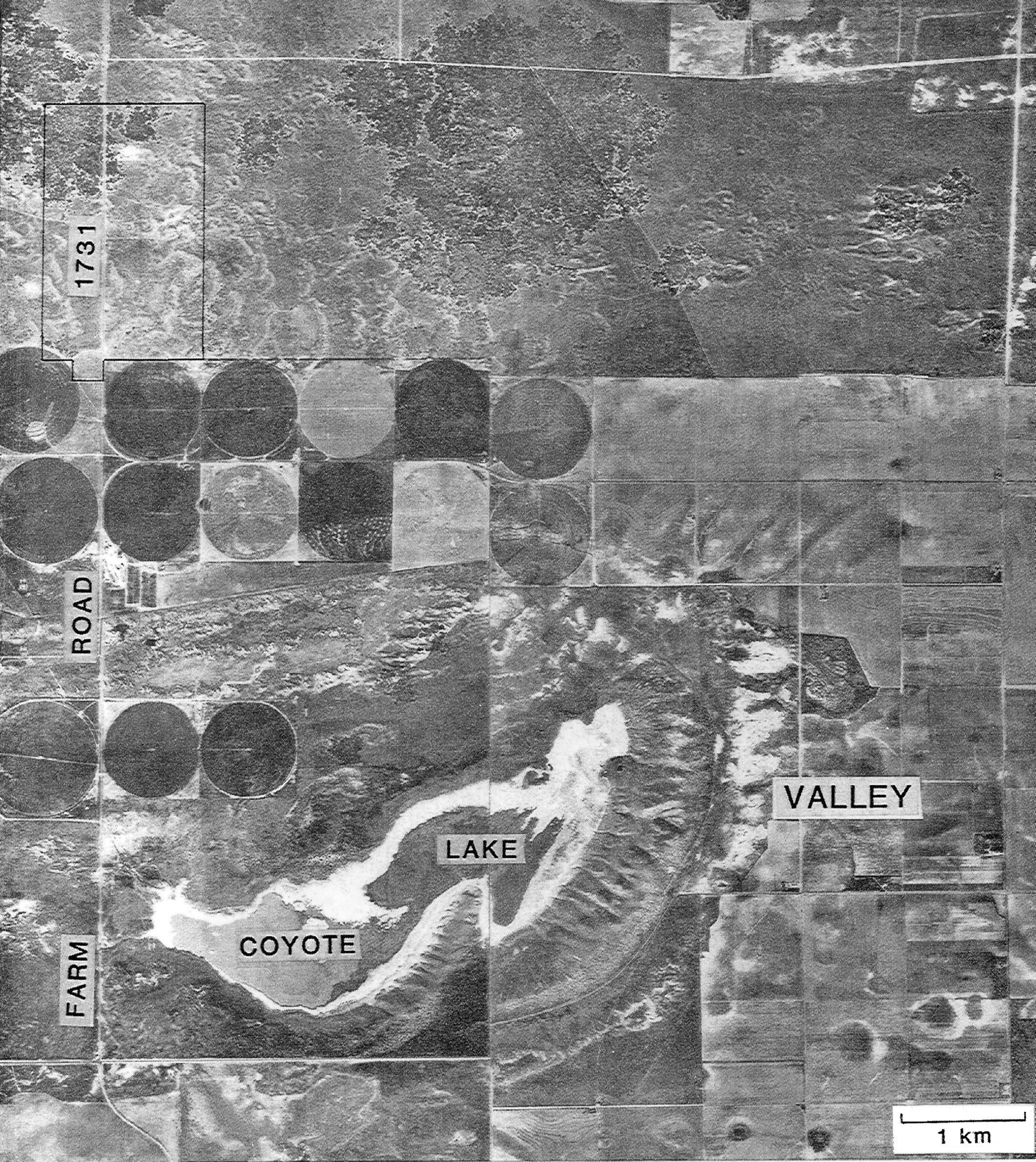
THE SANDHILLS PROJECT SOIL MONOGRAPH

Leland H. Gile

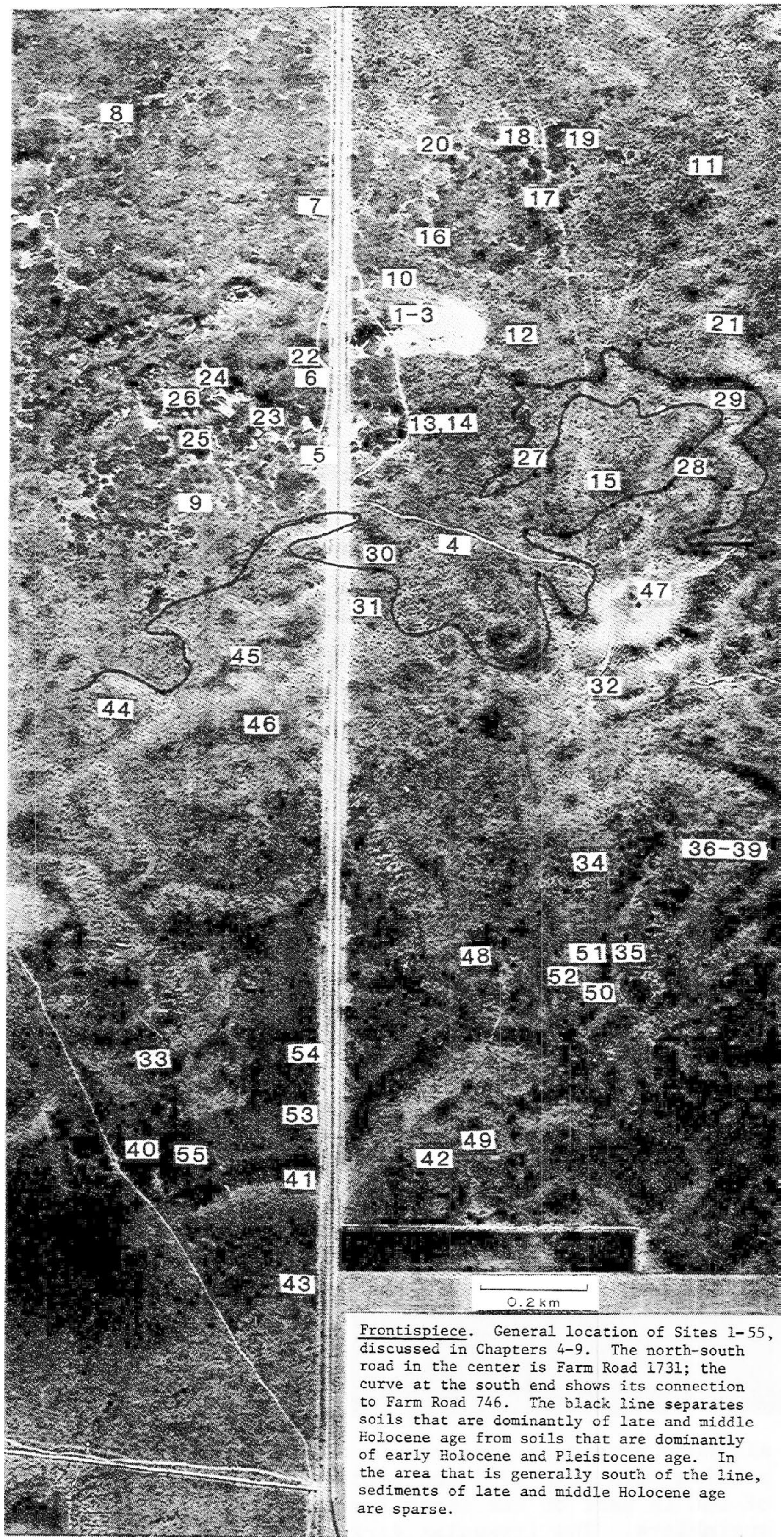
Natural Resources Conservation Service
U.S. Department of Agriculture
National Soil Survey Center, Lincoln, NE

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

Leland H. Gile

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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

CONTENTS

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

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Page

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		
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 1970, 1981	Distinct traces of XIT trail still present on dune crests of 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

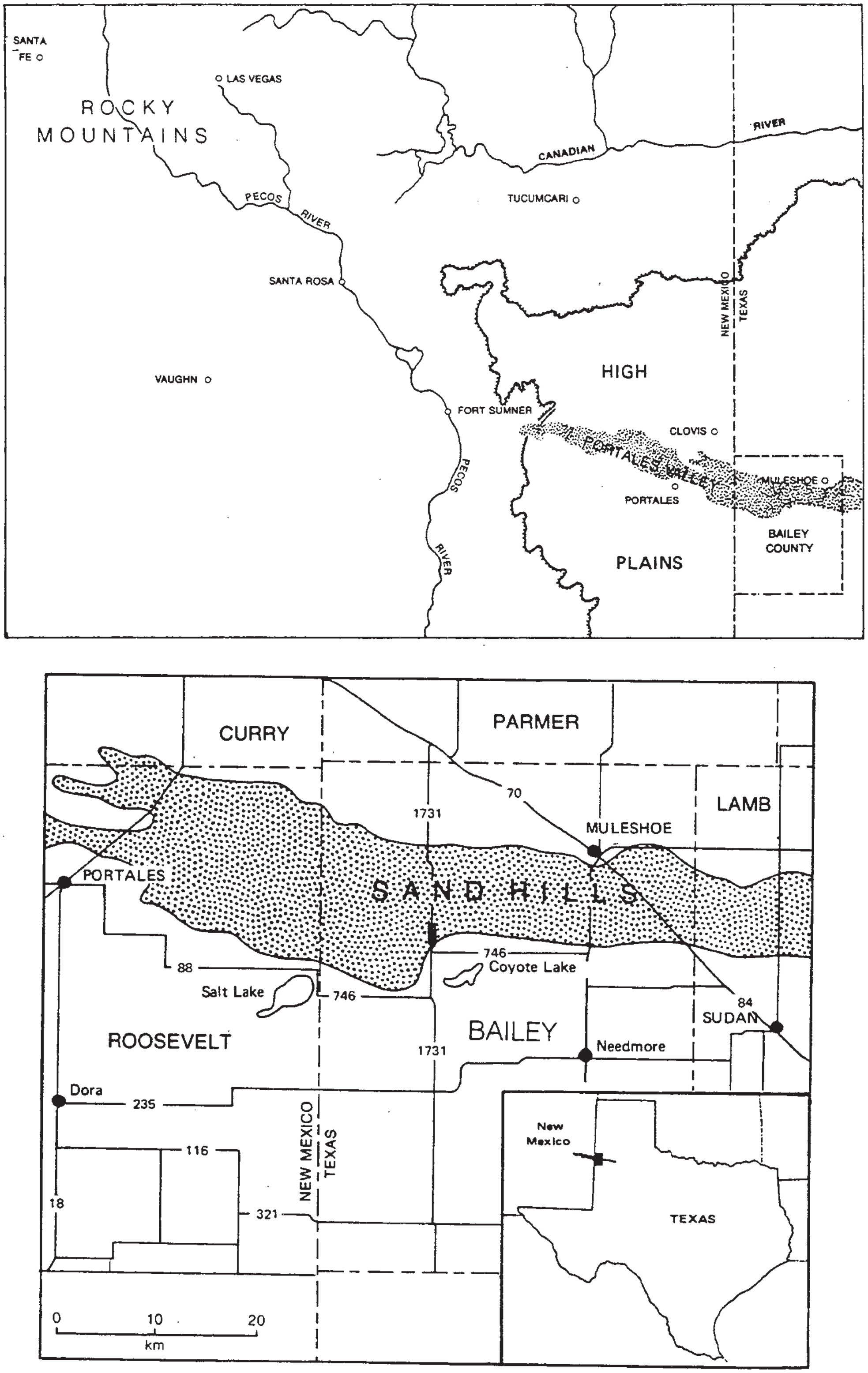


Figure 1. Upper. Location of the sandhills, Portales Valley and present course of the Pecos River. An ancestral upper Pecos-Brazos River once flowed eastward through the Portales Valley and across the High Plains. Deposits of the ancestral river are thought to have been the original source of eolian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

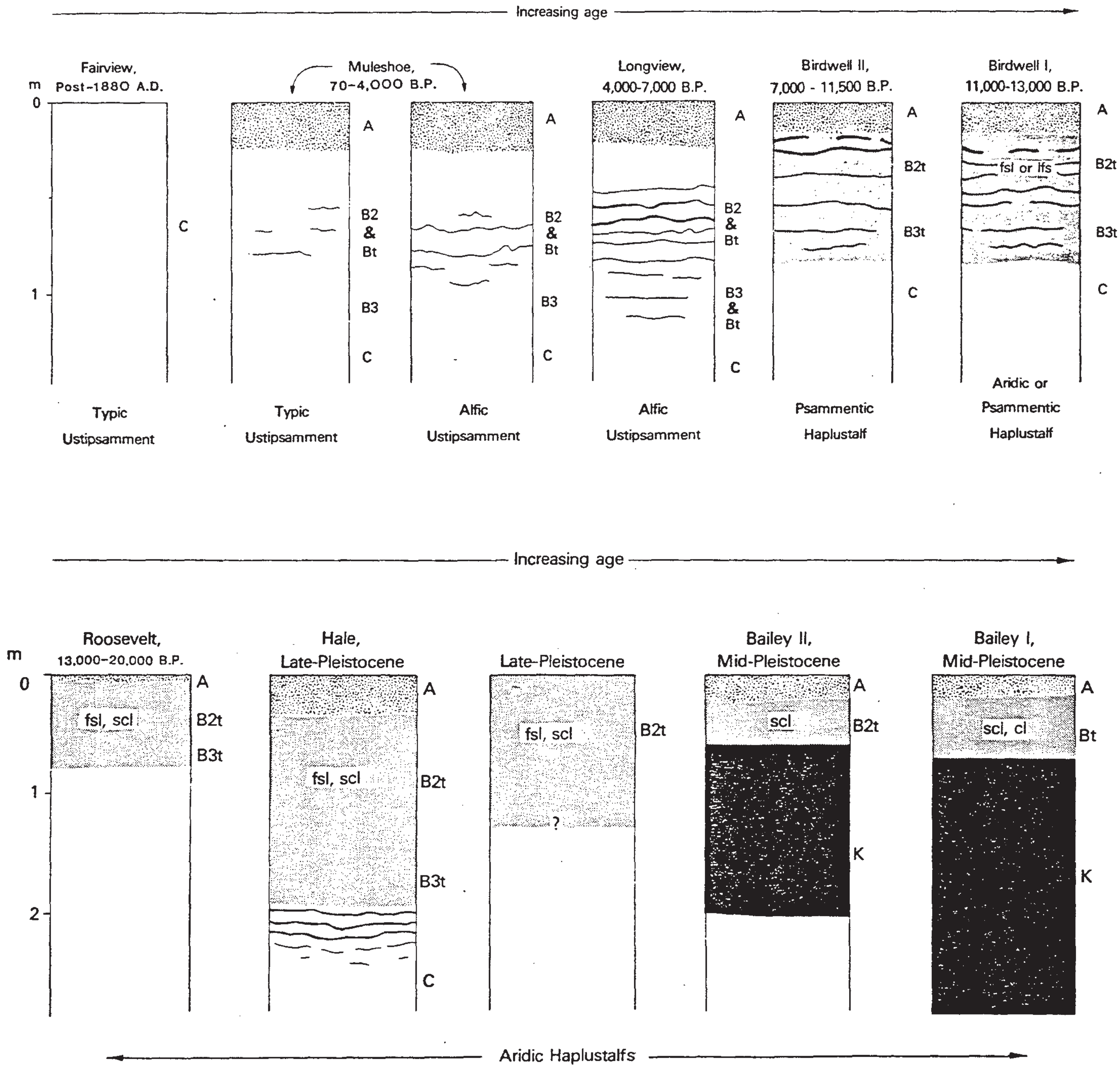


Figure 2. Diagram showing soil development with increasing age. The illustrative soils have formed in noncalcareous sandy sediments associated with geomorphic surfaces of indicated ages at the present land surface. Morphological variations from the indicated morphologies can be caused by erosion prior 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.

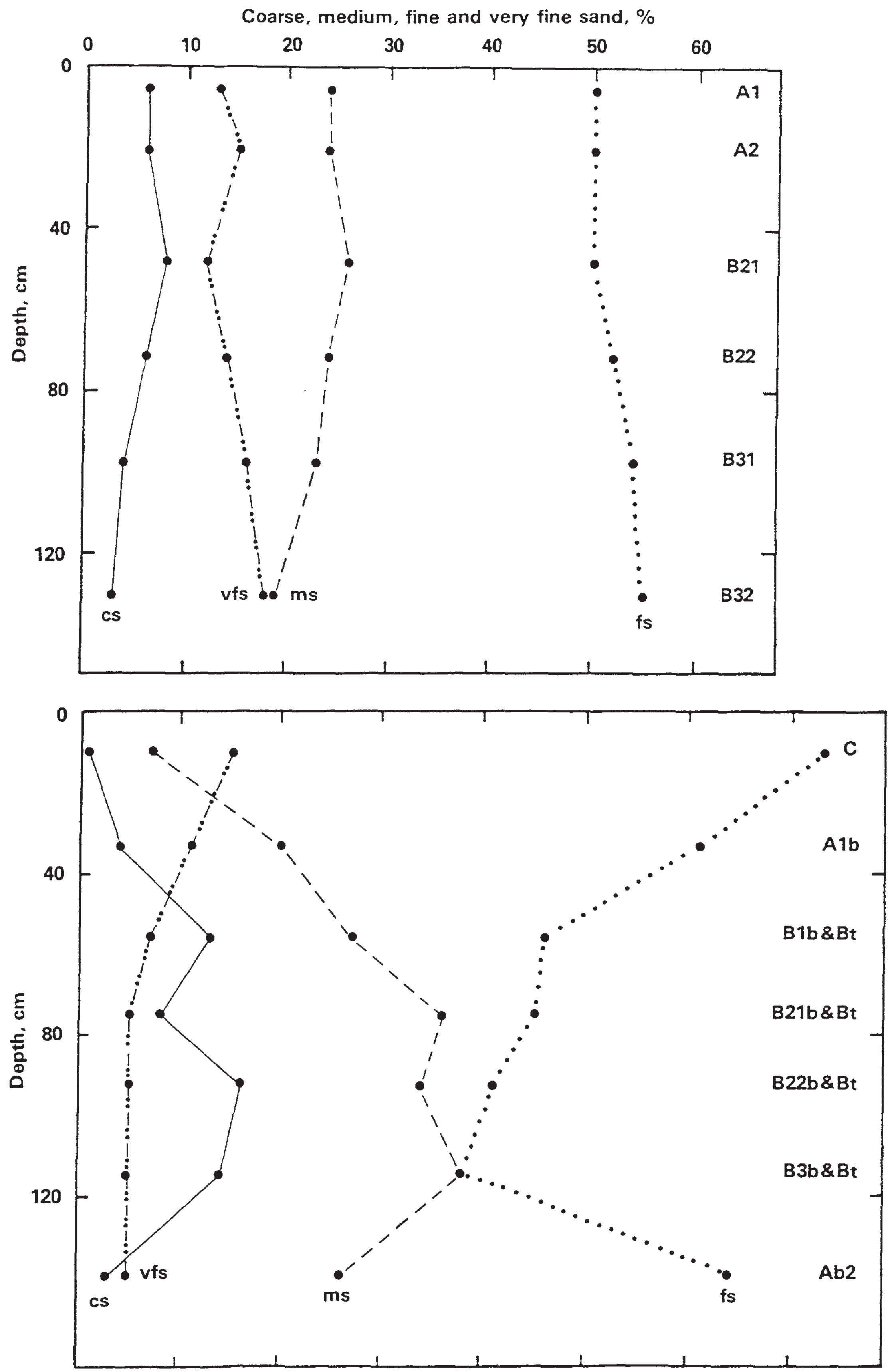


Figure 3. Percentages of four sand sizes in sediments of different ages. Horizon designations are at right.

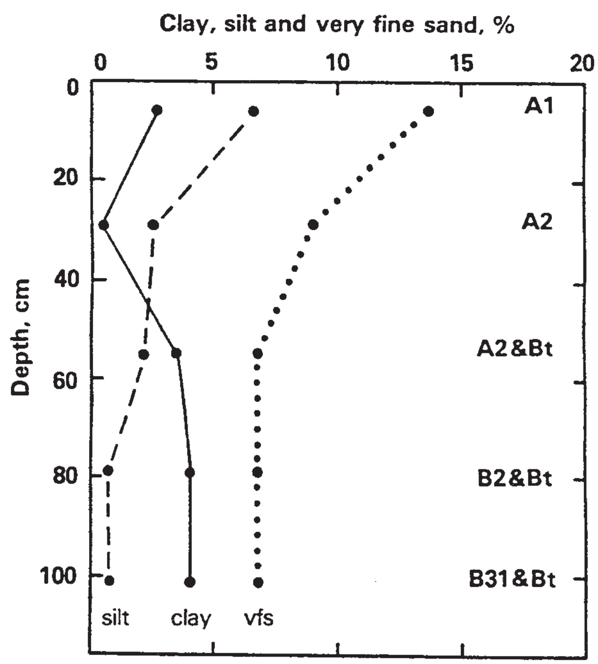
Upper. Sand size of Muleshoe sediments in Pedon 4.

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

<u>Additions from dustfall</u>. 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.



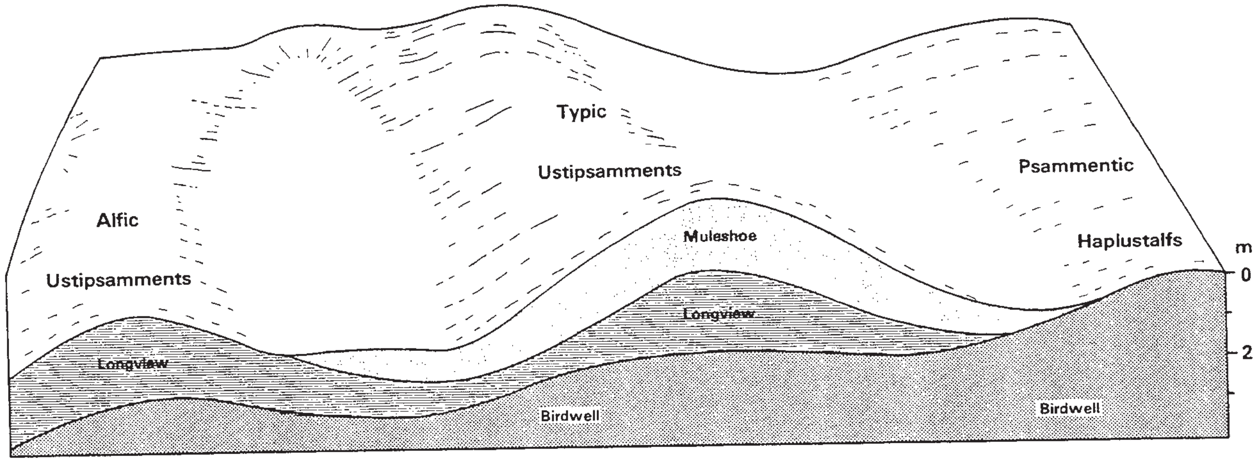
Although carbonate occurs in only a few soils, some of it has also been derived from dustfall as proposed earlier for many soils of arid regions (Gile and Grossman, 1979). This is discussed further in the carbonate section.

<u>Soil occurrence and prediction</u>. 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).



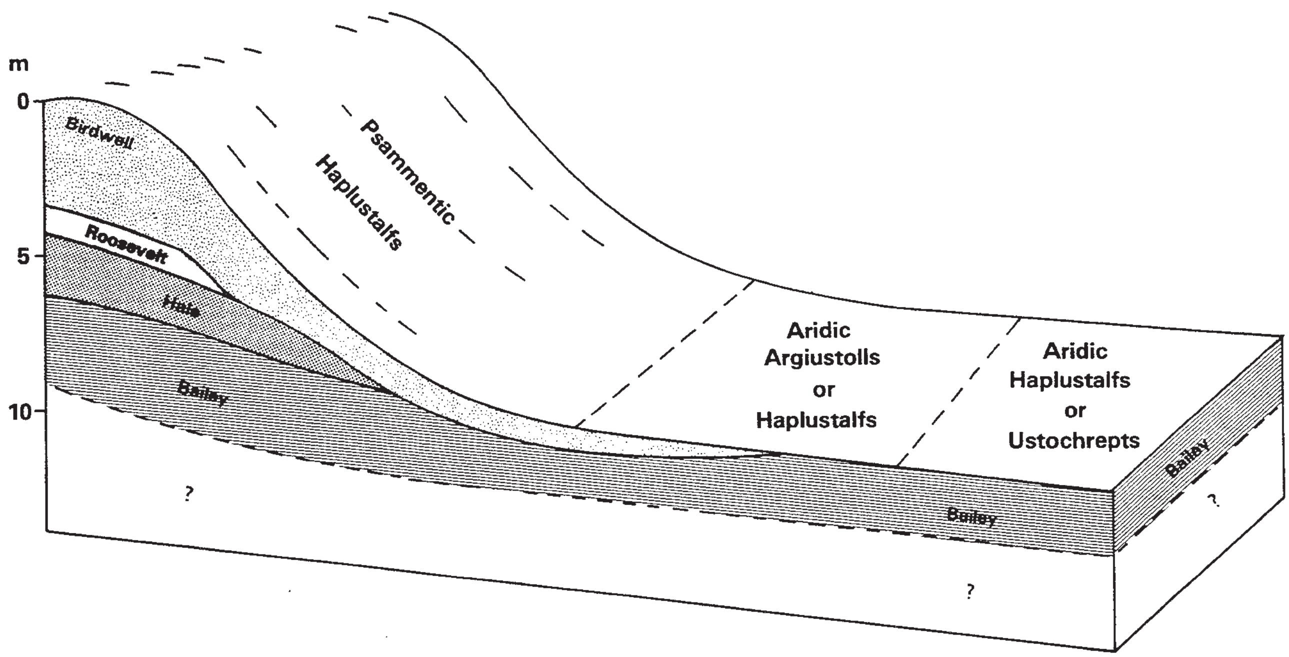


Figure 5. Generalized diagrams showing soils and sediments (morphostratigraphic units) in the sandhills.

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.

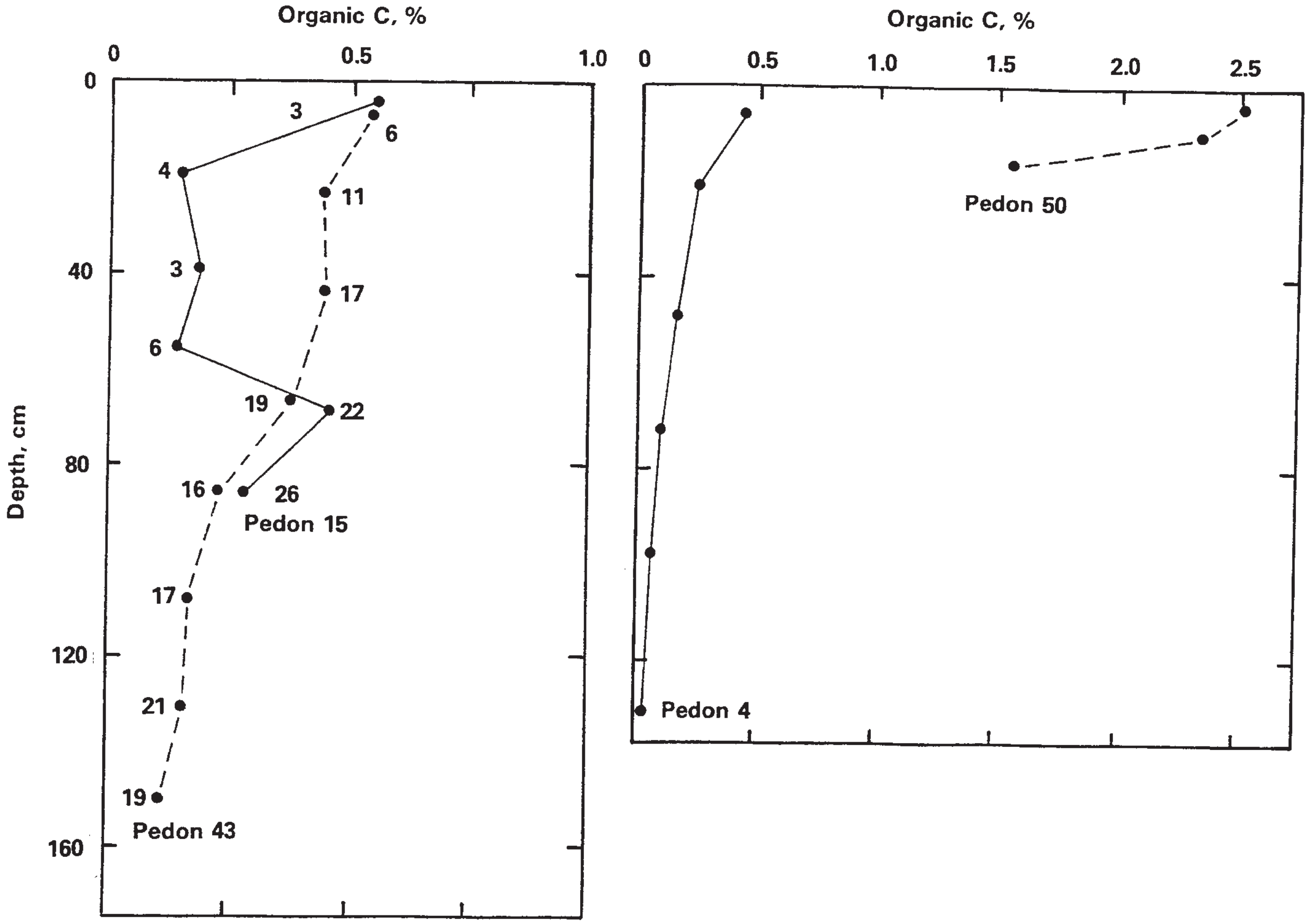


Figure 6. Left. The relation of organic carbon percentage to clay percentage and depth. Figures next to the plotted organic carbon values are clay percentages. Horizon designations for Pedon 15 are A1, B1, B21, B22, B21tb, B22tb; for Pedon 43 they are A1, B11t, B12t, B2t, B11tb, B12tb, B2tb, and B3tcab.

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).

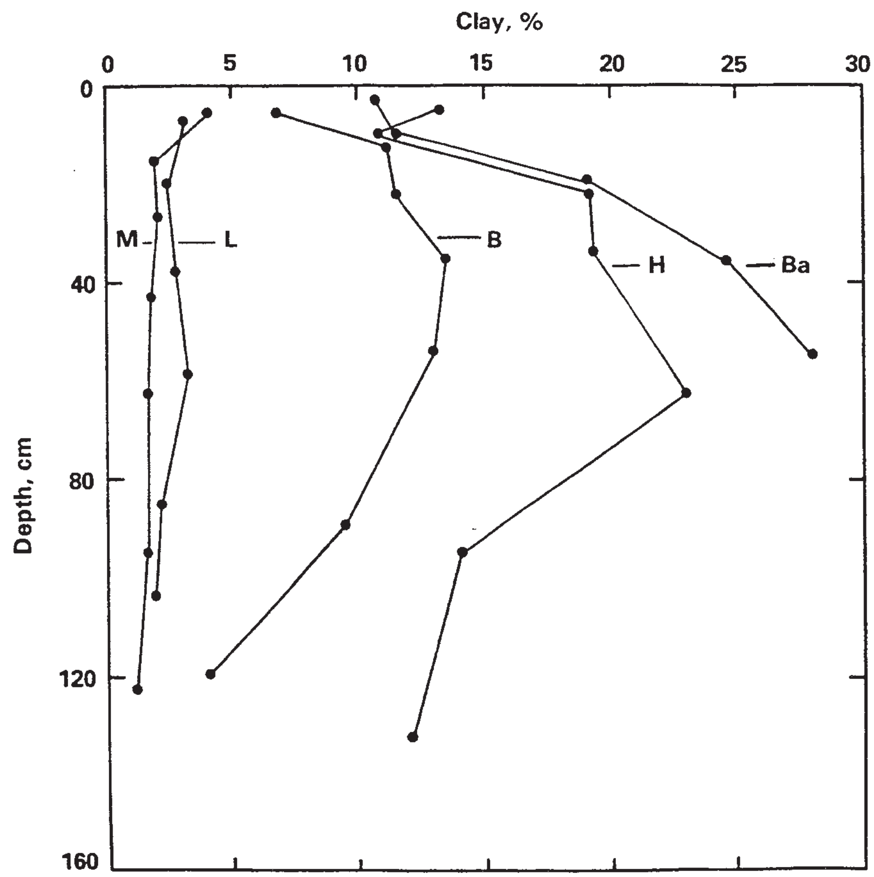


Figure 7. Increasing silicate clay with increasing soil age. M = Muleshoe (Pedon 5); L = Longview (Pedon 18c-4); B = Birdwell (Pedon 36a); H = Hale (Pedon 49); Ba = Bailey (Pedon 52a).

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.

<u>Textural sequence in Birdwell dunes and adjacent depressions</u>. 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.

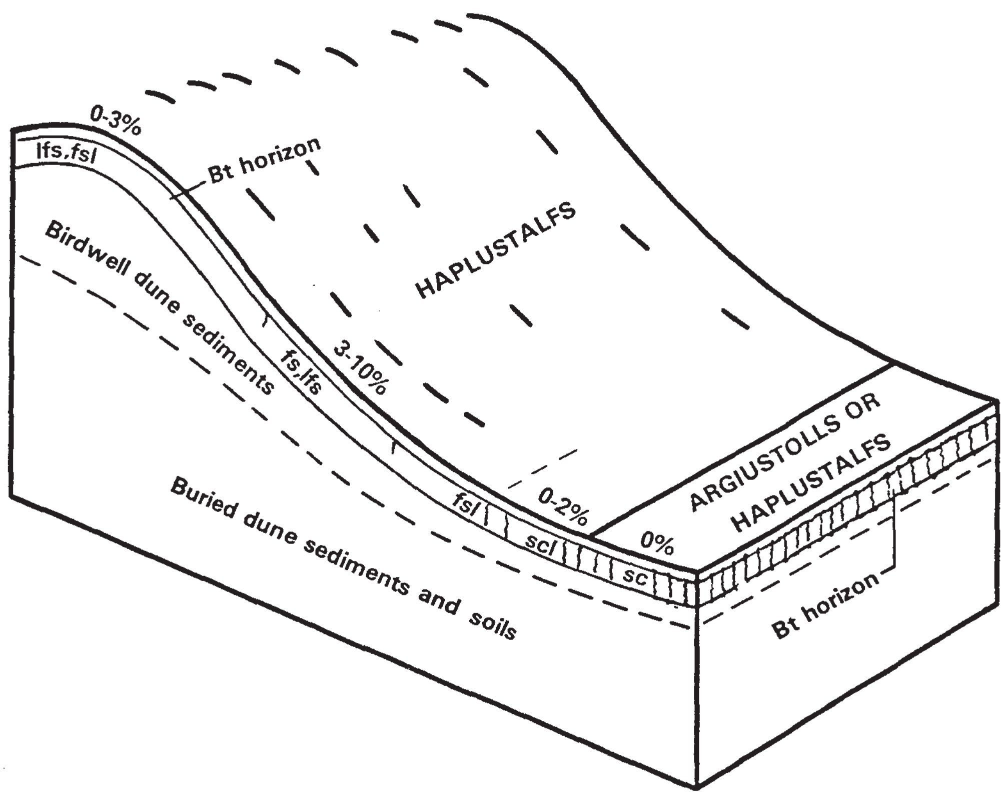


Figure 8. The relation of B2t horizon texture to landscape position on the crest and west-facing side of a Birdwell dune and adjacent depression.

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.

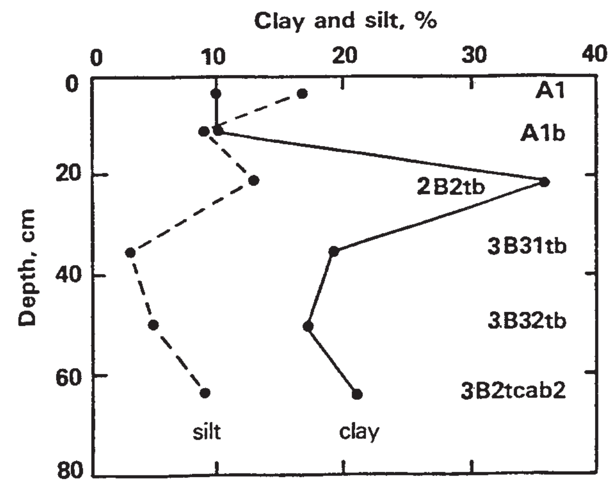


Figure 9. Percentages of silt and clay in Pedon 34c.

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.

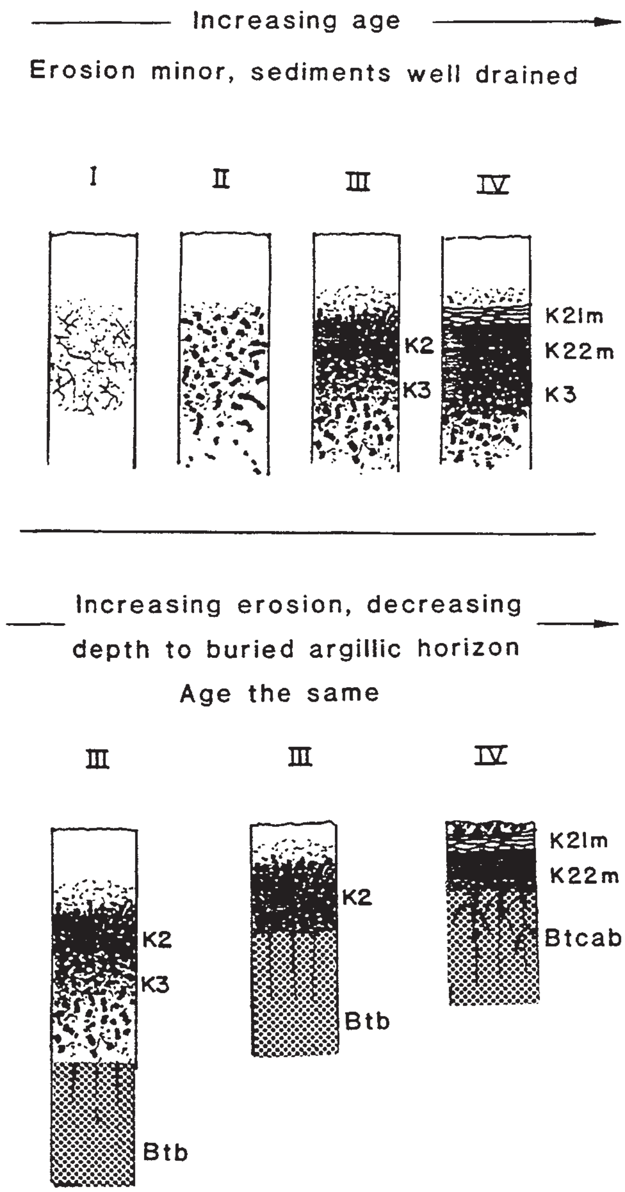


Figure 10. Upper. Schematic diagram of the diagnostic morphology for the stages of carbonate horizon formation in the nongravelly sequence. Carbonate accumulations are indicated in black for clarity. The morphology is summarized as follows (see Gile et al., 1966, for more detailed discussion): Stage 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.

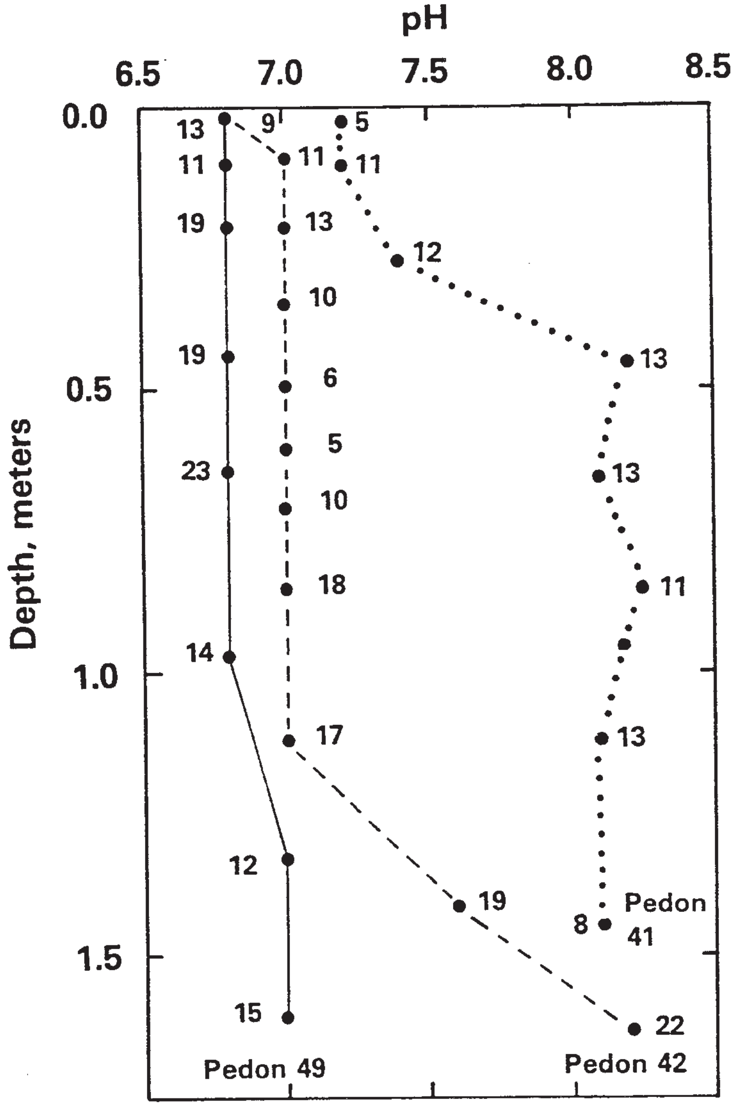


Figure 11. The pH and clay of Pedons 41, 42 and 49 (figures next to plotted pH values are clay percentages. Clay not available for the C1&B33t horizon). Horizon designations and sediments are given below. Sediments are designated as: M = Muleshoe, L = Longview, B = Birdwell, R = Roosevelt, H = Hale (see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

Pedon 49

M, L A1
H Ab
B21tb
B22tb
B23tb
B31tb
B32tb
Btb2

Pedon 42

B A1
B1t
B21t
B22t
B3t
C
R B1tb
B21tb
B22tb
H B21tb2
B22tcab2

Pedon 41

B A1
B1t
B21t
B22tca
B31tca
B32tca
C1&B33t
C2
C3

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.

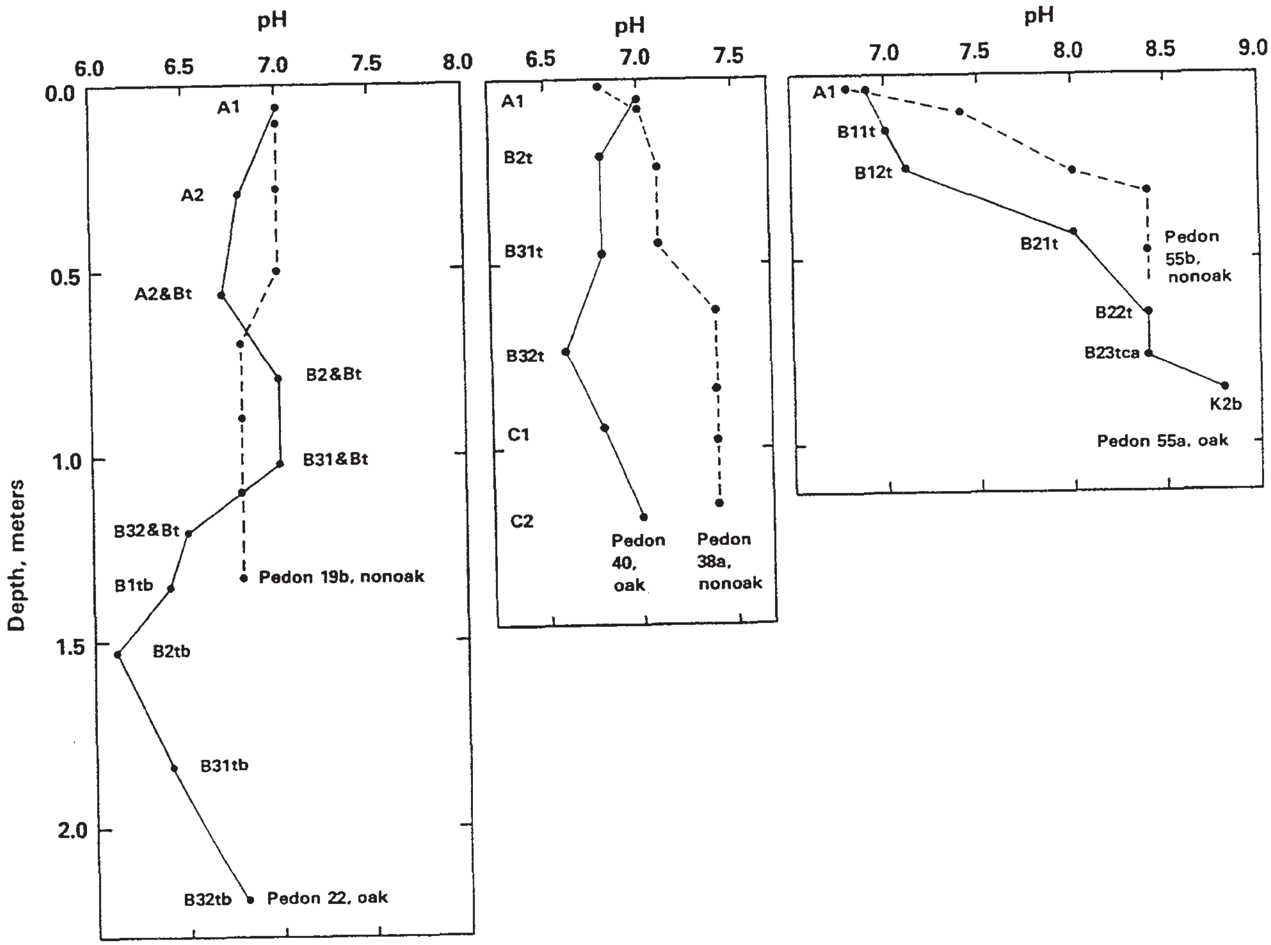


Figure 12. The pH of pedons under oak and nonoak vegetation under different conditions.

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.

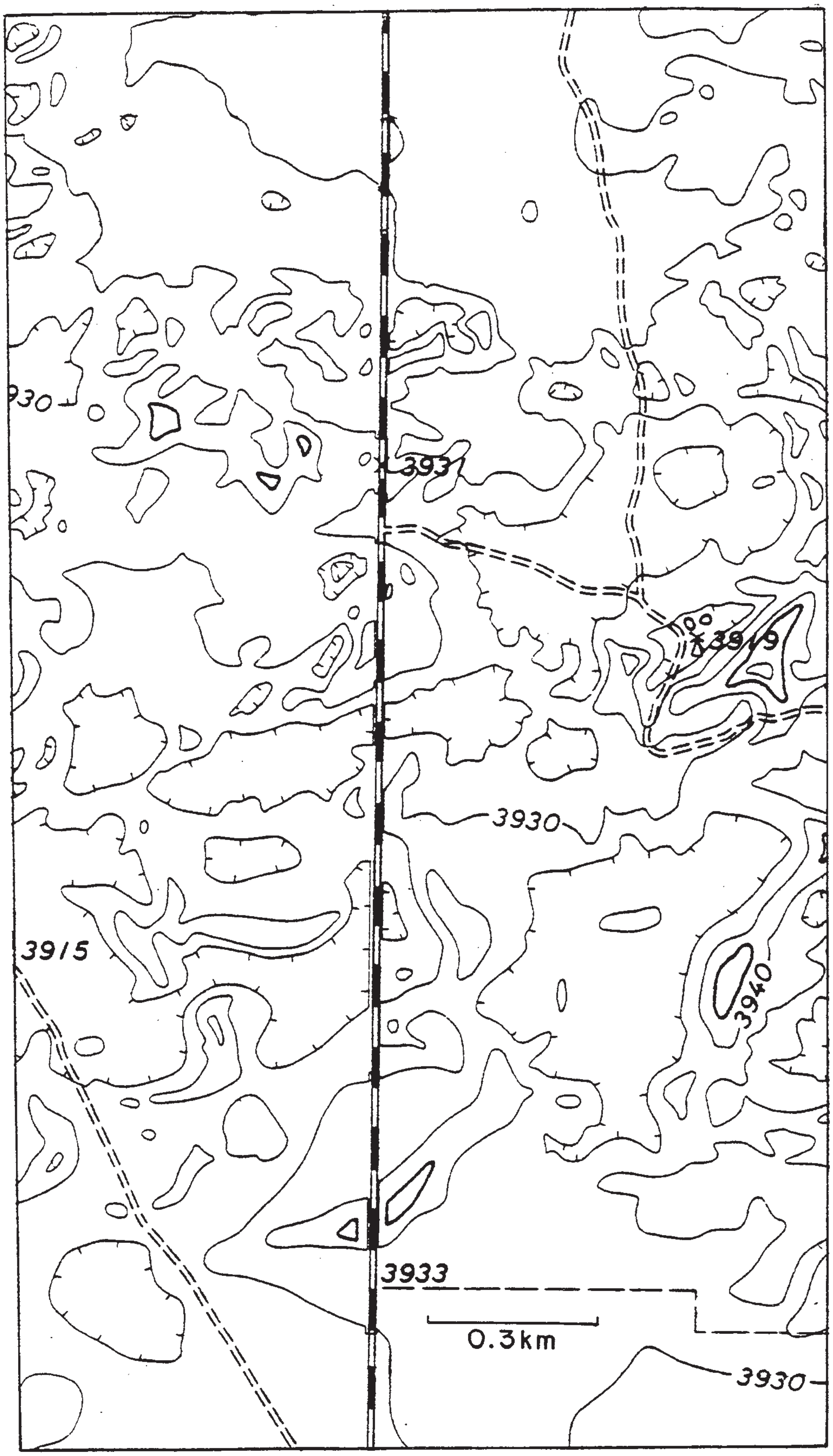


Figure 12a. Topographic map of the same area shown in the frontispiece. Hachures indicate blowouts; ridged areas are dunes.

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.

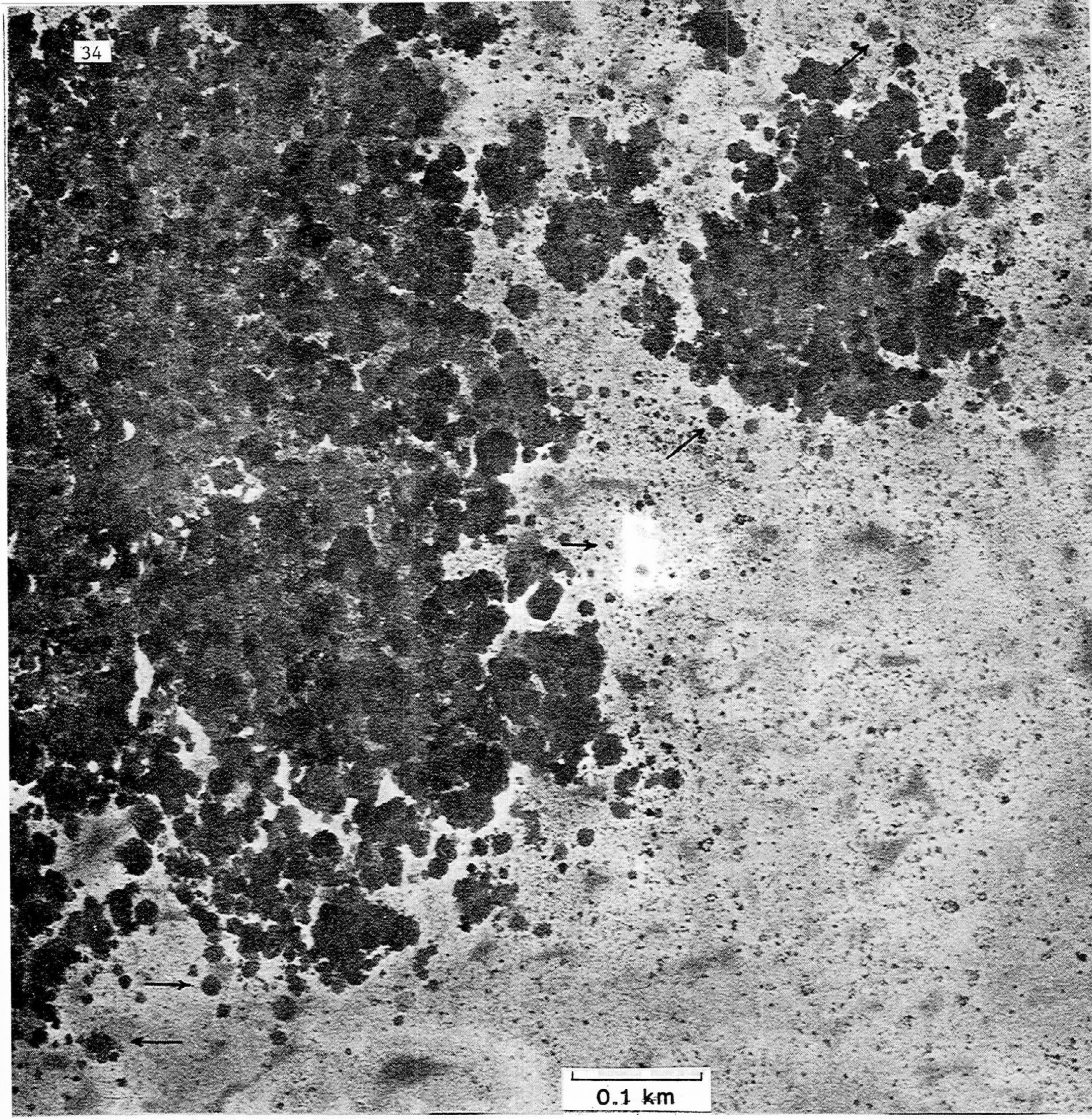


Figure 13. Aerial photograph taken August 3, 1941. Farm Road 1731 is not present and must have been built before 1953 (see fig. 14). The west face of the large active blowout at right center coincides with the old north-south XIT trail (see text discussion). Although traces of the old trail are still 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).

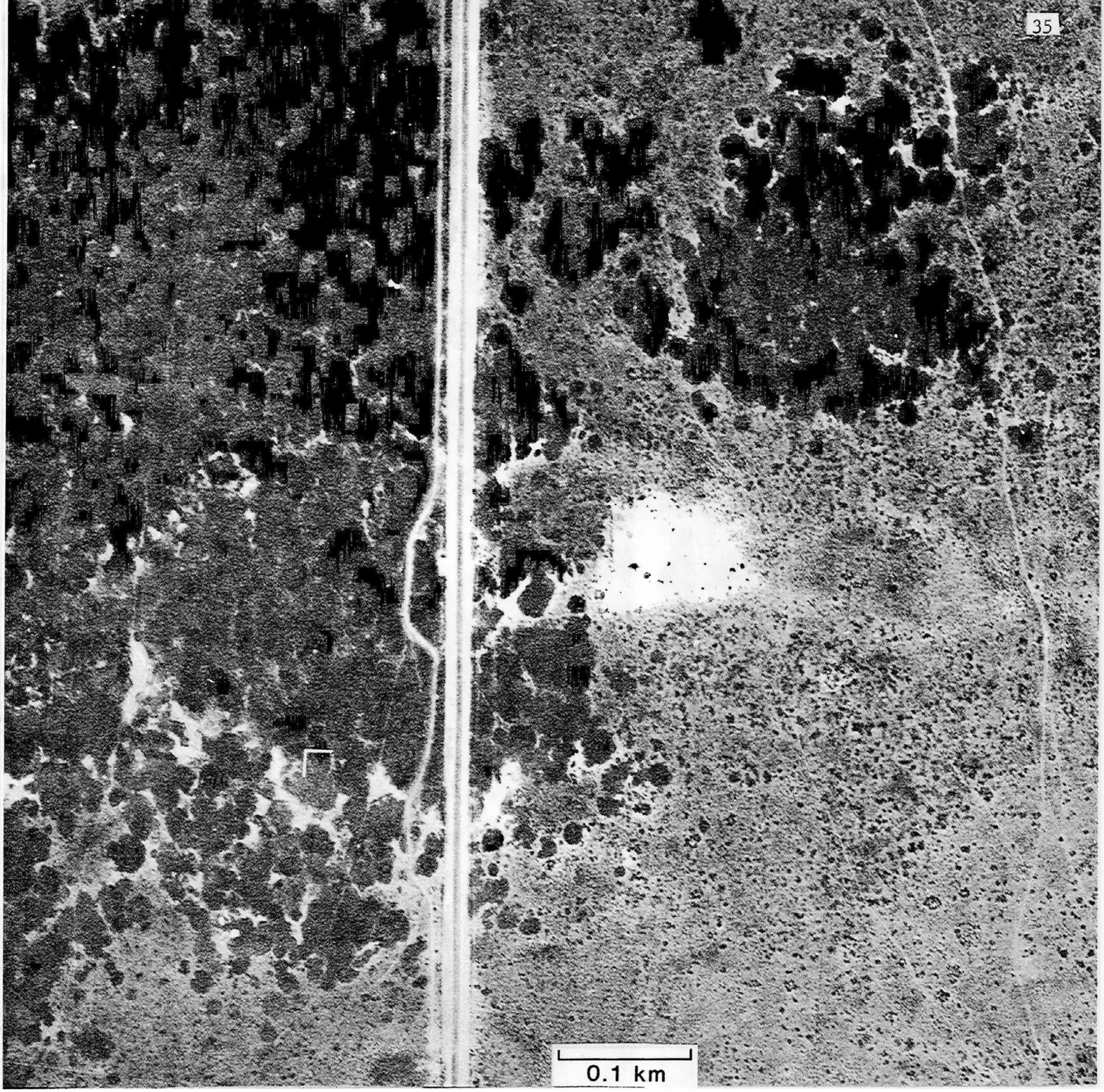


Figure 14. Aerial photograph taken February 25, 1953. Farm Road 1731 and a frontage road west of it have been constructed. The large active dune has moved a substantial distance to the east. The east face of the blowout is distinctly linear, and reflects erosion along a track on the east side of the 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).

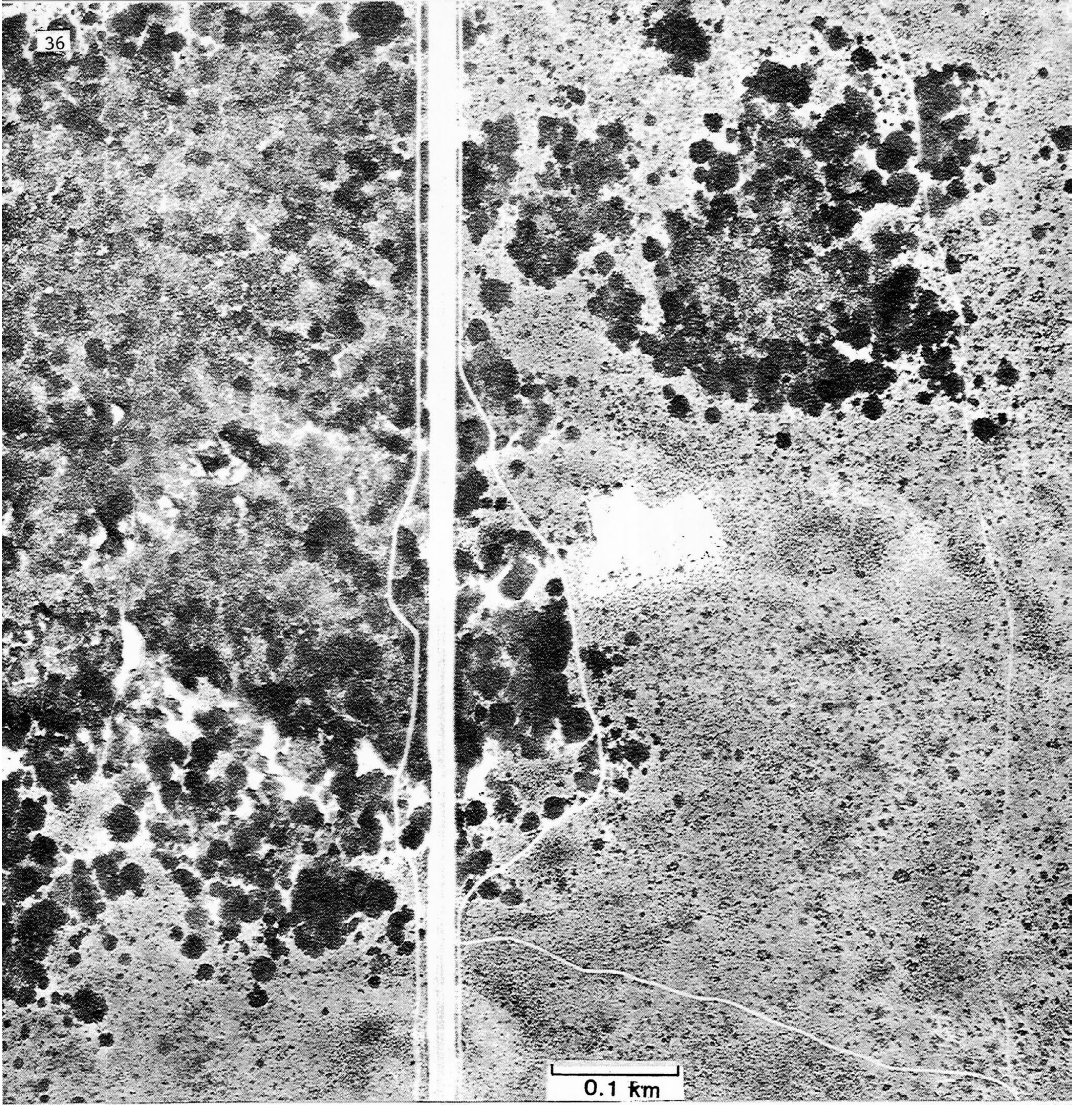


Figure 15. Aerial photograph taken October 31, 1962. Additional roads have been built, and connect to Farm Road 1731. On the east side of the blowout, parts of the dune still visible in the 1953 photograph have been breached and are furnishing sand for the dune to the east. Some of the blowouts between 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.

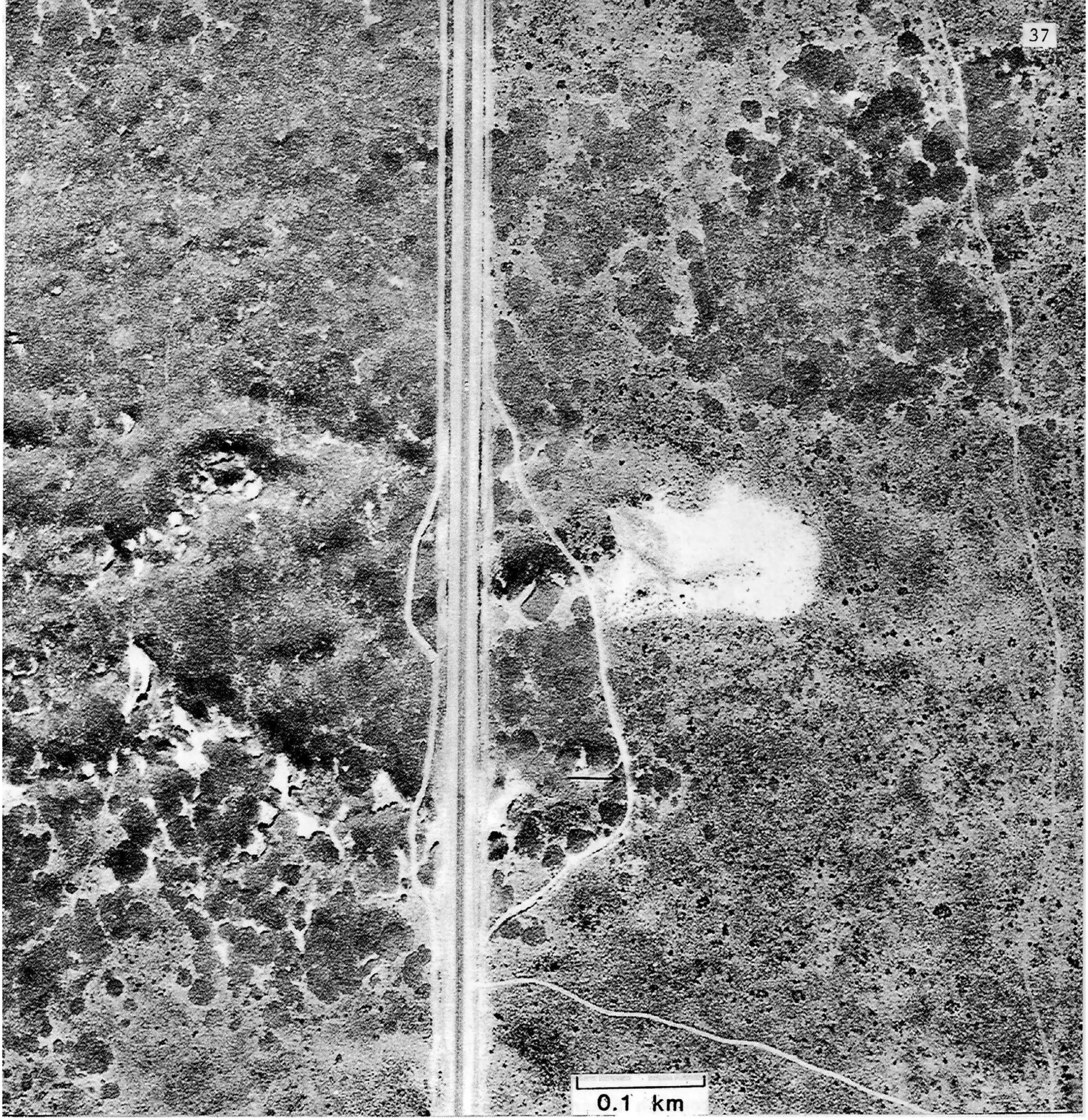


Figure 16. Aerial photograph taken December 13, 1970. Both the active blowout and its dune have enlarged considerably. The west face of the blowout is migrating westward due to slumping, observed on the ground at various times after 1972. Oak has impinged on or crossed the sandy frontage roads in places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

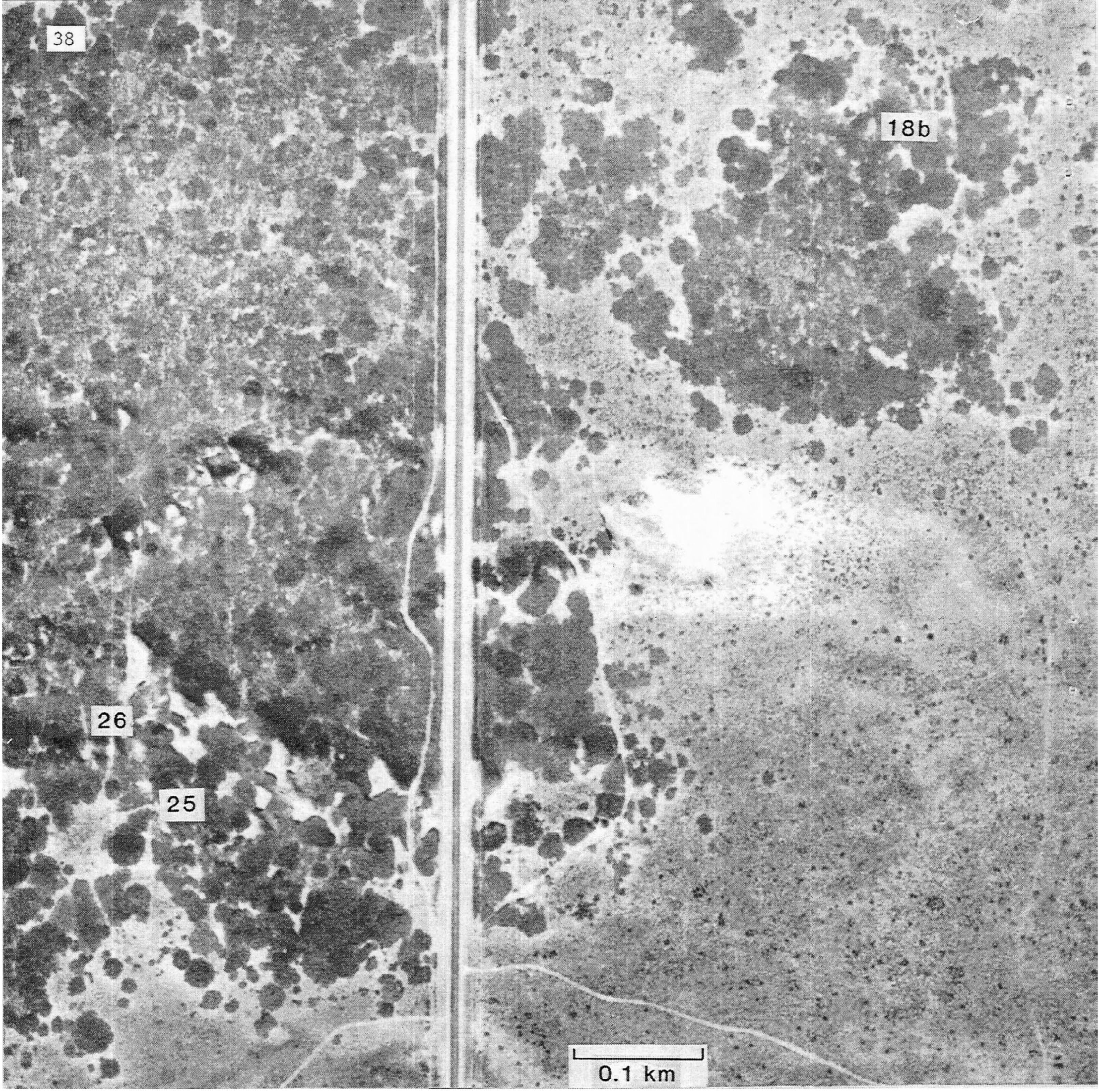


Figure 17. Aerial photograph taken November 26, 1981. The large active dune has continued to enlarge. Isolated oak clumps have continued to grow, and in places have merged with adjacent clumps to form larger ones. A new road has been started west of Farm Road 1731. Note trench locations at Sites 18b, 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.