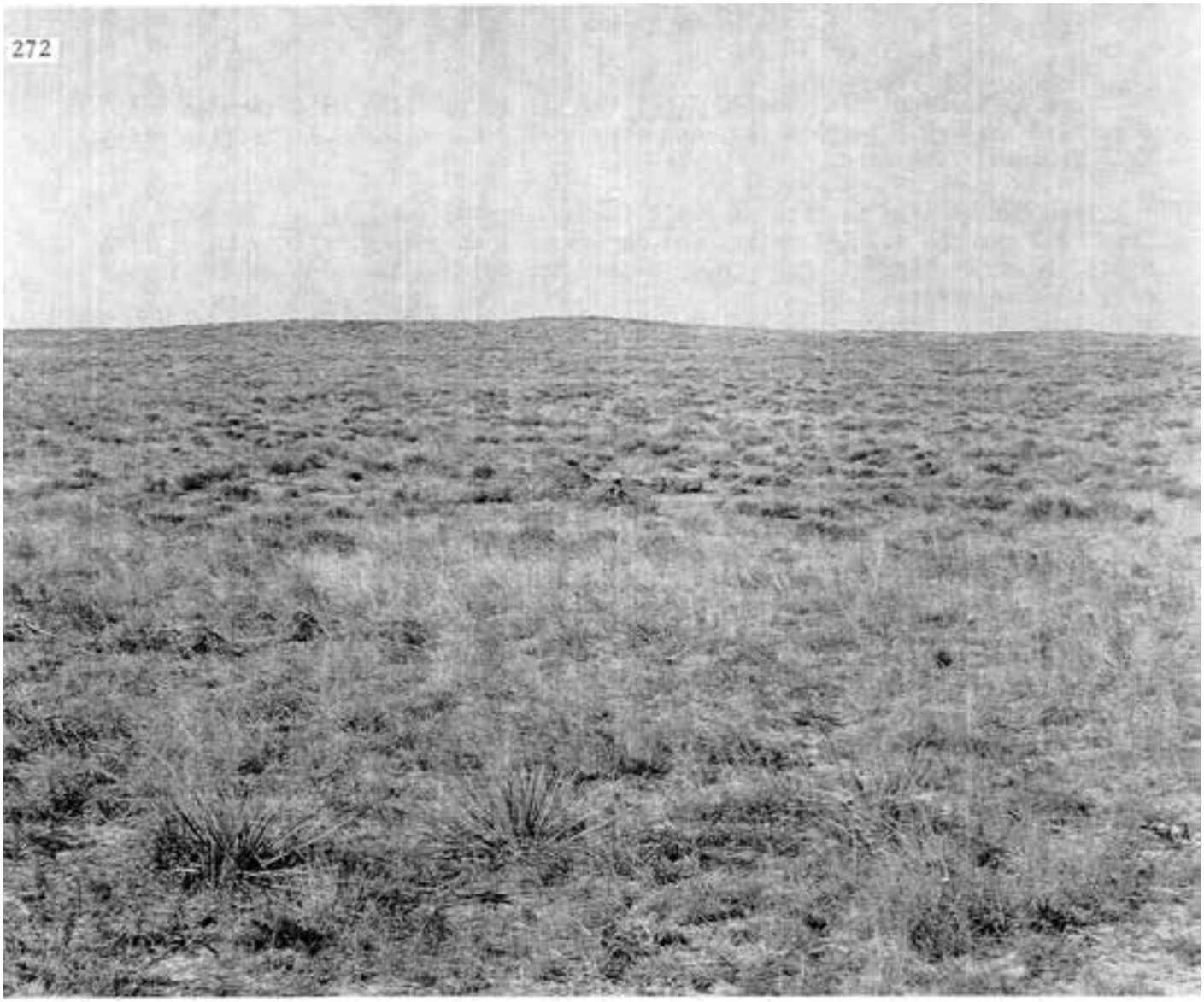


Figure 114. Landscape view of Birdwell surface in a topographic low at Site 44b, adjacent to slight dune, to which the slope in the foreground leads. The view is northwest. Photographed November 1976.

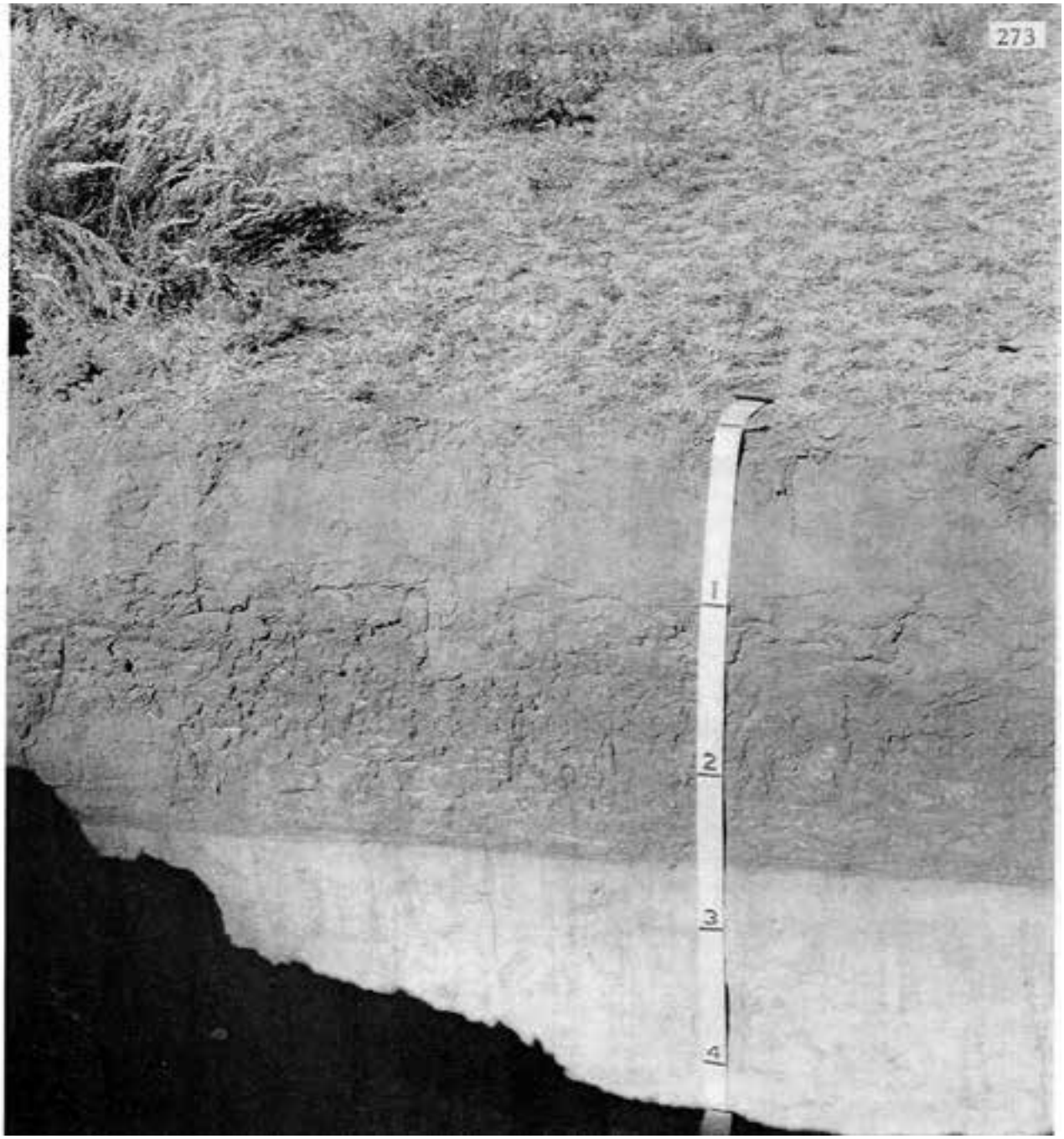


Figure 115. The Aridic Haplustalf, Keeney, at Site 44b. The prominent sedimentary contact at about 2½ ft (0.8 m) is the common basal contact of Birdwell I sediments. Scale is in feet.

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.

CHAPTER 8. HAPLUSTALFS AND ARGIUSTOLLS OF THE BIRDWELL, HALE AND BAILEY SURFACES

The soils occur in mapping units I and J (fig. 27).

ARIDIC HAPLUSTALFS AND ARGIUSTOLLS: MAPPING UNIT I, KEENEY COMPLEX

MAPPING UNIT COMPOSITION

Series or variant	Subgroup	Particle-size family	Percentage of mapping unit
KEENEY	ARIDIC HAPLUSTALFS	FINE-LOAMY	65
NEWELL	ARIDIC ARGIUSTOLLS	FINE-LOAMY	25
Farwell	Aridic Haplustalfs	Coarse-loamy	10

LOCATION, LANDSCAPE, SOIL OCCURRENCE, VEGETATION

Soils of unit I occur in five small depressions in the central and southern part of the study area. Adjacent dunes contribute runoff to soils of this unit, and dark upper horizons are common. Most soils lack mollic epipedons because high-chroma Bt horizons are too near the surface; these are the Farwell and Keeney soils. Soils with mollic epipedons occur in areas that have been less subject to strong wind erosion, so that the high-chroma Bt horizon is at greater depth and the epipedon qualifies as mollic.

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

TYPICAL PEDON AND RANGES IN SELECTED PROPERTIES

A typical pedon and ranges for Keeney are given in mapping unit H. Pedon 33d is a typical pedon for Newell. See table 40 for characteristics of Pedon 33d. Ranges in color and texture follow; underlined entries are typical.

The A horizon has hue of 7.5YR through 10YR, value of 3 through 5 (4) dry, 1.5 through 3 (2) moist, and chroma of 2 through 3. It is fine sandy loam or loamy fine sand.

The B2tb horizon has hue of 2.5YR through 4YR, value of 4 through 6 (5) dry, 3.5 through 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.

Newell soils lack a calcic horizon within 90 cm depth. Usually the Bt horizons of Newell soils are underlain by buried horizons instead of C horizons. Pedon 33d has a buried calcic horizon of Bailey age at 132 cm depth.

STUDY SITES

Sites 47-49, small depressions

Sites 47-49 illustrate the effect of run-in on soils of small blowouts. The sampled soils have dark upper horizons, but not mollic epipedons because lower parts of epipedons are not dark enough or have chromas that are too high.

Site 47

Figures 75-77 locate the blowout at Site 47. Much of the blowout has been heavily trampled by cattle using the water tank. East of the tank and windmill is a shallow, but quite long (about 18 m) trench that apparently was once used for water storage. The surface is level along its southeast side. But about 15 m due south, slope is 1 percent to the north. The lower slopes of the high Birdwell dune just southwest appear to slope to this spot and could have contributed sediments to it. The trench well illustrates the dark A horizon and the relatively clayey B horizon of the blowout. The soil surface in the vicinity is largely covered with spoil and feed.

Pedon 47 (fig. 116, table 56) occurs in the southwest corner of the trench. The epipedon is too light-colored in its lower part for a mollic epipedon (table 56).

The thick Bt horizon is thought to be primarily of Hale age, but the high percentage of clay at the very top of the Bt horizon (table 56) suggests the possibility of a colluvial accumulation. Coarse texture of the A1 horizon probably reflects Birdwell or post-Birdwell erosion and deposition of a younger sediment. Auger samples beneath the bottom of the trench showed that a noncalcareous sandy clay loam B2t horizon extended to about 165 cm depth. A B2tca horizon with carbonate nodules extended from about 165-175 cm depth, where a high-carbonate K horizon of Bailey age was encountered.

A different situation occurs in the northwest part of the trench, where the soils are on the north edge of the blowout and are very near the adjacent dune. The latter dune slopes to this part of the blowout and must have contributed sediment to it. Beneath 12 cm of spoil and feed is an A11 horizon, 15 cm thick, 10YR 3/2, moist, a fine sand, that is lighter-colored

Table 56. Characteristics of the Aridic Haplustalf, Keeney, at Site 47[1/]

Horizon	Depth, cm	Hue	Value/chroma Dry	Value/chroma Moist	Structure	Dry consistence	pH	Textural class	Sand 2.0-0.05 mm	Silt 0.05-0.002 mm	Clay < 0.002 mm
A1	0-19	10YR	5/2	3/2	m	sh	6.8	fs	91.7	1.1	7.2
B21t	19-38	7.5YR	5/3	4/3	2fsbk	h	7.6	sc	46.8	8.5	44.7
B22t	34-46	5YR	5/4	4/4	2msbk	vh	7.6	scl	59.6	13.3	27.1
B23t	46-60	4YR	5/6	4/6	2msbk	vh	7.6	scl	68.9	7.4	23.7

1/ Subordinate colors follow. A1: parts 10YR 4/1, dry. B22t: parts 5YR 5/6, dry. See text for characteristics of auger samples below 60 cm.

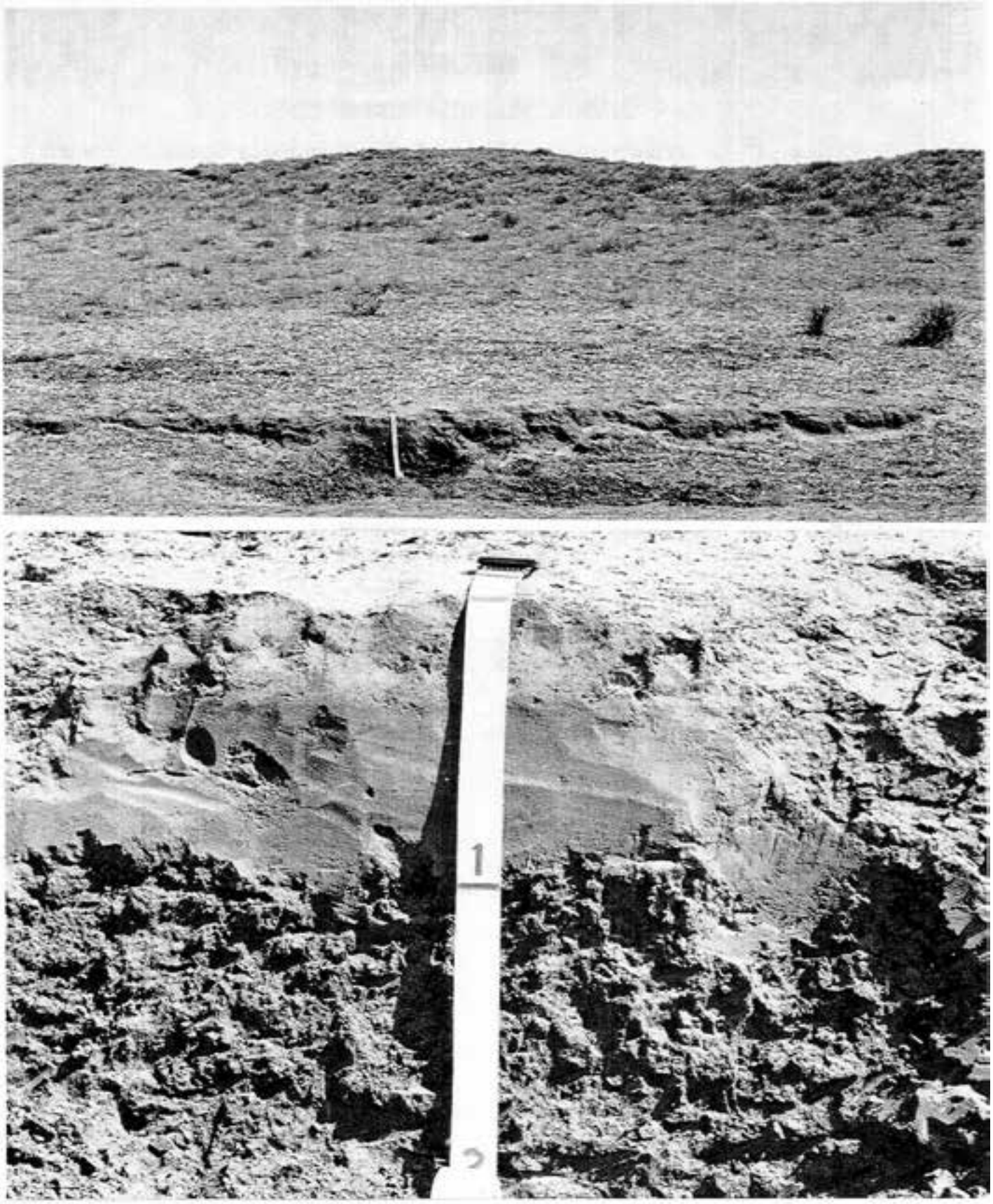


Figure 116. Upper. Landscape view of part of the blowout at Site 47 and the Birdwell dune in the background. The view is south. Photographed March 1981.
Lower. The Aridic Haplustalf, Keeney, at Site 47. Several inches of spoil are below the 0 mark at top. Scale is in feet.

and coarser-textured than the underlying A12 horizon, which is 12 cm thick, 10YR 2/2, moist, and a fine sandy loam. The sandy clay loam Bt horizon of Hale age occurs beneath the A12 horizon. The youthful-appearing A11 horizon is likely of Muleshoe age, since Muleshoe sediments occur nearby. The boundary between the A11 and A12 is abrupt, although it is broken in places by crotovinas, and illustrates a feature common along the margins of many blowouts; the accumulation of younger sand over an existing A1 horizon.

Site 48

Site 48 (figs. 88, 91, 117) consists of a study trench in a small depression bordered by high Birdwell dunes. Although content of organic carbon could be high enough for a mollic epipedon, values and chroma in the lower part of the epipedon do not quite meet the requirements. The site illustrates another situation with colluvium: a small depression, with run-in from dunes on the west and south.

Particle size data (table 57) illustrate silicate clay maxima in sediments of different ages. The surface horizon is unusually high in silt and clay, and apparently represents a colluvial deposit of Muleshoe and Longview age. Occurring as it does in the lee of high Birdwell ridges, Site 48 may have been largely protected from strong erosion.

Site 49

Site 49 is also in a small depression. Slopes that border the depression are slightly steeper and more distinct than at Site 48, but the depression at Site 49 lacks the bordering high dunes that are present at Site 48. Possibly because high dunes are absent, Birdwell colluvium does not occur at Site 49.

A photograph of Site 49 was shown earlier (see fig. 24). The soil has dark upper horizons, and organic carbon content would easily be high enough for a mollic epipedon. However, the soil lacks a mollic epipedon because the high-chroma Bt horizon is shallow. Some Bt horizons of Hale age are underlain by buried soils and others by C horizon (see Gile, 1981, for characteristics of soils of Hale age in exposures along Farm Road 1731).

Particle size data (table 57) show a prominent maximum in silicate clay. Clay increases in the lowermost horizon, a buried Bt horizon thought to be of early Hale age.

ARIDIC ARGIUSTOLLS AND HAPLUSTALFS DOMINANT: MAPPING UNIT J, NEWELL-EXTEE COMPLEX

MAPPING UNIT COMPOSITION

Series or variant	Subgroup	Particle-size family	Percentage of mapping unit
NEWELL, CALCIC VARIANT	ARIDIC ARGIUSTOLLS	FINE-LOAMY	35
NEWELL	ARIDIC ARGIUSTOLLS	FINE-LOAMY	30
EXTEE	ARIDIC HAPLUSTALFS	FINE-LOAMY	30
Other inclusions (Farwell, SND-2)			5

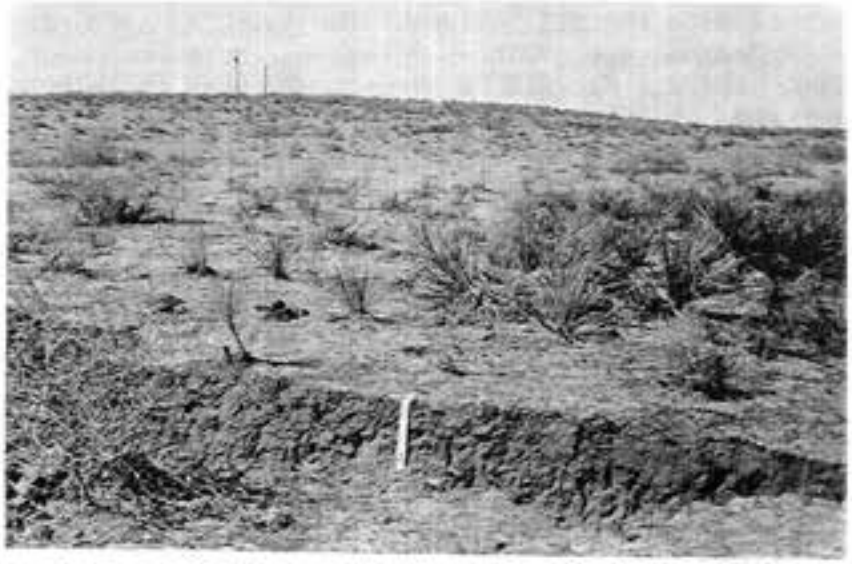


Figure 117. Above. Landscape at Site 48. Birdwell ridges are on the skyline. The view is northwest. Photographed March 1977.
Below. The Aridic Haplustalf, Keeney, Pedon 48. The base of Birdwell sediments is about at the 4 ft (1.2 m) mark. Scale is in feet.

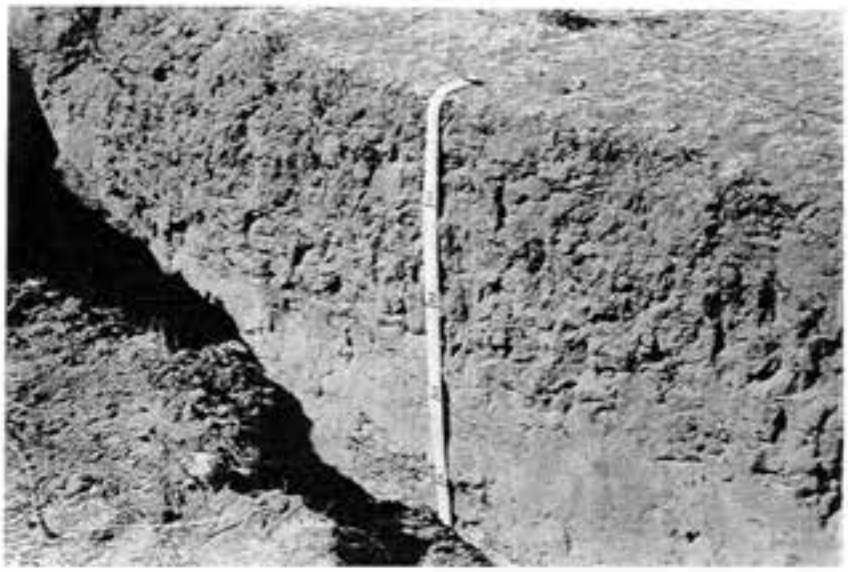


Table 57. Characteristics of Aridic Haplustalfs (Keeney) in depressions at Sites 48 and 49

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
Pedon 48 2/													
M, L	A1	0-3	7.5YR	4/3	2.5/2		sh,h	6.8	as	scl	51.6	28.9	19.5
B-II	Ab	3-13	7.5YR	4/2	2/2	1msbk	sh,h	6.4	as	fsl	78.5	10.6	10.9
	B1tb	13-20	5YR	5/4	3.5/4	1cpr-1msbk	h	6.6	aw	fsl	78.2	11.4	10.4
	B21tb	20-31	5YR	4.5/4	3/4	2mpr-1msbk	vh	6.4	cw	fsl	70.3	10.6	19.1
	B22tb	31-46	2.5YR	4/4	3/4	2mpr-2msbk	vh	6.6	as	scl	53.0	14.0	33.0
B-I	B2tb2	46-74	4YR	5/5	4/5	1cpr	vh	6.8	cw	fsl	75.9	5.5	18.6
	B3tb2	74-90	5YR	5/5	4/5	1cpr	h	6.8	cw	lfs	85.1	4.0	10.9
	Cb2	90-113	5YR	5.5/4	4/4	m	sh	6.8	as	fs	91.2	3.0	5.8
R?	B1tb3	113-128	5YR	5.5/4	4/4	1msbk	sh,h	6.8	cw	fsl	81.2	6.4	12.4
	B2tb3	128-142	5YR	5.5/4	4/4	1msbk	h	6.8		fsl	81.2	6.9	11.9
Pedon 49 3/													
M, L	A1	0-4	7.5YR	5/3	3/3	1f,mpl	sh	6.8	as	fsl	66.7	20.0	13.3
H	Ab	4-16	7.5YR	4.5/2	3/2	1csbk	h	6.8	as	fsl	76.5	12.8	10.7
	B21tb	16-26	4YR	5/6	4/6	1cpr	vh	6.8	as	fsl	68.9	11.7	19.4
	B22tb	26-42	2.5YR	5/6	4/6	1cpr-1csbk	vh	6.8	cw	fsl	75.9	4.8	19.3
	B23tb	42-82	2.5YR	5/6	4/6	2cpr-1csbk	vh	6.8	cw	scl	72.1	4.9	23.0
	B31tb	82-113	2.5YR	5.5/7	4/7	1cpr-1csbk	h	6.8	cw	lfs	84.1	2.2	13.7
	B32tb	113-153	5YR	6/6	4.5/6	1cpr-1csbk	sh	7.0	cw	lfs	84.5	3.4	12.1
	Btb2	153-170	5YR	6/6	4.5/6	1cpr-1csbk	h	7.0		fsl	82.1	3.2	14.7

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, R = Roosevelt, H = Hale.

2/ B21tb, B22tb: have discontinuous coatings of dark organic carbon on ped faces.

3/ A1: weak fine platy in upper cm. B1tb: coatings of organic carbon on ped faces are darker and have lower chroma.

LOCATION, LANDSCAPE, SOIL OCCURRENCE, VEGETATION

Soils of unit J occur in narrow, elongate portions of depressions that border high dunes. The dunes contribute runoff to these areas, and most soils have mollic epipedons. Some soils (Extee and Farwell) lack mollic epipedons because high-chroma Bt horizons are too shallow. These areas are difficult to predict because of smooth slopes, but their occurrence is thought to be due to wind erosion of soils that once had high-chroma Bt horizons at greater depths. Newell, calcic variant has a calcic horizon within 90 cm depth and is in sediments of Bailey age. SND-2, a Vertisol, occurs in a small depression in the southeasternmost delineation of the mapping unit (see figs. 88-91).

Vegetation observed in mapping unit J consists of catclaw, blue grama, hairy grama, snakeweed, sand sagebrush, vine mesquite, and blueweed. On aerial photographs the catclaw appears as irregular dark, patchy areas. The vine mesquite occurs in small, slightly lower areas of heavier texture and occurs with blueweed in the small area of Vertisols mentioned above.

TYPICAL PEDON AND RANGES IN SELECTED PROPERTIES

A typical pedon and ranges for Newell are given in mapping unit I. Pedon 50 is a typical pedon for Newell, calcic variant. See table 58 for characteristics of Pedon 50. Ranges in color and texture follow; underlined entries are typical. Two underlined entries indicate that it is typical for both entries to occur in the stated horizon.

The A horizon has hue of 7.5YR through 10YR, value of 3.5 through 4.5 (4) dry, 2 through 3 (2.5) 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 (3YR), value of 3 through 5 dry, 1.5 through 3.5 moist, and chroma of 2 through 4 (2, 3). It is sandy clay loam or clay loam.

The K2 horizon has hue of 7.5YR through 10YR, value of 8 through 9 dry, 7 through 8 moist, and chroma of 2 through 3. It is clay loam, sandy clay loam or clay.

In some soils, the K2 horizon is underlain by a C horizon. In other soils the K2 horizons are very thick and the underlying material is not known.

STUDY SITE

Site 50, blowout

Site 50 (figs. 88-91, table 58) has been illustrated (fig. 25). This area receives run-in from the high Birdwell dune to the east. Organic carbon is easily high enough for a mollic epipedon (table 58). Chromas and values qualify for a mollic epipedon, and the soil is the Aridic Argiustoll, Newell, calcic variant. These soils have a prominent calcic horizon within 90 cm depth (table 58).

Table 58. Characteristics of the Aridic Argiustoll, Newell, calcic variant, in a large blowout of Bailey age; Site 50 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	Organic C, %
A1	0-6	7.5YR	4/2	2.5/2	2f,msbk	h	7.0	cs	fsl	58.8	23.2	18.5	2.51
B21t	6-13	7.5YR	3/2	1.5/2	2f,msbk	vh	7.4	cs	scl	52.2	23.4	24.4	2.34
B22tca	13-20	5YR	5/3	3.5/3	2f,msbk	vh	7.6	as	scl	45.6	21.5	32.9	1.54
K1	20-37	6YR	6/3	5/4	1fsbk	vh		cw	scl				
K21	37-60	6YR	7/4	6/4	1msbk	vh		cw	clay				
K22	60-106	7.5YR	9/3	8/3	1fsbk	h,vh		cw	cl				
K3	106-131	7.5YR	8/3	7/4	1msbk	h,sh		cw	fsl				
C1ca	131-167	5YR	7/4	5.5/4	m	sh		s	fsl				
C2ca	167-177	5YR	7/4	5/4	m	s			lfs				

1/ B22tca: parts 5YR 7/3, dry; a few carbonate nodules; most parts effervesce weakly. K1: parts 7.5YR 8/2, dry. K21: parts 7.5YR 8/2, dry, and 6YR 6/4, dry. K22: parts 7.5YR 8/3, dry. C1ca: has carbonate in the form of occasional nodules and discontinuous grain coatings. C2ca: has carbonate in the form of occasional discontinuous grain coatings; a few parts noncalcareous.

CHAPTER 9. HAPLUSTALFS AND USTOCHREPTS OF THE BAILEY SURFACE

ARIDIC HAPLUSTALFS AND USTOCHREPTS DOMINANT: MAPPING UNIT K, EXTEE-VEAL COMPLEX

MAPPING UNIT COMPOSITION

Series or variant	Subgroup	Particle-size family	Percentage of mapping unit
EXTEE	ARIDIC HAPLUSTALFS	FINE-LOAMY	40
VEAL	ARIDIC USTOCHREPTS	FINE-LOAMY	35
Newell, calcic variant	Aridic Argiustolls	Fine-loamy	10
Other inclusions (Farwell, calcic variant, Keeney, Veal, petrocalcic variant)			15

LOCATION, LANDSCAPE, SOIL OCCURRENCE, VEGETATION

Soils of unit K occur in two large blowouts in the southern part of the area. The Ustochrepts, Veal soils, occur side by side with the Haplustalfs, Extee soils, the only difference being that the argillic horizon has been wind-truncated in the Ustochrepts but not in the Haplustalfs. With the argillic horizon gone, the calcic horizon that once was beneath it becomes diagnostic for the Ustochrepts. Veal and Extee soils occur in an intricate pattern, with Extee soils tending to occur in slight microlows where the argillic horizon has been preserved. Very minor areas of Ustochrepts with petrocalcic horizons occur in several small, low knolls near Farm Road 1731 (see Site 54). These soils show on the airphoto as small, light-colored areas. Mollisols are usually absent despite relatively fine textures and soil occurrence in a depression. Several factors are responsible for absence of Mollisols. In the eastern of the two delineations of this unit, runoff from bordering dunes is a minor factor. In most of the other delineations, the soils are sloping, thus water from adjacent dunes does not stand but runs off. Very minor areas of Mollisols do occur in some of the microlows, however (see Site 52).

Vegetation observed in mapping unit K consists of blue grama, snakeweed, soapweed, zinnia, buffalo grass, prickly pear, three-awn, hairy grama, and catclaw.

TYPICAL PEDONS AND RANGES IN SELECTED PROPERTIES

Pedon 51b is a typical pedon for Extee. See table 59 for characteristics of Pedon 51b. Ranges in color and texture follow; underlined entries are typical. Two underlined entries indicate that it is typical for both entries to occur in the stated horizon.

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

heavy fine sandy loam.

The K2 horizon has hue of 7.5YR through 10YR, value of 8 through 9 dry, 7 through 8 moist, and chroma of 2 through 4. It is sandy clay loam or clay loam.

Pedon 51a is a typical pedon for Veal. See table 59 for characteristics of Pedon 51a. Ranges in color and texture follow; underlined entries are typical. Two underlined entries for a given feature indicate that it is typical for both entries to occur in the stated horizon.

The A horizon has hue of 7.5YR through 10YR, value of 5 through 6 (5,5.5) dry, 3 through 4 (3,3.5) moist, and chroma of 2 through 3 (2.5). It is loamy fine sand and fine sandy loam.

The K2 horizon has hue of 7.5YR through 10YR, value of 8 through 9 dry, 7 through 8 moist, and chroma of 2 through 4. It is clay loam or sandy clay loam. The K horizon is thick and the material beneath it is not known.

STUDY SITES

Sites 51 and 52, complex patterns of Inceptisols and Alfisols

The largest blowouts occur as the Bailey surface, in the southern part of the area (fig. 19). In these large blowouts, most Mollisols border dunes that contribute runoff to level or nearly level areas (mapping unit J). But some parts of the large blowouts have distinct slopes where water runs off and these soils generally lack mollic epipedons.

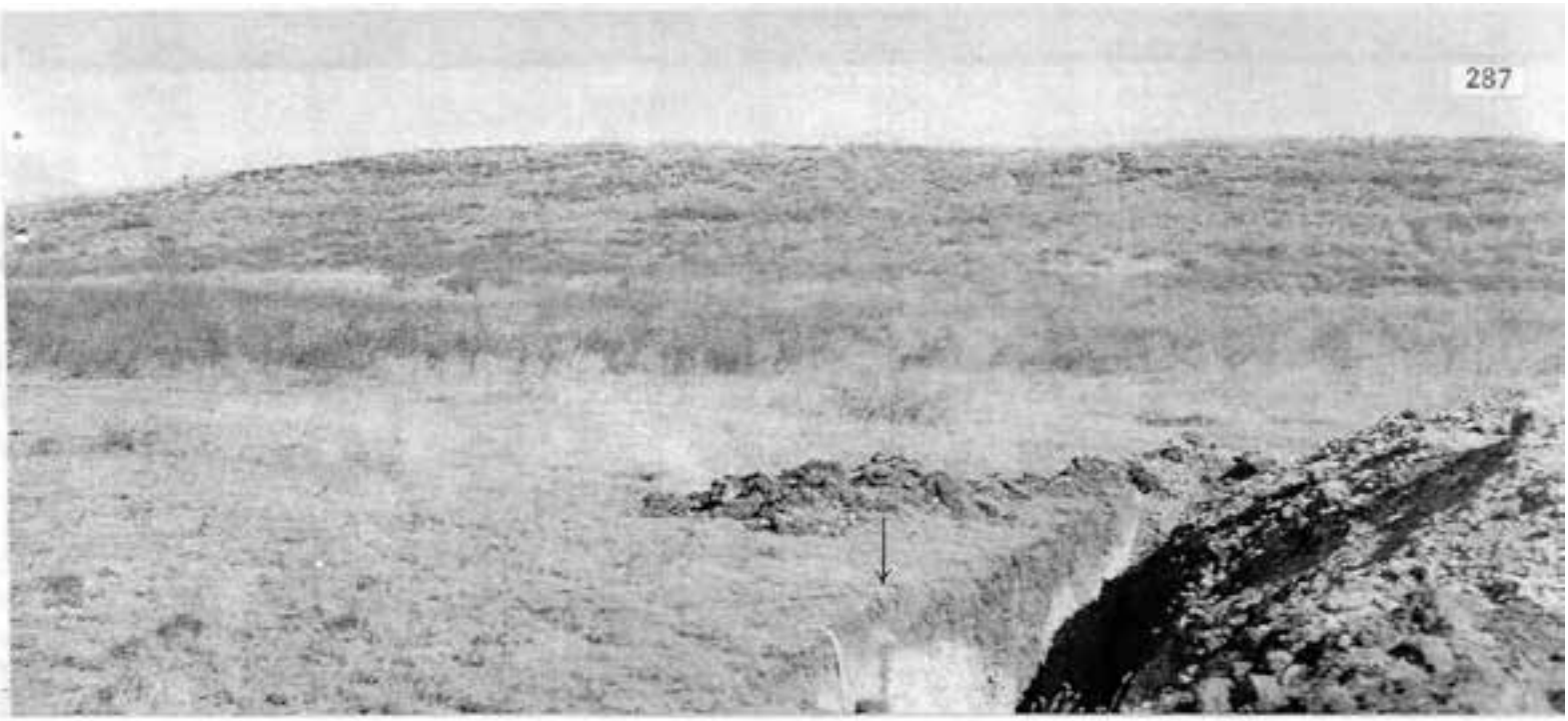
Sites 51 and 52 illustrate complex patterns of Inceptisols and Alfisols in the study area, the occasional occurrence of Mollisols, and the effect of strong erosion on the argillic horizon and soil classification. All soils of the blowout have the prominent calcic horizon of Bailey age; some of them have an argillic horizon, and a few have a mollic epipedon.

Although Birdwell sediments are thick in the large dune east of the blowout (see Sites 35-39), they are very thin or absent in the blowout itself, which is dominated by materials of Bailey age. Hale sediments, which must have been the main source of Birdwell sediments, are generally sparse or absent. The relationships indicate that winds of Birdwell time removed most post-Bailey sediments from the blowout, and that the blowout must have been in existence for a very long time -- since the beginning of Bailey time. In places along margins of the blowout, Hale sediments are preserved beneath Birdwell and Roosevelt sediments but are at the surface only in a few minor areas.

Site 51

The study trench (figs. 88-91, 118) is oriented east-west. Two pedons were sampled: an Inceptisol in the west end of the trench, and an Alfisol in the east end (figs. 118, 119). Table 59 gives characteristics of the sampled pedons.

Pedon 51a (fig. 118), an Aridic Ustochrept, is in the west end of the trench. The A11 horizon of Pedon 51a has abundant sand and little silt, clay and carbonate, and is thought to have formed in Birdwell sediments.



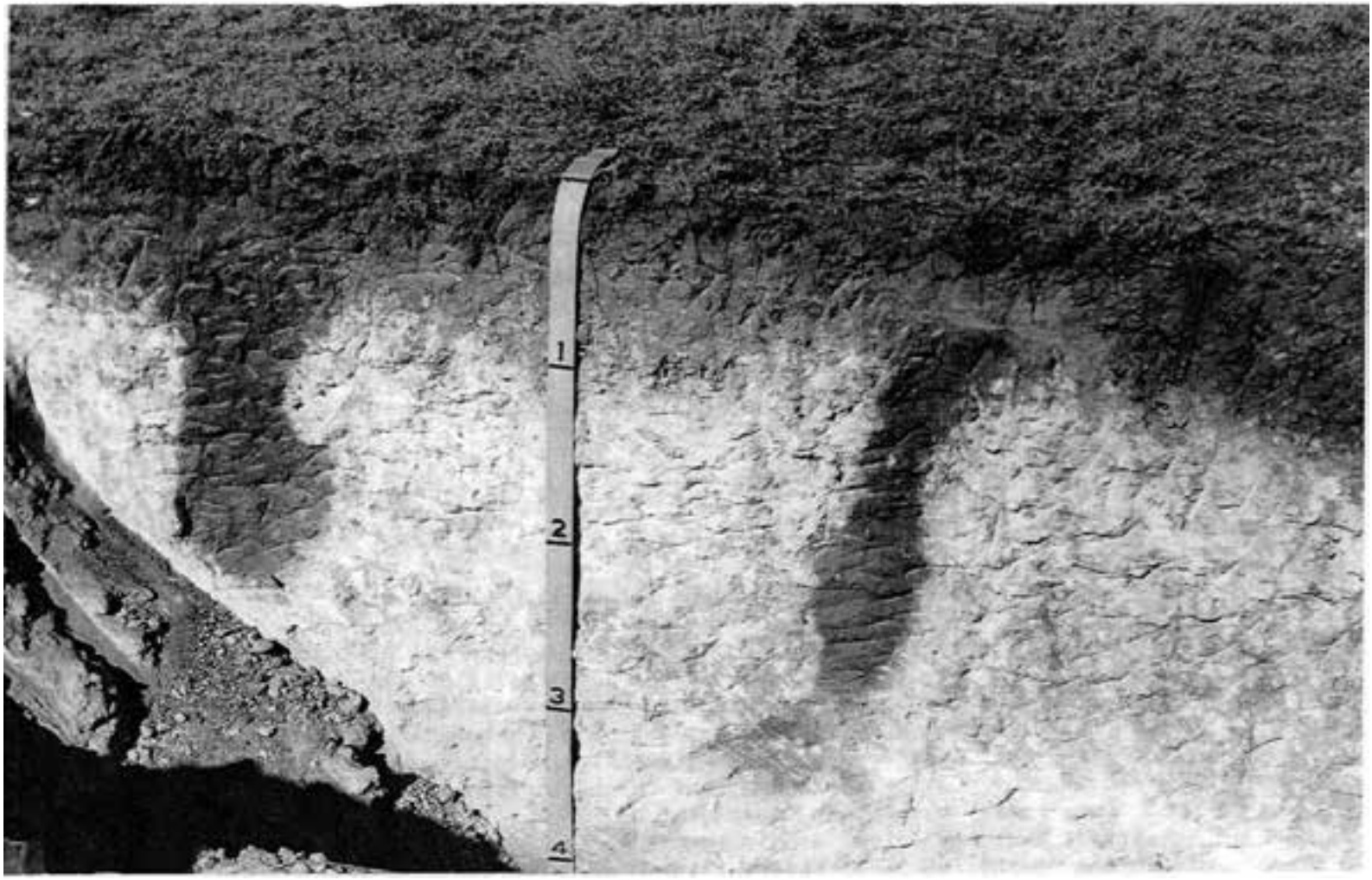


Figure 118. Upper. Landscape of the Bailey surface and east-west study trench at Site 51. Arrow locates boundary between Inceptisols in foreground, left of trench, and the Alfisols exposed in the far end of the trench. A Birdwell dune is in the background and on the skyline. The view is east.

Lower. The Aridic Ustochrept, Veal, at Site 51a, sampled between the pipes. The young pipes are too small for a pedon and are considered a part of the morphological range of the Veal soils. Scale is in feet.

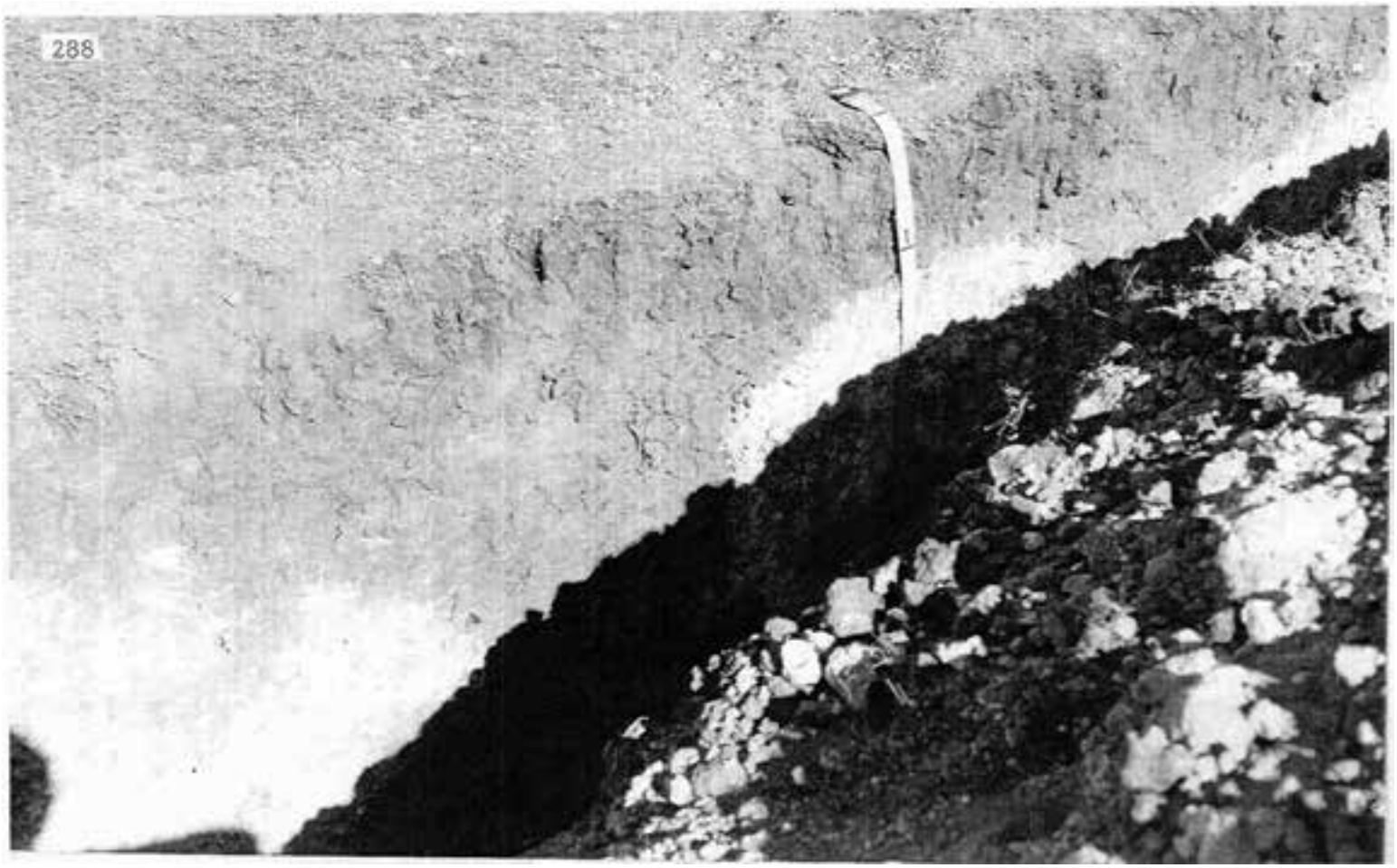


Figure 119. The Aridic Haplustalf, Extee, at Site 51b. The two downward extensions of the Bt horizon, one on each side of the tape, are thought to be true pipes, and not an eolian groove, because the maximum of silicate clay extends into the calcic horizon with no evidence of a discontinuity. Scale is in feet.

The epipedon is not quite dark enough for mollic (table 59).

Several factors indicate strong wind erosion in the blowout, and that it was a source of eolian sediments for development of the large dune to the east. Presence of sand-size carbonate grains in Birdwell strata of the dune (see Pedon 35b), and shallowness of the carbonate horizon at Pedon 51a indicate that wind erosion in Birdwell time penetrated to the top of the carbonate horizon. The prominent calcic horizon is very near the surface and must once have been overlain by a Bt horizon that has since been stripped away by wind erosion. This is indicated by the presence of Bt horizons nearby, at sites favoring their preservation (see Pedon 51b).

A small, reddish brown pipe occurs on each side of the sampled pedon (fig. 118). Similar pipes have developed in cavities once occupied by large roots (Gile and Grossman, 1979, p. 186). Both pipes contrast greatly with

the adjacent calcic horizon since they are coarser-textured and contain very little carbonate. The pipes consist of reddish brown, Bt-like material and must once have been connected to an argillic horizon. The relationships suggest that a post-Bailey deposit, possibly of Hale age, was once present at the surface. Decay of large roots could have created cavities; as the roots gradually decayed, fine earth from the surface could have moved downward into the soils. The pipes could then have formed in these more pervious materials.

Although upper horizons of Pedon 51b are quite dark, chromas are too high for a mollic epipedon (table 59). The Bt horizon in Pedon 51b has been preserved only because the calcic horizon is more resistant to erosion and is slightly higher to the west, where it has established a base level of erosion higher than the Bt horizon.

A large pipe occurs to the left of Pedon 51b. The pipe is wider and deeper than the two pipes near Pedon 51a and extends at least to the bottom of the trench, where at 130 cm depth the pipe is 90 cm wide and noncalcareous. Texture is clay in the upper part of the pipe and even at 130 cm depth is a sandy clay loam. Thus the pipe must be older than the two small pipes near Pedon 51a and may have been present throughout most of the development of these soils instead of representing a much later addition of sediment from the surface.

Site 52

Site 52 (figs. 88-91, 120, 121) is closer to the center of the blowout. Site 52 also illustrates soils with and without argillic horizon, and, in addition, illustrates a Mollisol well away from slopes that could contribute runoff. Table 59 gives soil characteristics.

Figure 120 locates subgroups and the sampled pedons along a surveyed line. Very slight differences in elevation exert major control on soil occurrence. Inceptisols occur almost wholly in the southern, higher part of the trench exposure; Mollisols occur only in the northern, slightly lower part. Upper horizons of Pedon 52a (figs. 120, 121) meet the requirements of the mollic epipedon, and illustrate that local conditions -- very slight lows in the landscape, only a few cm lower than the highs -- can create the conditions for dark color values and low chroma required for the mollic epipedon.

The relationships also indicate another contributing factor to the occurrence of Inceptisols and Mollisols at Site 52. An area in the low that lacks pipes also lacks both a mollic epipedon and an argillic horizon (fig. 121). This is because the prominent calcic horizon is so near the surface that it increases color value, precluding a mollic epipedon. Thus the Bt material of the pipes is essential for preservation of both the argillic horizon and the mollic epipedon. The pipes are thought to be true pipes, and not eolian grooves, because the clay maximum extends into the high-carbonate calcic horizon.

In Pedon 52b, the Inceptisol, the high-carbonate horizon is very near the surface (fig. 121). This soil occurs on the topographic high in the trench exposure (fig. 120). The base level of erosion established by the erosion-resistant calcic horizon on the slight highs would tend to protect soils in the slight lows from erosion, thus preserving the mollic epipedon

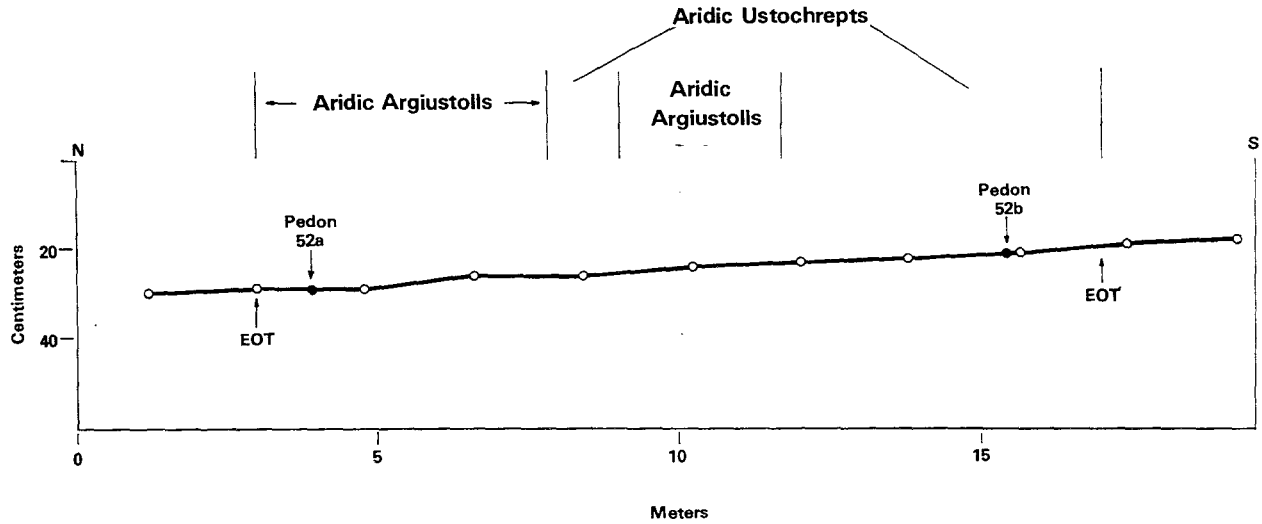


Figure 120. Cross section of land surface along study trench at Site 52. Aridic Argiustolls occur only in very slight topographic lows. Aridic Ustochrepts occur on very slight topographic highs, but also occur in the lows between pipes, where prominent calcic horizon is near the surface, increasing color value and precluding a mollic epipedon. EOT = end of study trench.

and the Mollisols. Also, runoff from these slight highs would increase the moisture for development of the mollic epipedon and the argillic horizon in the lows.

Site 53, Haplustalf of Bailey age

Site 53 is in a moisture exclosure (Soil Moisture Site 3, Appendix). Bailey sediments, deeply buried at Site 41 just south, are at the land surface at Site 53. Data for Pedon 53 are in table 60; photographs of the soil and landscape have been presented (Gile 1981, p. 54). Site 53 is visible in the 1981 aerial photograph as a small white spot caused by high-carbonate material in the trench fill (fig. 84). Pedon 53 has mixed mineralogy (table 51). However, the 89.8 percent of resistant minerals is very close to the siliceous mineralogy class, which must have more than 90 percent resistant minerals.

The boundary between the silicate clay and carbonate accumulations is not abrupt; and the silicate clay maximum is not well above the carbonate but extends into it and is partly engulfed by it (table 60). These factors suggest that both accumulations may have formed in parent materials of the same age. Carbonate in the upper part of the carbonate horizon is thought to be younger than in the lower, partly because of carbonate accumulation higher in the soil as the horizon below gradually became less pervious due to accumulated carbonate and clay. A shift to the drier climate at the end of the Tahoka pluvial may also have been a factor since lower effective moisture would cause carbonate accumulation at shallower depths.

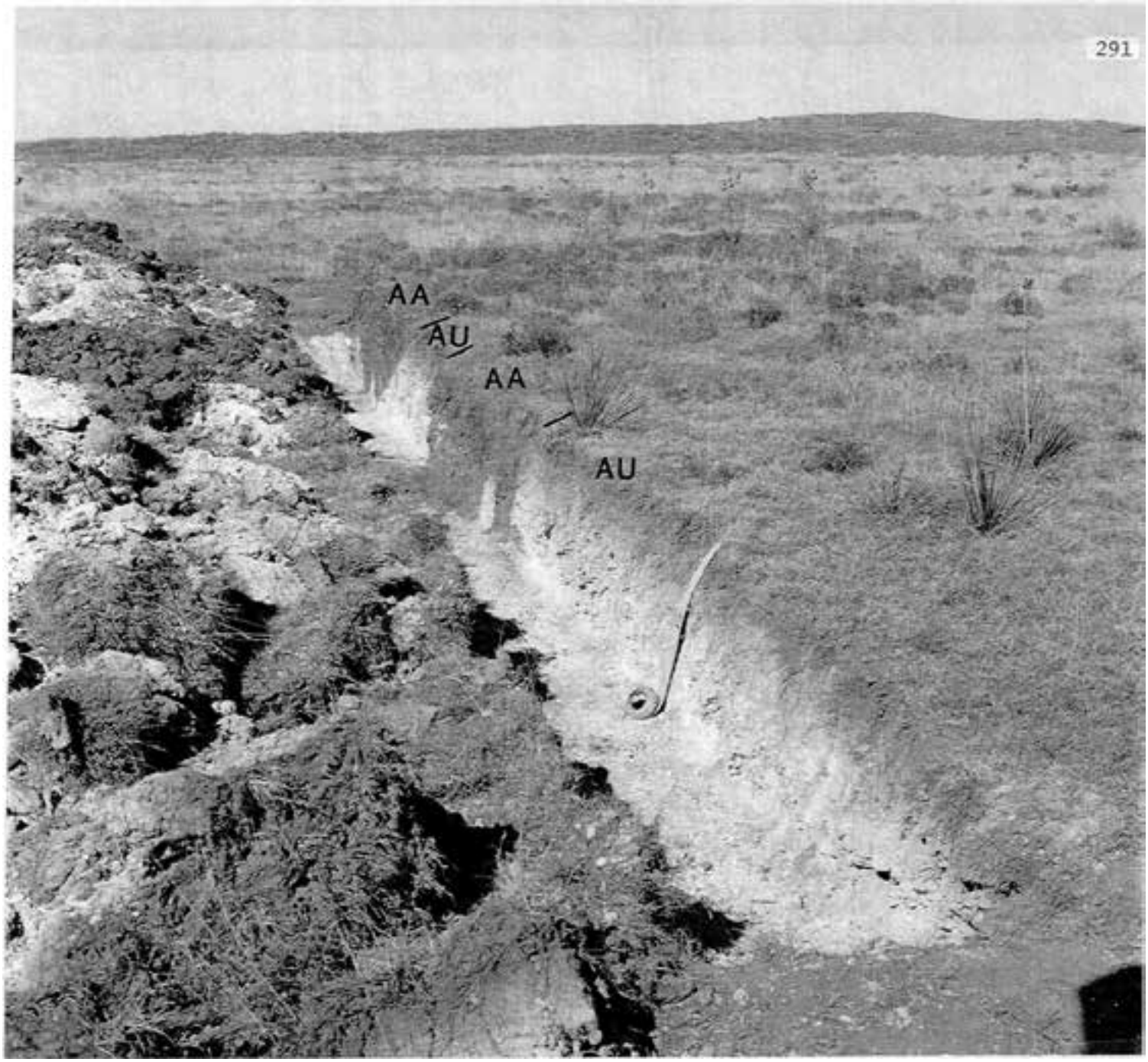


Figure 121. Landscape view of the Bailey surface and north-south study trench at Site 52. Subgroups between lines along soil surface (see fig. 120) identified as AA = Aridic Argiustolls; AU = Aridic Ustochrepts. The tape is at Pedon 52b, the Aridic Ustochrept. The view is north. Photographed October 1977. Scale is in feet.

Table 59. Characteristics of soils in a large blowout of Bailey age, Sites 51 and 52[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 Ustochrept, Veal, Pedon 51a[2/]													
Bailey	A1	0-5	7.5YR	5/2.5	3/2.5		s,sh		as	fsl	74.2	15.1	10.7
	A3ca	5-15	7.5YR	5.5/2.5	3.5/2.5	1m, csbk	sh		as	fsl	69.7	14.7	15.6
	K1	15-25	7.5YR	8/2	7/4	1msbk	h		cw	scl	55.1	19.7	25.2
	K21	25-39	7.5YR	8/2	7/4	2mpl	h,sh		cw	scl	46.0	25.6	28.4
	K22	39-70	7.5YR	8/3	7/4	1msbk	h,vh		cw	cl			
	K23	70-117	7.5YR	9/2	8/3	1msbk	h,vh		cw	cl			
	K3	117-140	5YR	7/4	5.5/4	m	sh			fsl			
Aridic Haplustalf, Extee, Pedon 51b[3/]													
Bailey	A1	0-5	7.5YR	5/3	3/3	1mpl	s,sh	7.0	as	fsl	65.4	20.8	13.8
	B21t	5-15	7.5YR	4/3	3/3	2cpr-	vh	7.6	as	fsl	71.7	14.9	13.4
			5YR	5/4	4/4	2csbk							
	B22tca	15-36	2.5YR	4/6	3/6	2cpr- 2csbk	vh			scl	64.3	7.4	28.3
	K	36- (not sampled - see Pedon 51a)											
Aridic Argiustoll, Newell, calcic variant, Pedon 52a[4/]													
Bailey	A1	0-5	7.5YR	5/3	3.5/3	fsl	s	7.0	as	fsl	79.2	10.2	10.6
	B11t	5-13	5YR	4.5/4	3/3	1cpr- 1csbk	h	7.2	cw	lfs	82.3	6.6	11.1
	B12t	13-27	5YR	4.5/3	3/3	1cpr- 1csbk	vh	7.4	cw	fsl	74.7	6.5	18.8
	B21tca	27-44	3YR	5/6	4/6	1cpr- 1csbk	vh	7.6	cw	scl	68.6	6.8	24.6
	B22tca	44-65	3YR	5.5/6	4/6	1cpr- 1csbk	vh	7.6	aw	scl	66.5	5.8	27.7
	K2	65-76	7.5YR	9/3	8/3	1f,msbk	h,vh	7.6		scl	40.3	34.4	25.3
Aridic Ustochrept, Veal, Pedon 52b[5/]													
Bailey	A11	0-10	7.5YR	5/3	3.4/3		s	7.6	as	lfs	80.0	10.9	9.1
	A12ca	10-25	7.5YR	5/2	4/2	1msbk	h		cw	fsl	66.5	15.7	17.8
	K1	25-43	7.5YR	9/3	8/3	1msbk	h		cw	cl	37.9	31.3	30.8
	K2	43-56	7.5YR	9/2	8/2	1f,msbk	vh			cl	25.7	44.4	29.9

1/ Subordinate colors and additional characteristics are footnoted to pertinent soils. All K horizons effervesce strongly throughout; other horizons are noncalcareous unless otherwise indicated. A few centimeters of post-Bailey sediments may occur at the surface.

2/ All horizons effervesce strongly with HCl. A3ca: has a few fine carbonate nodules and filaments. K1: parts 7.5YR 5/3, dry, and 5YR 5/4, dry.

3/ The upper two horizons are noncalcareous and most of the B22tca effervesces strongly with HCl; a few parts are noncalcareous. B21t: colors given are approximately equal in amount. B22tca: a few carbonate nodules and filaments.

4/ B12t: parts 5YR 54/, dry, in intricate pattern (parts 1-3 mm diameter) throughout; most parts effervesce weakly. B21tca, B22tca: few carbonate filaments on ped faces; some ped interiors effervesce weakly but most are noncalcareous.

5/ A11: effervesces weakly. A12ca: effervesces strongly; few parts 10YR 8/2, dry.

Table 60. Data for the Aridic Haplustalf Extee, S75TX-17-3, at Site 53[1/]

Sediment	Horizon	Depth	Particle size distribution, mm: Sand 2-1	1-0.5	0.5-0.25	0.25-0.1	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			
Bailey II	A1	0-5	0.1	3.3	9.1	39.9	26.5	12.9	8.2	0.6	1	0	0.67	0.4		8.1	fsl	7.5YR 5/3
	B1	5-19	tr	2.7	8.8	39.7	27.6	9.3	11.9	5.1	6	0	0.52	0.3	1.60	8.1	fsl	7.5YR 5/3
	B2tca	19-42	0.6	4.9	10.9	30.5	19.6	14.2	19.3	7.7	14	3	0.15	0.2	1.64	8.2	scl	5YR 5/6
	K21	42-65	0.4	4.1	8.4	21.1	13.7	26.5	25.8	5.4	43	15	0.06	0.2	1.75	8.1	scl	7.5YR 9/4
	K22	65-94	2.2	5.7	7.4	19.2	13.8	25.8	25.9	4.8	47	16	0.01	0.2	1.78	8.3	scl	7.5YR 9/4
	K31	94-133	0.3	4.6	11.6	34.1	20.2	12.7	16.5	6.6	10	2	0.01	0.3	1.69	8.3	scl	7.5YR 6/4
	K32	133-161	0.3	4.4	11.2	33.6	20.2	15.1	15.2	4.8	15	3	0.04	0.2	1.83	8.3	scl	5YR 6/4
	K33	161-181	0.7	5.6	12.2	38.1	19.2	11.8	12.4	3.0	9	2	0.05	0.2	1.75	8.2	scl	7.5YR 7/4
	Bca	181-197	0.1	3.6	10.1	40.6	20.6	5.4	19.6	9.0	1	0	0.02	0.3	1.78	8.1	fsl	7.5YR 7/4
Bailey I	B1tcab	197-224	0.4	4.0	9.1	36.3	16.9	6.3	27.0	12.2	5	0	0.04	0.3	1.70	8.1	scl	5YR 6/6
	B21tcab	224-250	0.7	4.1	9.4	33.8	17.5	6.4	28.1	13.7	7	0	0.03	0.3	1.91	7.8	scl	5YR 5/4
	B22tcab	250-286	0.5	4.0	9.1	34.7	19.2	6.7	25.8	11.6	4	0	0.02	0.4	1.77	8.1	scl	5YR 6/6

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).

This soil does not meet the clay distribution requirements of the Paleustalfs, since the clay decreases by more than 20 percent of its maximum within 1.5 m of the surface (table 60). Carbonate clay is included in the clay data shown in table 60; when carbonate clay is excluded, as it must be (Soil Survey Staff, 1975; Guy D. Smith, personal communication, January 1981), the pedon fails the requirements for Paleustalfs by an even wider margin. These requirements would seldom be met in K horizons because of the diluent effect of carbonate on silicate clay.

The K horizon has substantially less carbonate than in soils of Bailey I age (see Site 43). Since the buried Bt horizon is older than Bailey II (table 60), it is grouped with Bailey I. However, the character of horizons beneath the buried Bt horizon is not known. The buried Bt horizon may have formed in an isolated deposit late in Bailey I time; later, it could have been buried and preserved by Bailey II sediments. This could be a major reason for the prominent morphological difference from older soils of Bailey I (fig. 2). Although the buried Bt horizon contains a small amount of carbonate (table 60), it occurs as occasional downward extensions from the soil of Bailey II, and the Bt material between these downward extensions is noncalcareous. Clearly, the Bt horizon was noncalcareous before it was buried by sediments of Bailey II.

Site 54, development of the stage IV carbonate horizon

Horizons of carbonate accumulation may be ordered in four stages of development (fig. 10), and are more common in soils of arid regions than they are in this semiarid area. The geomorphic arrangement of soils that illustrate the carbonate stages is less apparent here than in other areas because carbonate horizons do not occur at all in the soils younger than Birdwell (fig. 2). Although carbonate horizons usually do not occur in soils of Birdwell age, weak stage I carbonate horizons do occur in them if

carbonate grains are in the parent materials (see Sites 39, 43). Prominent stage III horizons are common in soils of Bailey age as previously discussed (see Sites 43 and 50-53), but stage IV horizons are not. Site 54 illustrates localized development of the stage IV horizon, and shows the factors necessary for its development in semiarid soils that are of Bailey age and that formed in parent materials with virtually no carbonate, so that pedogenic carbonate must have been derived largely or wholly from dustfall.

Site 53, discussed in the previous section, occurs just upslope of Site 54. At Site 53, the carbonate horizon in Bailey II sediments is stage III and a buried Bt horizon is at 197 cm depth. But at Site 54 a buried Bt horizon is much nearer the surface, and the carbonate horizon is stage IV. Site 54 occurs on two small knolls, a few meters wide, that are several decimeters higher than adjacent north-trending drainageways (fig. 84). The only stage IV carbonate horizon found in the study area occurs in these knolls. Site 54 consists of two parts, 54a and 54b. Site 54a is an undisturbed knoll just west of the frontage road; Site 54b is a knoll along the frontage road.

The knoll at Site 54a shows as a light-colored spot on the aerial photograph. Here erosion has brought high-carbonate horizons practically to the surface, which is mantled with carbonate-cemented fragments. A small hand-dug pit showed an Aca horizon from 0-5 cm depth. Texture is gravelly sandy loam, with the gravel fragments consisting of indurated carbonate fragments ranging from 2 mm to 2 cm in diameter. A K1 horizon occurs from 5-12 cm depth. The K1 is a very gravelly sand with many indurated carbonate fragments, mostly from ½ to 3 cm diameter, from a formerly continuously cemented horizon. The K2m horizon occurs from 12-40 cm depth, and has a stage IV horizon in its upper part, with a laminar horizon underlain by a plugged horizon. The stage IV horizon is a petrocalcic horizon, diagnostic for the Ustochrepts (table 4).

At 40 cm depth the K2m horizon abruptly overlies nonindurated high-carbonate material. Evidence to be discussed indicates that this high-carbonate material is a buried, former argillic horizon that has now been engulfed by carbonate descending from the K2m horizon. At about 75 cm depth, noncalcareous, B3-like material was encountered with the auger. High-carbonate material occurred at a depth of about 1 m, and is thought to have accumulated while an overlying B horizon was developing. The B3-like material and underlying carbonate are suggestive of a former B2t horizon above; conclusive evidence of this is shown at Site 54b, along the frontage road (fig. 84) in the next knoll to the east.

Although the soil surface has been disturbed at Site 54b, the stage IV horizon is generally in place and has been exposed by erosion along the frontage road. A small pit showed that K2m horizon is underlain by a fine sandy loam Bt horizon, 5YR 5.5/5, dry, noncalcareous in prism interiors, but with tongues of carbonate descending from the petrocalcic horizon and occurring between the prisms. The reddish, noncalcareous interiors of prisms are 2 to 8 cm wide; the carbonate tongues between the prisms narrow with depth, and range from about 1 to 20 mm wide. Clearly, the wetting front has preferentially descended between the prisms to form the tongues. The carbonate tongues are shallow and wetted at times under current moisture. Thus the tongues must still be enlarging, although substantial volumes of low-carbonate zones remain in the prisms.

An auger showed noncalcareous B3-like material similar to that at Site 54a, at about 75 cm depth. At 90 cm depth a few carbonate nodules were encountered, and high-carbonate material was found at about 1 m depth.

A similar situation is shown just east of the roadside fence, where the road grader has scraped the thin stage IV horizon away. In places the situation is like that at Site 54a, with high-carbonate material directly beneath the petrocalcic horizon, and the reddish, B2t horizon absent. An auger boring in this nonindurated carbonate horizon passed through a clay maximum of fine sandy loam, and at 90 cm depth encountered less red, noncalcareous, B3-like material, a loamy fine sand. Visible carbonate is at a depth of about 130 cm.

The effectiveness of buried argillic horizons in holding up the wetting front, and in thus precipitating carbonate along the top of the buried horizons, has been observed at a number of places in arid regions. The evidence at Site 54 indicates that the same phenomenon can occur in semiarid regions, and that development of the stage IV horizon at Site 54 was caused primarily by two factors: (1) shallowness of the buried argillic horizon, which held up the wetting front, and (2) soil erosion, which (by decreasing depth to the carbonate maximum) speeded carbonate-plugging and development of the stage IV laminar horizon.

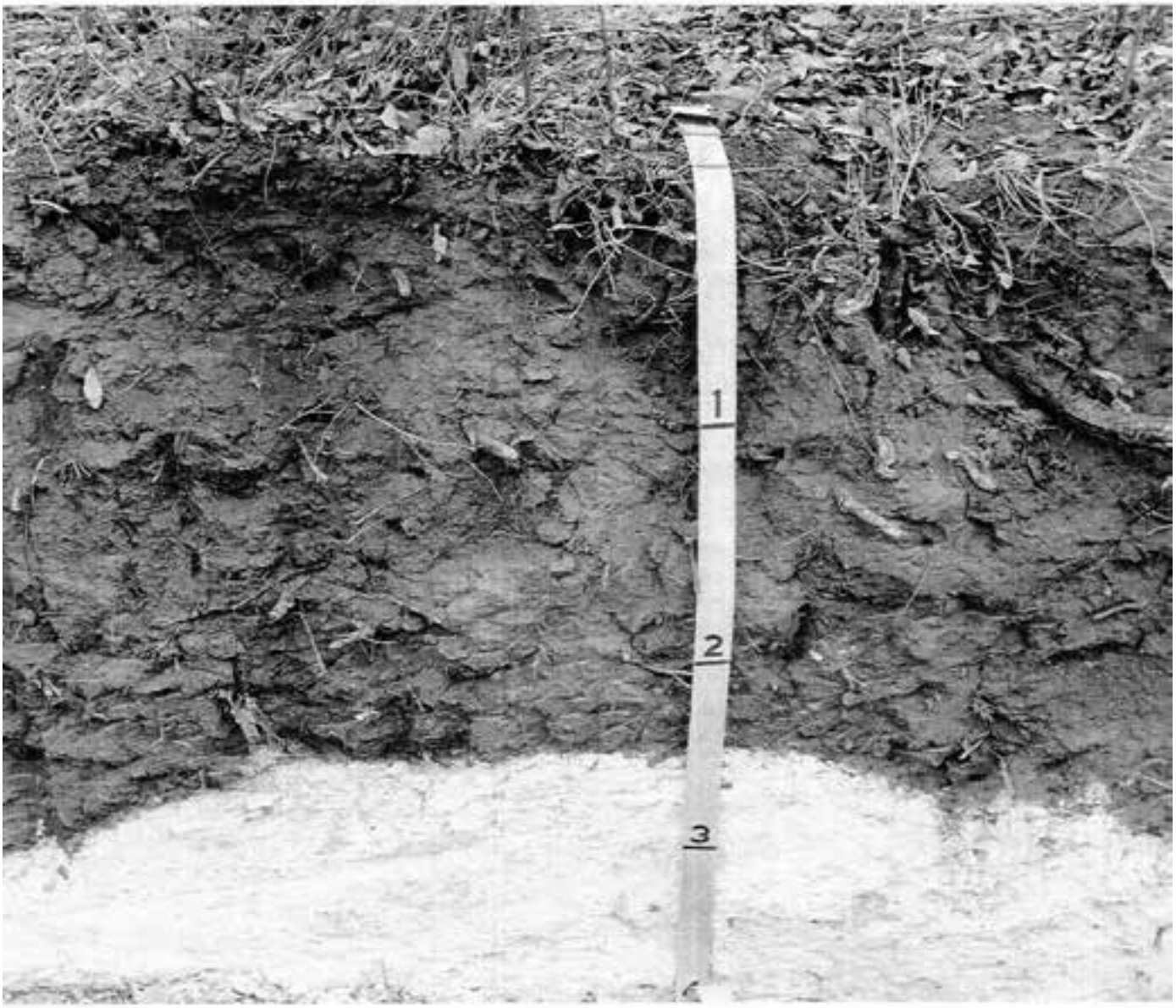
Low areas between the knolls are dark in the 1941 aerial photograph (fig. 83) and are drains that head in the high dune to the south. Dominant soils in the drains are fine-loamy Ustochrepts that are calcareous throughout. A shallow trench in one of these drains showed a soil that is quite dark in the upper few centimeters. But carbonate increases and color lightens just below the dark A horizon, which is not thick enough for a mollic epipedon. A fine sandy loam A horizon extends to about 25 cm depth. Below this a sandy clay loam B horizon extends to 40 cm depth, where scattered small hard carbonate nodules occur. A nonindurated K2 horizon starts at 45 cm depth. It is not known whether the soils in the drains are the same age as soils in the knolls, or are analogues of the buried soils in the knolls. This aspect needs further study.

Site 55, oak-nonoak transition

Very few oak shrubs occur in the large blowouts because sandy surficial layers (see Site 40) are less common there. Site 55 (figs. 83, 84, 122) illustrates one area in a large blowout that does have oak. The study trench (fig. 122) extends from oak into nonoak vegetation. Table 61 gives soil characteristics.

The study trench was oriented north-south and was about 10 m long. The northern 7 m was in oak and the remainder was in nonoak vegetation. Pedon 55a, under oak, was sampled about 2 m from the north end of the trench and Pedon 55b, under nonoak vegetation, was sampled about 1 m from the south end.

Both sampled pedons (table 61) have slightly more clay, and distinctly more silt in the surface horizon than in the horizon just beneath; and the soil under oak has slightly more of both silt and clay than the soil under nonoak vegetation. Both soils have a surficial zone of loamy fine sand (table 61) that is 31 cm thick under oak but only 15 cm thick under nonoak vegetation. Origin of the thicker zone under oak is not known; the sandy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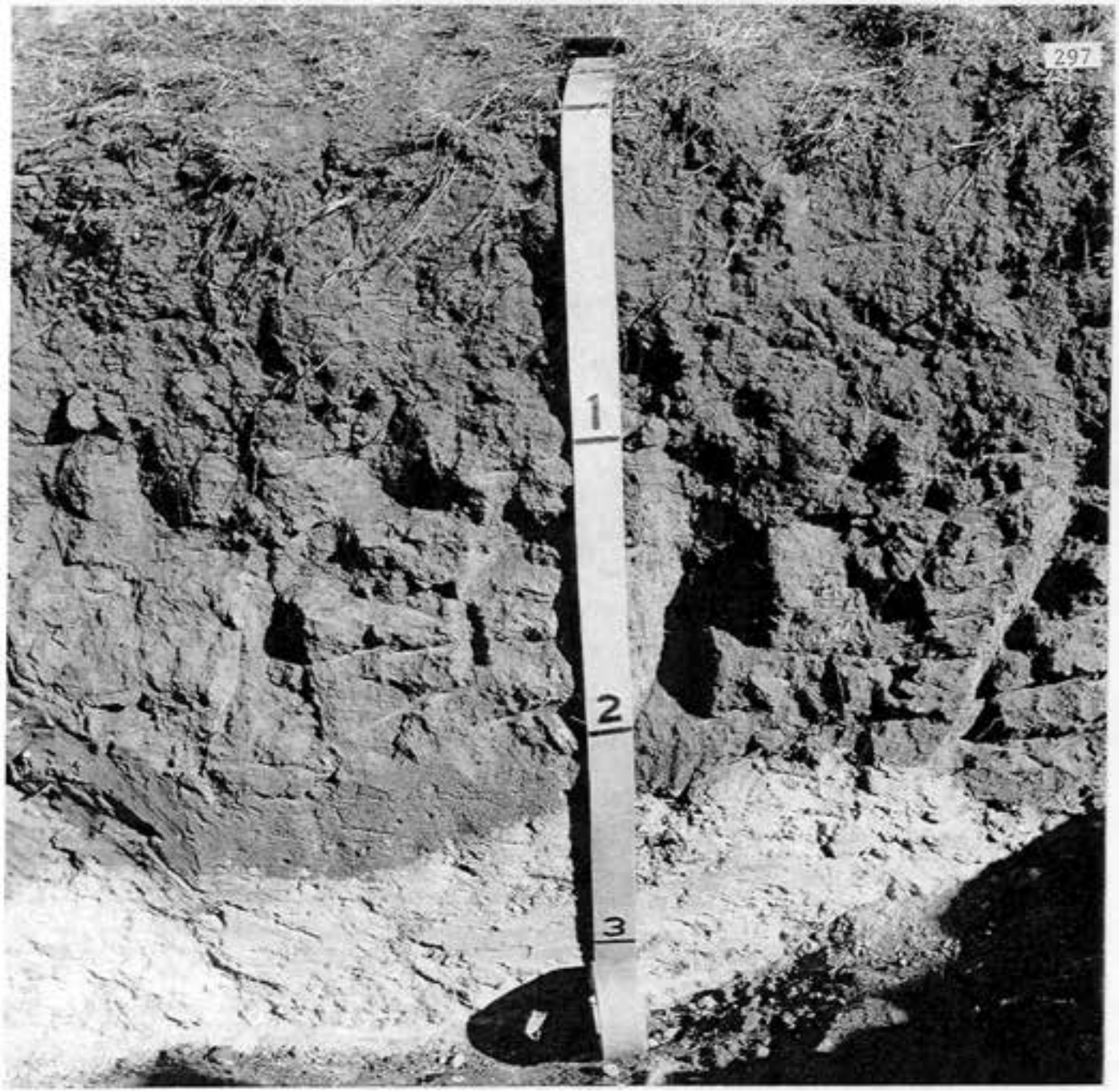

Figure 122. Opposite page, upper. View of the study trench from oak into non-oak vegetation at Site 55. The light-colored calcic horizon is thought to represent a soil of Bailey age, truncated by wind and then buried by Hale sediments. The view is north. Photographed November 1976.

Opposite page, lower. The Aridic Haplustalf Farwell, calcic variant, under oak vegetation at Site 55a. Scale is in feet.

Above. The Aridic Haplustalf Farwell, calcic variant, under nonoak vegetation at Site 55b. Scale is in feet.

Table 61. Characteristics of Aridic Haplustalfs, Farwell, calcic variant, in large blowout, Site 55[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
Pedon 55a, oak[2/]													
H	A1	0-9	7.5YR	4.5/3	3/3	m	s	6.8	cs	lfs	79.9	11.3	8.8
	B11t	9-22	6YR	5/4	3.5/4	m	s	7.0	cw	lfs	87.9	4.8	7.3
	B12t	22-31	6YR	5/4	4/4	lcsbk	h	7.2	cw	lfs	86.1	4.2	9.7
	B21t	31-55	3YR	5/6	4/6	lcpr-lcsbk	vh	8.0	cw	fsl	79.4	3.6	17.0
	B22t	55-74	3YR	5/6	4/6	lcpr-lcsbk	vh	8.4	as	fsl	82.0	2.6	15.4
	B23tca	74-78	3YR	5/6	4/6	lcpr-lcsbk	vh	8.4	as	fsl	78.2	4.8	18.0
Ba	K2b	78-93	5YR	8/3	7/3	lcsbk	vh	8.8	as	cl	40.5	24.1	35.4
Pedon 55b, nonoak[3/]													
H	A11	0-6	6YR	5/3.5	3/3.5	m,lfcr	s	6.8	as	lfs	81.7	10.8	7.5
	A12	6-15	6YR	5/3.5	3/3.5	m	s	7.4	as	lfs	86.8	6.2	7.0
	B1t	15-27	5YR	4/4	3/4	lcpr-m	sh	8.0	as	fsl	81.1	6.9	12.0
	B21t	27-38	5YR	5/4	4/4	lcpr-lmsbk	vh	8.4	as	scl	67.4	11.1	21.5
	B22tca	38-58	5YR	6/4	5/4	lcpr-lcsbk	h,vh	8.4	cw	fsl	81.3	5.7	13.0
	B23tca	58-72	5YR	6/4	5/4	lcpr-lcsbk	h,vh	8.4	as	fsl	81.8	6.1	12.1
Ba	K2b	72-98	5YR	8/3	7/3	m	vh	8.8		scl	62.7	13.9	23.4

1/ Subordinate colors and other comments are footnoted to pertinent soils. All K horizons effervesce strongly throughout; other horizons are noncalcareous unless otherwise indicated. Sediments identified as H = Hale, Ba = Bailey.

2/ B23tca: discontinuous carbonate coatings on peds; these effervesce, but ped interiors are noncalcareous. K2: ped coatings and crack fillings are 7.5YR 9/1, dry. There are many indurated nodules, ½ to 2 cm diameter.

3/ B21t: parts 5YR 4/3, dry; effervesces weakly. B22tca: a few spots of carbonate, 1-2 mm diameter. Most parts of ped interiors effervesce weakly, a few are noncalcareous. B23tca: patchy carbonate coatings and filaments on prism faces; some parts of ped interiors noncalcareous and others effervesce weakly. K2: ped coatings are 7.5YR 9/1, dry. There are many indurated nodules.

zone may have been locally thickened by Birdwell sediments. Such thickening could have been followed by migration of oak from the dunes into the blowout.

Soils under both oak and nonoak vegetation have argillic and prominent calcic horizons, but there are distinct differences between the two soils. The pH values of upper horizons are slightly lower under oak than under nonoak vegetation (table 61). The argillic horizon under oak is redder, harder, and more difficult to remove than the argillic horizon under grass. Structure under nonoak vegetation tends to be somewhat more distinct (prisms are more apparent) than under oak, but is related to depth to the K horizon. Under oak, no prisms could be found where the K horizon was shallower than about 80 cm (in the southern part of the oak portion of the trench). But where depth to the K horizon is greater than about 80 cm, prisms are present. And these prisms are carbonate-coated, but not closer than about 65 cm from the soil surface. The argillic horizon under oak is slightly redder than under nonoak vegetation (table 61).

Pipe-like features (downward extensions of the argillic horizon) are prominent in the trench (fig. 122). True pipes are thought to have been caused by differences in moisture concentration initiated by some means such as root decay (see Site 51). But the curved undulations in the top of the calcic horizon and the abrupt contact between the argillic and calcic horizons suggest the possibility of wind erosion down to the calcic horizon, forming grooves in it, and then the deposition of younger sediments.

Nearly continuous carbonate coatings on all prism faces are prominent in the soil under nonoak vegetation. The carbonate coatings extend from the calcic horizon upward to within 30 to 35 cm of the surface. There is more visible carbonate within the lower parts of prisms under nonoak than under oak. Lower parts of prism interiors are largely noncalcareous under nonoak and are usually wholly noncalcareous under oak.

Root distribution differs markedly between oak and nonoak vegetation. Under nonoak the roots are fine and, beneath the A horizon, are confined mainly to surfaces of prisms. The roots extend to the prominent calcic horizon. Under oak, large roots occur throughout the argillic horizon instead of being confined to surfaces of prisms. The difference in root size, number and distribution may be partly responsible for the observed differences in structure and carbonate occurrence. Growth of large roots, through time, would tend to disrupt prisms, the surfaces of which are favorable sites of carbonate accumulation in soils under grass. The oak roots generally do not penetrate the high-carbonate K horizon except for occasional small parts that have less carbonate than usual.

The distinct morphological differences suggest that both the oak and nonoak vegetation have been in place for some time, and that the boundary between them has also been quite stable. The period of time is unknown.

GLOSSARY

ACTIVE. ACTIVE blowouts and dunes are those that are presently losing or receiving substantial amounts of sand, as indicated by scarcity or absence of vegetation and the associated light-colored, sandy surface; missing sediments or soil horizons (in areas of erosion); and fresh, unmodified appearance of the sediments (in areas of deposition).

ALLUVIUM. Sediments deposited on land by streams.

BENCH. A long, narrow, relatively level or gently inclined strip or platform of land, earth, or rock, bounded by steeper slopes above and below....(Bates and Jackson, 1980).

BLOWOUT. A general term for a small saucer-, cup-, or trough-shaped hollow or depression formed by wind erosion on a preexisting dune or other sand deposit, esp. in an area of shifting sand or loose soil, or where protective vegetation is disturbed or destroyed; the adjoining accumulation of sand derived from the depression, where readily recognizable, is commonly included (Bates and Jackson, 1980). As used in this book, "blowout" designates only the level or nearly level bottom associated with a blowout dune. Areas above the blowout are designated dune and/or rim.

BURIED. Refers to geomorphic surfaces and soils that formed in the past and that were later buried by younger sediments.

CALCAREOUS. Containing sufficient free calcium carbonate or calcium-magnesium carbonate to effervesce visibly when treated with cold 0.1N hydrochloric acid (Soil Science Society of America, 1978).

CREST. SEE DUNE CREST.

CLAY BANDS. Thin, roughly horizontal, and dominantly to wholly pedogenic accumulations of silicate clay (termed lamellae in Soil Survey Staff, 1975). The adjective "clay" does not denote texture of the band but instead indicates the manner of clay occurrence in the horizon.

COLLUVIUM. Sediments deposited by concentrated surface runoff of sheet erosion, usually at the base of slopes (Bates and Jackson, 1980).

CROTOVINA. A former animal burrow in one soil horizon that has been filled with organic matter or material from another horizon. Also spelled "krotovina" (Soil Science Society of America, 1978).

DUNE. A low mound, ridge, bank, or hill of loose, windblown granular material (generally sand, sometimes volcanic ash), either bare or covered by vegetation, capable of movement from place to place but always retaining its characteristic shape (Bates and Jackson, 1980).

DUNE CREST. The highest part of the dune. Some dune crests are level or nearly level transversely; other crests are very narrow and no part is level transversely.

DUNE SIDE. That part of the dune below the crest. Divided into three general parts -- the upper side, near the crest; the lower side, near the blowout or trough; and the central side, between upper and lower sides.

ELUVIATION. The removal of soil material in suspension or in solution from the upper part of a soil, or from the soil surface, to deeper horizons. The A2 horizon is an eluvial horizon.

EOLIAN SEDIMENTS. Sediments deposited by wind.

FORESET. Pertaining to or forming a steep and advancing frontal slope, or the sediments deposited on such a slope (Bates and Jackson, 1980).

GEOMORPHIC SURFACE. This term was used by Ruhe and Scholtes (1956) as equivalent to soil landscape. The term was later defined (Ruhe, 1967) as part of the land that may be defined in space and time. As used here, the term is commonly shortened to "surface" for brevity. At stable sites a given geomorphic surface has a characteristic assemblage of soil horizons (See Chapter 2).

HOLOCENE. The later of two epochs of geologic time comprising the Quaternary period; the first is the Pleistocene. The boundary between the Holocene and the Pleistocene is generally considered to be about 10,000 years B.P. (Fairbridge, 1968; Hopkins, 1975).

Table 62 shows time division for the Holocene and the Pleistocene.

Table 62. Time divisions of the Holocene and Pleistocene

Epoch	Years B.P.1/	
Holocene	Late	2,500 to present
	Middle	2,500 to 7,500
	Early	7,500 to 10,000
Pleistocene	Late	10,000 to 250,000
	Middle	250,000 to 900,000
	Early	900,000 to 2,000,000

1/ Years B.P. = years before 1950, following the custom for reporting radiocarbon ages.

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

LAMINAR HORIZON. A horizon consisting of thin carbonate layers, usually ranging from white to brown in color, that are about parallel, roughly horizontal and more or less planar. In most soils the laminar horizon overlies a PLUGGED HORIZON.

MORPHOGENETIC SEQUENCES OF CARBONATE ACCUMULATION. Two morphogenetic sequences of carbonate accumulation, one in low-gravel and one in high-gravel materials. Carbonate morphology occurs in stages of increasing development that accord with increasing carbonate accumulation and increasing age of soil (Gile et al., 1966).

NONCALCAREOUS. Containing insufficient free calcium carbonate or calcium-magnesium carbonate to effervesce visibly when treated with cold 0.1N hydrochloric acid (Soil Science Society of America, 1978).

PARENT MATERIALS. The materials (such as eolian materials or alluvium) in which soil formation started. Materials in dustfall that have moved downward into soils during their development are not considered parent materials because dustfall occurred at various times after soil development started.

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

PEDON. A small volume of soil that, as a minimum, includes all genetic horizons of the soil at the land surface, but may also include one or more buried soils, as determined by the lower limit of the studied horizon. The pedon is roughly hexagonal in cross section; it has a surface area of 1 to 10 square meters and lateral dimensions ranging from about 1 to 3 m, depending on variability in horizons. If the horizons are continuous and of uniform thickness, the diameter of the pedon is one meter.

PIPE. A roughly vertical, commonly funnel-shaped zone of soil material that differs markedly from adjacent horizons. In the study area, the pipes contain Bt material and have less carbonate than adjacent horizons.

PLEISTOCENE. The earlier of two epochs in the Quaternary Period (table 62), extending from about 10,000 to 2,000,000 years B.P. In the Southwest, the Pleistocene Epoch was characterized by alternating PLUVIAL and INTERPLUVIAL intervals.

PLUVIAL. An interval when there was considerably more effective moisture than now. In the Southern High Plains the last major pluvial is termed the Tahoka pluvial, which extended from about 13,000 to prior to 20,000 years age (Haynes, 1975). Intervals between the pluvials are termed INTERPLUVIALS.

PLUGGED HORIZON. A horizon with so much pedogenic carbonate that the horizon is only slowly pervious to downward movement of soil water. Development of the plugged horizon initiates lateral movement of water and development of the LAMINAR HORIZON.

QUATERNARY. The youngest period of geologic time, consisting of the HOLOCENE and PLEISTOCENE, and having a duration of about 2 million years (table 62).

RIM. The border, margin, edge, or face of a land form....(Bates and Jackson, 1980). In this study the term is used primarily to designate eolian deposits that encircle, or nearly encircle small blowouts.

SANDHILLS. An area in which sand forms distinct hills or ridges.

STABLE SURFACE OR SOIL. An area that shows little or no evidence of erosion in the form of rills, drainageways, blowouts or missing horizons.

STAGE OF CARBONATE ACCUMULATION. Degree of carbonate accumulation, as indicated by morphology. The stages are ordered from I to IV by increasing carbonate accumulation that is closely related to age. The stages occur in two MORPHOGENETIC SEQUENCES of carbonate accumulation -- one in low-gravel and one in high-gravel materials (Gile et al.,1966).

TROUGH. A linear topographic low between dunes.

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APPENDIX. NSSL LABORATORY DATA AND DESCRIPTIONS OF SAMPLED PEDONS

Eleven pedons were analyzed by the NSSL. Eight of these were sampled at soil moisture sites in 1975. Samples from three additional pedons were submitted to the laboratory in 1978. The site and laboratory sample numbers are summarized below.

Pedons analyzed by the NSSL

Soil moisture site number	Site or subsite number (frontispiece)	Laboratory sample number
	1975	
1	43	S75TX-17-2
2	41	S75TX-17-1
3	53	S75TX-17-3
4	5	S75TX-17-4
5	6	S75TX-17-5
6	22	S75TX-17-6
7	7	S75TX-17-7
8	4	S75TX-17-8
	1978	
	3b	S78TX-17-3
	18c-4	S78TX-17-1
	21	S78TX-17-2

Following are names for vegetation listed at the various moisture sites and not given in Chapter 1: red three awn (*Aristida longiseta*), bundle flower (*Desmanthus* sp.), Riddell's groundsel (*Senecio Riddellii*), cotton flower (*Gossypianthus lanuginosa*), prairie greenthread (*Thelesperma megapotamicum*), woolly white (*Hymenopappus flavescens*), dryland sedge (*Cyperus uniflorus*), scarlet globemallow (*Sphaeralcea coccinea*), fall witchgrass (*Leptoloma cognatum*), plains blackfoot (*Melampodium leucanthum*), James nail-wort (*Paronychia Jamesii*), bladderpod (*Lesquerella sp.*) wild alfalfa (*Psoralea tenuiflora*), dotted gayfeather (*Liatris punctata*), white aster (*Leucelene ericoides*) lyreleaf greeneyes (*Berlandiera lyrata*), western ragweed (*Ambrosia psilostachya*), hairy evolvulus (*Evolvulus nutallianus*), stemmed bitterweed (*Hymenoxys scaposa*), scarlet gaura (*Gaura coccinea*), ring muhly (*Muhlenbergia torreyi*), giant dropseed (*Sporobulus giganteus*), mesa dropseed (*Sporobulusflexuosus*), spectacle-pod (*Dithyrea Wislizenii*), rushpea (*Hoffmanseggia densiflora*), fleabane (*Erigeron sp.*),gummy lovegrass (*Eragrostis curtipedicellata*), kuhnia (*Kuhnia eupatorioides*), tumble windmill grass (*Chloris verticillata*), needle-and-thread (*Stipa comata*), red lovegrass (*Eragrostis oxylepis*), four o'clock (*Mirabilis linearois*), sundrop (*Calylophus serrulatus*), dalea (*Dalea lanata*), tumble lovegrass (*Eragrostis sessilispica*), cryptantha (*Cryptantha Jamesii*), wild flax (*Linum rigidum*), spiny haplopappus (*Machaeranthura Pinnatifida*), and erect dayflower (*Commelina erecta*).

Soil: Texico.
Soil classification: Psammentic Haplustalf, mixed, thermic.
Pedon no.: S75TX-17-1.

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE, USDA
NATIONAL SOIL SURVEY LABORATORY
LINCOLN, NEBRASKA

GENERAL METHODS- - -1A,1B1B,2A1,2B SAMPLE NOS. 760239-760248

DEPTH CM	HORIZON	SAND 2-.05	SILT .05-.002	CLAY LT .002	FINE CLAY LT .0002	VCOS 2-1	COFS 1-.5	MEDS .5-.25	FNES .25-.10	VFNS .10-.05	COSI .05-.02	FNSI .02-.002	VFSI .002-.005	SAND 2-.10	INTR II .2-.02	FINE CLAY TO CLAY PCT	NON-CO3-CLAY PCT	RATIO 8D1 15-BAR TO CLAY
		PARTICLE SIZE ANALYSIS, LT 2MM, 3A1, 3A1A, 3A1B (PCT LT 2MM)																
000-004	A1	88.6	6.6	4.8	4.1	.2	2.2	13.5	56.1	16.6	3.9	2.7		72.0		85		.50
004-017	B1t	84.5	4.8	10.7	10.2	TR	1.9	11.5	51.3	19.8	2.7	2.1		64.7		95		.45
017-037	B21t	82.6	5.1	12.3	11.3	TR	3.3	11.0	42.8	25.5	3.1	2.0		57.1		92		.43
037-054	B22tca	82.0	4.8	13.2	11.1	.1	2.3	7.8	48.1	23.7	3.0	1.8		58.3		84		.39
054-078	B31tca	84.0	3.4	12.6	11.4	.1	1.0	4.4	52.6	25.7	1.9	1.5		58.3		90		.39
078-094	B32tca	85.3	3.5	11.2	10.5	.1	.8	7.6	58.8	18.0	2.0	1.5		67.3		94		.40
094-095	C1&B33t																	
095-130	C2	81.4	5.3	13.3	11.2	.1	1.9	9.5	45.4	24.5	3.5	1.8		56.9		84		.41
095-130	C2	84.8	3.6	11.6	9.9	TR	3.6	18.1	47.6	15.5	2.5	1.1		69.3		85		.37
130-160	C3	89.3	3.1	7.6	6.9	.1	10.3	26.6	42.3	10.0	1.7	1.4		79.3		91		.46

DEPTH CM	VOL. GT 2 PCT	WEIGHT GT 75 PCT	75-20	20-5	5-2	LT .074	20-2 PCT LT20	BULK DENSITY 4A1D 1/3-BAR G/CC	4A1H OVEN DRY G/CC	4D1 COLE	WATER CONTENT 4B1C 1/10 BAR PCT	4B1C 1/3-BAR PCT	4B2 15-BAR PCT	4C1 WRD CM/CM	CARBONATE 6E1B LT 2 PCT	3A1A LT .002 PCT	PH 8C1A 1/1 H2O	8C1B 1/2 CACL
	(PARTICLE SIZE ANALYSIS, MM, 3B, 3B1, 3B2) (PCT LT 75)																	
000-004	0	0	0	0	0	18	0	1.50B					2.4		0		7.2	6.6
004-017	0	0	0	0	0	24	0	1.54	1.61	.015		10.9	4.8	.09	0		7.2	6.6
017-037	0	0	0	0	0	29	0	1.54	1.62	.017		12.5	5.3	.11	TR		7.4	7.0
037-054	0	0	0	0	0	28	0	1.50	1.59	.020		13.5	5.2	.12	TR		8.2	7.6
054-078	0	0	0	0	0	26	0	1.51	1.56	.011		13.1	4.9	.12	TR		8.1	7.7
078-094	0	0	0	0	0	22	0	1.57	1.63	.013		14.1	4.5	.15	TR		8.3	7.7
094-095																		
095-130	0	0	0	0	0	28	0	1.51	1.58	.015		12.3	5.4	.10	TR		8.1	7.6
095-130	0	0	0	0	0	22	0	1.63	1.68	.010		9.9	4.3	.09	TR		8.2	7.7
130-160	0	0	0	0	0	14	0	1.60B					3.5		TR		8.1	7.7

DEPTH CM	ORGANIC MATTER 6A1A ORGA CARB PCT	6E1A NITG PCT	C/N	IRON 6C2B EXT FE PCT	PHOS TOTL PCT	EXTRACTABLE BASES 5B4A 6N2E CA	6O2D MG	6P2B NA	6Q2B K	SUM EXTB / 100	ACTY 6H1A BACL TRA G	AL 6G1E KCL EXT	(CAT EXCH) 5A3A EXTB ACTY	5A6A NHAC	RATIO 8D1 NHAC TO CLAY	RATIO 8D3 CA TO MG	CA SAT NHAC PCT	(BASE SAT) 5C3 EXTB ACTY PCT	5C1 NHAC PCT
						(MEQ / 100 G)													
000-004	.47	.043	11	.3		3.6	.7	.0	.4	4.7	.6		5.3	4.2	.88	5.1	86	89	112
004-017	.53	.054	10	.4		6.8	1.1	.0	.5	8.4	1.0		9.4	8.1	.76	6.2	84	89	104
017-037	.33	.032	10	.5		8.1	1.1	TR	.4	9.6	.9		10.5	8.7	.71	7.4	93	91	110
037-054	.16	.023	7	.5			1.0	.0	.4					8.3	.63				
054-078	.24			.5			.9	TR	.3					7.7	.61				
078-094	.11			.4			.9	.1	.3					7.2	.64				
094-095																			
095-130	.01			.5			1.4	.1	.3					8.1	.61				
095-130	.10			.4			1.2	.3	.3					6.4	.55				
130-160	.09			.3			1.6	.1	.3					4.8	.63				

DEPTH CM	(SATURATED PASTE) 8E1 REST OHM-CM	8C1B PH	8A H2O PCT	NA 5D2 ESP PCT	NA 5E SAR	SALT 8D5 TOTL SOLU PPM	GYP 6F1A PCT	SATURATION EXTRACT 8A1 8A1A EC MMHOS/CM	6M1B CA	6O1B MG	6P1B NA	6Q1B K	6I1A CO3	6J1A HCO3	6K1A CL	6L1A SO4	6M1A NO3	ATTERBERG 4F1 LIQID LIMIT PCT	4F2 PLST INDX
								(MEQ / LITER)											
000-004																			
004-017																			
017-037																			
037-054																			
054-078																			
078-094	5800	7.9	25.1					.27											
094-095																			
095-130																			
095-130																			
130-160																			

CLAY MINERALOGY (7A2C).
017-37 MM3 MI3 KK2.
130-210 MI3 MM3 KK2.
COMMENTS: MM IS POORLY ORDERED, MOSTLY A LOW CHARGE MONTMORILLONITE.
RELATIVE AMOUNTS: (X-RAY) 5 = DOMINANT 4 = ABUNDANT 3 = MODERATE 2 = SMALL 1 = TRACE.
MINERAL CODE: MI = MICA KK = KAOLINITE MM = MONTMORILLONITE-MICA.

SAND MINERALOGY (7B1) PLACEMENT: SILICEOUS.
017-37 VFNS - RE85 QZ81 FP2 ZR1 TM SP BK FD14 CL CB EP GN. FNES - RE93 QZ89 CD3 FK7 (328 GRAINS).
130-210 VFNS - RE91 QZ88 FP1 TM1 ZR1 SP FD8 TE8' GN.
COMMENTS: WEIGHTED AVERAGE OF 90.4 PCT. RESISTANT MINERALS IN B21T. BORDERLINE TO MIXED FAMILY MINERALOGY.
RELATIVE AMOUNTS: AS PERCENT
MINERAL CODE: RE = RESISTANT MINERALS CL = CHLORITE EP = EPIDOTE FD = FELDSPARS QZ = QUARTZ TM = TOURMALINE
ZR = ZIRCON FK = POTASSIUM FELDSPAR CB = CARBONATE AGGREGATES CD = CHALCEDONY SP = SPHENE
BK = BROOKITE GN = GARNET TE = TREMOLITE.

(A) NO SAMPLE
(B) ESTIMATED

Soil Moisture Site #2

Soil: Texico.
Soil classification: Psammentic Haplustalf, mixed, thermic.
Pedon no.: S75TX-17-1.
Location: In exclosure that is 175 feet west of Farm Road 1731, at a point about 2100 feet north of the junction between Farm Roads 1731 and 746.
Geomorphic surface: Birdwell.
Landform and slope: The crest of the dune ridge is nearly level longitudinally, with only slight undulations. The north and south sides of the exclosure are about on the shoulder of the crest, just above the more steeply sloping ridge sides. The crest is level transversely for only several m; this level part then slopes to the steeper part of the ridge side. Along the west side of the exclosure, for example, the crest is level for only about 2 m north-south, then each side slopes about 5 percent before slope increases to 10 percent (the upper sides of the ridges slope 10 percent to north and south).
Elevation: 3950.
Parent material: Eolian sediments.

Perennial vegetation (a sideoats grama - purple three-awn community): Purple three-awn, sideoats grama, dryland sedge, plains blackfoot, Riddell's groundsel, prairie greenthread, wild flax, dotted gayfeather, soapweed, woolly white, James nail-wort, stemmed bitterweed, sand dropseed, wolftail, gummy lovegrass, fleabane, spiny haplopappus, wild alfalfa, and bladderpod.

Soils samples collected by: Dan Blackstock, Russ Pettit, and George Threlkeld, October 13, 1975.
Soil described by: L. H. Gile.

Soil surface: Barren areas 10-30 cm diameter occupy about 30-40 percent of the area with barren areas smaller than this occurring between individual plants. The soil surface in these barren areas is generally smooth, with undulations of 1-2 mm. The smooth surface is the top of a crust about 1 mm thick. The clumps of vegetation preserve a surface that is commonly about 4-5 cm higher than the barren areas, suggesting some erosion between the clumps.

A1 760239 0-4 cm. Dark reddish brown (5YR 3/4 dry, 5YR 4/4 moist) fine sand; weak very fine crumb structure; soft, very friable; few roots except beneath plants where roots are common; noncalcareous; neutral; abrupt smooth boundary.

B1t 760240 4-17 cm. Dark reddish brown (5YR 3/3 dry, 5YR 4/4 moist) loamy fine sand; weak coarse prismatic, massive internally; hard, friable; few roots except beneath plants, where roots are common; noncalcareous; neutral; clear wavy boundary

B21t 760241 17-37 cm. Red (2.5YR-5YR 5/6 dry, 2.5YR-5YR 3/6 moist) loamy fine sand; weak coarse prismatic, massive internally; slightly hard and hard, friable; few roots; noncalcareous; moderately alkaline; clear wavy boundary.

B22tca 760242 37-54 cm. Yellowish red (slightly redder than 5YR 5/6 dry, 5YR 3/6 moist); fine sandy loam; compound weak coarse prismatic and weak coarse subangular blocky structure; slightly hard and hard, friable; few roots; common very fine tubular pores; common carbonate filaments on ped faces and in pores; most parts effervesce weakly, few spots noncalcareous; moderately alkaline; clear wavy boundary.

B31tca 760243 54-78 cm. Yellowish red (5YR 5/6 dry, and 5YR 4/6 moist) loamy fine sand; compound very weak coarse prismatic and very weak medium subangular blocky structure; slightly hard, very friable; few roots; few carbonate filaments on ped faces; effervesces weakly; moderately alkaline; clear wavy boundary.

B32tca 760244 78-94 cm. Yellowish red (5YR 5/6 dry, 4/6 moist) light loamy fine sand; massive; slightly hard, very friable; few roots; very few carbonate filaments; effervesces weakly; moderately alkaline, abrupt smooth boundary.

C1&B33t 760245 94-95 cm. Reddish yellow (7.5YR 8/6 dry, 7.5YR 6/6 moist) fine sand; massive and single grain; soft and loose; very few roots; effervesces weakly; moderately alkaline; abrupt smooth boundary (not sampled).

C2 760246 95-130 cm. Yellowish red (5YR 5/6 dry, 5YR 4/6 moist), massive slightly hard, very friable; very few roots; consists of fine sandy loam, generally without macroscopic stratification, dominant in upper parts of the horizon, and loamy fine sand with macroscopic stratification, dominant in the center of the horizon; very few carbonate filaments; effervesces weakly; moderately alkaline; clear wavy boundary.

C3 760248 130-160 cm. Yellowish red (5YR 5/6 dry, 4/6 moist); alternating zones of (1) light fine sandy loam, commonly ranging from 5 to 10 cm thick, in which strata cannot be seen or are faintly visible, and (2) coarser-textured material (loamy fine sand and fine sand) in which strata 1-2 mm thick are evident; massive; slightly hard, very friable; very few roots; noncalcareous except for occasional strata of sand, 0.5-1 cm thick, which effervesce weakly; moderately alkaline.

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Soil: Farwell, thin variant.
Soil classification : Aridic Haplustalf, coarse-loamy, mixed, thermic.
Pedon no.: S75TX-17-2.

GENERAL METHODS- - -1A,1B1B,2A1,2B SAMPLE NOS. 760249-760259

DEPTH CM	HORIZON	SAND 2-.05	SILT .05-.002	CLAY LT .002	FINE CLAY LT .0002	VCOS 2-1	CORS 1-.5	MEDS .5-.25	FMES .25-.10	VFNS .10-.05	COSI .05-.02	FNSI .02-.002	VFSI .005-.002	SAND 2-.10	INTR TT .2-.02	FINE CLAY TO CLAY PCT	NON-CO3-CLAY PCT	RATIO 8D1 15-BAR TO CLAY
		PARTICLE SIZE ANALYSIS, LT 2MM, 3A1, 3A1A, 3A1B (PCT LT 2MM)																
		SAND			FINE	SAND					SILT							
000-015	A1	83.9	10.0	6.1	4.1	.1	2.4	11.0	48.2	22.2	7.3	2.7		61.7		67		.44
015-032	B11t	82.4	7.0	10.6	8.1	TR	2.8	10.5	46.7	22.4	5.0	2.0		60.0		76		.43
032-057	B12t	71.4	11.6	17.0	13.2	TR	2.8	9.0	37.6	22.0	7.2	4.4		49.4		78		.39
057-076	B2t	68.2	12.8	19.0	14.6	TR	2.6	8.4	35.0	22.2	7.5	5.3		46.0		77		.37
076-096	B11tb	71.8	11.9	16.3	12.5	.1	2.8	9.3	37.4	22.2	7.2	4.7		49.6		77		.38
096-120	B12tb	75.4	7.7	16.9	13.5	.1	3.1	9.6	38.8	23.8	5.0	2.7		51.6		80		.39
120-142	B2tb	72.7	6.6	20.7	17.3	.1	3.0	8.9	38.9	21.8	4.8	1.8		50.9		84		.42
142-159	B3tcab	74.4	6.7	18.9	14.1	.1	3.7	8.9	38.4	23.3	5.1	1.6		51.1		75		.43
159-187	K21b2	53.9	22.6	23.5	1.7	13.9	8.4	6.3	14.2	11.1	7.0	15.6		42.8		7	9	.30
187-238	K22b2	44.4	28.2	27.4	2.3	2.3	4.9	5.9	17.4	13.9	7.0	21.2		30.5		8	7	.22
238-265	K3b2	53.7	22.6	23.7	4.3	1.3	4.5	6.6	25.1	16.2	6.4	16.2		37.5		18	11	.29

DEPTH CM	VOL. GT 2 PCT	GT 75 PCT	75-20	20-5	5-2	LT .074	20-2 PCT LT20	4A1D 1/3-BAR G/CC	4A1H OVEN DRY G/CC	4D1 COLE	4B1C 1/10 BAR PCT	4B1C 1/3-BAR PCT	4B2 15-BAR PCT	4C1 WRD CM/CM	6E1B LT 2 PCT	3A1A LT .002 PCT	8C1A 1/1 H2O	8C1B 1/2 CACL
	(PARTICLE SIZE ANALYSIS, MM, 3B, 3B1, 3B2) (WEIGHT PCT LT 75)							(BULK DENSITY)			(WATER CONTENT)				CARBONATE		(PH)	
000-015	0	0	0	0	0	26	0	1.50A					2.7		TR		7.1	6.9
015-032	0	0	0	0	0	27	0	1.50	1.57	.015		10.8	4.6	.09	TR		7.0	6.7
032-057	0	0	0	0	0	39	0	1.45	1.56	.025		18.1	6.7	.17	TR		7.2	6.7
057-076	0	0	0	0	0	42	0	1.53	1.65	.026		14.6	7.1	.11	0		7.1	6.6
076-096	0	0	0	0	0	39	0	1.64	1.70	.012		10.6	6.2	.07	0		7.2	6.7
096-120	0	0	0	0	0	35	0	1.63	1.70	.014		12.6	6.6	.10	TR		7.3	6.9
120-142	0	0	0	0	0	37	0	1.60	1.70	.021		14.8	8.7	.10	TR		7.5	7.2
142-159	0	0	0	0	0	35	0	1.57	1.71	.029		17.7	8.1	.15	TR		7.8	7.5
159-187	0	0	0	0	0	52	0						7.1		67	15	8.1	7.7
187-238	0	0	0	0	0	63	0						6.0		62	20	8.3	7.6
238-265	0	0	0	0	0	54	0						6.9		39	13	8.5	8.1

DEPTH CM	ORGANIC MATTER 6A1A ORGN CARB PCT	6E1A NITG PCT	C/N	IRON 6C2B EXT FE PCT	PHOS TOTL PCT	EXTRACTABLE BASES 5B4A 6N2E CA	6O2D MG	6P2B NA	6Q2B K	SUM EXTB MEQ / 100 G	ACTY 6H1A BACL TRA EXT	AL 6G1B KCL EXT	(CAT EXCH) 5A3A EXTB ACTY	5A6A NHAC	RATIO 8D1 NHAC TO CLAY	RATIO 8D3 CA TO MG	CA 5F1 SAT NHAC PCT	(BASE SAT) 5C3 EXTB ACTY PCT	5C1 NHAC PCT
000-015	.54	.046	12	.3			.7	TR	.4					4.8	.79				
015-032	.44	.046	10	.4			1.2	.1	.5		1.4			6.8	.64				
032-057	.45	.053	8	.6			2.1	TR	.7					10.3	.61				
057-076	.38	.047	8	.6		8.5	2.3	.1	.6	11.5	1.6		13.1	11.2	.59	3.7	76	88	103
076-096	.23			.5		7.0	2.0	.1	.5	9.6	1.1		10.7	9.4	.58	3.5	74	90	102
096-120	.17			.5			2.1	.1	.6		1.1			9.4	.56				
120-142	.16			.6			2.8	.1	.7					11.7	.57				
142-159	.14			.6			2.9	.1	.6					11.4	.60				
159-187	.15			.1			1.6	.1	.2					3.9	.17				
187-238	.11			.1			3.0	.1	.2					4.7	.17				
238-265	.08			.2			4.6	.2	.3					7.2	.30				

DEPTH CM	(SATURATED PASTE) 8E1 REST OHM-CM	8C1B PH	8A H2O PCT	NA 5D2 ESP PCT	NA 5E SAR	SALT 8D5 TOTL SOLU PPM	GYP 6F1A PCT	(SATURATION EXTRACT 8A1) 8A1A EC MMHOS/CM	6N1B CA	6O1B MG	6P1B NA	6Q1B K	6I1A CO3	6J1A HCO3	6K1A CL	6L1A SO4	6M1A NO3	ATTERBERG 4F1 LQID LIMIT PCT	4F2 PLST INDX
									(MEQ / LITER)										
000-015																			
015-032																			
032-057																			
057-076																			
076-096																			
096-120	3600	7.4	29.9					.43											
120-142																			
142-159																			
159-187																			
187-238																			
238-265																			

CLAY MINERALOGY (7A2C).
057-76 MI4 MM3 KK3.
120-142 MI4 KK3 MM2 MC1.
238-265 MT3 CA3 MI2 KK2.
COMMENTS: MM IS POORLY ORDERED, MOSTLY A LOW CHARGE MONTMORILLONITE.
RELATIVE AMOUNTS: (X-RAY) 5 = DOMINANT 4 = ABUNDANT 3 = MODERATE 2 = SMALL 1 = TRACE.
MINERAL CODE: MT = MONTMORILLONITE MI = MICA KK = KAOLINITE CA = CALCITE MM = MONTMORILLONITE-MICA
MC = MONTMORILLONITE-CHLORITE.

SAND MINERALOGY (7B1) PLACEMENT: SILICEOUS.
056-76 VFNS - RE90 QZ89 FE1 TM ZR SP FD10 CL GN HN. FNES - RE96 QZ95 CD1 FE4 (352 GRAINS).
120-142 VFNS - RE87 QZ85 FE1 TM ZR SP FD12 HN1 MS SO VR.
238-265 VFNS - RE69 QZ66 FE1 ZR1 TM SP CB19 FD11 HN MS GN.
COMMENTS: WEIGHTED AVERAGE OF 94 PCT. RESISTANT MINERALS IN THE B2T.
RELATIVE AMOUNTS: AS PERCENT
MINERAL CODE: RE = RESISTANT MINERALS CL = CHLORITE FD = FELDSPARS HN = HORNBLENDE MS = MUSCOVITE QZ = QUARTZ
TM = TOURMALINE ZR = ZIRCON FK = POTASSIUM FELDSPAR CB = CARBONATE AGGREGATES CD = CHALCEDONY
SP = SPHENE GN = GARNET SO = STAUROLITE VR = VERMICULITE.

(A) ESTIMATED

Soil Moisture Site #1

Soil: Farwell, thin variant.
Soil classification: Aridic Haplustalf, coarse-loamy, mixed thermic.
Pedon no.: S75TX-17-2.
Location: In exclosure about 150 feet west of Farm Road 1731, at a point about 1300 feet north of the junction between Farm Roads 1731 and 746.
Geomorphic surface: Birdwell.
Landform and slope: The northern edge of a nearly level plain. The site is level.
Elevation: 3930 feet.
Parent material: Eolian sediments.

Perennial vegetation (a blue grama - buffalo grass community): Sand sagebrush, blue grama, zinnia, red three-awn, bundle flower, snakeweed, Riddell's groundsel, catclaw mimosa, buffalo grass, cotton flower, prairie green-thread, woolly white, soapweed, dryland sedge, scarlet globemallow, fall witchgrass, and sideoats grama.

Soil samples collected by: Dan Blackstock and George Threlkeld, October 14, 1975.
Soil described by: L. H. Gile.
Soil surface: Covered with vegetation except for occasional barren patches, 10-30 cm across, which occupy about 10-15 percent of the area; numerous barren patches of smaller size occur between clumps of vegetation. The barren patches have a smooth surface which is the top of a thin (less than 1 mm) crust. The barren areas are generally about 1-2 cm (in places 5 cm) lower than the fine earth in grass clumps.

A1 760249 0-15 cm. Brown (7.5YR 5/3 dry) or dark brown (7.5YR 3.5/3 moist) loamy fine sand; breaks out as very weak coarse subangular blocks which commonly fracture into weak medium and coarse plates; soft, very friable; few roots between plants, roots common beneath them; noncalcareous; neutral; clear wavy boundary.

B11t 760250 15-32 cm. Reddish brown (5YR dry, 3.5/4 moist) loamy fine sand; weak coarse subangular blocky structure; slightly hard, friable; few roots; noncalcareous; mildly alkaline; clear wavy boundary.

B12t 760251 32-57 cm. Reddish brown (5YR 5/4 dry, 3.5/4 moist) heavy fine sandy loam; compound weak coarse prismatic and weak coarse subangular blocky structure; hard, friable; few roots; few fine tubular pores; noncalcareous; mildly alkaline; clear wavy boundary.

B2t 760252 57-76 cm. Reddish brown (6YR 5/4 dry, 3.5/4 moist) fine sandy loam; compound weak coarse prismatic and weak medium and coarse subangular blocky structure; very hard, firm; few roots; common fine and very fine tubular pores; noncalcareous; mildly alkaline; clear wavy boundary.

B11tb 760253 76-96. Reddish brown (5YR 5/4 dry, 4/4 moist) fine sandy loam; compound weak coarse prismatic and very weak coarse subangular blocky; very hard, friable; reddish clay coatings on sand grains; crotovina 15-20 cm diameter, filled with loose, fine earth; common fine and very fine tubular pores; noncalcareous; mildly alkaline; clear wavy boundary.

B12tb 760254 96-120 cm. Red (3.5YR 5/6 dry, 4/6 moist) fine sandy loam; compound weak coarse prismatic and weak medium subangular blocky; slightly hard, friable; common fine tubular pores; reddish clay coatings on sand grains; crotovina, about 10 cm wide, extends from horizon above, into and through this horizon, terminating (in cross section) in the horizon below; very few roots (mostly on faces of prisms) except for crotovina, where fine roots are common; noncalcareous; mildly alkaline, clear wavy boundary.

B2tb 760255 120-142 cm. Red (2.5YR 5/6 dry, 3.5/6 moist) sandy clay loam; compound weak coarse prismatic and weak medium and coarse subangular blocky; hard, friable; very few roots; common fine and very fine tubular pores; clay coatings on sand grains; noncalcareous; moderately alkaline; clear wavy boundary.

B3tcab 760256 142-159 cm. Red (2.5YR 5/6 dry, 3.5/6 moist) heavy fine sandy loam; compound weak coarse prismatic and weak coarse subangular blocky; hard, friable; very few roots; carbonate filaments on faces of some prisms, especially in lower part of horizon; common fine and very fine tubular pores; the lower 2 cm has texture of light sandy clay loam and has carbonate as filaments and grain coatings; most parts of this lower 2 cm effervesce strongly and a few parts are noncalcareous, remainder of horizon is noncalcareous; moderately alkaline; abrupt smooth boundary.

K21b2 760257 159-187 cm. Dominantly pink (7.5YR 8/4 dry, 6.5/4 moist), with smaller amount of 7.5YR 9/4 dry, 8/4 moist; the whiter material occurs as fillings between peds; most of material sufficiently cemented that it cannot be textured, but repeated breakings and wettings give a texture of sandy clay loam; horizon as a whole takes water readily; horizon very firm in place and breaks out as weak medium subangular blocky; generally the blocks are very hard; only a very few fine roots, which occur in some of the few softer areas; indurated nodules are common, take water only slowly, and generally cannot be broken with the hands; effervesces strongly; moderately alkaline; clear wavy boundary.

K22b2 760258 187-238 cm. Dominantly pink, (7.5YR 9/4 dry, 7/4 moist) sandy clay loam; weak coarse subangular blocky structure; generally hard and very hard, with only a few indurated nodules; occasional single fine roots, occurring at intervals usually 20-30 cm apart; effervesces strongly; moderately alkaline; clear wavy boundary.

K3b2 760259 238-265 cm. About equal parts of pink (7.5YR 8/4 dry, 7/4 moist) and pink (7.5YR 7/4 dry) or light brown (7.5YR 6/4 moist) with small amounts of 7.5YR 9/4 dry, and 8/4 moist; sandy clay loam; weak coarse subangular blocky; mostly slightly hard and hard, with a few parts very hard; generally no roots, but one root, brittle and dead-appearing, occurs in a root channel about 3 mm in diameter; the whitest parts occur as scattered carbonate nodules; effervesces strongly; moderately alkaline.

Soil: Extee.
Soil classification: Aridic Haplustalf, fine-loamy, mixed, thermic.
Pedon no.: S75TX-17-3.

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GENERAL METHODS- - -1A,1B1B,2A1,2B   SAMPLE NOS. 760260-760271

DEPTH CM	HORIZON	SAND 2-.05	SILT .05-.002	CLAY LT .002	FINE CLAY LT .0002	VCOS 2-1	CORS 1-.5	MEDS .5-.25	FNES .25-.10	VFNS .10-.05	COSI .05-.02	FNSI .02-.002	VFSI .005-.002	SAND 2-.10	INTR II .2-.02	FINE CLAY TO CLAY PCT	NON-CO3-CLAY PCT	RATIO 8D1 15-BAR TO CLAY
		(- - - PARTICLE SIZE ANALYSIS, LT 2MM, 3A1, 3A1A, 3A1B - - -) FINE (- - - SAND - - -)(- - -SILT- - -)																
		(- - - PCT LT 2MM - - -)																
000-005	A1	78.9	12.9	8.2	.6	.1	3.3	9.1	39.9	26.5	9.4	3.5		52.4		7		.52
005-019	B1	78.8	9.3	11.9	5.1	TR	2.7	8.8	39.7	27.6	6.7	2.6		51.2		43	12	.45
019-042	B2tca	66.5	14.2	19.3	7.7	.6	4.9	10.9	30.5	19.6	5.6	8.6		46.9		40	16	.35
042-065	K21	47.7	26.5	25.8	5.4	.4	4.1	8.4	21.1	13.7	5.1	21.4		34.0		21	11	.24
065-094	K22	48.3	25.8	25.9	4.8	2.2	5.7	7.4	19.2	13.8	5.6	20.2		34.5		19	10	.23
094-133	K31	70.8	12.7	16.5	6.6	.3	4.6	11.6	34.1	20.2	6.4	6.3		50.6		40	15	.39
133-161	K32	69.7	15.1	15.2	4.8	.3	4.4	11.2	33.6	20.2	6.4	8.7		49.5		32	12	.37
161-181	K33	75.8	11.8	12.4	3.0	.7	5.6	12.2	38.1	19.2	6.4	5.4		56.6		24	10	.43
181-197	Bca	75.0	5.4	19.6	9.0	.1	3.6	10.1	40.6	20.6	4.2	1.2		54.4		46	20	.40
197-224	B1tcab	66.7	6.3	27.0	12.2	.4	4.0	9.1	36.3	16.9	4.0	2.3		49.8		45	27	.41
224-250	B21tcab	65.5	6.4	28.1	13.7	.7	4.1	9.4	33.8	17.5	3.2	3.2		48.0		49	28	.42
250-286	B22tcab	67.5	6.7	25.8	11.6	.5	4.0	9.1	34.7	19.2	4.2	2.5		48.3		45	26	.42

DEPTH CM	VOL. GT 2 PCT	GT 75 PCT	75-20	20-5	5-2	LT .074	20-2 PCT LT20	4A1D 1/3-BAR G/CC	4A1H OVEN DRY G/CC	4D1 COLE	4B1C 1/10 BAR PCT	4B1C 1/3-BAR PCT	4B2 15-BAR PCT	4C1 WRD CM/CM	6E1B CARBONATE LT 2 PCT	3A1A LT .002 PCT	8C1A PH 1/1 H2O	8C1E PH 1/2 CACL
	(PARTICLE SIZE ANALYSIS, MM, 3B, 3B1, 3B2) (- - - WEIGHT - - -)		(- - - PCT LT 75 - - -)					(BULK DENSITY)			(- - - WATER CONTENT - - -)							
000-005	TR	0	0	TR	TR	34	TR	1.50A					4.3		1	0	8.1	7.6
005-019	0	0	0	0	0	35	0	1.49	1.60	.024		15.4	5.4	.15	6	0	8.1	7.7
019-042	0	0	0	C	0	59	0	1.60	1.64	.008		13.5	6.8	.11	14	3	8.2	7.7
042-065	0	0	0	0	0	60	0	1.63	1.75	.024		16.6	6.2	.17	43	15	8.1	7.9
065-094	5	0	0	4	2	40	6	1.65	1.78	.024		15.0	6.0	.15	47	16	8.3	7.8
094-133	3	0	0	2	2	38	4	1.59	1.69	.020		15.9	6.5	.15	10	2	8.3	7.9
133-161	4	0	0	4	1	38	5	1.77	1.83	.011		13.3	5.6	.13	15	3	8.3	7.8
161-181	0	0	0	0	0	35	0	1.69	1.75	.012		12.9	5.3	.13	9	2	8.2	7.8
181-197	0	0	0	C	0	35	0	1.67	1.78	.022		13.3	7.8	.09	1	0	8.1	7.8
197-224	0	0	0	0	0	42	0	1.59	1.70	.023		17.6	11.1	.10	5	0	8.1	7.7
224-250	1	0	0	TR	1	42		1.65	1.91	.050		13.3	11.7	.03	7	0	7.8	7.6
250-286	1	0	0	1	1	42	2	1.63	1.77	.028		18.1	10.9	.12	4	0	8.1	7.7

DEPTH CM	6A1A ORGN CARB PCT	6B1A NITG PCT	C/N	6C2B IRON EXT FE PCT	PHOS TOTL PCT	6N2E CA	6O2D MG	6P2B NA	6Q2B K	SUM EXTB	6H1A ACTY BACL TEA	6G1E AL KCL EXT	5A3A CAT EXCH EXTB ACTY	5A6A CAT EXCH NHAC	8D1 RATIO NHAC TO CLAY	8D3 RATIO CA TO MG	5F1 CA SAT NHAC PCT	5C3 BASE SAT EXTB ACTY PCT	5C1 BASE SAT NHAC PCT
	(ORGANIC MATTER)					(- -EXTRACTABLE BASES 5B4A- -)					(- - - MEQ / 100 G - - -)								
000-005	.67	.064	10	.4			.8	.0	.5					8.4	1.02				
005-019	.52	.050	10	.3			1.0	.0	.4					8.0	.67				
019-042	.15	.015	10	.2			1.9	TR	.3					5.8	.30				
042-065	.06	.009	7	.2			2.9	TR	.3					6.9	.27				
065-094	.01			.2			4.4	TR	.4					9.7	.37				
094-133	.01			.3			4.5	TR	.4					9.1	.55				
133-161	.04			.2			4.0	.1	.4					7.7	.51				
161-181	.05			.2			3.8	.1	.3					7.2	.58				
181-197	.02			.3			4.6	.1	.6					11.5	.59				
197-224	.04			.3			6.8	.1	.8					16.7	.62				
224-250	.03			.3			6.6	.1	.9					18.1	.64				
250-286	.02			.4			5.7	.0	.8					17.2	.67				

DEPTH CM	8E1 REST OHM-CM	8C1B PH	8A H2O PCT	NA 5D2 ESP PCT	NA 5E SAR	SALT 8D5 TOTL SOLU PPM	GYP 6F1A PCT	8A1A EC MMHOS/CM	6N1B CA	6O1B MG	6P1B NA	6Q1B K	6I1A CO3	6J1A HCO3	6K1A CL	6L1A SO4	6M1A NO3	ATTERBERG 4F1 LQID LMIT PCT	4F2 PLST INDX
	(SATURATED PASTE)							(- - - SATURATION EXTRACT 3A1 - - -)	(- - - MEQ / LITER - - -)										
000-005																			
005-019																			
019-042																			
042-065																			
065-094																			
094-133	4100	7.9	31.5					.32											
133-161																			
161-181																			
181-197																			
197-224																			
224-250																			
250-286																			

CLAY MINERALOGY (7A2C).
019-42 CA3 MM2 MI2 KK1.
181-197 MT3 MI3 KK2 QZ1 FD1 CA1.
250-286 MT4 MI3 KK2 MC1 QZ1 CA1.
RELATIVE AMOUNTS: (X-RAY) 5 = DOMINANT 4 = ABUNDANT 3 = MODERATE 2 = SMALL 1 = TRACE.
MINERAL CODE: MT = MONTMORILLONITE MI = MICA KK = KAOLINITE CA = CALCITE QZ = QUARTZ MM = MONTMORILLONITE-MICA
MC = MONTMORILLONITE-CHLORITE FD = FELDSPAR.

SAND MINERALOGY (7B1) PLACEMENT: MIXED.
019-42 VFNS - RE58 QZ57 FE1 TM ZR SP CB31 FD10 GN EP AU HN. FNES - QZ65 CD1 CB30 FK4 (340 GRAINS).
181-197 VFNS - RE84 QZ82 FE1 ZR1 TM SP FD14 CB1 MS VR GN HN.
250-286 VFNS - RE87 QZ86 FE1 TM ZR FD9 CB3 HN GN AU.
COMMENTS: WEIGHTED AVERAGE OF 64 PCT. RESISTANT MINERALS IN THE B2TCA. WEIGHTED AVERAGE OF 91 PCT. RESISTANT MINERALS IN THE B2TCA ON A CARBONATE-FREE BASE. PEDON SILICEOUS ON CARBONATE-FREE BASE.
RELATIVE AMOUNTS: AS PERCENT
MINERAL CODE: RE = RESISTANT MINERALS EP = EPIDOTE FD = FELDSPARS HN = HORNBLENDE MS = MUSCOVITE QZ = QUARTZ
TM = TOURMALINE ZR = ZIRCON FK = POTASSIUM FELDSPAR CB = CARBONATE AGGREGATES CD = CHALCEDONY
GN = GARNET AU = AUGITE SP = SPHENE VR = VERMICULITE.

(A) ESTIMATED

IHC900I EXECUTION TERMINATING DUE TO ERROR COUNT FOR ERROR NUMBER 217

IHC217I FIOCS - END OF DATA SET ON UNIT 5

TRACEBACK	ROUTINE	CALLED FROM ISN	REG. 14	REG. 15	REG. 0	REG. 1
	IBCOM		000548CC	00055908	00000060	00054880
	MAIN		000198F2	010524E0	000BEC8C	00076FFB

ENTRY POINT= 010524E0

Soil Moisture Site #3

Soil: Extee.
Soil classification: Aridic Haplustalf, fine-loamy, mixed, thermic.
Pedon no.: S75TX-17-3.
Location: In exclosure about 160 feet west of Farm Road 1731, about 0.5 mile north of the junction between Farm Roads 1731 and 746.
Geomorphic surface: Bailey II.
Landform and slope: Located in the northern part of a broad depression (blowout). Slope is about 1 percent to the northwest.
Elevation: 3935.
Parent material: Eolian sediments.

Perennial vegetation (a blue grama - soapweed community): Snakeweed, Riddell's groundsel, zinnia, buffalo grass, prairie greenthread, wild alfalfa, dotted gayfeather, scarlet globemallow, white aster, lyreleaf greeneyes, western ragweed, hairy evolvulus, stemmed bitterweed, scarlet gaura, ring muhly, purple 3-awn, blue grama, prickly pear, and soapweed.

Soils samples collected by: Dan Blackstock and George Threlkeld, October 14, 1975.
Soils described by: L. H. Gile.

Soil surface: Scattered barren areas, 10-30 cm diameter, are connected by smaller barren areas about 5 cm in diameter. Some of the barren areas are level with the soil around the plant clumps and other barren areas range up to 1-2 cm lower. The surface is smooth and constitutes the top of a crust that breaks out as plates 2-3 mm thick. Parts of the crusts are coated with a black lichen.

A1 760260 0-5 cm. Brown (7.5YR 5/3 dry) or dark brown (7.5YR 3.5/3 moist) fine sandy loam; weak fine and very fine crumb; soft, very friable; few roots except under grass clumps, where roots are common; effervesces strongly; moderately alkaline; clear smooth boundary.

B1 760261 5-19 cm. Brown (7.5YR 5/3 dry) or dark brown (7.5YR 3.5/3 moist) with a few parts slightly redder and lighter in color; fine sandy loam; massive; slightly hard, friable; few roots; few carbonate nodules, ½ to 3 cm diameter, most are indurated and thinly stained with brown fine earth; effervesces strongly; moderately alkaline; clear wavy boundary.

B2tca 760262 19-42 cm. Dominantly yellowish red (5YR 5/6 dry, 4/6 moist) with smaller amounts of 5YR 6/6 dry, 5/6 moist, and 5YR 8/4 dry, 7/4 moist; heavy sandy clay loam; weak medium and coarse subangular blocky structure; very hard, firm; few roots; common carbonate filaments and nodules; reddish parts effervese weakly, rest effervesce strongly; moderately alkaline; clear wavy boundary.

K21 760263 42-65 cm. Pink (7.5YR 9/4 dry, 8/4 moist) sandy clay loam; weak medium and coarse subangular blocky structure; hard and very hard, with some nodules, 1-3 cm diameter, extremely hard and indurated; most parts firm, a few friable and some extremely firm; very few fine roots; effervesces strongly; moderately akaline; clear wavy boundary.

K22 760264 65-94 cm. Dominantly pink (7.5YR 9/4 dry, 8/4 moist) with small amount of 7.5YR 6/4 dry, 7.5YR 5/4 moist; sandy clay loam; weak medium and coarse subangular blocky structure; mostly hard and very hard, most parts firm, a few friable, and a few extremely hard and indurated nodules; effervesces strongly; moderately alkaline; clear wavy boundary.

K31 760265 94-133 cm. Dominantly light brown (7.5YR 6/4 dry) or brown (7.5YR 5/4 moist) with lesser amount of 7.5YR 9/4 dry, 7.5YR 7/4 moist; sandy clay loam; weak medium and coarse subangular blocky structure; light brown material is very hard, friable; no roots; vertical cylindroids, 1-3 cm diameter, extend through this horizon and into the underlying horizon, at horizontal intervals of 2-6 cm; most are extremely hard and indurated; effervesces strongly; moderately alkaline; clear wavy boundary.

K32 760266 133-161 cm. Dominantly light reddish brown (5YR 6/4 dry)or yellowish red (5YR 5/6 moist) light sandy clay loam; weak coarse subangular blocky structure; most parts hard and very hard, friable, some carbonate nodules indurated; no roots; most nodules in cylindroidal form, 2-3 cm thick, extending vertically through the horizon; effervesces strongly; moderately alkaline; clear wavy boundary.

K33 760267 161-181 cm. Dominantly pink (7.5YR 7/4 dry) or light brown (7.5YR 6/4 moist) sandy clay loam, with smaller amount 7.5YR 8/3 dry, 7.5YR 6/4 moist, massive; very hard and hard, firm; no roots; effervesces strongly; moderately alkaline; clear wavy boundary.

Bca 760268 181-197 cm. An irregularly and discontinuously cemented horizon, white (10YR 9/2 dry) or light gray (10YR 7/2 moist) and 7.5YR 7/4 dry, 7.5YR 5/4 moist, separated by darker, low-carbonate zones; high-carbonate part commonly consists of upper layer of discontinuously cemented K-fabric, 1-2 cm thick; a middle layer 3-4 cm thick of browner, low-carbonate fine sandy loam which has discontinuous lenses of carbonate, 1-5 cm thick; and a layer of irregularly cemented carbonate that rests on the horizon below; most K-fabric extremely hard, extremely firm; no roots; effervesces strongly; moderately alkaline; abrupt smooth boundary.

B1tcab 760269 197-224 cm. Reddish yellow (5YR 6/6 dry) or yellowish red (5YR 5/6 moist) heavy fine sandy loam; weak coarse subangular blocky structure; very and extremely hard, friable; no roots; common black (Mn? Fe?) spots, 1-2 mm diameter, on ped faces; few very fine tubular pores; carbonate fillings between prisms descend from the overlying horizon and extend continuously to the bottom of the pit; fillings are about 3-5 mm thick and easily removed with the knife; noncalcareous, except for fillings between prism faces, which effervesce strongly; moderately alkaline; clear wavy boundary.

B21tcab 760270 224-250 cm. Dominantly reddish brown (5YR 5/4 dry, 4/4 moist) sandy clay loam; with lesser amount 7.5YR 9/2 dry, 7/2 moist; weak medium and coarse subangular blocky structure; very hard, friable; common carbonate filaments and nodules, and coatings on prism faces; common black (Mn? Fe?) spots, 1-2 mm diameter, some of which are faintly coated with carbonate; most parts effervesce strongly, a few effervesce weakly; moderately alkaline; clear wavy boundary.

B22tcab 760271 250-286 cm. Dominantly reddish yellow (5YR 6/6 dry) or yellowish red (5YR 4.5/6 moist) sandy clay loam; coarse angular and subangular blocky structure; very and extremely hard, friable; a few carbonate filaments and nodules; few fine tubular pores; common black spots (Mn? Fe?) 1-3 mm diameter; peds have thin carbonate coatings which effervesce strongly; most ped interiors effervesce weakly, some are noncalcareous; moderately alkaline.

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE, MTSC
NATIONAL SOIL SURVEY LABORATORY
LINCOLN, NEBRASKA

Soil: Tivoli.
Soil classification: Typic Ustipsamment, mixed, thermic.
Pedon no.: S75TX-17-4.

GENERAL METHODS- - -1A,1B1B,2A1,2B   SAMPLE NOS. 760272-760280

DEPTH CM	HORIZON	SAND 2-.05	SILT .05-.002	CLAY LT .002	FINE CLAY LT .0002	VCOS 2-1	CORS 1-.5	MEDS .5-.25	FNES .25-.10	VFNS .10-.05	COSI .05-.02	FNSI .02-.002	VFSI .005-.002	SAND 2-.10	INTR II .2-.02	FINE CLAY TO CLAY PCT	NON-CO3-CLAY PCT	RATIO 8D1 15-BAR TO CLAY
		(- - - PARTICLE SIZE ANALYSIS, LT 2MM, 3A1, 3A1A, 3A1B - - - PCT LT 2MM - - -)																
000-011	A1	90.8	5.2	4.0	1.2	TR	2.1	14.5	53.8	20.4	4.1	1.1		70.4		30	4	.83
011-020	A2	96.5	1.6	1.9	.2	TR	3.4	20.1	59.0	14.0	1.2	.4		82.5		11		.68
020-033	B1	97.0	1.0	2.0	.2	TR	4.2	22.9	57.1	12.8	.7	.3		84.2		10		.70
033-052	B21&Bt	97.2	1.0	1.8		.0	2.9	23.6	59.3	11.4	.3	.7		85.8				.67
052-082	B22&Bt	97.5	.9	1.6		TR	3.0	22.6	59.1	12.8	.3	.6		84.7				.69
082-109	B31	97.1	1.2	1.7		TR	4.8	24.2	56.1	12.0	.1	1.1		85.1				.59
109-137	B32	96.9	1.8	1.3		.1	6.2	25.9	51.9	12.8	1.5	.3		84.1				1.08
137-165	B1b	96.1	1.4	2.5		.0	6.2	26.7	53.1	10.1	1.0	.4		86.0				.52
165-198	B2b&Bt	94.2	2.3	3.5		.1	4.9	22.7	55.4	11.1	1.9	.4		83.1				.46

DEPTH CM	(PARTICLE SIZE ANALYSIS, MM, 3B, 3B1, 3B2) VOL. GT 2 PCT	WEIGHT GT 75 PCT	75-20 (PCT LT 75)	20-5	5-2	LT .074	20-2 PCT LT20	(BULK DENSITY) 4A1D 1/3-BAR G/CC	4A1H OVEN DRY G/CC	4D1 COLE	(WATER CONTENT) 4B1C 1/10 BAR PCT	4B1C 1/3-BAR PCT	4B2 15-BAR PCT	4C1 WRD CM/CM	CARBONATE 6E1B LT 2 PCT	3A1A LT .002 PCT	(PH) 8C1A 1/1 H2O	8C1E 1/2 CACL
000-011	0	0	0	0	0	18	0				8.0A		3.3		TR	0	7.5	7.2
011-020	0	0	0	0	0	9	0				3.1A		1.3		TR		7.4	6.9
020-033	0	0	0	0	0	8	0				2.8A		1.4		TR		7.2	6.6
033-052	0	0	0	0	0	6	0				3.2A		1.2		0		6.9	6.3
052-082	0	0	0	0	0	7	0				1.9A		1.1		0		7.2	6.5
082-109	0	0	0	0	0	7	0				3.4A		1.0		0		7.1	6.4
109-137	0	0	0	0	0	8	0				2.5A		1.4		0		7.2	6.4
137-165	0	0	0	0	0	8	0	1.68	1.69	.002	4.0A	4.2	1.3	.05	TR		7.3	6.7
165-198	0	0	0	0	0	11	0	1.68	1.71	.006	4.5A	4.2	1.6	.04	TR		7.5	6.7

DEPTH CM	(ORGANIC MATTER) 6A1A ORGN CARB PCT	6B1A NITG PCT	C/N	IRON 6C2B EXT FE PCT	PHOS TOTL PCT	(EXTRACTABLE BASES 5B4A) 6N2E CA	6O2D MG	6P2B NA	6Q2B K	SUM EXTB	ACTY 6H1A BACL TEA	AL 6G1E KCL EXT	(CAT EXCH) 5A3A EXTB ACTY	5A6A NHAC	RATIO 8D1 NHAC TO CLAY	RATIO 8D3 CA TO MG	CA 5F1 SAT NHAC PCT	(BASE SAT) 5C3 EXTB ACTY PCT	5C1 NHAC PCT
						(- - - MEQ / 100 G - - -)													
000-011	.97	.067	14	.2			.7	.0	.4					6.2	1.55				
011-020	.29	.024	12	.1			.3	.0	.2					2.4	1.26				
020-033	.15	.016	9	.1			.2	.0	.2					1.6	.40				
033-052	.10	.010	10	.1		1.2	.2	.0	.2	1.6	.2		1.8	1.4	.78	6.0	86	89	114
052-082	.06			.1		1.0	.3	.0	.2	1.5	.0		1.5	1.2	.75	3.3	83	100	125
082-109	.08			.1		1.0	.3	.0	.2	1.5	.2		1.7	1.3	.76	3.3	77	88	115
109-137	.08			.2		1.0	.4	TR	.2	1.6	.1		1.7	1.4	1.08	2.5	71	94	114
137-165	.07			.2		1.1	.5	.0	.2	1.8	.3		2.1	1.6	.64	2.2	69	86	113
165-198	.06			.2		1.5	.6	.0	.2	2.3	TR		2.3	2.2	.63	2.5	68	100	105

DEPTH CM	(SATURATED PASTE) 8E1 RESI OHM-CM	8C1B PH	8A H2O PCT	NA 5D2 ESP PCT	NA 5E SAR	SALT 8D5 TOTL SOLU PPM	GYP 6F1A PCT	(SATURATION EXTRACT 8A1) 8A1A EC MMHOS/CM	6N1B CA	6O1B MG	6P1B NA	6Q1B K	6I1A CO3	6J1A HCO3	6K1A CL	6L1A SO4	6M1A NO3	ATTERBERG 4F1 LQID LMIT PCT	4F2 PLST INDX
									(- - - MEQ / LITER - - -)										
000-011																			
011-020																			
020-033																			
033-052																			
052-082																			
082-109	27000	7.3	23.0					.13											
109-137																			
137-165																			
165-198																			

CLAY MINERALCGY (7A2C).
033-52 MI3 MM2 KK2.
165-198 MI3 MM2 KK2.
RELATIVE AMOUNTS: (X-RAY) 5 = DOMINANT 4 = ABUNDANT 3 = MODERATE 2 = SMALL 1 = TRACE.
MINERAL CODE: MI = MICA KK = KAOLINITE MM = MONTMORILLONITE-MICA.
SAND MINERALCGY (7B1) PLACEMENT: SILICEOUS.
033-52 VFNS - RE85 QZ84 FE1 ZR FD14 GN1. FNFS - RE95 QZ88 CD7 FK5 (338 GRAINS).
165-198 VFNS - RE93 QZ90 FE1 ZR1 SP RU FD7 HN AU.
COMMENTS: WEIGHTED AVERAGE OF 94 PCT. RESISTANT MINERALS IN THE B21&BT.
RELATIVE AMOUNTS: AS PERCENT
MINERAL CODE: RE = RESISTANT MINERALS FD = FELDSPARS HN = HORNBLENDE QZ = QUARTZ ZR = ZIRCON
FK = POTASSIUM FELDSPAR CD = CHALCEDONY RU = RUTILE GN = GARNET SP = SPHENE AU = AUGITE.

(A) METHOD 4B1A

Soil Moisture Site #4

Soil: Tivoli.
Soil classification: Typic Ustipsamment, mixed, thermic.
Pedon no.: S75TX-17-4.
Location: In exclosure about 50 feet west of Farm Road 1731, about 1.2 mile north of the junction between Farm Road 1731 and 746, and about 425 feet north of gate on west side of road.
Geomorphic surface: Muleshoe.
Landform and slope: Lower part of side of dune ridge. Slope is 3 percent to the south.
Elevation: 3930.
Parent material: Eolian sediments.

Perennial vegetation (an oak community): Shinnery oak, giant dropseed, soapweed, and sumac.

Soil samples collected by: B.L. Allen, Dan Blackstock, and George Threlkeld, Oct. 15, 1975.
Soil described by: L.H. Gile.

Soil surface: Covered with a layer of oak leaves and twigs about 1 cm thick.

A1 760272 0-11 cm. Dark grayish brown (10YR 4.5/2 dry) or very dark brown (10YR 2/2 moist) fine sand; massive; soft, very friable; fine roots range from few to common, with most being less than about 1 mm diameter; noncalcareous; neutral; clear wavy boundary.

A2 760273 11-20 cm. Yellowish brown (9YR 5/4 dry) or dark brown (10YR 4/3 moist) fine sand; massive; soft, very friable; roots common and many are large, ranging up to 6 cm diameter; noncalcareous; neutral; clear wavy boundary.

B1 760274 20-33 cm. Light brown (7.5YR 6/4 dry) or dark brown (7.5YR 4/4 moist) fine sand; massive; soft, very friable; roots are generally few but are common in places and range up to 5 cm diameter; few volumes of 9YR 7/3 dry, 5/3 moist, commonly range from approximately 2 to 10 cm diameter, some are roughly circular in cross section and others are of irregular shape; noncalcareous; neutral; clear wavy boundary.

B21&Bt 760275 33-52 cm. Dominantly light brown (7.5YR 6/4 dry) or dark brown (7.5YR 4/4 moist) fine sand; massive; slightly hard, very friable; few roots, generally 1-2 mm diameter, in places up to 5 mm diameter; scattered volumes of irregular shape, colored 7.5YR 7/4 dry, 7.5YR 5/4 moist; a discontinuous band of clay accumulation, about 1 mm thick and colored 5YR 6/6 dry, 5/6 moist, extends for about 50 cm in the center of the horizon, then disappears; noncalcareous; mildly alkaline; clear wavy boundary.

B22&Bt 760276 52-82 cm. Light reddish brown (6YR 6/4 dry) or reddish brown (6YR 4.5/4 moist) fine sand; massive; slightly hard, very friable; few roots, generally 1-2 mm in diameter, a few about 1 cm diameter and one 6 cm diamter; two discontinuous, roughly horizontal bands of clay accumulation about 1 mm thick occur in the center of the horizon and are 3-4 cm apart; noncalcareous; mildly alkaline; clear wavy boundary.

B31 760277 82-109 cm. Light reddish brown (6YR 6/4 dry) or reddish brown (6YR 4.5/4 moist) fine sand; massive; slightly hard, very friable; few roots; slightly acid; clear wavy boundary.

B32 760278 109-137 cm. Light reddish brown (6YR 6/4 dry) reddish brown (6YR 4.5/4 moist) fine sand; massive; mostly soft, few parts slightly hard; very friable; few roots; slightly acid; clear wavy boundary.

B1b 760279 137-165 cm. Light reddish brown (5YR 6/4 dry) or reddish brown (5YR 4.5/4 moist) fine sand; massive; slightly hard, very friable; very few roots, slightly acid; clear wavy boundary.

B2b&Bt 760280 165-198 cm. Dominantly light reddish brown (5YR 6/4 dry) or reddish brown (5YR 4.5/4 moist) fine sand; massive; slightly hard, very friable; very few roots; horizon has six roughly horizontal bands of clay accumulation, colored 5YR 5/6 dry, 4/6 moist, and from 2-8 cm apart; they range from 1-3 thick, being thickest in the upper part of the horizon; there are also several discontinuous clay bands; slightly acid.

Soil: Circleback.
Soil classification: Alfic Ustipsamment, mixed, thermic.
Pedon no: S75TX-17-5.

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SOIL CONSERVATION SERVICE, MTSC
NATIONAL SOIL SURVEY LABORATORY
LINCOLN, NEBRASKA

GENERAL METHODS- - -1A,1B1B,2A1,2B   SAMPLE NOS. 760281-760290

DEPTH	HORIZON	(- - PARTICLE SIZE ANALYSIS, LT 2MM, 3A1, 3A1A, 3A1B - -																)RATIO
					FINE	(- - SAND				- -)(	- -SILT- -)				INTR	FINE	NON-	8D1
		SAND 2-.05	SILT .05-.002	CLAY LT .002	CLAY LT .0002	VCOS 2-1	CORS 1-.5	MEDS .5-.25	FNES .25-.10	VFNS .10-.05	COSI .05-.02	FNSI .02-.002	VFSI .005-.002	SAND 2-.10	II .2-.02	CLAY TO CLAY	CO3-CLAY	15-BAR TO CLAY
CM		(- - - -						PCT LT 2MM							- - -)	PCT	PCT	
000-013	A1	90.6	6.2	3.2		.1	7.1	20.3	46.2	16.9	4.6	1.6		73.7				1.38
013-039	A2	96.4	2.5	1.1		.1	8.4	24.1	50.5	13.3	1.9	.6		83.1				1.36
039-056	B21&Bt	95.5	2.6	1.9		TR	7.0	22.6	50.9	15.0	1.8	.8		80.5				.68
056-082	B22&Bt	95.1	2.4	2.5		.1	7.2	23.4	51.6	12.8	1.6	.8		82.3				.60
082-109	B31	93.5	3.6	2.9		.1	5.8	20.4	50.2	17.0	2.6	1.0		76.5				.48
109-139	B32&Bt	92.0	4.6	3.4		.1	7.6	23.2	48.2	12.9	2.7	1.9		79.1				.50
139-181	C	90.1	6.0	3.9		TR	6.5	21.7	48.9	13.0	3.3	2.7		77.1				.49
181-208	B11tb	88.6	7.1	4.3		.1	6.3	22.7	48.8	10.7	3.2	3.9		77.9				.40
208-226	B12tb	87.4	8.5	4.1		.1	5.3	22.0	49.3	10.7	3.0	5.5		76.7				.46
226-247	B2tb	78.8	10.5	10.7		.2	5.7	20.4	43.6	8.9	3.4	7.1		69.9				.47

DEPTH	(PARTICLE SIZE ANALYSIS, MM, 3B, 3B1, 3B2)							(BULK DENSITY		)	(- - -WATER CONTENT- - -)				CARBONATE		(- -PH - -)	
	VOL.	(- - WEIGHT					- -)	4A1D	4A1H	4D1	4B1C	4B1C	4B2	4C1	6E1B	3A1A	8C1A	8C1E
	GT 2	GT 75	75-20	20-5	5-2	LT .074	20-2 PCT	1/3-BAR	OVEN DRY	COLE	1/10 BAR	1/3-BAR	15-BAR	WRD CM/	LT 2	LT .002	1/1 H2O	1/2 CACL
CM	PCT	PCT	(- - - PCT LT 75		- - -)		LT20	G/CC	G/CC		PCT	PCT	PCT	CM	PCT	PCT		
000-013	0	0	0	0	0	17	0	1.50A			9.3B		4.4		0		7.0	6.5
013-039	0	0	0	0	0	10	0	1.50A			3.1B		1.5		TR		6.9	6.3
039-056	0	0	0	0	0	10	0	1.60A			4.1B		1.3		0		7.3	6.6
056-082	0	0	0	0	0	10	0	1.62	1.63	.002	4.7B	4.5	1.5	.05	0		7.8	6.9
082-109	0	0	0	0	0	14	0	1.66	1.68	.004	5.2B	4.8	1.4	.06	0		7.8	7.0
109-139	0	0	0	0	0	14	0	1.65	1.68	.006	5.4B	5.0	1.7	.05	0		7.8	7.0
139-181	0	0	0	0	0	16	0	1.67	1.69	.004	6.3B	4.7	1.9	.05	0		7.2	6.4
181-208	0	0	0	0	0	17	0	1.70	1.71	.002	7.2B	4.4	1.7	.05	TR		7.3	6.5
208-226	0	0	0	0	0	18	0	1.70	1.73	.006	8.9B	6.4	1.9	.08	0		7.0	6.4
226-247	0	0	0	0	0	26	0	1.80	1.84	.007	15.3B	10.5	5.0	.10	0		7.2	6.7

DEPTH	(ORGANIC MATTER		)	IRON	PHOS	(- -EXTRACTABLE BASES 5B4A- -)					ACTY	AL	(CAT EXCH)		RATIO	RATIO	CA	(BASE SAT)	
	6A1A	6B1A	C/N	6C2B		6N2E	6O2D	6P2B	6Q2B		6H1A	6G1E	5A3A	5A6A	8D1	8D3	5F1	5C3	5C1
	ORGN CARB	NITG		EXT FE	TOTL	CA	MG	NA	K	SUM EXTB	BACL TEA	KCL EXT	EXTB ACTY	NHAC	NHAC TO	CA TO	SAT NHAC	EXTB ACTY	NHAC
CM	PCT	PCT		PCT	PCT	(- - -				MEQ / 100	G- - -			- - -)	CLAY	MG	PCT	PCT	PCT
000-013	.66	.053	12	.2		4.4	.6	.0	.2	5.2	.6		5.8	4.7	1.47	7.3	94	90	111
013-039	.13	.016	8	.1			.2	.0	.2		.4			1.6	1.45				
039-056	.08	.008	10	.1		1.6	.3	TR	.2	2.1	.4		2.5	1.9	1.00	5.3	84	84	111
056-082	.07	.010	7	.2		1.6	.5	.0	.2	2.3	.0		2.3	2.1	.84	3.2	76	100	110
082-109	.09			.2		1.5	.5	.0	.2	2.2	.0		2.2	2.0	.69	3.0	75	100	110
109-139	.06			.2		1.7	.6	TR	.3	2.6	.0		2.6	2.2	.65	2.8	77	100	118
139-181	.06			.2		1.8	.6	TR	.3	2.7	TR		2.7	2.5	.64	3.0	72	100	108
181-208	.04			.2			.5	TR	.2					2.1	.49				
208-226	.03			.2		1.9	.5	TR	.2	2.6	.0		2.6	2.4	.59	3.9	79	100	108
226-247	.07			.4		5.0	1.4	.1	.4	6.9	.4		7.3	4.5	.42	3.6	111	95	153

DEPTH	(SATURATED PASTE)			NA	NA	SALT	GYP	(- - - SATURATION EXTRACT 8A1-									- - -)	ATTERBERG	
	8E1	8C1B	8A	5D2	5E	6D5	6F1A	8A1A	6N1B	6O1B	6P1B	6Q1B	6I1A	6J1A	6K1A	6L1A	6M1A	4F1	4F2
	REST OHM-CM	PH	H2O	ESP	SAR	TOTL SOLU		EC MMHOS/	CA	MG	NA	K	CO3	HCO3	CL	SO4	NO3	LQID LMIT	PLST INDX
CM			PCT	PCT		PPM	PCT	CM	(- - -				MEQ / LITER				- - -)	PCT	
000-013																			
013-039																			
039-056																			
056-082																			
082-109	19000	8.1	21.2					.23											
109-139																			
139-181																			
181-208																			
208-226																			
226-247																			

CLAY MINERALOGY (7A2C).
226-247 MM3 MI3 KK2 MC1.
COMMENTS: MM IS POORLY ORDERED, MOSTLY LOW CHARGE MONTMORILLONITE.
RELATIVE AMOUNTS: (X-RAY) 5 = DOMINANT 4 = ABUNDANT 3 = MODERATE 2 = SMALL 1 = TRACE.
MINERAL CODE: MI = MICA KK = KAOLINITE MM = MONTMORILLONITE-MICA MC = MONTMORILLONITE-CHLORITE.
SAND MINERALOGY (7B1) PLACEMENT: SILICEOUS.
056-82 VFNS - RE87 QZ95 FE1 ZR1 TM SP FD13 KY GN. FNES - RE96 QZ96 FK4 (320 GRAINS).
226-247 VFNS - RE89 QZ87 ZR1 FE TM SP FD10 GS AU GN CL.
COMMENTS: WEIGHTED AVERAGE OF 95 PCT. RESISTANT MINERALS IN THE B22&BT.
RELATIVE AMOUNTS: AS PERCENT
MINERAL CODE: RE = RESISTANT MINERALS CL = CHLORITE FD = FELDSPARS GS = GLASS QZ = QUARTZ TM = TOURMALINE
ZR = ZIRCON FK = POTASSIUM FELDSPAR SP = SPHENE KY = KYANITE GN = GARNET AU = AUGITE.

(A) ESTIMATE
(B)) BY METHOD 4B1A

Soil Moisture Site #5

Soil: Circleback.
Soil classification: Alfic Ustipsamment, mixed, thermic.
Pedon no.: S75TX-17-5.
Location: In exclosure about 130 feet west of Farm Road 1731, about 1.3 mile north of the junction between Farm Roads 1731 and 746, and 800 feet north of gate on west side of road.
Geomorphic surface: Muleshoe.
Landform and slope: Gently undulating trough between dune ridges. Slope is variable within the exclosure, being slightly (about 1 percent) to the south on the east side, and slightly to the north on the west side.
Elevation: 3925 feet.
Parent material: Eolian sediments.

Perennial vegetation (an oak community): Sand sagebrush, soapweed, little bluestem, mesa dropseed, sand dropseed, spectacle-pod, rushpea, fleabane, sideoats grama, gummy lovegrass, purple three-awn, kuhnia, and shinnery oak.

Soil samples collected by: B. L. Allen, Dan Blackstock, and George Threlkeld, October 15, 1975.
Soil described by: L. H. Gile.

Soil surface: The surface is variable. In places it is covered by about 1 cm of oak leaves and twigs; in others the surface is not covered and is barren. The latter surface is smooth in places and in others has a thin veneer of loose sand. The crust breaks out as fragile plates 1-3 cm across and 2-4 cm thick.

A1 760281 0-13 cm. Brown (10YR 5/3 dry) or very dark grayish brown (10YR 3/2 moist) sand; massive; soft, very friable; common fine roots; slightly acid; abrupt wavy boundary.

A2 760282 13-39 cm. Pale brown (9YR 6.5/3 dry) or brown (10YR 4.5/3 moist) fine sand; massive; slightly hard and soft, very friable; roots common, most ranging from 1 mm-3 cm diameter; noncalcareous; mildly alkaline; clear wavy boundary.

B21&Bt 760283 39-56 cm. Dominantly light reddish brown (6YR 6/4 dry) or reddish brown (6YR 4.5/4 moist) fine sand; massive; slightly hard, very friable; few roots, ranging from 1 mm-1 cm diameter; horizon has two discontinuous bands of clay accumulation and two continuous bands, 5YR 5/6 dry, 3.5/6 moist, 1-2 mm thick, with texture of loamy fine sand; bands range from 2-6 cm apart; very few circular volumes, 2-3 cm diameter, 7.5YR 7.5/4 dry; noncalcareous; mildly alkaline; clear wavy boundary.

B22&Bt 760284 56-82 cm. Dominantly light reddish brown (6YR 6/4 dry) or reddish brown (6YR 4.5/4 moist) fine sand; massive; slightly hard, very friable; few roots, ranging from 1-5 mm diameter; several roughly circular, light colored volumes, 2-3 cm diameter, that may be root channel fillings; horizon has four to six bands of clay accumulation, ranging from 1-3 mm thick and 2-4 cm apart, 5YR 5/6 dry, 3.5/6 moist, with texture of loamy fine sand; in places the bands disappear laterally but on this end of trench usually appear again where wall of trench is scraped back; bands generally sparse or absent in west end of trench; undulations in bands are common, ranging up to about 6 cm; noncalcareous; mildly alkaline; clear wavy boundary.

B31 760285 82-109 cm. Light reddish brown (6YR 6/4 dry) or reddish brown (6YR 4.5/4 moist) fine sand; massive; slightly hard, very friable; very few roots; noncalcareous; moderately alkaline; clear wavy boundary.

B32&Bt 760286 109-139 cm. Light reddish brown (6YR 6/4 dry) or reddish brown (6YR 4.5/4 moist) sand; massive; slightly hard, friable; very few roots; one clay-enriched band, about 1 mm thick, 5YR 5/6 dry, 3.5/6 moist, occurs discontinuously in center of horizon; noncalcareous; moderately alkaline; clear wavy boundary.

C 760287 139-181 cm. Light brown (7.5YR 6/4 dry) or brown (7.5YR 4.5/4 moist) sand; massive; slightly hard, very friable; very few roots; noncalcareous; moderately alkaline; clear wavy boundary.

B11tb 760288 181-208 cm. Dominantly pale brown (10YR 6.5/3) or brown (10YR 4.5/3 moist) with few parts slightly lighter in color; sand; massive; slightly hard and hard, very friable; very few roots; few very fine tubular pores; noncalcareous; neutral; clear wavy boundary.

B12tb 760289 208-226 cm. Pale brown (10YR 6.5/3 dry) or yellowish brown (10YR 5/4 moist) sand; very weak medium subangular blocky structure; slightly hard, very friable; few very fine tubular pores; noncalcareous; neutral; clear wavy boundary.

B2tb 760290 226-247 cm. Dominantly gray (5Y 6/1 dry, 5/1 moist) with some 5Y 7/1 dry; few mottles of 10YR 4/3 dry and 7.5YR 5/4 dry; fine sandy loam; weak coarse subangular blocky structure; very hard, very firm; very hard in place and difficult to remove; very few roots; common very fine and fine tubular pores; slightly acid.

Soil: Texico.
Soil classification: Psammentic Haplustalf, mixed, thermic.
Pedon no.: S75TX-17-6.

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GENERAL METHODS- - -1A,1B1B,2A1,2B SAMPLE NOS. 760291-760300

DEPTH CM	HORIZON	PARTICLE SIZE ANALYSIS, LT 2MM, 3A1, 3A1A, 3A1B: SAND 2-.05	SILT .05-.002	CLAY LT .002	FINE CLAY LT .0002	VCOS 2-1	CORS 1-.5	MEDS .5-.25	FNES .25-.10	VFNS .10-.05	COSI .05-.02	FNSI .02-.002	VFSI .002-.002	SAND 2-.10	INTB II .2-.02	FINE CLAY TO CLAY PCT	NON-CO3-CLAY PCT	RATIO 8D1 15-BAR TO CLAY
		PCT LT 2MM																
000-012	A1	90.8	6.6	2.6		.1	4.3	21.4	51.4	13.6	4.1	2.5		77.2				1.12
012-046	A2	97.2	2.4	.4		TR	5.9	25.9	56.3	9.1	1.3	1.1		88.1				2.75
046-066	A2&Bt	94.4	2.2	3.4		TR	5.9	27.4	54.4	6.7	.9	1.3		87.7				.53
066-092	B2t	94.5	1.1	4.4	2.9	.1	8.3	27.5	51.8	6.8	.8	.3		87.7		66		.39
092-112	B31&Bt	94.5	1.3	4.2	3.1	.1	10.6	29.2	48.0	6.6	.9	.4		87.9		74		.40
112-131	B32&Bt	94.3	1.7	4.0	2.7	.2	7.2	26.9	50.6	9.4	1.5	.2		84.9		68		.43
131-141	B1tb	89.5	1.4	9.1	5.5	.1	6.3	23.8	49.7	9.6	1.0	.4		79.9		60		.35
141-164	B2tb	83.3	2.8	13.9	11.9	TR	6.3	21.7	47.5	7.8	2.5	.3		75.5		86		.46
164-205	B31tb	88.8	3.5	7.7	7.4	.2	10.9	26.7	45.1	5.9	2.9	.6		82.9		96		.52
205-235	B32tb	92.7	2.3	5.0	4.4	.1	8.7	27.3	50.4	6.2	1.7	.6		86.5		88		.46

DEPTH CM	(PARTICLE SIZE ANALYSIS, MM, 3B, 3B1, 3B2) VOL. GT 2 PCT	GT 75 PCT	WEIGHT 75-20	20-5	5-2	LT .074	20-2 PCT LT20	BULK DENSITY 4A1D 1/3-BAR G/CC	4A1H OVEN DRY G/CC	4D1 COLE	WATER CONTENT 4B1C 1/10 BAR PCT	4B1C 1/3-BAR PCT	4B2 15-BAR PCT	4C1 WRD CM/CM	CARBONATE 6E1B LT 2 PCT	3A1A LT .002 PCT	PH 8C1A 1/1 H2O	8C1B 1/2 CACL
			PCT LT 75															
000-012	0	0	0	0	0	16	0	1.50A			8.3B		2.9		0		7.0	6.5
012-046	0	0	0	0	0	7	0	1.50A			2.2B		1.1		0		6.8	6.1
046-066	0	0	0	0	0	8	0	1.60A			4.7B		1.8		0		6.7	6.1
066-092	0	0	0	0	0	8	0	1.65	1.72	.014	4.4B	7.6	1.7	.10	0		7.0	6.4
092-112	0	0	0	0	0	8	0	1.66	1.71	.010	4.8B	7.9	1.7	.10	0		7.0	6.3
112-131	0	0	0	0	0	10	0	1.72	1.72	.000	3.8B	6.8	1.7	.09	0		6.5	5.7
131-141	0	0	0	0	0	15	0	1.65	1.70	.010	8.9B	6.8	3.2	.06	0		6.4	5.9
141-164	0	0	0	0	0	20	0	1.70	1.78	.016	18.9B	10.9	6.4	.08	0		6.1	5.8
164-205	0	0	0	0	0	14	0	1.72	1.78	.012	11.5B	7.8	4.0	.07	0		6.4	6.0
205-235	0	0	0	0	0	10	0	1.73	1.76	.006	7.3B	5.4	2.3	.05	0		6.8	6.2

DEPTH CM	(ORGANIC MATTER) 6A1A ORGN CARB PCT	6B1A NITG PCT	C/N	IRON 6C2B EXT FE PCT	PHOS TOTL PCT	(EXTRACTABLE BASES 5B4A) 6N2E CA	6O2D MG	6P2B NA	6Q2B K	SUM EXTB	ACTY 6H1A BACL TEA G	AL 6G1E KCL EXT	(CAT EXCH) 5A3A EXTB ACTY	5A6A NHAC	RATIO 8D1 NHAC TO CLAY	RATIO 8D3 CA TO MG	CA 5F1 SAT NHAC PCT	(BASE SAT) 5C3 EXTB ACTY PCT	5C1 NHAC PCT
						MEQ / 100 G													
000-012	.81	.058	14	.2		4.4	.6	.0	.2	5.2	.3		5.5	4.7	1.81	7.3	94	95	111
012-046	.13	.009	14	.2		1.3	.2	TR	.1	1.6	.0		1.6	1.3	3.25	6.5	100	100	123
046-066	.11	.014	8	.2		2.1	.6	TR	.2	2.9	.0		2.9	2.7	.79	3.5	78	100	107
066-092	.08	.012	7	.2		1.9	.7	TR	.2	2.8	.0		2.8	2.6	.59	2.7	73	100	108
092-112	.05	.008	6	.2		1.6	.7	TR	.2	2.5	.1		2.6	2.4	.57	2.3	67	96	104
112-131	.09			.2		1.3	.6	TR	.2	2.1	.1		2.2	2.0	.50	2.2	65	95	105
131-141	.07			.3		2.6	1.1	.1	.3	4.1	.5		4.6	4.0	.29	2.4	65	89	103
141-164	.11			.4		5.2	2.1	.1	.5	7.9	1.4		9.3	8.2	.89	2.5	63	85	96
164-205	.04			.3		3.7	1.5	.1	.3	5.6	.6		6.2	5.4	.70	2.5	69	90	104
205-235	.02			.2		2.3	.9	.1	.2	3.5	.2		3.7	3.4	.68	2.6	68	95	103

DEPTH CM	(SATURATED PASTE) 8E1 REST OHM-CM	8C1B PH	8A H2O PCT	NA 5D2 ESP PCT	NA 5E SAR	SALT 8D5 TOTL SOLU PPM	GYP 6F1A PCT	(SATURATION EXTRACT 8A1) 8A1A EC MMHOS/CM	6N1B CA	6O1B MG	6P1B NA	6Q1B K	6I1A CO3	6J1A HCO3	6K1A CL	6L1A SO4	6M1A NO3	ATTERBERG 4F1 LQID LMIT PCT	4F2 PLST INDX
									MEQ / LITER										
000-012																			
012-046																			
046-066																			
066-092																			
092-112	19000	7.1	19.7					.16											
112-131																			
131-141																			
141-164																			
164-205																			
205-235																			

CLAY MINERALOGY (7A2C).
066-92 MI3 MM2 KK2 MC1.
205-235 MI3 MM3 KK2.
RELATIVE AMOUNTS: (X-RAY) 5 = DOMINANT 4 = ABUNDANT 3 = MODERATE 2 = SMALL 1 = TRACE.
MINERAL CODE: MI = MICA KK = KAOLINITE MM = MONTMORILLONITE-MICA MC = MONTMORILLONITE-CHLORITE.
SAND MINERALOGY (7B1) PLACEMENT: SILICEOUS.
066-92 VFNS - RE89 QZ87 FE1 TM1 ZR SP FD11 GN HN. FNES - RE94 QZ94 FK6 (332 GRAINS).
205-235 VFNS - RE91 QZ88 FE2 TM1 ZR FD8 CL1.
COMMENTS: WEIGHTED AVERAGE OF 95 PCT. RESISTANT MINERALS IN THE B2T.
RELATIVE AMOUNTS: AS PERCENT
MINERAL CODE: RE = RESISTANT MINERALS CL = CHLORITE FD = FELDSPARS HN = HORNBLENDE QZ = QUARTZ TM = TOURMALINE
ZR = ZIRCON FK = POTASSIUM FELDSPAR SP = SPHENE GN = GARNET.

(A) ESTIMATED
(B) METHOD 4B1A

Soil Moisture Site #6

Soil: Texico.
Soil classification: Psammentic Haplustalf, mixed thermic.
Pedon no.: S75TX-17-6.
Location: In exclosure about 150 feet west of Farm Road 1731, about 1.4 mile north of the junction between Farm Roads 1731 and 746, and about 140 feet north of Soil Moisture Site #5.
Geomorphic surface: Longview.
Landform and slope: Crest of dune ridge oriented approximately east-west. The crest (where the exclosure is located) slopes about 2 percent to the north.
Parent material: Eolian sediments.

Perennial vegetation (an oak community): Shinnery oak, sand dropseed, purple 3-awn, little bluestem, kuhnia, soapweed, sand sagebrush, and prickly pear.

Soil samples collected by: Dan Blackstock and George Threlkeld, October 16, 1975.
Soil described by: L. H. Gile

Soil surface: Layer of shrub leaves and twigs (mostly oak) about 1 cm thick, except for area around the moisture tubes, where it is partly bare.

A1 760291 0-12 cm. Brown (10YR 5.5/3 dry) or very dark brown (10YR 2/2 moist) loamy fine sand; massive; soft, very friable and loose; fine roots common; noncalcareous; neutral; abrupt wavy boundary.

A2 760292 12-46 cm. Very pale brown (10YR 7/3 dry) or brown (10YR 5/3 moist) fine sand; massive; soft and slightly hard, very friable; roots common and range from 1 mm-3 cm diameter; slightly acid; abrupt wavy and irregular boundary.

A2&Bt 760293 46-66 cm. Dominantly very pale brown (10YR 7/3 dry) or brown (10YR 5/3 moist); with lesser amounts reddish brown (5YR 5/4 dry,4/4 moist); the brown A2 material is fine sand, the reddish brown Bt material is loamy fine sand; weak medium subangular blocky structure; mostly hard, with a few parts slightly hard; few roots, ranging from 1-5 mm thick; the Bt part occurs as discontinuous clay bands and as irregularly shaped volumes between the bands; noncalcareous; neutral; abrupt smooth boundary (bottom of clay band).

B2t 760294 66-92 cm. Dominantly light reddish brown (5YR 6/4 dry) or reddish brown (5YR 5/4 moist) loamy fine sand; massive; slightly hard, very friable; few roots, ranging from 1-5 mm diameter; horizon has four essentially horizontal bands of clay accumulation, with the uppermost being about 1 cm thick, the second usually being about 1 cm thick but in places only ½ cm thick, and the third and fourth ranging from 1-4 mm thick; distance between the bands ranges from 6-10 cm; the bands are light fine sandy loam, have color of 5YR 4.5/6 dry, 3.5/6 moist and are hard and firm; noncalcareous; mildly alkaline; abrupt smooth boundary.

B31&Bt 760295 92-112 cm. Dominantly light reddish brown (6YR 6/4 dry) or reddish brown (6YR 4.5/5 moist) sand; massive; slightly hard, very friable; few roots; horizon has four to six bands of clay accumulation ranging from 1-3 mm in thickness, and from 1-3 cm apart; noncalcareous; mildly alkaline; clear wavy boundary.

B32&Bt 760296 112-131 cm. Reddish yellow (6YR 6/5 dry) or yellowish red (6YR 4.5/5 moist) fine sand; massive; slightly hard, very friable; few roots; one discontinuous clay band, about 1 mm thick; noncalcareous; neutral; clear wavy boundary.

B1tb 760297 131-141 cm. About equal parts of light reddish brown (5YR 6/4 dry) or reddish brown (6YR 4.5/4 moist) and yellowish red (5YR 5/6 dry, 3.5/6 moist) loamy fine sand; massive; slightly hard, very friable; few roots; noncalcareous; neutral; clear smooth boundary.

B2tb 760298 141-164 cm. Red (2.5YR 5/6 dry, 2.5YR 4/6 moist) fine sandy loam; very hard, friable; compound weak coarse prismatic and very weak subangular blocky structure; generally few roots except for faces of prisms, where fine roots are common; noncalcareous; neutral; clear wavy boundary.

B31tb 760299 164-205 cm. Reddish yellow (5YR 6/6 dry) or yellowish red (5YR 4.5/6 moist) light fine sandy loam; compound weak coarse prismatic and weak coarse subangular blocky structure; very hard, friable; very few roots except for faces of prisms, where fine roots are common; noncalcareous; neutral; clear wavy boundary.

B32tb 760300 205-235 cm. Dominantly reddish yellow (5YR 6/6 dry) or yellowish red (5YR 4.5/6 moist) fine sand; massive; slightly hard, friable; very few roots; few parts of 5YR 5/6 dry, 3.5/6 moist, occur as clay bands; noncalcareous; neutral.

Soil: Tivoli.
Soil classification: Typic Ustipsamment, mixed, thermic.
Pedon no.: S75TX-17-7.

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GENERAL METHODS- - -1A,1B1B,2A1,2B   SAMPLE NOS. 760301-760309

DEPTH CM	HORIZON	SAND 2-.05	SILT .05-.002	CLAY LT .002	FINE CLAY LT .0002	VCOS 2-1	CORS 1-.5	MEDS .5-.25	FNES .25-.10	VFNS .10-.05	COSI .05-.02	FNSI .02-.002	VFSI .005-.002	SAND 2-.10	INTR II .2-.02	FINE CLAY TO CLAY PCT	NON-CO3-CLAY PCT	RATIO 8D1 15-BAR TO CLAY
		(- - PARTICLE SIZE ANALYSIS, LT 2MM, 3A1, 3A1A, 3A1B - - PCT LT 2MM)				(- - SAND				- -)	(- - SILT		- -)					
000-011	A1	92.9	3.8	3.3	1.5	.2	8.1	23.5	49.2	11.9	3.3	.5		81.0		45		.70
011-034	A2	97.3	1.0	1.7		.3	9.9	25.9	50.1	11.1	.8	.2		86.2				.65
034-053	B1	97.1	.6	2.3		.3	8.9	24.9	51.4	11.6	.5	.1		85.5				.39
053-081	B21&Bt	96.0	1.7	2.3		.4	8.9	25.0	50.8	10.9	1.4	.3		85.1				.39
081-111	B22	93.7	2.8	3.5		.2	8.1	23.6	50.9	10.9	2.6	.2		82.8				.34
111-143	B2b&Bt	95.6	1.2	3.2		.3	10.5	27.4	49.8	7.6	1.0	.2		88.0				.38
143-164	C1b&Bt	97.1	.8	2.1		.3	9.9	26.5	52.7	7.7	.4	.4		89.4				.33
164-191	C2b	97.0	1.4	1.6		.2	6.8	22.1	55.1	12.8	1.2	.2		84.2				.56
191-221	Btb2	81.6	1.7	16.7		.1	7.0	19.8	43.9	10.8	1.5	.2		70.8				.41

DEPTH CM	VOL. GT 2 PCT	GT 75 PCT	75-20	20-5	5-2	LT .074	20-2 PCT LT20	4A1D 1/3-BAR G/CC	4A1H OVEN DRY G/CC	4D1 COLE	4B1C 1/10 BAR PCT	4B1C 1/3-BAR PCT	4B2 15-BAR PCT	4C1 WRD CM/CM	CARBONATE 6E1B LT 2 PCT	3A1A LT .002 PCT	PH 8C1A 1/1 H2O	PH 8C1E 1/2 CACL
	(PARTICLE SIZE ANALYSIS, MM, 3B, 3B1, 3B2)	(- - WEIGHT	(- - - PCT LT 75	- - -)				(BULK DENSITY		)	(- - - WATER CONTENT			- - -)				
000-011	0	0	0	0	0	13	0				5.0A		2.3		0		7.0	6.4
011-034	0	0	0	0	0	7	0				3.2A		1.1		0		7.2	6.5
034-053	0	0	0	0	0	8	0				3.5A		.9		TR		7.4	6.7
053-081	0	0	0	0	0	9	0				3.9A		.9		TR		7.4	6.7
081-111	0	0	0	0	0	12	0				5.1A		1.2		TR		7.4	6.7
111-143	0	0	0	0	0	8	0				4.2A		1.2		TR		7.1	6.4
143-164	0	0	0	0	0	6	0				2.5A		.7		0		6.3	5.5
164-191	0	0	0	0	0	9	0				3.0A		.9		0		6.2	5.3
191-221	0	0	0	0	0	24	0	1.85	1.92	.013	20.5A	9.1	6.9	.04	0		6.4	5.8

DEPTH CM	(ORGANIC MATTER) 6A1A ORGN CARB PCT	6B1A NITG PCT	C/N	IRON 6C2B EXT FE PCT	PHOS TOTL PCT	6N2E CA	6O2D MG	6P2B NA	6Q2B K	SUM EXTB	ACTY 6H1A BACL TEA	AL 6G1E KCL EXT	(CAT EXCH) 5A3A EXTB ACTY	5A6A NHAC	RATIO 8D1 NHAC TO CLAY	RATIO 8D3 CA TO MG	CA 5F1 SAT NHAC PCT	(BASE SAT) 5C3 EXTB ACTY PCT	5C1 NHAC PCT
						(- - EXTRACTABLE BASES 5B4A - -) MEQ / 100 G													
000-011	.52	.041	13	.2		3.6	.5	TR	.2	4.3	.1		4.4	3.7	1.12	7.2	97	98	116
011-034	.15	.015	10	.1		1.6	.2	.0	.1	1.9	.0		1.9	1.4	.82	8.0	114	100	136
034-053	.08	.013	6	.1			.3	TR	.1		.0			1.3	.57				
053-081	.06	.008	8	.1			.4	TR	.2		.0			1.5	.65				
081-111	.06			.2			.6	TR	.2					1.8	.51				
111-143	.05			.1			.5	TR	.2					1.6	.50				
143-164	.00			.1		.7	.2	TR	.1	1.0	.0		1.0	.9	.43	3.5	78	100	111
164-191	.00			.1		.5	.2	TR	.1	.8	.0		.8	.7	.44	2.5	71	100	114
191-221	.01			.3		7.0	1.8	.2	.3	9.3	1.2		10.5	9.6	.57	3.9	73	89	97

DEPTH CM	(SATURATED PASTE) 8E1 REST OHM-CM	8C1B PH	8A H2O PCT	NA 5D2 ESP PCT	NA 5E SAR	SALT 8D5 TOTL SOLU PPM	GYP 6F1A PCT	8A1A EC MMHOS/CM	6N1B CA	6O1B MG	6P1B NA	6Q1B K	6I1A CO3	6J1A HCO3	6K1A CL	6L1A SO4	6M1A NO3	ATTERBERG 4F1 LQID LMIT PCT	4F2 PLST INDX
								(- - SATURATION EXTRACT 8A1 - -)	(- - MEQ / LITER								- -)		
000-011																			
011-034																			
034-053																			
053-081																			
081-111	18000	7.7	20.4					.23											
111-143																			
143-164																			
164-191																			
191-221																			

CLAY MINERALOGY (7A2C).
081-111 MI3 MM2 KK2.
191-221 MI3 MM3 KK2 MC1.
COMMENTS: MM MOSTLY LOW CHARGE MONTMORILLONITE.
RELATIVE AMOUNTS: (X-RAY) 5 = DOMINANT 4 = ABUNDANT 3 = MODERATE 2 = SMALL 1 = TRACE.
MINERAL CODE: MI = MICA KK = KAOLINITE MM = MONTMORILLONITE-MICA MC = MONTMORILLONITE-CHLORITE.

SAND MINERALOGY (7B1)   PLACEMENT: SILICEOUS.
081-111 VFNS - RE88 QZ85 FE1 ZR2 TM SP RU FD12 HN. FNES - RE93 QZ93 FK7 (330 GRAINS).
111-143 VFNS - RE86 QZ84 FE1 TM1 ZR SP FD14 EP HN.
191-221 VFNS - RE90 QZ88 FE1 TM ZR SP FD[illegible] GN.
COMMENTS: WEIGHTED AVERAGE OF 93 PCT. RESISTANT MINERALS IN THE B22.
RELATIVE AMOUNTS: AS PERCENT
MINERAL CODE: RE = RESISTANT MINERALS EP = EPIDOTE FD = FELDSPARS HN = HORNBLENDE QZ = QUARTZ TM = TOURMALINE
ZR = ZIRCON FK = POTASSIUM FELDSPAR SP = SPHENE RU = RUTILE.

(A) METHOD 4B1A

Soil Moisture Site #7

Soil: Tivoli.
Soil classification: Typic Ustipsamment, mixed, thermic.
Pedon no.: S75TX-17-7.
Location: In exclosure about 75 feet west of Farm Road 1731, about 1.5 mile north of the junction between Farm Road 1731 and 746.
Geomorphic surface: Muleshoe.
Landform and slope: In the northern part of a broad, gently undulating plain. There is slight variability of slope within the exclosure, but the area of the sample site and moisture tubes slopes about 1 percent to the north.
Parent material: Eolian sediments.

Perennial vegetation (an oak community): Shinnery oak, sand dropseed, giant dropseed, purple 3-awn, tumble windmill grass, Riddell's groundsel, kuhnia, and prickly pear.

Soil samples collected by: Dan Blackstock and George Threlkeld, October 16, 1975.
Soil described by: L. H. Gile.

Soil surface: Generally covered by a thin (1 mm-1 cm) layer of leaves and twigs (mostly from oak). There are a few patches, 10-20 cm across, with fine earth at the surface. The latter has a smooth-topped crust in some places, and in others the fine earth is slightly mixed with twigs and leaves.

A1 760301 0-11 cm. Grayish brown (10YR 5/2 dry) or very dark grayish brown (10YR 3/2 moist) sand; massive; soft, very friable; fine roots common in some areas, only few in others; noncalcareous; mildly alkaline; clear wavy boundary.

A2 760302 11-34 cm. Dominantly light brownish gray (10YR 6.5/3 dry) or dark brown (10YR 4/3 moist) with lesser amount 10YR 7/3 dry, 10YR 5/3 moist; fine sand; massive; soft, very friable; few roots in some parts, common in others, ranging from less than 1 mm-3 cm in diameter; noncalcareous; neutral; clear wavy boundary.

B1 760303 34-53 cm. Very pale brown (10YR 7/4 dry) or yellowish brown (10YR 5/4 moist) in fine pattern with 10YR 6/4 dry, 10YR 4/4 moist; fine sand; massive; slightly hard, very friable; few roots; noncalcareous; mildly alkaline; clear wavy boundary.

B21&Bt 760304 53-81 cm. Pink (7.5YR 7/4 dry) or brown (7.5YR 5/4 moist) fine sand; massive; soft, very friable; few roots; one discontinuous band of clay accumulation, 5YR 5/4 dry, ½-1 mm thick, occurring as segments a few cm in length, separated by much wider zones in which the band is absent; noncalcareous, mildly alkaline; clear wavy boundary.

B22 760305 81-111 cm. Light brown (7.5YR 6/4 dry) or dark brown (7.5YR 4/4 moist) fine sand; massive:slightly hard, very friable; few roots; noncalcareous; mildly alkaline; clear wavy boundary.

B2b&Bt 760306 111-143 cm. Very pale brown (9YR 7/4 dry) or yellowish brown (9YR 5/4 moist) sand; massive; hard and slightly hard, very friable; very few roots, horizon usually has about four, mostly continuous, clay-enriched bands, colored 5YR 5/6 dry, 5YR 4.5/6 moist; most bands are from 2-3 mm thick, with one being about ½ cm thick; bands usually 5-6 cm apart, varying from 4-12 cm apart; slightly acid; clear wavy boundary.

C1b&Bt 760307 143-164 cm. Very pale brown (10YR 7/3 dry) or yellowish brown (10YR 5/4 moist) fine sand; massive; slightly hard, very friable; two clay-enriched bands, 5YR 5/4 dry, are continuous, approximately 2 mm thick, and range from 5-10 cm apart; slightly acid; clear wavy boundary.

C2b 760308 164-191 cm. Very pale brown (10YR 8/3 dry) or pale brown (10YR 6/3 moist) fine sand; massive; soft, very friable; very few roots; slightly acid; abrupt wavy boundary.

Btb2 760309 191-221 cm. Dominantly light brownish gray (2.5YR 6/2 dry) or grayish brown (2.5YR 5/2 moist) and 10YR 7/4 dry, 10YR 5/4 moist, and 10YR 8/1 dry, 7/1 moist; fine sandy loam in upper few cm, then a sandy clay loam; weak coarse subangular blocky structure; very hard, very firm; very few roots except along some ped faces; clay skins, 10YR 4/3 dry, on some ped faces along with a concentration of fine roots; slightly acid.

Soil: Tivoli.
Soil classification: Typic Ustipsamment, mixed, thermic.
Pedon no.: S75TX-17-8.

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SOIL CONSERVATION SERVICE, MTSC
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GENERAL METHODS- - -1A,1B1B,2A1,2B SAMPLE NOS. 760637-760645

DEPTH CM	HORIZON	SAND 2-.05	SILT .05-.002	CLAY LT .002	FINE CLAY LT .0002	VCOS 2-1	CORS 1-.5	MEDS .5-.25	FNES .25-.10	VFNS .10-.05	COSI .05-.02	FNSI .02-.002	VFSI .005-.002	SAND 2-.10	INTR II .2-.02	FINE CLAY TO CLAY	NON-CO3-CLAY	BD1 15-BAR TO CLAY
		(- - - - - - - - - - - - - - PARTICLE SIZE ANALYSIS, LT 2MM, 3A1, 3A1A, 3A1B - - - - - - - - - -)																
						(- - - - SAND - - - - - -)					(- - -SILT- - - -)							
		PCT LT 2MM															PCT	PCT
000-012	A1	91.9	3.9	4.2	1.0	.3	5.9	23.6	49.6	12.5	3.6	.3		79.4		24		.48
012-031	A2	94.4	1.7	3.9	.5	.1	5.9	24.0	49.9	14.5	1.4	.3		79.9		13		.41
031-061	B21	95.3	.8	3.9	.8	TR	7.5	26.0	50.2	11.6	.6	.2		83.7		21		.41
061-084	B22	96.3	1.6	2.1	.4	TR	5.6	24.4	51.9	14.4	1.3	.3		81.9		19		.71
084-112	B31	96.5	1.3	2.2	1.3	TR	4.2	22.7	53.9	15.7	.9	.4		80.8		59		.45
112-151	B32	95.0	3.0	2.0	.4	TR	3.1	19.1	55.3	17.5	2.8	.2		77.5		20		.40
151-168	B1b	95.2	3.0	1.8	.4	TR	3.4	22.3	55.0	14.5	2.6	.4		80.7		22		.50
168-182	B21tb	80.3	5.9	13.8	8.7	.0	2.6	14.4	46.6	16.7	4.0	1.9		63.6		63		.41
182-206	B22tb	82.5	7.6	9.9	6.2	TR	2.9	15.1	45.0	19.5	5.6	2.0		63.0		63		.43

DEPTH CM	VOL. GT 2 PCT	(PARTICLE SIZE ANALYSIS, MM, 3B, 3B1, 3B2) (- - - - - - - WEIGHT - - - - - - -) GT 75 PCT	75-20	20-5	5-2	LT .074	20-2 PCT LT20	(BULK DENSITY) 4A1D 1/3-BAR G/CC	4A1H OVEN DRY G/CC	4D1 COLE	(- - - -WATER CONTENT- - - -) 4B1C 1/10 BAR PCT	4B1C 1/3-BAR PCT	4B2 15-BAR PCT	4C1 WRD CM/CM	CARBONATE 6E1B LT 2 PCT	3A1A LT .002 PCT	(- -PH - -) 8C1A 1/1 H2O	8C1E 1/2 CACL
		(- - - PCT LT 75 - - -)																
000-012	0	0	0	0	0	14	0				6.2A		2.0		TR		7.1	6.7
012-031	0	0	0	0	0	12	0				3.9A		1.6		0		6.8	6.4
031-061	0	0	0	0	0	10	0				4.7A		1.6		0		7.1	6.2
061-084	0	0	0	0	0	9	0				3.0A		1.5		0		6.9	5.9
084-112	0	0	0	0	0	9	0				3.3A		1.0		0		6.6	5.9
112-151	0	0	0	0	0	14	0				3.7A		.8		0		7.0	6.0
151-168	0	0	0	0	0	10	0				4.0A		.9		0		6.9	6.3
168-182	0	0	0	0	0	28	0				20.1A		5.7		0		6.9	6.4
182-206	0	0	0	0	0	27	0				16.3A		4.3		0		6.1	5.6

DEPTH CM	(ORGANIC MATTER) 6A1A ORGN CARB PCT	6B1A NITG PCT	C/N	IRON 6C2B EXT FE PCT	PHOS TOTL PCT	(- -EXTRACTABLE BASES 5B4A- -) 6N2E CA	6O2D MG	6P2B NA	6Q2B K	SUM EXTB	ACTY 6H1A BACL TEA	AL 6G1E KCL EXT	(CAT EXCH) 5A3A EXTB ACTY	5A6A NHAC	RATIO 8D1 NHAC TO CLAY	RATIO 8D3 CA TO MG	CA 5F1 SAT NHAC PCT	(BASE SAT) 5C3 EXTB ACTY PCT	5C1 NHAC PCT
						(- - - - - - - - - - - -MEQ / 100 G- - - - - - - - - -)													
000-012	.44	.056	8	.2			.6	TR	.3		.4			3.5	.83				
012-031	.24	.038	6	.2		2.0	.4	TR	.2	2.6	.4		3.0	2.3	.59	5.0	87	87	113
031-061	.16	.020	8	.2		1.7	.4	TR	.2	2.3	.4		2.7	2.2	.56	4.3	77	85	105
061-084	.10	.015	7	.2		1.3	.3	TR	.2	1.8	.2		2.0	1.9	.58	4.3	68	90	95
084-112	.07			.2		1.0	.4	TR	.1	1.5	.3		1.8	1.4	.47	2.5	71	83	107
112-151	.04			.2		1.0	.3	TR	.1	1.4	.1		1.5	1.4	.45	3.3	71	93	100
151-168	.04			.2		1.1	.4	TR	.2	1.7	.1		1.8	1.5	.48	2.8	73	94	113
168-182	.13			.4		5.7	1.8	TR	.4	7.9	1.4		9.3	8.1	.59	3.2	70	85	98
182-206	.07			.3		4.4	1.4	.1	.3	6.2	1.1		7.3	6.2	.63	3.1	71	85	100

DEPTH CM	(SATURATED PASTE) 8S1 RESI OHM-CM	8C1B PH	8A H2O PCT	NA 5D2 ESP PCT	NA SR SAR	SALT 8D5 TOTL SOLU PPM	GYP 6F1A PCT	(- - - - - - - - - SATURATION EXTRACT 8A1- - - - - - - - -) 8A1A EC MMHOS/CM	6N1B CA	6O1B MG	6P1B NA	6Q1B K	6I1A CO3	6J1A HCO3	6K1A CL	6L1A SO4	6M1A NO3	ATTERBERG 4F1 LQID LMIT	4F2 PLST INDX
								(- - - - - - - - - - MEQ / LITER - - - - - - - - - - -)										PCT	
000-012																			
012-031																			
031-061																			
061-084																			
084-112	24000	7.2	22.6					.17											
112-151																			
151-168																			
168-182																			
182-206																			

CLAY MINERALOGY (7A2C).
031-61 MI3 KK2 MM1.
168-182 MM3 MI3 KK3.
RELATIVE AMOUNTS: (X-RAY) 5 = DOMINANT 4 = ABUNDANT 3 = MODERATE 2 = SMALL 1 = TRACE.
MINERAL CODE: MI = MICA KK = KAOLINITE MM = MONTMORILLONITE-MICA.
SAND MINERALOGY (7B1) PLACEMENT: SILICEOUS.
031-61 VFNS - RE88 QZ85 FE2 TM -ZR SP FD11 MS GN. FNES - RE94 QZ91 CD3 FK6 (342 GRAINS).
168-182 VFNS - RE86 QZ83 FE2 ZR1 TM SP FD14 GN.
COMMENTS: WEIGHTED AVERAGE OF 94 PCT. RESISTANT MINERALS IN THE B21.
RELATIVE AMOUNTS: AS PERCENT
MINERAL CODE: RE = RESISTANT MINERALS FD = FELDSPARS MS = MUSCOVITE QZ = QUARTZ TM = TOURMALINE ZR = ZIRCON
FK = POTASSIUM FELDSPAR CD = CHALCEDONY SP = SPHENE GN = GARNET.

(A) METHOD 4B1A

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IHC900I EXECUTION TERMINATING DUE TO ERROR COUNT FOR ERROR NUMBER  217

IHC217I FIOCS - END OF DATA SET ON UNIT    5

TRACEBACK  ROUTINE  CALLED FROM ISN   REG.  14   REG.  15   REG.   0   REG.   1

           IBCOM                      000690CC   0006A108   0000005D   00069080

           MAIN                       000193BA   01066CE0   000CA8BC   0008B7F8

ENTRY POINT=  01066CE0
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Soil Moisture Site #8

Soil: Tivoli.
Soil classification: Typic Ustipsamment, mixed, thermic.
Pedon no.: S75TX-17-8.
Location: In exclosure about 800 feet east of Farm Road 1731, about 1.1 mile north of the junction between Farm Roads 1731 and 746, and about100 feet south of dirt road.
Geomorphic surface: Muleshoe.
Landform and slope: Lower side of slight ridge, near margin of broad depression. Slope is 4 percent to the east where the moisture tubes and west end of the sample trench are located. Slope decreases to the east and is nearly level on the east side of the exclosure.
Parent material: Eolian sediments.

Perennial vegetation (a sumac - red lovegrass community): Sand sagebrush, western ragweed, woolly white, purple 3-awn, needle-and-thread, sand bluestem, little bluestem, red lovegrass, fall witchgrass, four o'clock, sumac, queen's delight, hairy grama, kuhnia, sundrop, dalea, tumble lovegrass, cryptantha, wild flax, prairie green-thread, rushpea, spiny haplopappus, and erect dayflower.

Soil samples collected by: L. H. Gile, November 8, 1975.
Soil described by: L. H. Gile.

Soil surface: Barren between clumps of vegetation; 50-60 percent of the surface has barren areas ranging from 20-50 cm diameter. The barren areas are partially covered by a discontinuous, loose litter of stems and leaves. Where undisturbed the surface has a fragile crust 1-5 mm thick, which breaks out as plates 1-3 cm in diameter.

A1 760637 0-12 cm. Brown (7.5YR 5/4 dry) or dark brown (7.5YR 3/4 moist) fine sand; massive; soft, very friable, some parts loose; fine roots common; noncalcareous; moderately alkaline; abrupt wavy boundary.

A2 760638) 12-31 cm. Dominantly light brown (7.5YR 6/4 dry) or brown (7.5YR 5/4 moist) with some parts slightly darker as in the A1, and some slightly redder as in the B21; fine sand; massive; slightly hard, very friable; few roots; noncalcareous; moderately alkaline clear wavy boundary.

B21 760639 31-61 cm. Yellowish red (5YR 5.5/6 dry, 5YR 4/6 moist) fine sand; massive; slightly hard, very friable; few roots, mostly 1-2 mm diameter, but several up to 5 cm diameter; scattered crotovinas, with one being diagonal, about 35 cm long and 10 cm wide, filled with loose material including sand, fecal pellets and fine roots; noncalcareous; moderately alkaline; clear wavy boundary.

B22 760640 61-84 cm. Reddish yellow (5YR 6/6 dry) or yellowish red (5YR 4/6 moist) fine sand; massive; slightly hard, very friable; few roots, mostly 1-2 mm diameter, but several 8-10 cm diameter; several crotovinas, with the longest being diagonal, about 45 cm long and 10 cm wide, most of which is tightly packed with fine sand which is lighter in color than the main part of the horizon; organic material, fecal pellets, and loose sand occur along the lower margin and the east end of the crotovina; noncalcareous; moderately alkaline; clear wavy boundary.

B31 760641 84-112 cm. Reddish yellow (6YR 6/6 dry) or yellowish red (6YR 4/6 moist) fine sand; massive; slightly hard, very friable; very few roots; noncalcareous; moderately alkaline; clear wavy boundary.

B32 760642 112-151 cm. Reddish yellow (6YR 6/6 dry) or yellowish red (6YR 4/6 moist) fine sand; massive; slightly hard, very friable; very few roots; noncalcareous; moderately alkaline; abrupt wavy boundary.

B1b 760643 151-168 cm. Dominantly light reddish brown (5YR 6/4 dry) or reddish brown (5YR 5/4 moist) with parts 5YR 6/6 dry; fine sand; massive; slightly hard, very friable; very few roots; noncalcareous; moderately alkaline; abrupt smooth boundary.

B21tb 760644 168-182 cm. Reddish brown (5YR 5/4 dry, 4/4 moist) fine sandy loam; very hard, friable; compound very weak coarse prismatic and weak coarse subangular blocky structure; very few roots, about 1 mm and less in diameter; moderately alkaline; noncalcareous; clear wavy boundary.

B22tb 760645 182-206 cm. Yellowish brown (9YR 5/4 dry) or dark yellowish brown (9YR 4/4 moist) with a few parts of 5YR hue; loamy fine sand; very hard, friable; compound very weak coarse prismatic and very weak coarse subangular blocky structure; very few roots, 1 mm and less in diameter; noncalcareous; neutral.

Pedon S78TX-17-1

Soil: Circleback.
Soil classification: Alfic Ustipsamment, mixed, thermic.

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NATIONAL SOIL SURVEY LABORATORY
LINCOLN, NEBRASKA

GENERAL METHODS 1B1A, 2A1, 2B

-1-- -2-- -3-- -4-- -5-- -6-- -7-- -8-- -9-- -10- -11- -12- -13- -14- -15- -16- -17- -18- -19- -20-

SAMPLE NO.	HZN NO.	DEPTH (CM)	HORIZON	(- - -TOTAL - - -) CLAY LT .002	SILT .002 -.05	SAND .05 -2	FINE LT .0002	(- -CLAY- -) CO3 LT .002	(- -SILT- -) FINE .002 -.02	COARSE .02 -.05	VF .05 -.10	(- - - - - -SAND- - - - - -) F .10 -.25	M .25 -.50	C .5 -1	VC 1 -2	(-COARSE FRACTIONS(MM)-) 2 -5	5 -20	20 -75	.1- 75	(>2MM) WT PCT OF WHOLE SOIL
				<- - - - - - - - - - - - PCT OF <2MM						(3A1)	- - - - - - - - - - - -					<- PCT OF <75MM(3B1) ->				
79 237	1S	0- 15	A1	3.2	4.6	92.2			0.8	3.8	7.5	46.3	28.5	9.6	0.3	--	--	--	85	--
79 238	2S	15- 28	A2	2.4	1.8	95.8			0.4	1.4	7.3	52.5	27.1	8.7	0.2	--	--	--	88	--
79 239	3S	28- 49	B1	2.8	1.3	95.9			--	1.3	5.8	48.3	34.1	7.7	--	--	--	--	90	--
79 240	4S	49- 69	B21&Bt	3.2	1.7	95.1			0.4	1.3	5.9	49.3	31.0	8.8	0.1	--	--	--	89	--
79 241	5S	69- 94	B22&Bt	2.0	2.6	95.4			--	2.6	8.7	50.0	27.3	9.3	0.1	--	--	--	87	--
79 242	6S	94-114	C	1.6	3.0	95.4			--	3.0	9.3	51.5	26.3	8.1	0.2	--	--	--	86	--

SAMPLE NO.	HZN NO.	ORGN TOTAL C 6A1C	N 6B1B	EXTR TOTAL P 6S1A	S 6R3A	(- - DITH-CIT - -) EXTRACTABLE FE 6C2B	AL 6G7A	MN 6D2A	CEC 8D1	(RATIO/CLAY) 15 BAR 8D1	(ATTERBERG) - LIMITS - LL 4F1	PI 4F	(- BULK DENSITY -) FIELD MOIST 4A3A	1/3 BAR 4A1D	OVEN DRY 4A1H	COLE WHOLE SOIL 4D1	(- - -WATER CONTENT - -) FIELD MOIST 4B4	1/10 BAR 4B1C	1/3 BAR 4B1C	15 BAR 4B2	WRD WHOLE SOIL 4C1
		<- - - - - - -PCT OF <2MM - - - - - - ->									PCT <0.4MM		<- - G/CC - - ->			CM/CM	<- - -PCT OF <2MM - ->				CM/CM
79 237	1									0.59										1.9	
79 238	2									0.46										1.1	
79 239	3									0.50										1.4	
79 240	4									0.38										1.2	
79 241	5									0.50										1.0	
79 242	6									0.63										1.0	

SAMPLE NO.	HZN NO.	(- NH4OAC EXTRACTABLE BASES -) CA 5B4A 6N2E	MG 5B4A 6O2D	NA 5B4A 6P2B	K 5B4A 6Q2B	SUM BASES	ACID- ITY 6H2B	EXTR AL 6G1E	(- - - -CEC - - -) SUM CATS 5A3A	NH4- OAC 5A8A	BASES + AL 5A3B	AL SAT 5G1	-BASE SAT- SUM 5C3	NH4 5C1	CO3 AS CACO3 <2MM 6E1B	RES. OHMS /CM 8E1	(- - - -PH - - -) CACL2 .01M 8C1E 1:2	H2O 8C1A 1:1
		<- - - - - - - - - - - - -MEQ / 100 G - - - - - - - - - - - - ->										<- - - - -PCT - - - ->						
79 237	1																6.3	6.9
79 238	2																5.7	6.3
79 239	3																6.1	6.7
79 240	4																6.1	6.7
79 241	5																6.0	6.7
79 242	6																5.8	6.4

ANALYSES: S= ALL ON SIEVED <2MM BASIS

Pedon S78TX-17-1

Soil: Circleback.
Soil classification: Alfic Ustipsamment, mixed, thermic.
Location: East rim of blowout dune, about 1100 feet east of Farm Road 1731, at a point that is about 8500 feet north of the junction between Farm Road 1731 and 746, and that is about 2300 feet north of gate on east side of road.
Geomorphic surface: Longview.
Landform and slope: Near crest of blowout dune, nearly level.
Parent material: Eolian sediments.
Soil samples collected by: L. H. Gile, November 9, 1976.
Soil described by: L. H. Gile.

A1 79P237 0-15 cm. Brown (9YR 5/3, dry) or dark brown (9YR 3/3, moist) sand; massive; soft, very friable; few roots; noncalcareous; neutral, clear wavy boundary.

A2 79P238 15-28 cm. Very pale brown (9YR 7/4, dry) or yellowish brown (9YR 5/4, moist) fine sand; massive; soft, very friable; roots few and common; slightly acid; clear wavy boundary.

B1 79P239 28-49 cm. Light reddish brown (5YR 6/4, dry) or reddish brown (5YR 5/4, moist) sand; massive; slightly hard, very friable; roots common; noncalcareous; neutral; abrupt wavy boundary.

B21&Bt 79P240 49-69 cm. Light reddish brown (5YR 6/4, dry) or reddish brown (5YR 5/4, moist) sand; massive; slightly hard, very friable; roots few and common; two discontinuous clay bands, 1-2 mm thick; noncalcareous; neutral; abrupt smooth boundary.

B22&Bt 79P241 69-94 cm. Light reddish brown (6YR 6.5/4, dry) or reddish brown (6YR 5/4, moist) fine sand; massive; slightly hard, very friable; few roots; usually about five continuous clay bands, 2 mm thick in upper part of horizon and about 1 mm thick in lower part; noncalcareous; neutral; abrupt smooth boundary.

C 79P242 94-114 cm. Light reddish brown (6YR 6.5/4, dry) or reddish brown (6YR 5/4, moist) fine sand; massive; slightly hard, very friable; noncalcareous; neutral.

Pedon S78TX-17-2

Soil: Circleback.
Soil classification: Alfic Ustipsamment, mixed, thermic.

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LINCOLN, NEBRASKA

GENERAL METHODS 1B1A, 2A1, 2B

SAMPLE NO.	HZN NO.	DEPTH (CM)	HORIZON	TOTAL CLAY LT .002	TOTAL SILT .002 -.05	TOTAL SAND .05 -2	CLAY FINE LT .0002	CLAY CO3 LT .002	SILT FINE .002 -.02	SILT COARSE .02 -.05	SAND VF .05 -.10	SAND F .10 -.25	SAND M .25 -.50	SAND C .5 -1	SAND VC 1 -2	COARSE FRACTIONS (MM) WEIGHT 2 -5	5 -20	20 -75	.1- 75	(>2MM) WT PCT OF WHOLE SOIL
				<- - - - - - - - - - - PCT OF <2MM						(3A1)	- - - - - - - - - - - -					<- PCT OF <75MM (3B1) ->				
79 243	1S	0- 5	A11	2.4	2.3	95.3			1.6	0.7	6.4	50.7	31.9	6.3	--	--	--	--	89	--
79 244	2S	5- 16	A12	2.8	2.4	94.8			1.6	0.8	8.6	59.3	22.5	4.4	--	--	--	--	86	--
79 245	3S	16- 25	B11	3.2	2.1	94.7			0.4	1.7	13.5	57.8	20.4	3.0	--	--	--	--	81	--
79 246	4S	25- 32	B12	2.8	1.8	95.4			--	1.8	9.0	59.1	23.1	4.2	--	--	--	--	86	--
79 247	5S	32- 53	B21&Bt	2.0	2.0	96.0			1.2	0.8	9.6	58.8	23.2	4.4	--	--	--	--	86	--
79 248	6S	53- 71	B22&Bt	2.8	9.5	87.7			0.8	8.7	10.3	51.4	22.1	3.9	--	--	--	--	77	--
79 249	7S	71- 86	B23&Bt	2.0	1.7	96.3			1.2	0.5	10.9	69.3	12.9	3.2	--	--	--	--	85	--
79 250	8S	86-106	B3&Bt	1.9	5.1	93.0			0.4	4.7	11.3	48.7	22.5	10.3	0.2	--	--	--	82	--
79 251	9S	106-128	C	1.6	3.3	95.1			--	3.3	13.4	51.9	20.9	8.8	0.1	--	--	--	82	--

SAMPLE NO.	HZN NO.	ORGN C 6A1C	TOTAL N 6B1B	EXTR P 6S1A	TOTAL S 6R3A	DITH-CIT EXTRACTABLE FE 6C2B	AL 6G7A	MN 6D2A	CEC 8D1	RATIO/CLAY 15 BAR 8D1	ATTERBERG LIMITS LL 4F1	PI 4F	BULK DENSITY FIELD MOIST 4A3A	1/3 BAR 4A1D	OVEN DRY 4A1B	COLE WHOLE SOIL 4D1	WATER CONTENT FIELD MOIST 4B4	1/10 BAR 4B1C	1/3 BAR 4B1C	15 BAR 4B2	WRD WHOLE SOIL 4C1
		<- - - - - - -PCT OF <2MM - - - - - - ->									PCT <0.4MM		<- - G/CC - - ->			CM/CM	<- - -PCT OF <2MM - ->				CM/CM
79 243	1									0.54										1.3	
79 244	2									0.54										1.5	
79 245	3									0.41										1.3	
79 246	4									0.46										1.3	
79 247	5									0.60										1.2	
79 248	6									0.46										1.3	
79 249	7									0.60										1.2	
79 250	8									0.32										0.6	
79 251	9									0.63										1.0	

SAMPLE NO.	HZN NO.	NH4OAC EXTRACTABLE BASES CA 5B4A 6N2E	MG 5B4A 6Q2D	NA 5B4A 6P2B	K 5B4A 6Q2B	SUM BASES	ACID-ITY 6H2B	EXTR AL 6G1E	CEC SUM CATS 5A3A	NH4-OAC 5A8A	BASES + AL 5A3B	AL SAT 5G1	BASE SAT SUM 5C3	NH4 OAC 5C1	CO3 AS CACO3 <2MM 6E1B	RES. OHMS /CM 8E1	PH CACL2 .01M 8C1E 1:2	H2O 8C1A 1:1
		<- - - - - - - - - - - - - -MEQ / 100 G - - - - - - - - - - - - ->										<- - - - -PCT - - - ->						
79 243	1														--		6.4	7.0
79 244	2																6.3	6.9
79 245	3																6.1	6.7
79 246	4																6.1	6.7
79 247	5																6.1	6.7
79 248	6																6.1	6.7
79 249	7														--		6.1	6.9
79 250	8																6.0	6.6
79 251	9																5.6	6.2

ANALYSES: S= ALL ON SIEVED <2MM BASIS

Pedon S78TX-17-2

Soil: Circleback.
Soil classification: Alfic Ustipsamment, mixed, thermic.
Location: North rim of blowout dune, about 2300 feet east of Farm Road 1731, at a point that is about 7000 feet north of the junction between Farm Roads 1731 and 746 and that is about 1100 feet north of gate on east side of road; due east of large blowout that has its western edge about 350 feet east of Farm Road 1731.
Geomorphic surface: Longview.
Landform and slope: Near crest of blowout dune, nearly level.
Parent materials: Eolian sediments.
Soil samples collected by: L. H. Gile, November 1, 1977.
Soil described by: L. H. Gile.

A11 79P243 0-5 cm. Light brown (7.5YR 6/3, dry) or dark brown (7.5YR 4/3, moist) fine sand; massive; soft, very friable; few roots; noncalcareous; neutral; abrupt smooth boundary.

A12 79P244 5-16 cm. Brown (7.5YR 5/4, dry) or dark brown (7.5YR 3.5/4, moist) fine sand; massive; soft, very friable; few roots; noncalcareous; neutral; clear wavy boundary.

B11 79P245 16-25 cm. Light reddish brown (5YR 6/4, dry) or reddish brown (5YR 4/4, moist) fine sand; massive; soft, very friable; few roots; noncalcareous; neutral; clear wavy boundary.

B12 79P246 25-32 cm. Light reddish brown (5YR 6/4, dry) or reddish brown (5YR 4/4, moist) fine sand; massive; soft, very friable; few roots; noncalcareous; neutral; abrupt smooth boundary.

B21&Bt 79P247 32-53 cm. Light reddish brown (5YR 6/4, dry) or reddish brown (5YR 5/4, moist) fine sand; massive; slightly hard, very friable; few roots; two continuous clay bands, 2-3 mm thick, color 5YR 5/4, dry; noncalcareous; neutral; abrupt smooth boundary.

B22&Bt 79P248 53-71 cm. Light reddish brown (5YR 6/4, dry) or reddish brown (5YR 5/4, moist) fine sand; massive;slightly hard, very friable; few roots; three continuous clay bands, 2-3 mm thick, color 5YR 5/4, dry; noncalcareous; neutral; abrupt smooth boundary.

B23&Bt 79P249 71-86 cm. Light reddish brown (5YR 6/4, dry or reddish brown (5YR 5/4, moist) fine sand; massive; slightly hard, very friable; few roots; one continuous clay band about 2 mm thick, color 5YR 5/4, dry; noncalcareous; neutral; abrupt wavy boundary.

B3&Bt 79P250 86-106 cm. Light reddish brown (6YR 6/4, dry) or reddish brown (6YR 4.5/4, moist) sand;massive; slightly hard, very friable; very few roots; two discontinuous clay bands, about 1 mm thick, 5YR 5/4, dry; noncalcareous; neutral; clear wavy boundary.

C 79P251 106-128 cm. Light reddish brown (6YR 6/4, dry) or reddish brown (6YR 4.5/4, moist) fine sand; massive; slightly hard, very friable; very few roots; noncalcareous; neutral.

Pedon S78TX-17-3

Soil: Circleback.
Soil classification: Alfic Ustipsamment, mixed, thermic.

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LINCOLN, NEBRASKA

GENERAL METHODS 1B1A, 2A1, 2B

SAMPLE NO.	HZN NO.	DEPTH (CM)	HORIZON	TOTAL CLAY LT .002	TOTAL SILT .002 -.05	TOTAL SAND .05 -2	CLAY FINE LT .0002	CLAY CO3 LT .002	SILT FINE .002 -.02	SILT COARSE .02 -.05	SAND VF .05 -.10	SAND F .10 -.25	SAND M .25 -.50	SAND C .5 -1	SAND VC 1 -2	COARSE FRACTIONS (MM) WEIGHT 2 -5	5 -20	20 -75	.1- 75	(>2MM) WT PCT OF WHOLE SOIL
				<- PCT OF <2MM						(3A1)	<-					<- PCT OF <75MM (3B1)				
79 220	1S	0- 20	C	1.6	2.2	96.2			--	2.2	14.8	73.3	7.4	0.7	--	--	--	--	81	--
79 231	2S	20- 46	A1b	1.6	2.5	95.9			0.8	1.7	11.3	60.6	20.3	3.7	--	--	--	--	85	--
79 232	3S	46- 66	B1b&Bt	4.4	1.9	93.7			--	1.9	6.9	46.2	27.4	13.0	0.2	--	--	--	87	--
79 233	4S	66- 84	B21b&Bt	4.0	1.7	94.3			--	1.7	5.3	44.8	35.8	8.3	0.1	--	--	--	89	--
79 234	5S	84-101	B22b&Bt	3.6	1.0	95.4			--	1.0	4.8	40.6	33.6	16.1	0.3	--	--	--	91	--
79 235	6S	101-127	B3b&Bt	2.8	1.5	95.7			--	1.5	5.2	38.4	37.9	14.1	0.1	TR	--	--	90	TR
79 236	7S	127-150	Ab2	1.2	0.6	98.2			--	0.6	5.2	64.2	25.9	2.9	--	--	--	--	93	--

SAMPLE NO.	HZN NO.	ORGN C 6A1C	TOTAL N 6B1B	EXTR P 6S1A	TOTAL S 6R3A	DITH-CIT EXTRACTABLE FE 6C2B	AL 6G7A	MN 6D2A	CEC 8D1	RATIO/CLAY 15 BAR 8D1	ATTERBERG LIMITS LL 4F1	PI 4F	BULK DENSITY FIELD MOIST 4A3A	1/3 BAR 4A1D	OVEN DRY 4A1H	COLE WHOLE SOIL 4D1	WATER CONTENT FIELD MOIST 4B4	1/10 BAR 4B1C	1/3 BAR 4B1C	15 BAR 4B2	WRD WHOLE SOIL 4C1
		<- PCT OF <2MM							->		PCT <0.4MM		<- G/CC		->	CM/CM	<- PCT OF <2MM			->	CM/CM
79 230	1									0.75										1.2	
79 231	2									0.63										1.0	
79 232	3									0.43										1.9	
79 233	4									0.45										1.8	
79 234	5									0.42										1.5	
79 235	6									0.36										1.0	
79 236	7									0.67										0.8	

SAMPLE NO.	HZN NO.	NH4OAC EXTRACTABLE BASES CA 5B4A 6N2E	MG 5B4A 6O2D	NA 5B4A 6P2B	K 5B4A 6Q2B	SUM BASES 6H2B	ACID-ITY 6G1E	EXTR AL	CEC SUM CATS 5A3A	NH4-OAC 5A8A	BASES + AL 5A3B	AL SAT 5G1	BASE SUM 5C3	SAT- NH4 OAC 5C1	CO3 AS CACO3 <2MM 6E1B	RES. OHMS /CM 8E1	PH CACL2 .01M 8C1E	H2O 8C1A
		<-				-MEQ / 100 G					->	<-			-PCT	->	1:2	1:1
79 230	1														--		6.7	7.5
79 231	2														--		6.4	7.0
79 232	3														--		6.2	6.9
79 233	4																6.2	6.9
79 234	5																5.9	6.6
79 235	6																5.8	6.4
79 236	7																5.9	6.5

ANALYSES: S= ALL ON SIEVED <2MM BASIS

Pedon S78TX-17-3

Soil: Circleback.
Soil classification: Alfic Ustipsamment, mixed, thermic.
Location: North side of dune ridge, on west face of large blowout about 350 feet east of Farm Road 1731, at a point about 7000 feet north of the junction between Farm Roads 1731 and 746.
Geomorphic surface: Longview.
Landform and slope: North side of dune ridge that slopes 15% to the north.
Parent materials: Eolian sediments.
Soil samples collected by: L. H. Gile, March 22, 1977.
Soil described by: L. H. Gile.

C 79P230 0-20 cm. Light brown (7.5YR 6/4, dry) or brown (7.5YR 4.5/4, moist) fine sand; massive; soft, very friable; generally few roots, common in places; noncalcareous; neutral; abrupt wavy boundary.

A1b 79P231 20-46 cm. Brown (8YR 5.5/3, dry) or dark brown (8YR 4/3, moist) fine sand; massive; slightly hard, very friable; few roots; noncalcareous; neutral; clear wavy boundary.

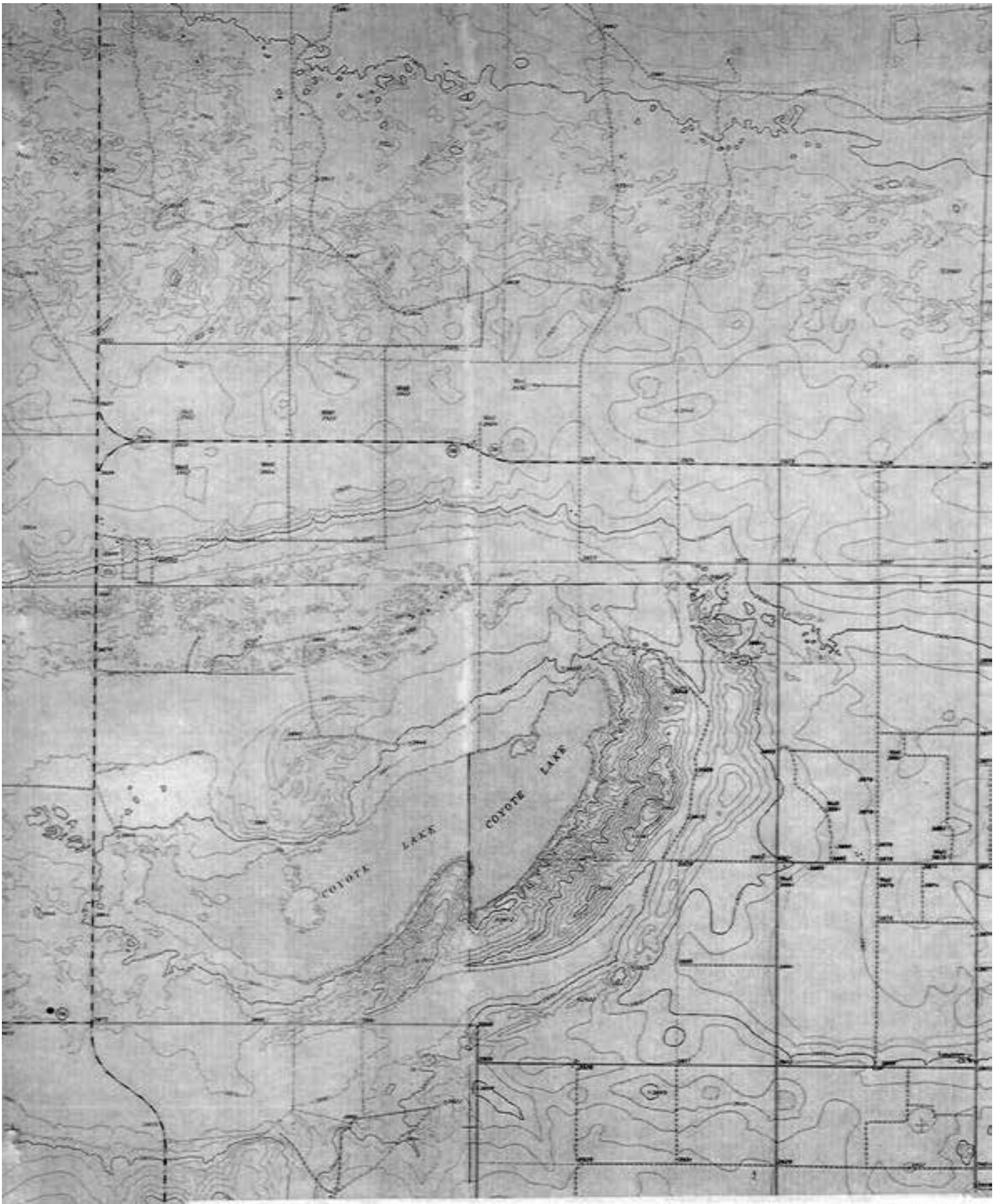
B1b&Bt 79P232 46-66 cm. Light brown (7.5YR 6/4, dry) or brown (7.5YR 4.5/4, moist) sand; massive; slightly hard, very friable; few roots; two discontinuous clay bands, 3-5 mm thick; noncalcareous; neutral; abrupt wavy boundary.

B21b&Bt 79P233 66-84 cm. Light reddish brown (5YR 6/4, dry) or reddish brown (5YR 4.5/4, moist) sand; massive; slightly hard, very friable; few roots; three clay bands, 3-5 mm thick; noncalcareous; neutral; abrupt smooth boundary.

B22b&Bt 79P234 84-101 cm. Light reddish brown (5YR 6/4, dry) or reddish brown (5YR 5/4, moist) sand; massive; slightly hard, very friable; few roots; four clay bands, 1-3 mm thick; noncalcareous; neutral; abrupt smooth boundary.

B3b&Bt 79P235 101-127 cm. Light reddish brown (5YR 6/4, dry) or reddish brown (5YR 5/4, moist) sand; massive; slightly hard, very friable; few roots; five clay bands, 1-2 mm thick; noncalcareous; neutral; abrupt smooth boundary.

Ab2 79P236 127-150 cm. Light brown (7.5YR 6.5/4, dry) or brown (7.5YR 5.5/4, moist) fine sand; massive; slightly hard, very friable; very few roots; noncalcareous; neutral.



Topographic map of most of the area shown on the front flyleaves, assembled from parts of the Birdwell Ranch, Stegall, Baileyboro, and Baileyboro NE 7.5 minute quadrangles.

Accessibility Statement

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